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Behavioural adaptation of domestic animals on the example of different breeds of domestic cat (*Felis silvestris catus* L., 1758)

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Abstract.The excessive increase in the anthropogenic burden on wildlife, namely the uncontrolled use of natural resources, including deforestation, mining, wasteful nature management systems, a decrease in biodiversity due to intensive agricultural development, and more recently, war, affect the living conditions of both wild and domestic animals. In the new realities of the modern world, pets, losing their usual natural environment, are forced to either adapt to changes or cease to exist. *The purpose of the study* was to investigate the level of adaptation of the body (*Felis silvestris catus* L., 1758) of domestic cats in home conditions. Long-term methods were used to achieve this goal: daily visual observation, time budget, followed by the analysis of data on greater animal activity. The behaviours of cats were evaluated on a six-point scale: imitation of hunting – active play using toys

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(5 points) and territory inspection, jumping, scratching claws (4 points); communication with the owner – food search and bunting (3 points); self-cleaning – passive walk, toilet (2 points); rest – state of light sleep or napping (1 point), state of deep sleep (0). The selected samples were compared statistically using Kendall's rank correlation coefficient It is established that intra-breed and inter-breed differences in the duration of behavioural acts of obligate and facultative behaviours are largely determined by the temperament and character of the animals under study. The daily activity of cats of different breeds is described, which is determined by the imposition of the influence of genetically determined cycles on specific character traits and is formed during selection breeding. It is statistically proved that there is a substantial consistency between the traits under study in animals with different temperaments. If the temperament is similar, behaviour and motor activity do not correlate with each other, and the differences in the behaviour and activity of male and female purebred cats are poorly expressed. It is substantiated that the results obtained can serve as a basis for understanding the problems and difficulties that arise in purebred cats in the process of adaptation to life together with humans and, thereby, provide an understanding of the main manifestations of behavioural adaptation of domestic animals

Keywords: ethology; adaptation; behavioural acts; crossbred cats; purebred animals

INTRODUCTION

The excessive increase in the anthropogenic burden on wildlife, namely the uncontrolled use of natural resources, including deforestation, mining, wasteful systems, reduced biodiversity due to intensive agricultural development, and more recently, war, affect the living conditions of both wild and domestic animals. People, realising their unity with nature, rethink their attitude to it. Understanding that pets with different breed characteristics have specific environmental needs to achieve a good quality of life requires investigating their ability to adapt, including from the standpoint of behavioural adaptation. This determines the relevance of the chosen study subject and the feasibility of its development.

Notably, a person, even faithfully caring for their pets, often has superficial knowledge and understanding of their behaviour. The solution to this problem is possible only if both general theoretical issues and the ethology of animal adaptation to the environment are comprehensively investigated, at least at the level of systems of interrelated behavioural acts. Recently, a substantial number of papers have been devoted to the examination of pet behaviour. The adoption of an evolutionary and adaptive approach to investigating mechanisms and processes of behaviour development is becoming increasingly popular in various fields of knowledge, including ethology, behavioural ecology, and adaptive evolution. Since all levels of organisation in the body are united by behavioural traits, it can be stated that there is a unity in the evolution of behaviour, morphology, physiology, and immunology of animals in the process of creating a unique functional phenotype (Natoli *et al.*, 2022). Although even today, most papers are reduced to stating the characteristic morphological and ethological features of purebred animals (Pusis, 2021).

A study by M. Salonen *et al.* (2019) identified variations in behavioural responses to genetic and environmental components and proved the presence of substantial genetically determined variations in breed populations. J. Faure and E. Mills (2014) also considered the genetically determined individual reactions of the animal body to the effect of various environmental factors to prevent or minimise negative consequences. According to P. Jensen (2017), this is especially true for rare animal breeds that are able to maintain genetic diversity and thus guarantee them an appropriate level of viability.

According to the findings of Japanese researchers (Nagasawa *et al.*, 2020), the cohabitation of pets with humans has a positive effect on physiological and psychological health, including improving the mood of the owner. In relation to animals, physical communication is a common and necessary factor for building a good relationship with the owner, ensuring a fairly high quality of life for the animal. However, the relationship between the health benefits provided by the presence of a cat in the home, characteristic behaviour, and behavioural responses of cats requires further study.

Thus, by rethinking the human relationship with domestic and other animals, researchers (Tarazona *et al.*, 2020) are increasingly promoting the transition to the concept of unity and integrity of living nature, embodied through the narrative: one health, one well-being, and one biology, as prerequisites for global change based on the observance of ethics of actions, considering the consequences of human activity.

Researchers pay considerable attention to the examination of the applied importance of ethology for agriculture both in Ukraine and in the world. Ethologists identified many aspects of animal behaviour that can be used in agricultural production and veterinary medicine (Doylidov, 2021; Suprovych *et al.*, 2022). Therewith, more and more often in the literature by Dohertya (2016), A. Trouwborst (2020), a warning about the negative impact of domestic cats, as representatives of predatory animals of invasive fauna, on the abundance and biodiversity of wildlife, is noted (Krauze-Gryz, 2018; Loss, 2017).

In the new realities of the modern world, domestic animals, losing their usual natural living conditions, are forced to either adapt to changes or cease to exist

(Calvert, 2013; Loss, 2018). Actually, this why is the reason to investigate the natural adaptation of animals comes to the fore.

The purpose of this study is to investigate the level of adaptation of the body of domestic cats (*Felis silvestris catus* L., 1758) in home conditions.

MATERIALS AND METHODS

The study dates back to the spring-summer-autumn seasons of 2019-2022. The examination of species-specific behaviour of crossbred representatives of different domestic cat breeds (*Felis silvestris catus* L., 1758) was conducted by observing: a four-year-old female Siamese cat (SIA♀); a five-year-old female Persian Chinchilla (PER♀), a three-year-old female (BRI♀), and a six-year-old male (BRI♂) of the British Shorthair breed; a six-year-old female Siberian cat (SIB♀).

The age of animals was determined according to the classical method of N.P. Zapadnyuk (1983) considering the EMS code (Easy Mind System), namely the system created by the International Federation of felinology (FIFe) for easy identification of purebred cats (Breed standard, 2023).

The examination of the behaviour and temperament of cats was conducted using long-term methods of daily visual observation (Shevchyk, 2021) (observing the behaviour of cats during the day once a month under the usual conditions of keep and daily routine, a total of 5-7 observations of each of the cats per year) and the time budget method, followed by the analysis of data on greater daily animal activity (Nagasawa, 2020; Paliy, 2010). The time budget, namely the daily list of behavioural acts, was timed using ethograms (catalogues) for each breed.

The point scale for classifying behavioural acts is developed based on the recommendations: G. Katzen (2008), L.V. Krushynskyi (Dotsenko, 2019). The following criteria for evaluating the activity of animals, expressed in points (on a six-point scale) are selected: imitation of hunting – active play using toys (5 points) and territory inspection, jumping, scratching claws (4 points); communication with the owner – food search and bunting (3 points); self-cleaning – passive walk, toilet (2 points); rest – state of light sleep (1 point), state of deep sleep (0).

Comparison of the selected samples was conducted statistically, using Kendall's rank correlation coefficient, which characterises the measure of consistency between the ranks (where rank is the degree of difference) of two random variables (namely, a point assessment of the daily activity of cats) (Bakhrushin, 2011).

When justifying the conclusion, it was proceeded from the statement: if the Kendall's correlation coefficient ($|\tau|$) is less than the critical point (T_{cr}) – the rank correlation between the qualitative characteristics of the two samples is insubstantial. If $|\tau|>T_{cr}$ – there is a substantial rank correlation between the qualitative features of samples. If ($|\tau|>T_{cr}$ – there is a substantial rank correlation between|) is equal to "0" – there is no rank correlation. For the calculation, the Microsoft Excel programme of the Microsoft Office suite was used. The reliability of the obtained results was checked using the Student's t-criterion. The observation was conducted in accordance with ethical standards and recommendations for the humanisation of work with laboratory animals, which are reflected in the "European Convention for the protection of vertebrates used for experimental and other purposes" (1999), and the requirements of the bioethics Commission of I. Horbachevsky TNMU of the Ministry of Health of Ukraine (protocol No. 14 of 23.11.2021).

The study is a fragment of the individual R&D "Fauna of the Western region of Ukraine: biological classification, state of diversity, ecology, genetics, protection, educational and methodological aspects of teaching" (state registration number 0121U107913) (2021). The results are published for the first time.

RESULTS

Like all animals, cats are characterised by a certain temperament, specific behavioural characteristics, and different environmental needs. In fact, these properties ensure the adaptation to achieve a good quality of life for the animal.

The identified dependence of cat behaviour on the temperament in sanguine cats showed a tendency to reduce the duration of facultative behavioural responses compared to innate ones (SIA♀:10.33±0.71 (43.0%); 13.67±0.66 (56.96%); p<0.01) (SIB♀:11.57±0.27 (48.58%); 12.33±0.27 (51.38%); p<0.1) (Table 1).

***Table 1**. Manifestation of various forms of behavioural reactions of purebred cats*

No.	Breed	n	Temperament	Duration of acts of obligate behaviour		Duration of acts of optional behaviour	
				hours	%	hours	%
1	SIA♀	7	sanguine	13.67±0.66	56.96	10.33±0.71[2]	43.0
2	SIB♀	7	sanguine	12.33±0.27	51.38	11.57±0.27[1]	48.58
3	BRI♀	7	melancholic	10.66±0.51	44.42	13.29±0.50[2]	55.54
4	BRI♂	5	melancholic	11.40±0.46	47.50	14.20±0.33[3]	59.17
5	PER♀	7	with features of both sanguine and melancholic	11.71±0.27	48.58	12.31±0.33[1]	51.38

Note: *[1]p<0.1; [2]p<0.01; [3]p<0.001*
Source: *compiled by the authors*

In melancholic cats, this ratio is diametrically opposite (BRI♀ ($p<0.01$) and BRI♂ ($p<0.001$) – obligate reactions (BRI♀: 10.66±0.51 (44.42%), BRI♂: 11.40±0.46 (47.50 %)), optional (BRI♀: 13.29±0.50 (55.54%), BRI♂: 14.20±0.33 (59.17 %)).

Persian kittens are usually sanguine. With age, depending on the conditions of the keep, the temperament may remain unchanged, or acquire the traits of both sanguine and melancholic, and the ratio of the duration of obligate (11.71±0.27 (48.58%)) and facultative reactions (12.31±0.33 (51.38%)) tends to equalise ($p<0.1$).

Analysis of the duration of behavioural acts of both behaviour forms between purebred cats showed tendentious differences in pairs of sanguine cats (SIA♀ and SIB♀), melancholic cats (BRI♀), and Persian cats (PER♀) ($p<0.1$). While in pairs: sanguine-melancholic (SIA♀ and BRI♀; SIB♀ and BRI♀), sanguine animals and representatives of the Persian breed (SIA♀ and PER♀; SIB♀ and PER♀) the difference in the temperament of animals causes statistically substantial differences in both obligate and facultative behaviours (at to $p<0.05$).

A vivid manifestation of the innate behavioural acts of purebred cats is sleep and rest. In a Siberian cat, the duration of sleep and napping increases from 4.40±0.22 (18.3%) (days of greatest activity) to 8.6±0.46 (35.8%) (at rest) ($p<0.01$) (Table 2).

***Table 2**. Manifestation of innate behavioural acts in cats of different breeds*

No.	Breed	n	In active state				At rest			
			sleep and rest		self-cleaning and toilet		sleep and rest		self-cleaning and toilet	
			hours	%	hours	%%	hours	%	hours	%
1	SIA♀	5	9.60±0.46[3]	40.0	6.0±0.75	25.0	11.0±0.63[3]	45.8	6.6±0.61	27.5
2	SIB♀	5	4.40±0.22[1]	18.3	6.0±1.33	25.0	8.6±0.46[1]	35.8	3.4±0.46	14.2
3	BRI♀	5	6.60±0.46[2]	27.5	3.2±0.72	13.33	9.4±0.46[2]	39.2	4.0±0.40	16.7
4	BRI♂	5	6.60±0.36[3]	27.50	3.00±0, 63[1]	12.50	8.20±0.52[3]	34.17	4.20±0.33[1]	17.50
5	PER♀	5	8.80±0.33[3]	36.7	3.2±0.59	13.33	7.4±0.46[3]	30.8	3.6±0.36	15.0

***Note:** $p<0.1$; [1]$p<0.01$; [2]$p<0.001$; [3]$p<0.05$*
***Source:** compiled by the authors*

A similar pattern is observed in British Shorthair females. The females (BRI♀) spend 6.60±0.46 (27.5%) hours sleeping and resting in an agitated state, and at rest, the duration of these behavioural acts increases to 9.4±0.46 (39.2%) ($p<0.001$). For the male (BRI♂), changes occur within the range of 6.60±0.36 (27.50%) to 8.20±0.52 (34.17 %) ($p<0.05$), for Siamese cats – from 9.60±0.46 (40.0%) to 11.0±0.63 (45.8%) hours ($p<0.05$). In the Persian cat that is best adapted to home conditions, as it moves from an agitated state to a state of rest, the duration of sleep and rest decreases from 8.80±0.33 (36.7%) to 7.4±0.46 (30.8%) hours ($p<0.05$). Such differences in the duration of innate behavioural acts (namely, the predominance of obligate behaviour at rest over the agitated state of the animal) are explained by genetic characteristics, and therefore by the adaptation of the body of the animal. It is due to the selection and domestic maintenance of animals that interbreed differences in the duration of the described behavioural acts are not reliable ($p<0.1$).

Acts of optional behaviour: communication with the host – begging for food and bunting were more pronounced on days of increased activity of animals (BRI♀: $p<0.05$; BRI♂: $p<0.01$; PER♀: $p<0.01$), while in a Siberian female, which, due to its affectionate nature, was quite actively looking for the attention from the owner at rest, SIB♀: 5.40±0.46 (22.5%) versus 3.40±0.22 (14.2%) of the agitated state of the animal ($p<0.001$) (Table 3).

***Table 3**. Manifestation of acquired behavioural acts in cats of different breeds*

No.	Breed	n	**In active state**						**At rest**					
			communication		exploration of territories		imitation of hunting		communication		exploration of territories		imitation of hunting	
			hours	%	hours	%	hours	%	hours	%	hours	%	hours	%
1	SIA♀	5	1.60± ±0.36	6.7	6.60± ±0.83[3]	27.5	1.40± ±0.22[3]	5.8	1.80± ±0.18	7.5	2.40± ±0.36[3]	10.0	4.60± ±0.36[3]	19.2
2	SIB♀	5	3.40± ±0.22[3]	14.2	4.40± ±0.46	18.3	4.00± ±0.63	16, 7	5.40± ±0.46[3]	22.5	4.40± ±0.22	18.3	3.40± ±0.22	14.2

Table 3, Continued

No.	Breed	n	In active state						At rest					
			communication		exploration of territories		imitation of hunting		communication		exploration of territories		imitation of hunting	
			hours	%	hours	%	hours	%	hours	%	hours	%	hours	%
3	BRI♀	5	9.40± ±0.36[2]	39.2	6.80± ±0.72	28.3	1.80± ±0.18	7.5	2.80± ±0.44[2]	11.7	6.80± ±0.52	28.3	2.0± ±0.28	8.3
4	BRI♂	5	10.60± ±0.61[1]	44.17%	4.40± ±0.36[2]	18.33%	2.00± ±0.40	8.33%	3.00± ±0.49[1]	12.50%	5.60± ±0.36[2]	23.33%	2.40± ±0.61	10.00%
5	PER♀	5	6.60± ±0.61[1]	27.5	1.40± ±0.22	5.8	3.80± ±0.52[3]	15.8	3.80± ±0.44[1]	15.8	1.20± ±0.18	5.0	7.80± ±0.18[3]	32.5

Note: *[1]p<0.01; [2]p<0.05; [3]p<0.001; p<0.1*
Source: *compiled by the authors*

On the other hand, in Siamese females, exploration of territory – walking around the apartment, exploring, jumping, and scratching their claws – was more pronounced in the state of agitation (SIA♀: p<0.001). While a statistically substantial predominance of the duration of this behavioural act at rest was established for a male of the British breed (BRI♂: p<0.05).

Imitation of hunting in the form of playing was substantially more often recorded at rest in experimental animals (SIA♀ and PER♀, p<0.001). The identified differences in this behaviour in the Siberian female and the British Shorthair breed are unreliable (p<0.1). Interbreeding differences in the duration of behavioural acts are largely determined by the personal factors of animals. If at rest these differences are statistically substantial (from p<0.001 to p<0.01), then in the agitated state they are more often tendentious (p<0.1).

In general, studies of the daily dynamics of behavioural responses showed a fairly long time of activity of animals under study (4-5 points) in the morning (from 6:00 to 9:00), in the afternoon (from 13:00 to 15: 00, no higher than 3-4 points), and a short flash of activity (3-5 points) – in the twilight hours (19:00-20: 00). As a rule, outbreaks of activity are short and rarely reach 5 points (Fig.1).

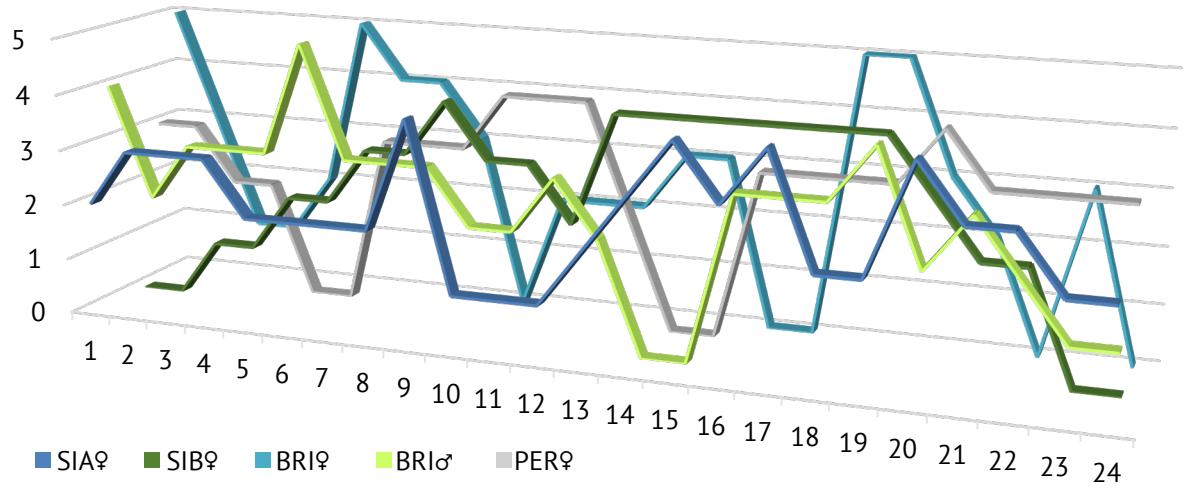

Figure 1*. Daily activity of purebred cats*
Source: *compiled by the authors*

A decrease in activity (in the range of 1-3 points) was recorded for 9:00-12:00. Cats sleep and rest (0-1 points) quite often, namely in the morning – (from 5:00 to 7:00 and from 10:00 to 12:00) and in the evening 22:00-24:00. Genetically close Siberian and Persian cats also sleep in the afternoon for one hour (15:00-16:00 and 17:00-18:00, respectively), and the British Shorthair – at night (0:00-4 :00). On average, according to the point score (2-3 points), acts of behaviour of purebred cats most often occur at night (1:00-4:00). In the morning (8:00-9:00), they can alternate with napping (SIA♀), and in the evening (21:00-24:00) – with sleep (BRI♀ and SIB♀), as well as with napping (PER♀). Statistical analysis was performed using Kendall's rank correlation coefficient to verify the relationship between the frequency of short-term cycles of cats of different breeds (Table 4).

***Table 4**. Assessment of the reliability of the frequency of occurrence of short-term cycles of cats of different breeds (based on Kendall's rank correlation coefficient)*

	SIA♀	BRI♀	SIB♀	*PER*♀	BRI♂	*Tkr*
SIA♀	1	0.37**	0.1*	0*		0.29
BRI♀		1	0.32**	0.27*	0.4*	
SIB♀			1	0.36**		
PER♀				1		

***Note:** for all the examined pairs, the Student's criterion p<0.05* – coincidence of temperament; ** – temperament is different*
***Source:** compiled by the authors*

Observations of animals with different temperaments showed a predominance of the factual value of the rank correlation coefficient (τ) compared to the critical value (Tcr), which allowed concluding that there is a substantial consistency between the traits under study. In a pair of shorthair cats of the Siamese (SIA♀) (sanguine cat) and British Shorthair (BRI♀) (melancholic cat) breeds (0.37>0.29; p<0.05). A similar pattern is observed when comparing the frequency of short-term rhythms of fairly active, mobile, and freedom-loving cats of the British Shorthair and Siberian (SIB♀) breeds (sanguine cat) (0.32>0.29; p<0.05). As well as cats of Siberian and Persian breeds (PER♀) (animals with sanguine and melancholic traits) the factual value of the rank correlation coefficient (τ) was also more than the critical (*Tcr*) (0.36>0.29; p<0.05). On the other hand, in a pair of "Siamese – Persian" cats, the rank correlation coefficient is zero, that is, the ranking of the frequency of manifestation of short-term rhythms is linearly independent (they do not reliably correlate with each other). Pronounced proximity to zero of the absolute value of the correlation coefficient in the "Siamese – Siberian" pair (0.1<0.29; p<0.05) and less than the actual value of the rank correlation coefficient (τ) compared to critical (Tcr) in the "British – Persian" pair (0.27<0.29; p<0.05) suggests a slight correlation between the traits. A comparison of the sexual characteristics of the manifestation of the main behavioural acts and synchronisation of daily cycles was conducted in pairs (BRI♀ and BRI♂) (Fig. 2).

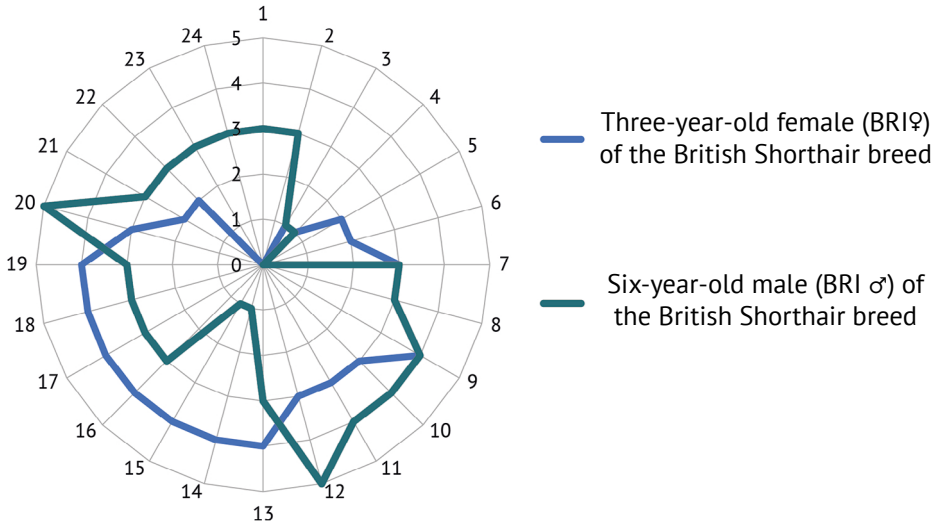

***Figure 1**. Daily activity of purebred cats*
***Source:** compiled by the authors*

Both males and females spend six hours a day sleeping and napping (25.0%). For the female, deep sleep lasts at night (from 23:00 to 4:00), and for the male – in the morning (5:00-6:00). In addition, the sleep phase in the male was recorded both at night (3:00-4:00) and during the day (14:00-15:00). The phases of the greatest activity (4-5 points) in both sexes coincide in time. For the female, these indicators were detected in the morning (at 9:00), from lunch (13:00) to twilight (19:00), and for males, such activity was recorded in the morning during 9:00-12:00 and in the evening at 20:00. Average activity (3 points) in animals of both sexes was recorded during daylight hours. For the BRI♀ female (7:00-8:00; 10:00-12:00) and in the evening at 20:00. And for the BRI♂ male (7:00-8:00; 16:00-19:00), in the evening and at night (21:00-2:00).

In accordance with the points assessment of the activity of animals of the British Shorthair breed in the pair BRI♀ and BRI♂, the results obtained were confirmed statistically. When the values of Kendall's rank correlation coefficient are 0.4 and the critical point is 0.29|τ|>Tkr ($p<0.05$). Therefore, the reliability of the correlation between the manifestation of behavioural acts and the synchronisation of the daily activity of these animals is confirmed.

The results obtained, which characterise the temperament and character of cat breeds, differ little from those described in the literature. Active, mobile cats of the Siamese, British, and Siberian breeds are very freedom-loving and, moreover, British females do not like excessive affection, often show waywardness, demonstrate aristocracy with all their appearance. Siamese cats are aggressive and vindictive, often showing jealousy. The Siberian like to climb and play hunting. But cats of the Persian breed prefer a slower pace of life, a calm atmosphere, and an affectionate attitude. More often they move on the ground and are not tend to climb trees. These cats enjoy playing with toys, but also enjoy a relaxing rest in a secluded place (Cosgrove, 2022; Crowley, 2019).

According to the data of M. Mendl *et al.* (2010), it was confirmed that the dependence of the duration of behavioural responses and animal activity is determined genetically (i.e., depending on temperament). And according to the opinion (Stamps *et al.*, 2010) – it is formed under the influence of an external stimulus or environmental conditions at the time of manifestation of a behavioural act.

In an extended review of cats, Travnik *et al.* (2020) identified the main parameters of temperament, namely: activity, courage, friendliness, aggressiveness, openness, impulsivity, and dominance. However, according to M. Arahori *et al.* (2016,) little attention is paid to investigating the genetic basis of cat temperament. Although the papers of L. Stella and S. Croney (2019) partially confirmed expectations that animals with a proactive behaviour style (active and brave) will show higher motor activity. Instead, those with reactive responses to the stimulus (passive or fearful behaviour styles) are characterised by low motor activity.

Based on the results obtained and according to (Stella *et al.*, 2019), it is possible to state a decrease in the duration of innate acts of behaviour from lively, active representatives of the Siamese and Siberian to the slow aristocracy of the British Shorthair breed. Regarding the duration of acquired behavioural acts, there is an increase in the indicator between the Siamese, Siberian, and British Shorthair breeds. In lazy Persian cats, innate and acquired behaviours tend to align.

Only based on studies aimed at assessing the genetic correlation of heredity and temperament traits of animals (activity level, ability to contact people and others), the authors (Salonen *et al.*, 2019) stated differences in behaviour between breeds with different temperaments. The results of this study showed unreliability ($p<0.1$) of differences in the behaviour of breeds with the same temperament, whereas in animals with different temperaments, they were statistically substantial ($p<0.05$) for both behaviours.

In addition, the studies conducted by S. Mikkola (2021) established the existence of a relationship between the genetic characteristics of the breed and the behaviour with personal factors (the nature of the condition) of the animal. The identified predominance of the duration of innate behavioural acts (sleep and rest) – at rest, acts of optional behaviour – on days of increased activity of animals is offset by the integration (Dotsenko, 2019) of conditional and unconditional reflexes as part of unitary behavioural reactions (self-cleaning and toilet). Certain differences in behaviour both within the breed and between different breeds are genetically determined and are formed as a result of the adaptation of the animal body to certain living conditions.

The realisation that observing the behaviour of cats over relatively long intervals provides greater efficiency in creating a behaviour model as a reflection of the personality of the animal (Stella *et al.*, 2019) prompted a statistical comparison of the selected samples using Kendall's rank correlation coefficient (Bakhrushin, 2011).

The observation of animals with different temperaments demonstrated a predominance of the factual value of the rank correlation coefficient (τ) compared to the critical value (Tcr), which allowed concluding that there is a substantial consistency between the traits under study (Trouwborst, 2020). The results of the study once again proved that the behaviour and motor activity of animals with the same temperament do not correlate with each other. According to the points assessment of the activity of animals of the British Shorthair breed (in BRI♀ and BRI♂ pair), the authenticity of correlations of the manifestation of behavioural acts and synchronisation of the daily activity of the animals, due to specific breed characteristics formed during breeding under the influence of humans, can be certified.

CONCLUSIONS

The research on the adaptation of purebred cats, from the standpoint of the manifestation of the main forms of behaviour, behavioural acts, and daily cycles, confirmed their dependence on the genetic characteristics of the breed, personal factors of the condition of the animal, and the effect of an external stimulus or environmental conditions at the time of occurrence.

A decrease in the duration of innate behavioural acts and an increase in the duration of acquired behavioural acts were identified from lively, active representatives of the Siamese and Siberian to the slow British Shorthair breed. In lazy Persian cats, obligate and facultative behavioural responses tend to equalise ($p<0.1$).

The dependence of cat behaviour on temperament is was established. Sanguine cats showed a tendency to reduce the duration of facultative behavioural responses

compared to innate ones ($p<0.1$). While in melancholic cats, this ratio is diametrically opposite ($p<0.01$). Differences in the behaviour of breeds with the same temperament are unreliable ($p<0.1$), while in animals with different temperaments, they are statistically substantial ($p<0.05$) for both behaviour forms.

The identified predominance of the duration of innate behavioural acts (sleep and rest) – at rest, acts of optional behaviour – on days of increased activity of animals is levelled by the integration of conditional and unconditional reflexes in the composition of unitary behavioural reactions (self-cleaning and toilet). Statistical analysis of verification of the frequency of occurrence of individual short-term cycles of cats of different breeds showed the presence of substantial consistency between the traits in animals with different temperaments, while the behaviour and motor activity of animals with the same temperament do not correlate with each other.

Noticeable differences in the behaviour and activity of male and female purebred cats are poorly expressed because the temperament and character of these animals are determined by specific breed characteristics that were formed during breeding under the influence of humans. That is why this requires further research.

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CONFLICT OF INTEREST

None.

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Етологічна адаптивність домашніх тварин на прикладі різних порід кота свійського (*Felis silvestris catus* L., 1758)

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Анотація. Надмірне зростання антропогенного навантаження на живу природу, а саме неконтрольоване використання природних ресурсів, включаючи вирубку лісів, видобуток корисних копалин, марнотратні системи природокористування, зменшення біорізноманіття через інтенсивний розвиток сільського господарства, а останнім часом – війна, впливають на умови існування як диких, так і свійських тварин. У нових реаліях сучасного світу домашні тварини, втрачаючи звичне природне середовище, змушені або адаптуватися до змін, або припинити своє існування. *Метою роботи* було вивчення рівня адаптивності організму кота свійського (*Felis silvestris catus* L. ., 1758) в домашніх умов утримання. Для досягнення мети застосовували довготривалі методи: добового візуального спостереження, бюджету часу, з подальшим аналізом даних більшої активності тварин. Поведінку котів оцінювали за шестибальною шкалою: імітація полювання – активна гра з використанням іграшки (5 балів) та огляд території, стрибки, точіння кігтів (4 бали); спілкування з господарем – «пошук їжі» та «лащення» (3 бали); особиста гігієна – пасивна прогулянка, туалет (2 бали); відпочинок – стан «лінивої дрімоти»(1 бал), стан глибокого сну (0). Порівняння обраних вибірок здійснювали статистично, з використанням коефіцієнта рангової кореляції Кендала. Встановлено, що внутрішньо-породні та міжпородні відмінності тривалості поведінкових актів облігатної та факультативної форм поведінки в значній мірі визначається темпераментом та характером піддослідних тварин. Описано добову активність кішок різних порід, що визначається накладанням впливу генетично обумовлених циклів на специфічні риси характеру і формується в процесі селекції порід. Статистично доведено наявність значної узгодженості між досліджуваними ознаками у тварин з різним темпераментом. За умови подібності темпераменту, поведінка та рухова активність між собою не корелюють, а відмінності у поведінці й активності самців і самок породистих котів виражені слабо. Обґрунтовано, що отримані результати можуть послужити підґрунтям для розуміння проблем та складностей, що виникають у породистих кішок в процесі адаптації до життя поряд із людиною і, тим самим, забезпечать осмислення основних проявів етологічної адаптивності домашніх тварину

Ключові слова: етологія; адаптивність; поведінкові акти; неплемінні коти; породисті тварини

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Formation of seed potato yield depending on the elements of cultivation technology

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Abstract. It is possible to realise the maximum genetic potential of modern potato varieties by improving the elements of agricultural technology, in particular, optimising plant nutrition, which determines the relevance of this study. The purpose of the study was to substantiate the specific features of potato productivity formation depending on the elements of growing technology in Forest-Steppe conditions. Field studies were conducted during 2019-2021 on chernozem soils. The features of growth and development of potato varieties of various ripeness groups Laperla, Granada, and Memphis in Forest-Steppe conditions are examined. It is established that the yield of potato seed tubers of the varieties under study varies depending on the dose and method of fertilisation, the fraction of planting tubers, and varietal characteristics. The highest indicators of

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individual productivity of potato plants of the Laperla, Granada, and Memphis varieties were formed when locally applied in rows $N_{45}R_{45}K_{45}$ against the background of semi-rotted manure, phosphorus-potassium fertiliser, and the use of seed tubers with a fraction of >60 mm. As a result of the action of the factors under study, the number of stems in the bush and under it increased. A strong direct correlation was established between the number of stems in the bush and the number of tubers (r=0.78), with a coefficient of determination of 61.0%. The maximum yield of potato tubers of the examined potato varieties (29.7-41.1 t/ha) was obtained by local application of $N_{45}R_{45}K_{45}$ against the background of semi-rotted manure and phosphorus-potassium fertiliser, depending on the size of seed tubers by the largest transverse diameter. It was identified that the use of tubers with a fraction of >60 mm for planting the potato varieties under study is irrational since the consumption of seed material exceeds the yield growth indicators. It was determined that Laperla, Granada, and Memphis tubers with a fraction of 28-60 mm are optimal for planting potato varieties of different ripeness groups. The research results can be used to adjust the elements of agricultural technology of seed potatoes, obtain high-quality planting material, and conduct profitable agribusiness

Keywords: fertiliser; yield structure; individual plant productivity; variety; tuber size; tuber fraction

INTRODUCTION

Potatoes are one of the most widespread agricultural crops in the world, which ranks fourth after rice, wheat, and corn in terms of value and importance for the world's population and ensuring food security. Potato cultivation in many countries is conducted not only by large agricultural enterprises but also by small farms. This popularity of potato commercialisation is explained by its balance as a human food product, animal feed, and raw materials for the processing industry. Modern potato varieties and hybrids have a high potential for adaptability and productivity, which is the basis for obtaining stable high yields with valuable consumer, technical, and economic properties. Currently, many potato varieties have been imported to Ukraine from other countries, which are not yet fully adapted to the new growing conditions. Therefore, studies of the response of modern varieties to fertiliser optimisation depending on the fraction of seed tubers are relevant and of practical interest.

Balanced use of nitrogen, phosphorus and potash fertilisers is an important factor for maximising crop yields and achieving the desired quality. The study by researchers (Kyryliuk *et al.*, 2020; Biliavska *et al.*, 2021; Kotelnytska *et al.*, 2021) confirmed the improvement of the nutrient regime of the arable soil layer, optimisation of its agrophysical and water-physical indicators by applying organic and mineral fertilisers, which are mineralised by soil microorganisms and provide plants with available nutrients. The positive effect of optimising potato fertiliser on the yield and quality of tubers was noted in the works of many researchers. According to O. Iskakova and V. Gamajunova (2021), application of mineral fertilisers in autumn ($N_{32}P_{32}K_{32}$), before planting ($N_{48}P_{48}K_{48}$) and three-time foliar top dressing (Plantafol, 6 kg/ha) at the beginning of budding in 8-10 days ensures the formation of tuber yield at the level of 37-39 t/ha. The authors also investigated the effect of optimising potato nutrition on reducing the content of dry substances and starch in tubers and increasing the content of ascorbic acid. According to M. Polishchuk (2021a) application of organic and mineral fertilisers (manure 40 t/ha+$N_{90}P_{90}K_{90}$ and manure 40 t/ha+ +$N_{120}P_{120}K_{120}$) and potato planting rates of 50 thousand tubers/ha ensures the formation of the highest yield – 29.3 and 30.5 t/ha, respectively.

Now there is a discrepancy between the norms of planting potatoes and the yield of tubers. Thus, the consumption rates of planting material range from 3.0 to 5 t/ha, and the yield is only 11.0-16.0 t/ha, depending on the year of cultivation (Polishchuk, 2021b). Thus, the ratio between the yield and the planting rate (reproduction rate) is only 2.5-3.0, which makes the cultivation of this crop economically impractical. The correct choice of the size of planted potato tubers and compliance with scientifically based planting density are the crucial factors in solving this problem (Kumar & Aulakh, 2022).

A study by M.J. Sadawarti *et al.* (2021) established the effect of seed tuber size on the overall yield and output of commercial tubers. In the paper of S. Ebrahim *et al.* (2018), a research on the effect of seed tuber size (fractions 25-54, 35-45, and 46-55 mm) on the productivity of three potato varieties Gudenie, Jalene, and Kellacho in Ethiopia is presented. It is established that planting potatoes with large seed tubers ensures the formation of a maximum yield of 42.9 t/ha.

Studies conducted in the northwestern part of India are devoted to the examination of the influence of seed tuber size (25-55 mm, 35-45 mm, 45-55 mm) on potato tuber contamination and yield (Kumar *et al.*, 2021). Researchers identified that planting potatoes with medium (35-45 mm) and large (45-55 mm) seed tubers reduces the number and biomass of weeds, improves seed productivity and increases potato yield to 42.6 and 42.9 t/ha, respectively. However, they identified that it is more reasonable to plant tubers of medium size (35-45 mm).

The fraction of seed tubers affects the stem-forming ability of potato varieties (Ilchuk & Ilchuk, 2021). The maximum potato stalk was formed by varieties Kimmeriia (330

and 342 thousand stems/ha, respectively) and Shchedryk (268 and 375 thousand stems/ha, respectively) when planted with tubers with a fraction of ⩾45 mm and ⩾60 mm.

Consequently, the production of high-quality potato seed tubers is an important issue in traditional potato growing regions and should be improved by optimising agricultural technologies. Considering the above, the solution to the problem of growing potato seed material becomes relevant and requires the optimisation of elements of cultivation technology. The purpose of the study was to establish the dependence of the formation of the number of stems, the number of tubers under the bush, the mass of tubers from one bush on fertiliser, the fraction of seed material, and the varietal characteristics of potatoes.

MATERIALS AND METHODS

Research on the study of technology elements for potato productivity was conducted during 2019-2021 in the conditions of the farm "Olvia-S" (Sopyn village, Vinnytsia district, Vinnytsia region). The territory of the farm is located in the Forest-Steppe zone. The soil cover of the territory where the study was conducted is represented by deep low-humus medium-loamy chernozems. The arable layer (0-30 cm) of the soil of the experimental site has the following agrochemical indicators: humus content (according to Tyurin) 4.42%, easily hydrolysed nitrogen (according to Kornfield) – 12.0 mg/100 g, mobile phosphorus (according to Chirikov) – 17.1 mg/kg of soil, exchange potassium (according to Chirikov) – 17.8 mg/kg of dry soil, pH of salt extract – 6.5, hydrolytic acidity – 1.44 mg-eq/100 g, the sum of exchange bases is 35.2 mg-eq/100 g. The hydrothermal regime over the years of research was contrasting. According to the Vinnytsia meteorological station, during the growing season of 2019, 317.0 mm fell, which is 28.0 mm less than the annual average and 23.0 mm more than the amount of precipitation in 2020. The highest amount of precipitation (323 mm) was recorded in 2021. The air temperature during all the years of research (2019, 2020, and 2021) was higher by 0.8, 0.1, and 0.2°C, respectively, compared to the perennial average.

The three-factor field experiment was conducted according to the following scheme:

Factor A – varieties: Laperla – early, Granada – medium-early, Memphis – mid-season.

Factor B – fertiliser: 1. Control (without fertilisers); 2. 40 t/ha of semi-rotted manure under the predecessor $+K_{56}Mg_{16}S_{300}+P_{30}$ (background); 3. Background $+N_{30}R_{30}K_{30}$ (local application); 4. Background $+N_{45}P_{45}K_{45}$ (local application); background $+N_{60}P_{60}K_{60}$ (scattering application).

Factor C – tuber fraction (size according to the largest transverse diameter, mm and weight, g): 1. size <28 mm, weight 25-50 g; 2. size 28-60 mm, weight 51-80 g; 3. size 60 mm, weight 81-100 g.

Potatoes were grown according to the generally accepted technology for the Forest-Steppe zone. The potato planting rate was: for the fraction of <28 mm – 2-2.15 t/ha, 28-60 mm – 3.6-3.75 t/ha, 60 mm – 5.4-5.55 t/ha. Basic seed material of potato varieties was used for the study. The predecessor was winter wheat. Semi-rotted manure was applied under the predecessor – 40 t/ha. Potassium magnesium ($K_{28}Mg_8S_{15}$) and superphosphate (P_{30}) were applied for the main potato cultivation. During planting, Azofoska ($N_{15}R_{15}K_{15}$) was applied either in a scattering technique for pre-sowing cultivation. During the growing season of potatoes, phenological observations of plant growth and development were conducted and the following phases were visually noted: germination, budding, flowering, and tops dying off (Kutsenko *et al.*, 2002). Individual potato productivity was determined according to generally accepted methods (Bondarchuk & Koltunov, 2019). The fractional composition of seed potato tubers was determined by selection from all variants of the experimental sites in the first and third repetition. The mass of one sample was 10 kg. Potato tubers in the selected samples were divided into three fractions according to the largest transverse diameter: less than 28 mm, 28-60 mm, and over 60 mm. The number of tubers of each fraction was counted, weighed, and determined as a percentage of the total number. Accounting of tuber yield and determination of potato seed productivity was conducted in accordance with generally accepted methods (Kucenko *et al.*, 2002). The obtained results were processed according to modern statistical methods using computer programmes Excel and Statisaca 6.0.

RESULTS AND DISCUSSION

It is possible to ensure the full realisation of the genetic potential of potato varieties by creating optimal conditions for the growth and development of plants in accordance with their needs during the growing season. Individual potato productivity depending on fertiliser, the fraction of planting tubers, and varietal characteristics is shown in Table 1.

With an increase in the fraction of planting tubers, the number of stems in the Laperla variety increased from 3.1 to 3.6 pcs./bush, the number of tubers – from 6.1 to 6.5 pcs./bush, and the mass of tubers – from 358.1 to 391.3 g/bush on the version without fertiliser. Application of 40 t/ha of semi-rotted manure under the precursor, potassium magnesia $K_{56}Mg_{16}S_{30}$, and superphosphate (P_{30}), basic potato cultivation, and an increase in the fraction of planting tubers contributes to an increase in the number of stems from 3.3 to 3.9 pcs./bush, the number of tubers – from 6.9 to 7.3 pcs./bush, and the mass of tubers – from 438.2 to 484 g/bush. An increase in individual potato productivity was observed against the background of phosphorus-potassium fertiliser and the aftereffect of semi-rotted manure and the local application of Azofoska ($N_{30}R_{30}K_{30}$). In this variant, the number of stems increases from 3.5 to 4.0 pcs./bush, the number of tubers – from 7.1 to 7.6 pcs./bush, and the mass of tubers from one bush – from 499.8 to 548.7 g.

***Table 1**. Individual potato productivity depending on fertiliser, seed tuber fraction, and variety, average for 2019-2021*

Fertiliser (factor C)	Tuber fraction, mm (Factor B)	Quantity, pcs./bush		Mass of tubers, g/bush
		stems	tubers	
Laperla variety – factor A				
Control (without fertilisers)	1	3.1	6.1	358.1
	2	3.4	6.3	374.2
	3	3.6	6.5	391.3
40 t/ha+$K_{56}Mg_{16}S_{30}+P_{30}$ (background)	1	3.3	6.9	438.2
	2	3.6	7.1	460.1
	3	3.9	7.3	484
Background +$N_{30}R_{30}K_{30}$ (local application)	1	3.5	7.1	499.8
	2	3.8	7.3	520.5
	3	4.0	7.6	548.7
Background +$N_{45}P_{45}K_{45}$ (local application)	1	3.7	7.5	545.3
	2	4.0	7.8	570.2
	3	4.3	8.1	595.4
Background +$N_{60}P_{60}K_{60}$ (scattering application)	1	3.6	7.2	515.5
	2	3.9	7.5	543.0
	3	4.2	7.8	571.0
Variety Granada – factor A				
Control (without fertilisers)	1	3.5	6.5	464.8
	2	3.7	6.7	483.1
	3	3.9	7.0	510.3
40 t/ha of manure +$K_{56}Mg_{16}S_{30}+P_{30}$ (background)	1	3.7	7.8	581.9
	2	3.9	8.0	600.8
	3	4.1	8.3	629.1
Background +$N_{30}R_{30}K_{30}$ (local application)	1	3.9	8.6	665.6
	2	4.2	8.8	688.2
	3	4.5	9.1	718.9
Background +$N_{45}P_{45}K_{45}$ (local application)	1	4.2	9.0	702.9
	2	4.5	9.2	725.9
	3	4.8	9.5	755.3
Background + $N_{60}P_{60}K_{60}$ (scattering application)	1	4.1	8.8	864.6
	2	4.3	9.0	707.4
	3	4.4	9.3	735.6
Memphis – factor a variety				
Control (without fertilisers)	1	3.2	6.2	390
	2	3.4	6.4	405.1
	3	3.6	6.7	428.8
40 t/ha of manure +$K_{56}Mg_{16}S_{30}+P_{30}$ (background)	1	3.3	8.1	552.4
	2	3.6	8.2	569.1
	3	3.9	8.5	596.7
Background + $N_{30}R_{30}K_{30}$ (local application)	1	3.5	8.2	577.3
	2	3.8	8.5	606.1
	3	4.1	8.8	632.7
Background +$N_{45}P_{45}K_{45}$ (local application)	1	3.7	8.5	609.5
	2	4.0	8.9	645.3
	3	4.3	9.2	675.3
Background + $N_{60}P_{60}K_{60}$ (scattering application)	1	3.6	8.5	605.2
	2	3.8	8.7	625.5
	3	4.2	9.0	653.4

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

The highest indicators of individual productivity of potato plants are formed with an increase in the fraction of planting tubers against the background of phosphorus-potassium fertiliser and the aftereffect of semi-rotted manure and the local application of Azofoska ($N_{45}R_{45}K_{45}$). For these options, the number of stems per bush increases from 3.7 to 4.3 pcs., the number of tubers per bush – from 7.5 to 8.1 pcs., and the weight of tubers per bush – from 545.3 to 595.4 g. Application of Azofoska by scattering under pre-sowing cultivation ($N_{60}R_{60}K_{60}$) against the background of phosphorus-potassium fertiliser and the aftereffect of semi-rotted manure does not provide an increase in individual productivity indicators compared to the previous version. Therefore, it is more effective for plants to use nutrients when applying fertilisers locally compared to applying them in a scattering technique.

The highest indicators of individual productivity among the varieties under study were observed in the Granada Variety at all variants of the experiment. Thus, in the control (without fertilisation), the number of stems was 3.5-5.9 pcs., the number of tubers under the bush – 6.5-7.0 pcs., and the mass of tubers from one bush – 464.8-510.3 g. Against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser for the main cultivation of Granada potatoes, an increase in the number of stems from 3.7 to 4.1 pcs., the number of tubers from one bush and from 7.8 to 8.3 pcs., and the mass of tubers from the bush from 581.9 to 629.1 g was observed, depending on the fraction of planting tubers. Local application of Azofoska in rows ($N_{30}R_{30}K_{30}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser provided an improvement in the indicators of individual productivity of the Granada variety. Thus, in this variant, the number of stems is 3.9-4.5 pcs./bush, the number of tubers is 8.6-9.1 pcs./bush, and the weight of tubers is 665.6-718.9 g/bush, depending on the fraction of planting tubers. The highest indicators of individual productivity of the Granada variety were identified in the local application of Azofoska ($N_{45}R_{45}K_{45}$) against the background of the aftereffect of manure and phosphorus-potassium fertiliser. Thus, the number of stems increases from 4.2 to 4.8 pcs./bush, the number of tubers – from 9.0 to 9.5 pcs./bush, and the weight of tubers – from 702.9 to 755.3 g/bush, depending on the fraction of planting tubers.

Application of Azofoska by scattering under pre-sowing cultivation ($N_{60}R_{60}K_{60}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser does not provide an increase in the number of stems and tubers in the bush, the mass of tubers from one Granada potato bush compared to the previous version. This indicates a smaller efficiency of applying fertilisers in a scattering technique compared to the local one. When applied locally, fertilisers are placed at a certain depth of the soil with a better moisture regime, where a zone with an increased concentration of nutrients is created. This contributes to the full use of nutrients by plants during the growing season.

The number of stems in the bush also has a substantial impact on the potato yield In the process of potato growth and development, each stem becomes an independent plant that has its own root system, forms stolons and tubers. A strong direct correlation was established between the number of stems and the number of tubers in the bush (r=0.78), with a coefficient of determination of 61.0 %. Thus, an increase in the first indicator leads to an increase in the second (Figure 1). The yield of potato tubers depends on the productivity of each main stem, the number of stems in the bush, and the number of plants per area unit.

During three years of research, the structure of the potato yield was determined depending on the fertiliser, the fraction of planting tubers and varietal characteristics (Fig 2-4). As a result of the research, it was identified that with an increase in the fraction of planting tubers (from <28 to 60 mm) in the structure of the potato yield, the share of the tubers with the largest transverse diameter of 28-60 mm increases. Thus, in the Laperla Variety, the proportion of tubers in control (without fertilisers) with the largest transverse diameter of 28-60 mm is 42-51.1%, depending on the increase in the fraction of planting tubers (Fig. 2).

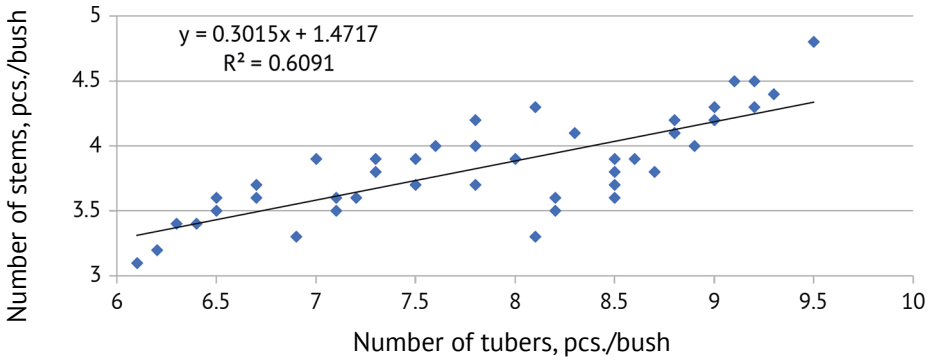

Figure 1. *Correlation between the number of stems and the number of tubers in the bush*
Source: *compiled by the authors*

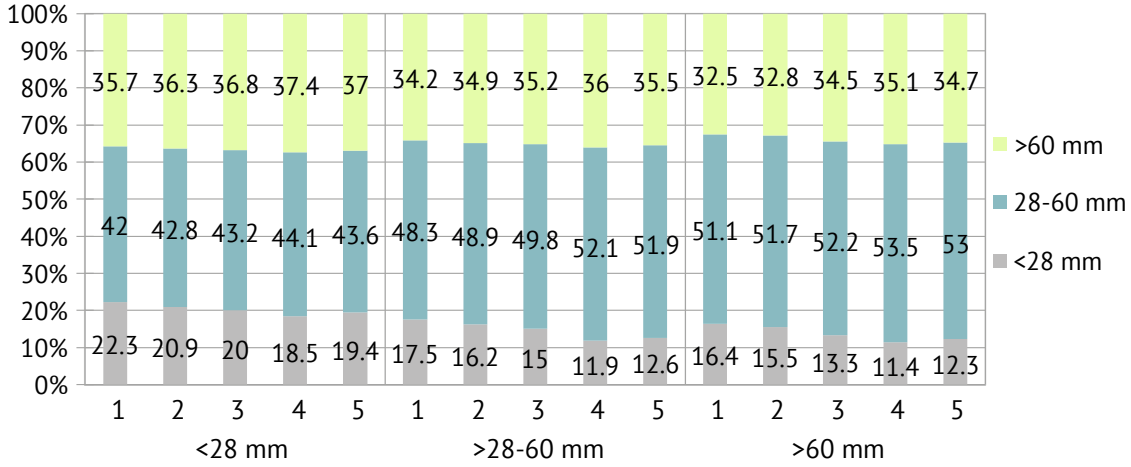

***Figure 2**. Structure of the Laperla potato yield depending on the fraction of seed tubers and fertiliser (2019-2021), %*
***Note:** 1. Control (without fertilisers); 2. 40 t/ha semi-rotted manure under the predecessor +$K_{56}Mg_{16}S_{30}$+P_{30} (background); 3. Background +$N_{30}R_{30}K_{30}$ (local application); 4. Background +$N_{45}P_{45}K_{45}$ (local application); 5. Background +$N_{60}P_{60}K_{60}$ (scattering application).*
***Source:** compiled by the authors*

An increase in the fraction of planting tubers in the control caused a decrease in the proportion of tubers with the largest transverse diameter of >60 mm from 35.7 to 32.5%. This indicates that small planting tubers usually form one or two main stems with a small number of stolons and tubers. However, during the harvesting period, such potato plants usually form larger tubers. Notably, when planted with large seed tubers, more stems and tubers are formed, but smaller. Local application of Azofoska ($N_{45}R_{45}K_{45}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser provides the highest indicators (44.1-53.5%) of the yield of potato tubers of the Laperla variety with the size of the largest transverse diameter of 28-60 mm. This indicator exceeds that on the control by 2.1-2.4 %. The yield of tubers of the Laperla variety with the largest transverse diameter of >60 mm in this variant is 35.1-37.4%, which is 1.7-2.6% more compared to the control.

The highest rates of tuber yield (44.9-54.6%) for the largest transverse diameter of 28-60 mm were provided by the medium-early Granada variety with local application of Azofoska ($N_{45}R_{45}K_{45}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser (Fig. 3).

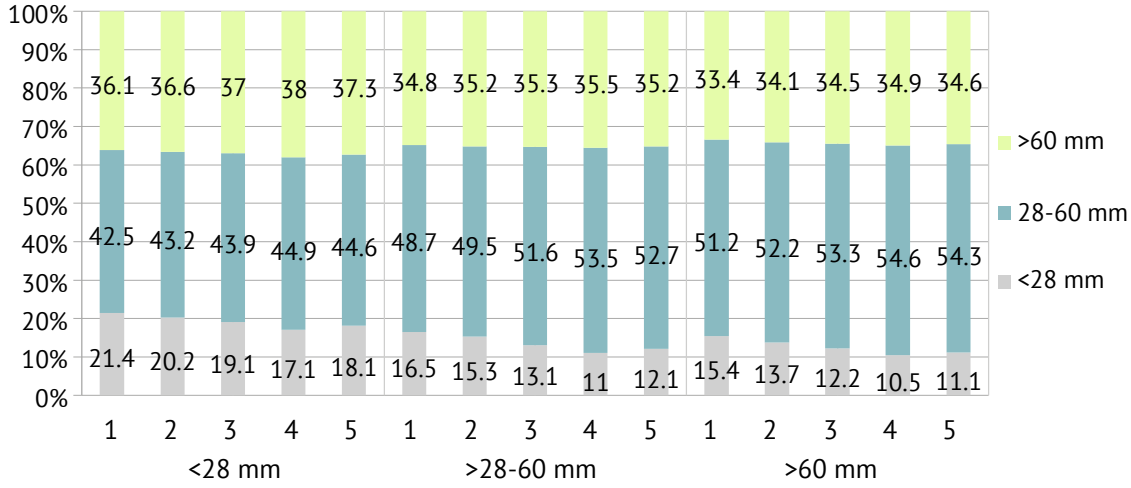

***Figure 3**. Structure of the Granada potato yield depending on the seed tuber fraction and fertiliser (2019-2021), %*
***Note:** 1. Control (without fertilisers); 2. 40 t/ha of semi-rotted manure under the predecessor +$K_{56}Mg_{16}S_{30}$+P_{30} (background); 3. Background +$N_{30}R_{30}K_{30}$ (local application); 4. Background +$N_{45}P_{45}K_{45}$ (local application); 5. Background +$N_{60}P_{60}K_{60}$ (scattering application)*
***Source:** compiled by the authors*

Notably, the proportion of tubers of this fraction varied depending on the size of the tubers of the planting material. Thus, the yield share of tubers of the Granada variety with the largest transverse diameter of >60 mm in this variant is 34.9-38.0%. The lowest yield rates of tubers (10.5-17.1%) for the largest transverse diameter of <28 mm were formed by the Granada variety depending on the fraction of planting material, which is 4.3-4.9% less compared to the control. The best developed were plants from seed tubers of a >60 mm fraction. However, the yield structure (excluding seed material) was maximal in the case of planting slightly smaller tubers (fraction of 28-60 mm), so along with the average seed fraction of tubers, it is advisable to plant healthy small tubers (<28 mm).

The highest rates of tuber yield (44.9-54.3%) for the largest transverse diameter of 28-60 mm were provided by the mid-season Memphis variety with local application of Azofoska ($N_{45}R_{45}K_{45}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser (Fig. 4).

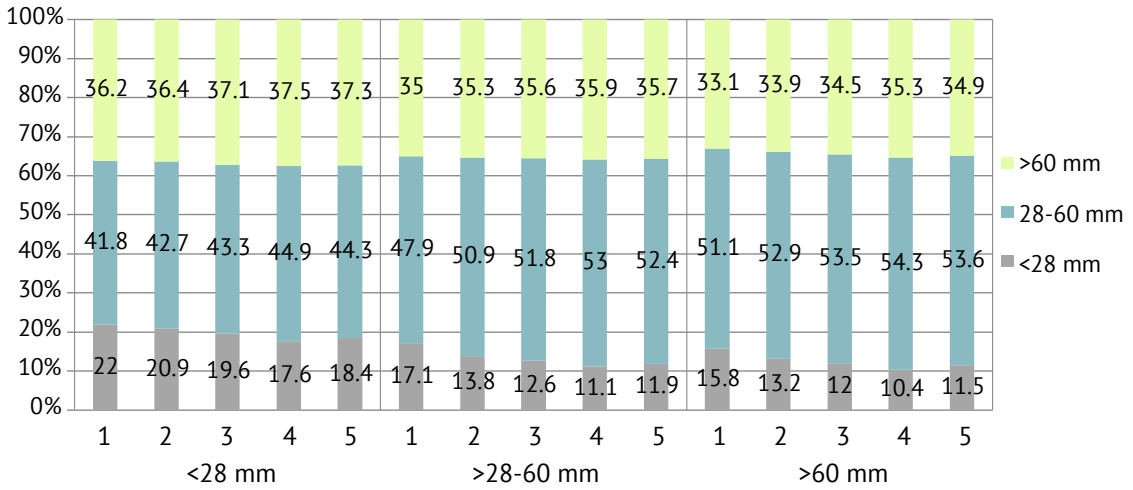

Figure 4. *Structure of the Memphis potato yield depending on the fraction of seed tubers and fertiliser (2019-2021), %*
Note: *1. Control (without fertilisers); 2. 40 t/ha semi-rotted manure under the predecessor +$K_{56}Mg_{16}S_{30}$+P_{30} (background); 3. Background +$N_{30}R_{30}K_{30}$ (local application); 4. Background +$N_{45}P_{45}K_{45}$ (local application); 5. Background +$N_{60}P_{60}K_{60}$ (scattering application)*
Source: *compiled by the authors*

The yield share of Memphis tubers with the largest transverse diameter of >60 mm in this variant is 35.3-37.5%, which is 1.3-2.2% more compared to the control. It is known that the yield of potatoes depends on the fraction of planting tubers. The features of the formation of yields of three potato varieties of different ripeness groups depending on fertiliser and seed tuber fraction were examined (Fig. 5)

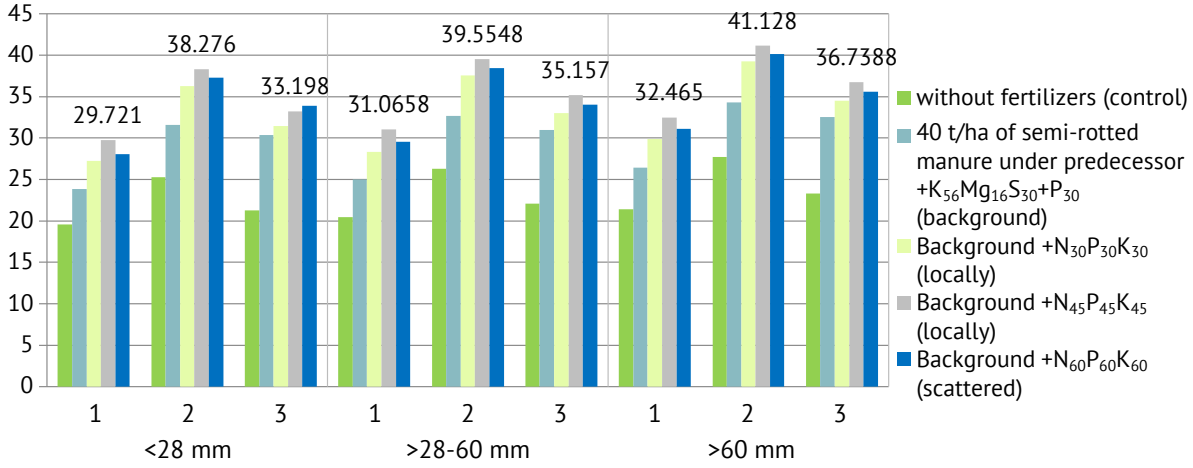

Figure 5. *Yield of potato varieties of different ripeness groups depending on fertiliser and factions seed tubers (2019-2021), t/ha*
Note: *1. Laperla Variety; 2. Granada Variety; 3. Memphis Variety*
Source: *compiled by the authors*

On average, over three years, the highest yield of tubers (41.13 t/ha) was provided by the medium-early potato variety Granada in experimental plots where Azofoska ($N_{45}R_{45}K_{45}$) was locally applied against the background of the aftereffect semi-rotted manure and phosphorus-potassium fertiliser, planted with tubers with a fraction of >60 mm. The increase in tuber yield was 32.6% compared to the control (without fertilisers). The use of seed tubers with a fraction of >60 mm for planting Granada potatoes increases the yield by 1.5 t/ha compared to the fraction of planting tubers of 28-60 mm with the same method and background of fertilisation. Therefore, when noting yield gains from planting large tubers, it is necessary to mention the consumption of planting material. That is, the difference in the consumption of planting material between the best two variants of the Granada potato variety in the experiment was 1.85 t/ha. Consequently, the increase in consumption of planting material was higher than the resulting increase in the yield of tubers.

A similar pattern was obtained in the early-maturing Laperla potato variety and the medium-maturing Memphis variety, where the yield was 32.5 and 36.7 t/ha, respectively, which is 34.2 and 36.5% more compared to the control (without fertilisers). The yield increase for planting these varieties with large tubers was 1.4 and 1.6 t/ha, respectively, and the difference in seed material consumption was 1.8 t/ha. That is, the seed material consumption on the variants for planting potatoes of Laperla and Memphis varieties with tubers with a fraction of >60 mm was also larger compared to the yield increases of these two varieties. Yield of seed potato varieties of different ripeness groups depending on fertiliser and the fraction of planting tubers (Fig. 6).

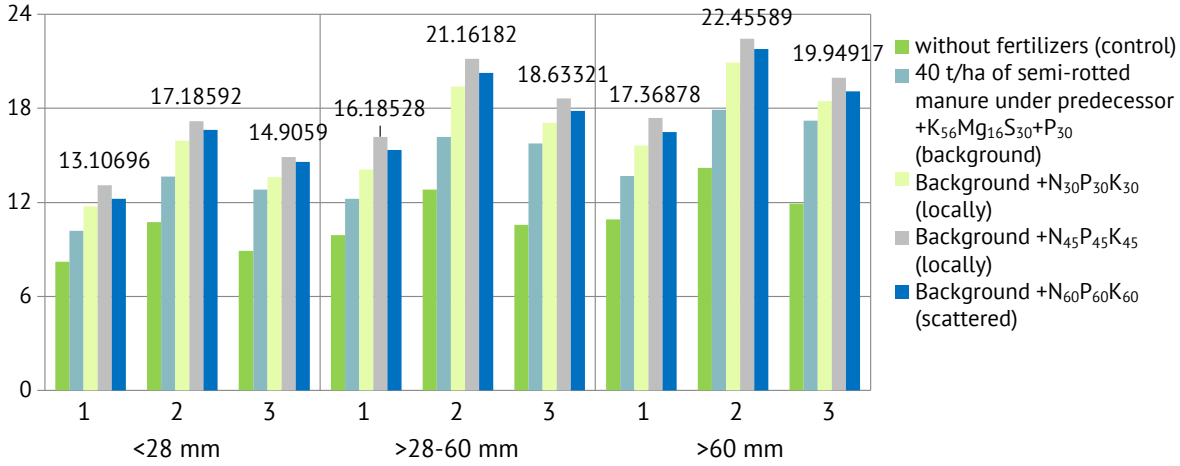

***Figure 6**. Yield of seed potato varieties of different ripeness groups depending on fertiliser and seed tuber fraction (2019-2021), t/ha*

***Note:** 1. Laperla Variety; 2. Granada Variety; 3. Memphis Variety*

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

The highest yield (22.45 t/ha) of seed potatoes (fraction of 28-60 mm) was provided by the Granada variety in experimental plots where Azofoska ($N_{45}R_{45}K_{45}$) was locally applied against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser, planted with tubers with a fraction of >60 mm. For local application of Azofoska ($N_{45}R_{45}K_{45}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser, planting tubers with a fraction of 28-60 mm, the yield was 21.2 t/ha. However, given the previously justified inexpediency of planting potatoes with tubers of the maximum size (>60 mm), due to the substantial consumption of planting material that was not overpowered by yield increases, it is advisable to use seed tubers with a fraction of 28-60 mm.

It is possible to ensure the formation of high tuber yields and increase resistance to adverse environmental conditions by providing potato plants with mineral nutrients adapted to their needs (Petropoulos *et al.*, 2020; Salikhov *et al.*, 2021; Naumann & Pawelzik, 2023). A study established that the application of mineral fertilisers affects the formation of the number of tubers and their mass (Mhango *et al.*, 2021). In the paper of P. Meise *et al.* (2019), the role of nitrogen in potato yield formation is highlighted. Sicilian researchers S. Lombardo *et al.* (2020) substantiated the application of nitrogen fertilisers (N_{140}) on typical soils of the region under study to obtain maximum yields of potato tubers with high consumer properties and increase the profits of producers. The dependence of the formation of individual potato productivity indicators on the application of organic and mineral fertilisers is confirmed by the obtained experimental data.

Similar studies by A. Podhaietskyi *et al.* (2019) confirm that the development of a large number of tubers in potato plants depends on the genetic characteristics of the variety or hybrid. The results are consistent with studies conducted in Ethiopia. It was identified that

planting potatoes with large seed tubers (46-55 mm) increases the number of stems and tubers per plant (Ebrahim *et al.*, 2018). S. Nasir and B. Akassa (2018) also reported an increase in the number of stems and tubers per plant when planted with large seed tubers. An increase in the number of stems in one potato bush under the influence of mineral fertilisers was also noted in the study by Y. Ilchuk & R. Ilchuk (2021). Thus, applying mineral fertilisers ($N_{60}P_{60}K_{90}$) increased the number of stems in the Shchedryk bush by 9.1 and 13.2% compared to the control, depending on the size of the planting tubers.

According to researchers (Podhaietsky *et al.*, 2019), one of the main factors in the productivity of potato varieties is the number of tubers formed in one plant. The dependence of potato yield on the number of stems and tubers in the bush is confirmed by the conducted research.

The results of this study are also consistent with those of D. AL-Taey *et al.*, (2008) on the positive impact of the use of organic and mineral fertilisers on improving the agrophysical condition of the soil, enhancing plant growth and development, and crop yield. According to U. Demirel (2023), to maximise the genetic potential of potato varieties during the growing season, it is necessary to create optimal conditions in accordance with the needs of plants. V. Gamajunova *et al.* (2021) confirmed that the selection of varieties and optimisation of plants with nutrients provides an increase in the yield of potato tubers by 64.7% compared to the control. M. Kravchuk *et al.* (2019) identified that using the organic-mineral fertiliser system (manure, 50 t/ha +straw, 3 t/ha +30 kg/ha +green manure, 22.5 t/ha +$N_{45}P_{50}K_{60}$) increases the yield of potato tubers by 28.3-30.6% compared to the control. The data obtained is also consistent with the studies by Polishchuk (2021a, 2021b), which report the formation of the highest indicators of tuber yield in the Serpanok variety at different planting rates (50-60 thousand units/ha) on variants with the application of organic and mineral fertilisers. Optimisation of elements of crop cultivation technology should ensure not only an increase in their yield but also the profitability of production (Kotelnytska, 2020). Therefore, when noting yield gains from planting large tubers, it is necessary to mention the consumption of planting material.

According to researchers (Singh *et al.*, 2003), small seed tubers lead to reduced productivity, while large tubers become uneconomical due to their increased cost. The findings of this stidy are also consistent with the data from obtained by V. Kumar *et al.* (2021). Thus, they received the highest net profit from planting potatoes with medium-sized seed tubers compared with small and large ones. Therefore, they also recommend using medium-sized tubers (35-45 mm) to obtain high yields of high-quality seed material and increase profitability in Northwestern India.

It was identified that planting potatoes with medium (35-45 mm) and large (45-55 mm) seed tubers provided the formation of yields of small tubers (<35 mm) up to 7.4 and 8.3 t/ha, respectively, and medium-sized tubers (35-45 mm) up to 16.6 and 17.3 t/ha, respectively. The highest yield of tubers (20.2 t/ha) of large size (>45 mm) was obtained by planting small seed tubers (25-55 mm).

CONCLUSIONS

The formation of individual productivity indicators of potato varieties (the number of stems and tubers per bush, the mass of tubers per bush) depends on the method and background of fertilisation, varietal characteristics, and the fraction of seed tubers. Local application of Azofoska ($N_{45}R_{45}K_{45}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser provides an increase in the number of stems and tubers in the bush, the mass of tubers per bush, and the yield of potato varieties of different ripeness groups Laperla, Granada, and Memphis in Forest-Steppe conditions. The maximum indicators of the yield structure and the number of stems of Laperla, Granada, and Memphis varieties were observed in the experiment, where with an increase in the fraction of planting tubers against the background of phosphorus-potassium fertiliser and the action of semi-rotted manure, local application of Azofoska was conducted ($N_{45}R_{45}K_{45}$).

The highest yield rates of tubers of the Laperla, Granada, and Memphis varieties, the size of which with the largest transverse diameter of 28-60 mm, were obtained in the experiment, where locally applied Azofoska ($N_{45}R_{45}K_{45}$) against the background of the aftereffect of semi-rotted manure and phosphorus-potassium fertiliser for increasing the fraction of planting material. The yield of tubers in the varieties Laperla, Granada, and Memphis was 44.1-53.5%, 44.9-54.6%, 44.9-54.3% accordingly, the proportion of tubers with the largest transverse diameter of >60 mm varied from 37.4 to 35.1%, from 38.0 to 34.9%, and from 37.5 to 35.3%, respectively.

For rational use of seed material, potato varieties of different ripeness groups Laperla, Granada, and Memphis should be planted with tubers with a fraction of 28-60 mm. The inexpediency of using seed tubers with a fraction of >60 mm is explained by an increase in the consumption of planting material compared to the obtained yield increases. In addition, the yield structure (excluding seed material) was maximal when used for planting seed tubers with a fraction of 28-60 mm. Further research should focus on identifying the features of the formation of seed productivity of potatoes depending on the fertiliser and fraction of planting tubers due to the emergence of new varieties, subject to a change in the climate of the growing area.

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CONFLICT OF INTEREST

None.

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Формування урожайності насіннєвої картоплі залежно від елементів технології вирощування

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Анотація. Реалізувати максимальний генетичний потенціал сучасних сортів картоплі можна за рахунок удосконалення елементів агротехнології, зокрема оптимізації живлення рослин, що зумовлює актуальність цього дослідження. Метою роботи було обґрунтувати особливості формування продуктивності картоплі залежно від елементів технології вирощування в умовах Лісостепу. Польові дослідження проводили впродовж 2019-2021 рр. на чорноземних ґрунтах. Досліджено особливості росту і розвитку сортів картоплі різних груп стиглості Лаперла, Гранада і Мемфіс в умовах Лісостепу. Встановлено, що урожайність та вихід насіннєвих бульб картоплі досліджуваних сортів змінюється залежно від дози і способу внесення добрив, фракції садивних бульб та сортових особливостей. Найвищі показники індивідуальної продуктивності рослин картоплі сортів Лаперла, Гранада і Мемфіс сформовано за локального внесення в рядки $N_{45}P_{45}K_{45}$ на фоні дії напівперепрілого гною і фосфорно-калійного удобрення та використання насіннєвих бульб з фракцією >60 мм. У результаті дії досліджуваних факторів збільшується кількість стебел у кущі, кількість та маса бульб під одним кущем. Встановлено високої сили прямий кореляційний зв'язок між кількістю стебел у кущі і кількістю бульб (r=0,78), з коефіцієнтом детермінації 61,0%. Максимальну урожайність бульб картоплі досліджуваних сортів картоплі (29,7-41,1 т/га) отримали за локального внесення $N_{45}P_{45}K_{45}$ на фоні дії напівперепрілого гною і фосфорно-калійного удобрення залежно від розміру насіннєвих бульб за найбільшим поперечним діаметром. З'ясовано, що використання бульб фракцією >60 мм для садіння досліджуваних сортів картоплі є не раціональним, оскільки витрати насіннєвого матеріалу перевищують показники приросту урожайності. Визначено, що оптимальним для садіння сортів картоплі різних груп стиглості Лаперла, Гранада і Мемфіс бульб з фракцією 28-60 мм. Результати досліджень можуть бути використані для корегування елементів агротехнології насіннєвої картоплі, отримання якісного садивного матеріалу і введення прибутного агробізнесу

Ключові слова: удобрення; структура врожаю; індивідуальна продуктивність рослин; сорт; розмір бульб; фракція бульб

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Tomato leaf color as predictor of soil moisture value using machine learning techniques

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Abstract. Fresh water supplies for irrigation purposes must be used sparingly and judiciously, as water is an invaluable natural resource that is in short supply in much of the Earth. Soil moisture in fields is not uniform everywhere, and deploying thousands of sensors is unnecessarily expensive. The purpose of this publication is to model and predict the relationship between tomato plants leaf color, soil moisture, and thus manage the irrigation process in an optimal manner. The research was conducted using generally accepted methods, the field method, and the method of statistical evaluation of results. Machine learning algorithms (MLA) and data mining are utilized in this paper to model the relationship between RGB color values from tomato leaves and soil moisture and temperature. The color of the leaves of open field tomato plantations grown without stakes is the focus of this study. Three main tasks are fulfilled: to prove that there is a relationship between leaf color and soil moisture, to study its supposedly nonlinear type and to model this relationship with MLA. First, a classifier is trained, and then a model is created and saved. Finally, the efficiency of the chosen model is tested using a different test data set. The name "12-9-6-3" for the methodology of measurements is fgiven. It is proven that the young leaves are more informative about the need for watering. As a result, there is less than a 1% error in predicting soil moisture using the color of tomato leaves

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considering also soil temperature, using M5P regression model. This predictive model can be used in creation of automated systems for optimal irrigation management and water saving

Keywords: plant water status; soil moisture; leaves color; canopy color; nonlinear estimation

INTRODUCTION

Various methods and sensors for soil moisture measuring are available – direct and indirect, wireless or not. In general, they are expensive and the process of measuring soil moisture is labour-intensive, even overwhelming on the agricultural fields with a huge size of several thousand hectares, for example, or if it is a matter of deploying thousands of sensors. This also includes the non-uniformity of irrigation throughout the entire fields. That is why the relevance of the study is determined by the search for alternative ways to measure soil moisture.

For centuries, farmers have known the condition of their crops by their appearance and colour alone. Experienced farmers and professors from agricultural universities and faculties share their observations based on years of experience that "When a plant (whatever it is – tomato, pepper, wheat, etc.) is dried its leaves turn dark green and when the soil moisture is too high the leaves turn light green" (United Nations Development Programme, 2021).

Irrigation is critical to global agricultural productivity. However, the most effective use of water for irrigation and water-saving efficacy are frequently unexpectedly low (Jägermeyr *et al.*, 2015). It is also estimated that agriculture uses over 70% of global fresh water supplies, with around half of this being lost and wasted (United Nations Development Programme, 2021).

Tomatoes require hundreds of litres of water per square metre. Nederhoff & Stanghellini (2010) note that an average of 300-400 litres of water are used to produce 1 kg of fresh tomatoes in the open field, indicating that the use of irrigation water is extremely high. The authors point out that two other things are specific to watering tomatoes: they require a moderate amount of moisture in the soil. If the watering is overdone, in a short time they form a powerful vegetative mass and less fruit. Another important fact arising from drowning is that tomatoes are quite sensitive to soil deficiency of oxygen.

Koumanov *et al.* (2018) report on two well-known conventional methods of monitoring the irrigation process: groundwater monitoring and plant water monitoring. A number of authors emphasise the following methods of measuring soil moisture: gravimetric approach, dielectric methods (TDR, FDR), neutron probe, tensiometers (Bianchi *et al.*, 2017), thermal probe, soil psychrometer and resistance blocks (Pardossi *et al.*, 2000) are direct and indirect methods of monitoring soil water status (Dobriyal *et al.*, 2012). Some techniques for measuring plant water status include ZIM probes, pressure chambers (Levin, 2019), dendrometers, infrared thermometry measurements (Kalaidjieva *et al.*, 2015), pulse methods (Sela *et al.*, 20007), infrared gas analysers, and porometers.

Some researchers like Afzal *et al.* (2017) utilise electrical capacitance and leaf thickness as indicators of a plant's water condition in predicting plant water status and conducting appropriate watering. Mahan *et al.* (2015) consider canopy temperature as an indicator of plant water status. Ko-Madden *et al.* (2017) employs a proximal leaf monitoring device for determining plant water status to provide precise irrigation in wine grapes. The "sap flow method" measures flow directly through the plant, but the sensor is affixed to the stem and can limit development (Afonso *et al.*, 2020).

The authors of this study suggest that plants themselves can be a kind of biosensor or "high-tech biogadget", an indicator of soil moisture, and therefore, the purpose of the study is to develop an intelligent method for obtaining soil moisture values based on the colour of tomato plants' leaves in the open field.

MATERIALS AND METHODS

The impact of field microclimate variables soil moisture and soil temperature on the leaf colour (Fig. 1) in field tomato plantations (Solanum Lycopersicum, "Nikolina" variety, growing without stake) is the focus of this research. The studies were conducted on the experimental field of Agricultural University of Plovdiv's Faculty of Viticulture and Horticulture (Bulgaria), where all environmental parameters and plants health are kept at their peak. Tomatoes are sown in May. Colour measurements are taken at the start of July, 24 hours before watering. The climatic parameters of the field at that time: the air temperature during the experiments: about 31°C, humidity: 34%, illumination: 75.6 klx. The days preceding the experiment were with extremely high temperatures (about 40°C).

PCE RGB-1002 spectrum colorimeter and environmental parameter measuring equipment PCE-EM 883 was utilised. RGB (red-green-blue) colour space is a basic additive colour model which is mixed with white. Three values describe one colour: red, green, and blue. Each colour percentage can be anywhere between 0% and 100%. The RGB colour space is created using colour perception theories and research.

The Frequency-domain sensors (FDR) for measuring the volumetric water content Onset W-SMC and its pre-calibration to the specific field soil are described by Atanasov (2015). The volumetric water content (VWC) is the ratio of water volume to soil unit volume. The sensor

for measuring the soil temperature is Onset WTMB. The field's soil is an alluvial meadow with moisture on FC in the layer 0-40 cm equal to 30.9% VWC (Harizanova-Petrova & Ovcharova, 2015).

Figure 1. *Example of the plants under study*

Source: *photo by the authors*

Based on the authors plant measuring experience, a methodology for conducting the experiment which was used is proposed (Atanasov *et al.*, 2016; Atanasov, 2021), but in this study, the name "**12-9-6-3**" is given: 12 plants studied, 9 plants for model creation (training data set), 6 RGB values from young leaves (from the top of every plant, it's the most upper part), 3 RGB values from old leaves (from the bottom part) for each plant were measured and 3 plants for model testing (testing data set).

The procedure of training classifiers using the training data set consists of three steps. Step one: training a classifier – with a full training data set (9 plants, 54 young and 27 old leaves values). Step two: creating and storing a suitable model and stet three: testing the stored model with additional testing data set (3 plants, 18 young and 9 old leaves values).

Modelling does not account for instances of ill or diseased plants with discoloured leaves. The both testing and training data sets are numerical that trying to predict numerical values, which includes a regression problem. Classifier is trained using entire training data (referred into tables as "all leaves"), as well small datasets filtered using specific criteria (referred into the tables as "young leaves" and "old leaves").

It has been proved that the plant's young leaves are the most informative about the necessity of irrigation (Atanasov *et al.*, 2016; Atanasov, 2021). As a result, twice as many RGB colour samples are collected, and twice as many sample values are displayed in Table 1. At each measurement, the colour values are measured manually and randomly, one by one, from different leaves.

Table 1. *Examples of training data*

Plant No.	Leaf	R	G	B	Soil Mois	Soil Temp	Plant No.	Leaf	R	G	B	Soil Mois	Soil Temp
1	young	111	123	89	17.41	21.72	**5**	old	150	170	105	20.39	23.67
1	young	122	140	100	17.41	21.72	**6**	young	122	142	88	17.74	23.09
1	old	153	176	112	17.41	21.72	**6**	young	135	168	98	17.74	23.09
2	young	128	146	103	15.94	22.68	**6**	old	144	163	107	17.74	23.09
2	young	133	150	102	15.94	22.68	**7**	young	139	159	100	20.44	23.16
2	old	142	161	98	15.94	22.68	**7**	young	130	152	99	20.44	23.16
3	young	106	120	83	14.55	23.85	**7**	old	178	194	108	20.44	23.16
3	young	128	143	87	14.55	23.85	**8**	young	152	167	118	25.56	24.92
3	old	140	156	98	14.55	23.85	**8**	young	143	160	110	25.56	24.92
4	young	108	124	92	18.73	23.50	**8**	old	131	148	99	25.56	24.92
4	young	120	138	92	18.73	23.50	**9**	young	140	158	102	17.29	24.22
4	old	132	151	100	18.73	23.50	**9**	young	143	164	103	17.29	24.22
5	young	130	149	102	20.39	23.67	**9**	old	162	186	122	17.29	24.22
5	young	140	158	114	20.39	23.67							

Source: *developed by the authors*

Table 1 contains only sample input data. The colour measurements are made directly on each random leave with above mentioned pre-calibrated RGB colorimeter, not from photos. Soil moisture and soil temperature are measured once for each plant, near the stem, on 25-30 cm soil depth. Temperature of the soil is in degrees Celsius, and moisture of the soil is in percentages of VWC.

In this study, gravimetric soil moisture was also measured. The equipment is shown in Figure 2. The value obtained for the gravimetric soil moisture in the layer 0-20 cm (the root zone for tomatoes) is 22%. This corresponds to the average value for the obtained volumetric humidity, which ranged from 15% to 22% VWC in the measurements.

***Figure 2**. Equipment for gravimetric soil moisture measuring*
***Source:** photo by the authors*

The models of the relationship soil moisture – leaf colour were created using capabilities of the software applications Statsoft Statistica and Weka (Eibe *et al.*, 2016; Hall *et al.*, 2009). Linear and nonlinear MLAs were used in the modelling.

RESULTS AND DISCUSSION

Normal distribution check. The RGB colour model's Gaussian distribution is verified, and it can be found in the majority of colour components. Conclusions in Table 2 regarding the Gaussian distribution are made using the Shapiro-Wilk test and its significance level (probability). The values for W and p>>0.05 imply that the data is normally distributed. The results reveal that, with the exception of the R component in old leaves, all components have a Gaussian distribution. Table 2 also includes parameters: the arithmetic mean value, the standard deviation, median. The last two parameters: asymmetry and excess show how the distribution is deformed.

***Table 2**. Normal distribution check of RGB colour values; before irrigation*

Young leaves								
Colour	**Mean**	**SD**	**Median**	**Skew.**	**Kurt.**	**Shap.-Wilk W**	**p**	**Gauss. Distr.**
R	131.17	15.97	132.50	-0.31	-0.83	0.963	0.097	Yes
G	149.63	18.41	151.00	-0.10	-0.41	0.972	0.226	Yes
B	100.46	9.66	102.00	-0.47	-0.31	0.967	0.140	Yes
Old leaves								
Colour	**Mean**	**SD**	**Median**	**Skew.**	**Kurt.**	**Shap.-Wilk W**	**p**	**Gauss. Distr.**
R	145.78	17.38	142.00	1.02	0.75	0.921	0.042	No
G	164.85	18.18	161.00	0.94	0.89	0.939	0.114	Yes
B	105.93	9.43	107.00	-0.04	-0.36	0.973	0.701	Yes

***Source:** developed by the authors*

Training of classifier and storing of model. Seven regression algorithms for testing have been chosen. When evaluating regression algorithms, two parameters are particularly important: correlation coefficient and the root mean squared error. The correlation coefficient indicates how well the predictions correlate or change in relation to the actual output value. A value of 0 reflects the worst-case scenario, while a value of 1 represents a group of predictions that are completely correlated.

Root-mean-squared error – a metric that indicates how close the model's predictions are to the actual target values. It is the square root of the mean square

error, which is the sum of the squared deviations between the predicted and actual values. This statistic can be used to calculate the average error rate of a given prediction. (Brownlee, 2016). In the tables below, three further indications are presented for each MLA: mean absolute error, mean value, and relative absolute error.

Mean absolute error – a metric determining how accurate forecasts or predictions are in terms of actual outcomes. The Relative absolute error (also known as the Root relative squared error) is calculated by dividing the Mean absolute error by the ZeroR classifier error (a classifier that ignores all predictions and chooses the most often occurring value). Amount by which the result differs from the true value is known as absolute error. The relative error is a measure in % compared to the real value.

Applying Zero Rule Regression (ZeroR). This is a fundamental method in the regression algorithm that predicts the mean of the training dataset (Eibe *et al.*, 2016; Brownlee, 2016; Bouckaert *et al.*, 2009). Table 3 shows the obtained results.

***Table 3**. Zero Rule Regression Results*

	All leaves	Young leaves	Old leaves
Correlation coefficient	-0.30	-0.33	-0.60
Mean absolute error	2.33	2.36	2.46
Root-mean-squared error	3.06	3.06	3.16
Relative absolute error	100%	100%	100%
Root-relative squared error	100%	100%	100%
The mean value	18.67	18.67	18.67

***Source:** developed by the authors*

For the whole set of training data, the ZeroR algorithm predicts a mean soil moisture value of 18.67 (in% volumetric water content) and a root-relative squared error of 3.06. Every other suitable and working MLA must have a greater value.

Linear Regression. When there are more instances than attributes, this technique works well (Witten, 2013). The linear algorithm assumes that the predicted attribute has a linear relationship with the other input attributes. Table 4 shows achieved outcomes.

***Table 4**. Linear Regression Results*

	All leaves	Young leaves	Old leaves
Correlation coefficient	0.52	0.51	0.25
Mean absolute error	2.16	2.16	2.43
Root mean squared error	2.61	2.62	3.12
Relative absolute error	92.80%	91.55%	99.02%
Root relative squared error	85.30%	85.72%	98.73%

***Source:** developed by the authors*

Thus, the analysed parameters have a confirmed extremely non-linear connection. As a result, authors continue with nonlinear algorithms modelling. **Locally Weighted Learning (LWL) Regression.** Authors use an instance-based algorithm to assign instance weights which are then used by a specified weighted instances handler (Huan *et al.*, 2021). Table 5 shows the outcomes achieved.

***Table 5**. Locally Weighted Learning Regression Results*

	All leaves	Young leaves	Old leaves
Correlation coefficient	0.80	0.80	0.79
Mean absolute error	1.39	1.40	1.50
Root-mean-squared error	1.81	1.82	1.84
Relative absolute error	59.54%	59.29%	60.65%
Root-relative squared error	59.31%	59.50%	58.46%

***Source:** developed by the authors*

Utilising Model Tree Regression (M5P). The model is a tree, with each leaf containing a linear regression model (Witten, 2013). R. Quinlan created the original M5 algorithm, and Yong Wang improved it. Table 6 displays the acquired results.

There are six linear models (LM) in the nonlinear model:

***Table 6**. Model Tree Regression Results*

	All leaves	Young leaves	Old leaves
Correlation coefficient	0.91	0.84	0.51
Mean absolute error	1.24	1.49	2.06
Root-mean-squared error	1.47	1.80	2.61
Relative absolute error	53.35%	62.90%	83.83%
Root-relative squared error	48.20%	58.67%	82.84%
Number of Rules (Leafs)	6	6	8

***Source:** developed by the authors*

LM num: 1
Soil_Mois=0.0921
*Soil_Temp+14.6772
LM num: 2
Soil_Mois=0.6291
*Soil_Temp+3.0529

LM num: 3
Soil_Mois=1.1355
*Soil_Temp-7.3392
LM num: 4
Soil_Mois=3.8151
*Soil_Temp-70.7297

LM num: 5
Soil_Mois=5.5662
*Soil_Temp-115.8946
LM num: 6
Soil_Mois=4.4335
*Soil_Temp-86.8402

Figure 3 shows the resultant tree depicted graphically after testing with the M5P method:

Decision Tree Regression (REPTree). Decision tree learning is a type of predictive modelling that employs a decision tree (as a predictive model) for progressing from observations about an item (represented by branches) to conclusions about the goal value of the item (represented in the leaves) (Brownlee, 2016). Table 7 shows the collected results.

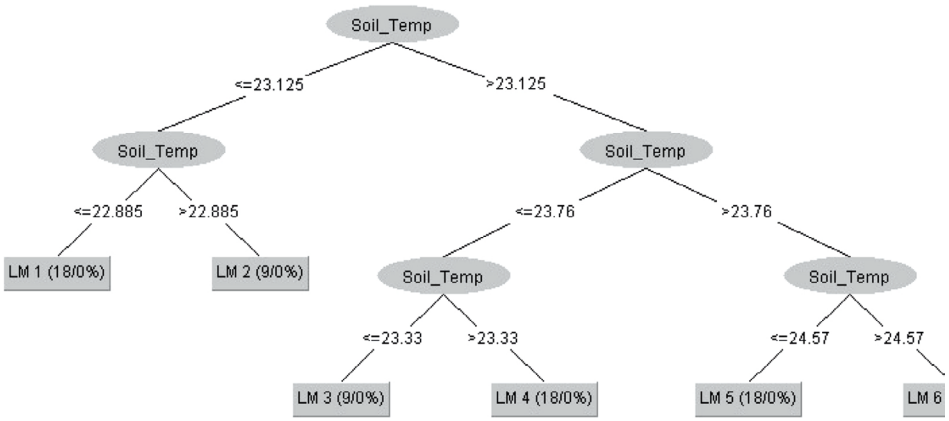

***Figure 3**. Visualisation of the resulting tree after M5P algorithm testing*

***Source:** developed by the authors*

***Table 7**. Decision Tree Regression Results*

	All leaves	Young leaves	Old leaves
Correlation coefficient	0.98	0.83	0.45
Mean absolute error	0.24	0.68	1.85
Root-mean-squared error	0.63	1.69	2.75
Relative absolute error	10.31%	28.84%	75.35%
Root-relative squared error	20.53%	55.11%	87.01%
Size of the tree (rules)	17	7	13

***Source:** developed by the authors*

The tree is turned upside down, beginning at the top or root and progressing through the leaves until a prediction can be made (Brownlee, 2016).

Applying Support Vector Regression (SMOreg). Support Vector Machines (SVM) finds a line of best fit that minimises a cost function's error. These instances are known as support. SVM is a classification method that requires teacher training (Kocaoglu & Akdogan, 2020). Table 8 shows the results obtained.

***Table 8**. Support Vector Regression Results*

	All leaves	Young leaves	Old leaves
Correlation coefficient	0.42	0.46	0.44
Mean absolute error	2.18	2.12	2.05
Root-mean-squared error	2.76	2.71	2.85
Relative absolute error	93.69 %	89.61 %	83.55 %
Root-relative squared error	90.32 %	88.66 %	90.30 %

***Source:** developed by the authors*

SMOreg is a regression support vector machine implementation (Smola & Schölkopf, 2004). Several algorithms can be used to learn the parameters. The algorithm is chosen by configuring the RegOptimizer.

Multilayer Perceptron Regression. Other names for it include artificial neural networks and neural networks. Neural networks are a tough method to utilise for predictive modelling since there are so many configuration parameters that can only be adequately tweaked by intuition and a lot of trial and error. (Brownlee, 2016). Table 9 shows the outcomes.

Summary table. Table 10 summarises the above calculations in a concise manner

***Table 9**. Multilayer Perceptron Regression Results*

	All leaves	Young leaves	Old leaves
Correlation coefficient	0.64	0.48	0.17
Mean absolute error	2.04	2.17	3.29
Root-mean-squared error	2.54	2.83	4.66
Relative absolute error	87.42%	91.95%	133.8%
Root-relative squared error	87.03%	92.48%	147.7%

***Source:** developed by the authors*

***Table 10**. Summary table*

All leaves	ZeroR	Linear Regr.	LWL	M5P	REPTree	SMOreg	MultyPerc
Correlation coefficient	-0.30	0.52	0.80	0.91	0.98	0.42	0.64
Mean absolute error	2.33	2.16	1.39	1.24	0.24	2.18	2.04
Root-mean-squared error	3.06	2.61	1.81	1.47	0.63	2.76	2.54
Relative absolute error	100 %	92.80 %	59.54 %	53.35 %	10.31 %	93.69 %	87.42 %
Root-relative squared error	100 %	85.30 %	59.31 %	48.20 %	20.53 %	90.32 %	87.03 %
Number of Rules (Leafs)				6	17		

***Source:** developed by the authors*

Testing the selected and stored model using the additional data set provided for this purpose, which is not included in the stored model. Despite the fact that Decision Tree has strong correlation coefficient (0.98), M5P MLA (0.91) is selected for testing the operability of the stored model. This is conditioned by the fact that the Decision Tree contains 17 leaves or rules, while M5P has only 6. With the help of stored M5P model, Table 11 shows the resulting prediction error and percentage, with less than a 1% inaccuracy in predicting soil moisture using leaf colour:

***Table 11**. Data obtained during the model's approbation*

Inst.	Actual	Predicted	Error	Error, %	Leaf	Inst.	Actual	Predicted	Error	Error, %	Leaf
1	20.61	20.584	-0.03	**-0.13%**	young	**14**	20.61	20.577	-0.03	**-0.16%**	young
2	17.85	17.747	-0.10	**-0.58%**	young	**15**	20.61	20.577	-0.03	**-0.16%**	old
3	17.85	17.973	0.12	**0.69%**	old	**16**	17.85	17.734	-0.12	**-0.65%**	young
4	20.61	20.577	-0.03	**-0.16%**	young	**17**	17.85	17.734	-0.12	**-0.65%**	young
5	17.85	17.975	0.13	**0.70%**	young	**18**	17.85	17.97	0.12	**0.67%**	old
6	20.61	20.577	-0.03	**-0.16%**	old	**19**	17.85	17.747	-0.10	**-0.58%**	young
7	17.85	17.747	-0.10	**-0.58%**	young	**20**	20.61	20.584	-0.03	**-0.13%**	young
8	20.61	20.584	-0.03	**-0.13%**	young	**21**	17.85	17.973	0.12	**0.69%**	old
9	17.85	17.973	0.12	**0.69%**	old	**22**	20.61	20.582	-0.03	**-0.14%**	young
10	17.85	17.984	0.13	**0.75%**	young	23	17.85	17.743	-0.11	**-0.60%**	young
11	17.85	17.751	-0.10	**-0.55%**	young	**24**	17.85	17.973	0.12	**0.69%**	old
12	17.85	17.984	0.13	**0.75%**	old	**25**	17.85	17.746	-0.10	**-0.58%**	young
13	17.85	17.975	0.13	**0.70%**	young	**26**	20.61	20.582	-0.03	**-0.14%**	young

***Source:** developed by the authors*

To determine the requirement for watering, it is feasible to develop and apply mathematical models that predict soil moisture content and plant water content, based on gathered data utilising conventional statistical approaches, using machine learning classification models (neural network, support vector machine, random forest and so on), combined – using classic methods and machine learning.

Guo *et al.*(2017) combined phenotyping and machine learning techniques to create a discrimination method for plant root zone water status in a greenhouse. Three root zone moisture levels, 40%, 60%, and 80% relative water content, were used and treated on pakchoi plants. Random Forest (RF), Neural Network (NN), and Support Vector Machine (SVM) classification models were developed and validated in different conditions, with overall accuracy of more than 90% for all. The SVM model had the highest value, but it required the most time to train. In all scenarios, all models achieved accuracy greater than 85%, while the RF model had more stable performance. The simplified SVM model created by the top five most contributing traits showed the greatest accuracy reduction of 29.5%, while the simplified RF and NN models maintained roughly 80% accuracy.

The study by Alhnaity *et al.* (2019) uses ML and DL algorithms to predict production and plant growth variance in two different scenarios, tomato yield forecasting and Ficus benjamina stem growth, under controlled greenhouse conditions. In the prediction formulas, they used a new deep recurrent neural network (RNN) model based on the Long Short-Term Memory (LSTM). The RNN architecture models the intended growth parameters using the previous yield, growth, and stem diameter values, as well as the microclimate variables. A comparison analysis is presented that employs ML approaches such as support vector regression and random forest regression, as well as the mean square error criterion, to evaluate the performance of the various methods.

Gutiérrez *et al.* (2018) describe a mobile method for estimating vineyard water status based on thermal imaging and machine learning. A thermal camera was mounted on an all-terrain vehicle traveling at 5 km/h to capture on-the-fly thermal photos of the vineyard canopy at 1.2 m and 1.0 m above ground. The canopy's two sides were measured in order to create side-specific and global models. The potential of stem water was measured and utilised as a reference method. Additionally, reference temperatures Tdry and Twet were determined for the calculation of two thermal indices: the crop water stress index (CWSI) and the Jones index (Ig). Prediction models were created both with and without the use of reference temperatures as input to the training algorithms. Using the reference temperatures, the best models had R^2 determination coefficients of 0.61 and 0.58 for cross validation and prediction, respectively (RMSE values of 0.190 MPa and 0.204 MPa). Yet, when the reference temperatures were not considered during model training, their performance statistics responded similarly, with R^2 values up to 0.62 and 0.65 for cross validation and prediction, respectively (RMSE values of 0.190 MPa and 0.184 MPa).

Dhillon (2015) created a continuous leaf monitoring system to monitor the water status of almond and walnut plants. The "Leaf Monitor" technology continuously measured leaf temperature and other microclimatic factors

in the area of the leaf to check plant water status. It included a thermal infrared sensor to monitor leaf temperature, and sensors to measure ambient temperature and relative humidity, photosynthetically active radiation (PAR), and wind speed. The sensor system additionally included a leaf holder, a solar radiation diffuser dome, and a wind barrier to increase the unit's effectiveness. Each leaf monitor system was integrated into a mesh network of wireless nodes, allowing data collection and transmission over the web at 16-minute intervals.

Based on the foregoing approach, the same researcher and his team (Dhillon *et al.*, 2019) created a method for predicting plant water status in almond and walnut trees using a continuous leaf monitoring system. Using leaf temperature and environmental data collected by the leaf monitor, a Modified Crop Water Stress Index (MCWSI) was constructed to measure plant water status. A linear association with a coefficient of determination (r^2) of 0.67 was discovered in the instance of walnut crop. In the instance of almonds, a quadratic association with a coefficient of multiple determination (R^2) value of 0.75 was discovered. Based on the relationship discovered between MCWSI and DSWP, the irrigation amount for low frequency variable rate irrigation (VRI) was calculated, and variable rate irrigation (VRI) resulted in an average 39% reduction in water usage when compared to the fixed 100% ET replacement irrigation method for all trees. Based on the findings, the leaf monitor has the potential to be used as an irrigation scheduling tool.

Japanese scientists (Zhao *et al.*, 2020) investigated the application of hyperspectral imaging to assess the water status of tomato leaves in plant factories. Five varieties of tomatoes were sampled for testing in this experiment – three Japanese varieties suitable for direct consumption and two Dutch varieties suitable for processing and cooking. Three plants were selected from each of the five varieties. A portable hyperspectral camera was used to non-destructively measure the water status of tomato leaves. The measurement area was divided into three parts: leaves were measured from the highest part of the plants (near the growing point, 250 cm from the ground), from the middle of the plants (150 cm from the ground) and from the bottom of the plants (60 cm from the ground). Sampling was done 267 days after the plants were sown. 45 measurements (photographs) and samples were taken. After processing and analysing the hyperspectral data the tomato leaf raw relative reflection (RAW), inversion-logarithm relative reflection (LOG), and first derivative of relative reflection (DIFF) were analysed using the normalised difference vegetation index (NDVI) and two-band vegetation index (TBI) from 900 nm to 1700 nm. TBI regression using DIFF at wavelengths of 1.410 nm and 1.520 nm produced the best regression model for WC assessment, whereas NDVI regression using RAW produced the best regression model for MC evaluation. The MC evaluation produced better model performance than the WC assessment. The findings will aid our knowledge of the link between hyperspectral reflectance and leaf hydration status.

Except studies of Atanasov *et al.* (2016) – conventional statistical approach and Atanasov (2021) – using machine learning techniques, there is a lack of information regarding the colour of the leaves to be utilised as an indicator of the requirement for irrigation or any water stress. Difference between these previous studies and the current one is as follows: using nonlinear regression statistical Quasi-Newton method in (Atanasov *et al.*, 2016) soil moisture is predicted utilising piecewise linear regression and using data mining and machine learning techniques by Atanasov (2021). Both studies (Atanasov *et al.*, 2016) and (Atanasov, 2021) are conducted in different tomato varieties and different conditions of tomato growing (greenhouse).

There is a lack of scientific research that establishes a direct relationship or models (whether linear or non-linear) between plant colour change (lightening or darkening) and thus predicting soil moisture and the need for watering.

CONCLUSIONS

With the help of machine learning techniques and data mining, the relationship between RGB colour values from open field tomato leaves and soil moisture and temperature is investigated and modelled. It was proven nonlinear relationship. The name "12-9-6-3" for the methodology of measurements of field data was given. It is proven that the young leaves are more informative about the need for watering.

In the process of predicting soil moisture based on the colour of field tomato leaves and soil temperature, seven regression machine learning classifiers with three training data sets were trained: Zero Rule, Linear Regression, Locally Weighted Learning, M5P Model Tree, Support Vector Machin, Decision Tree and Multilayer Perceptron. For each MLA a classifier was trained, and then a model was created and saved. The efficiency of the chosen model was tested using a different test data set.

M5P produced best results. It was chosen to check the performance with M5P (0.91), despite that Decision Tree has a high correlation coefficient (0.98) since Decision Tree contains a significant number of rules (17), whereas M5P only has 6 (Table 10). Using the stored M5P model, Table 11 displays the resulting prediction error and percentage.

Based on the findings in Tables 3 to 9, it was demonstrated again that young leaves before watering are a stronger indicator of the need for irrigation (better results received than using the old leaves). As a result, the chosen regression model M5P predicts soil moisture with a precision of 1% error based on the colour of the tomato leaves and soil temperature. Such soil moisture prediction models, based on plant leaf

colour change, besides saving labour time, automating routine repetitive actions, saving money and resources for expensive sensors and equipment, can be the basis of creating automated systems for automatic irrigation and saving water – only in the areas where it is needed, not in the entire agricultural field, a kind of precise irrigation based on the colour of the leaves of the plants themselves, the leaves serve as a natural biosensor.

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CONFLICT OF INTEREST

The authors report no conflict of interest.

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Колір листя томатів як показник вологості ґрунту з використанням методів машинного навчання

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Анотація. Запаси прісної води для зрошення повинні використовуватися економно і розумно, оскільки вода є безцінним природним ресурсом, якого не вистачає на більшій частині Землі. Вологість ґрунту на полях не всюди однакова, а встановлення тисяч датчиків є невиправдано дорогим. Мета цієї публікації - змоделювати та спрогнозувати взаємозв'язок між кольором листя рослин томатів та вологістю ґрунту, і таким чином оптимально керувати процесом зрошення. Дослідження проводили з використанням загальноприйнятих методів, польового методу та методу статистичної обробки результатів. Алгоритми машинного навчання (АМН) та інтелектуального аналізу даних були використані в даній роботі для моделювання зв'язку між значеннями кольору RGB листя томатів та вологістю і температурою ґрунту. У фокусі цього дослідження – колір листя томатів, вирощених у відкритому ґрунті без кілків. Було виконано три основні завдання: доведено, що існує зв'язок між кольором листя і вологістю ґрунту, досліджено його ймовірний нелінійний тип і змодельовано цей зв'язок за допомогою АМН. Спочатку навчався класифікатор, потім створюється і зберігається модель. Нарешті, ефективність обраної моделі перевірено за допомогою іншого тестового набору даних. Методологія вимірювань отримала назву "12-9-6-3". Доведено, що молоде листя є більш інформативним щодо потреби в поливі. В результаті, за допомогою регресійної моделі M5P можна, з похибкою менше 1%, прогнозувати вологість ґрунту за кольором листя томатів, враховуючи також температуру ґрунту. Ця прогнозна модель може бути використана при створенні автоматизованих систем для оптимального управління поливом та водозбереження

Ключові слова: водний статус рослин; вологість ґрунту; колір листя; колір накриття; нелінійне оцінювання

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Onion stemphiliosis in the South of Ukraine

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Abstract. Onion stemphiliosis is a relatively new disease in Ukraine, so a deeper study of *Stemphylium*, the species composition of the pathocenosis, and isolation and determination of the species belonging of pathogens of the disease are relevant. The purpose of the study was to examine the species composition of pathocenosis, the biofenology of the causative agent of stemphiliosis, and determine the effectiveness of fungicides for further control of stemphiliosis in onion crops. The main research methods were: field – to determine the spread, development, and harmfulness of stemphiliosis; laboratory – to examine pathogens of onion diseases; visual and mathematical – statistical. The method of mycological crops on potato-dextrose agar (PDA) was used in the work. Field surveys in 2019-2021 established the spread and development of

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stemphiliosis in onion plantings in the Odesa District of the Odesa region. It was identified that the growing season of 2021 was the most favourable for stemphiliosis, when against the background of high humidity and air temperatures, the spread of the disease was 100%, and the development of the disease reached 79%. In onion crops, the disease developed unevenly, its spread was low in June, with rapid growth in July. At the beginning of August, the percentage of the disease reached 80%. Eight types of fungi were identified, of which *Stemphylium vesicarium (Wallr.) Simm, Stemphylium botryosum Wallr, Stemphylium herbarum Simm*. – are pathogens of onion stemphiliosis. Laboratory studies established the frequency of their distribution in samples. It is proved that five-time spraying with fungicides helps to reduce the further development of stemphiliosis in onion plantings. The high effectiveness of spraying plants with appropriate fungicides with the active substance fluopyram (200 g/l) + tebuconazole (200 g/l) and fluoxastrobin (100 g/l) + prothioconazole (100 g/l) to suppress the development of spores of pathogens is proven. The provisions and conclusions on the phytosanitary condition of onion plantations in the Odesa region are further developed. The results of the research can serve to develop recommendations for production on the implementation of measures to protect onions from stemphiliosis

Keywords: *Allium cepa* L.; monitoring; fungal mycoflora; Stemphylium vesicarium; effectiveness of fungicides

INTRODUCTION

Onion (onion *Allium cep*a L.) is one of the most important crops in the world, which is the second most valuable after tomatoes. The yield of onions can substantially decrease due to a number of factors, in particular, disease damage. Stemphiliosis is the most harmful and poorly investigated disease in Ukraine, the study of which is an urgent issue.

In recent years, there has been a substantial spread of stemphiliosis or black-grey spotting of onions. Stricker *et al*. (2021) indicate that stemphiliosis, causing premature leaf death, shortening the period of mass growth and maturation, can lead to a loss of onion yield by 28-38%, in the case of epiphytotics – up to 74%. Hausbeck & Werling (2018) notes that the disease has been reported sporadically on onion leaves over the past 30 years and has been considered a secondary pathogen, but in recent years *Stemphylium vesicarium* became the dominant pathogen that presumably displaced *Alternaria porri*, the causative agent of purple spotting. A study by Hay (2018) attributes this to the development of resistance to the fungicides used.

Hay *et al*. (2019) report that onion stemphiliosis is common in many regions of the world where onions and garlic are grown. However, it causes the most problems in warm regions. *S. vesicarium* can infect a wide range of plants: garlic, onion, asparagus, tomato, soy, alfalfa, lupine, mango, pear, etc. (CABI, 2021).

Effective control of stemphiliosis can be achieved only if a comprehensive approach is provided, including agrotechnical techniques, biological, chemical, and other methods. There are no varieties of onions that are resistant to stemphiliosis. Singh *et al*. (2018) in their research conducted in Taiwan, report that all onion varieties were susceptible to infection with *S. vesicarium* however, the degree of susceptibility was different.

Agrotechnical methods of controlling stemphiliosis are aimed at reducing the pathogen load on seed material and creating conditions less favourable for infection. Du Toit (2017) noted that drip irrigation reduces the risk of stemphiliosis infection by reducing the crop moisture period. Ways to reduce the duration of leaf moisture also include: reducing the density of standing plants, planning the rows of crops in the direction of prevailing winds, and irrigation late in the morning or early in the afternoon.

Biologics containing *Bacillus subtilis, Saccharomyces cerevisiae, Pseudomonas uorescens*, and *Trichoderma* spp are used to control stemphiliosis. Their use is possible only in combination with other methods of protection since they are not able to independently provide effective disease control in the field (Meena & Verma, 2017).

Treatment of plants with fungicides can substantially reduce the level of disease development, but studies by Tayviah (2017) report that *S. vesicarium* is at risk of developing resistance to fungicides since it has a short asexual reproductive cycle, produces several generations per season, forms many spores by sexual and asexual reproduction, in addition, it is necessary to repeatedly use fungicides during each growing season. Today, most publications about the resistance of *S. vesicarium* to fungicides are dedicated to pear stemphiliosis, but the same risk factors are characteristic of onion stemphiliosis.

Leach *et al*. (2020) examined the relationship between nutrition and thrips movement in the development of stemphiliosis on onions in a series of laboratory and field experiments. In laboratory studies, onion plants with varying degrees of thrips damage were infected with *S. vesicarium*. The results showed that reducing the number of thrips reduced the colonisation of onion plants by *S. vesicarium* by 2.3-2.9 times and leaf death – by 40-50%.

The purpose of the study was to investigate the epidemiology of stemphiliosis in onion plantings in the Odesa region. The objectives of the study were to examine the influence of climatic conditions on the development of the disease and assess the effectiveness of fungicides in protecting plants from it.

MATERIALS AND METHODS

Field experiments were conducted on planting onions of the Banco variety on the farm of the Ahrofirma "Petrodolynske" of the Odesa district of the Odesa region in 2019-2021. The crop was sown in the second decade of March. The soil is southern loamy chernozem, with a humus content of 3.67% and a pH of about 6.7. The seeding rate is 11 thousand seed/ha. Seeds sprouted 20-22 days after sowing.

The Totril 225 EC herbicide was used to control weeds in accordance with the recommendations: the first spraying – in the phase of 1-2 leaves of the crop, the consumption rate is 1.0-1.5 l/ha, the second spraying – as the weeds grow back, the consumption rate is 1.0-1.5 l/ha. In the second half of the growing season, 2 manual weeding operations were conducted.

Methods of mycological sowing on potato-dextrose agar (PDA) were used to examine the species composition of onion mycoflora. Isolates were collected from the leaves of 20-30 bulbs. Small leaf fragments with visible lesions were placed on potato agar and incubated at 22°C for two weeks in a thermostat. After the formation of mycelium, pathogens were identified by morphological characteristics. Identification of phytopathogens was conducted in accordance with the papers (MycoBank Database, 2022). Monitoring of the spread and development of stemphiliosis was conducted in dynamics during the growing season, starting from the moment the first signs of the disease appeared. 3 leaves were examined on 20 randomly selected plants from the accounting area on a 5-point scale: 0 points – no damage; 1 – affecting up to 10% of the surface; 2 – affected from 11 to 25% of the surface; 3 – affected from 26 to 50% of the surface; 4 – affected over 51% of the surface. The spread of the disease was determined by the following formula:

$$S = \frac{n * 100}{N} \quad (1)$$

where S – the spread of the disease; n – the number of affected plants; N – the total number of plants examined.

The development of the disease was determined by the following formula:

$$P = \frac{100 \sum(\mathrm{a} \times b)}{n * S} \quad (2)$$

where $\Sigma(a \times b)$ – the sum of the products of the number of plants (a) and the corresponding infection score (b); n – the total number of plants in the sample, pcs.; S – the highest infection score on the scale.

Table 1 shows the fungicides and their consumption rates that were used on onions from stemphiliosis. Preparations were applied using a mounted satchel sprayer with 6 flat-jet nozzles, the distance between the nozzles is 50 cm, calibrated for applying 400 l/ha. The size of the experimental plot is 24 m^2, repetition is fourfold. Accounting for leaf damage began with the appearance of the first signs of the disease, the following before each spray, and even 10-15 days after the last treatment.

***Table 1**. Fungicides, active ingredients and consumption rates used to evaluate effectiveness in field trials for stemphiliosis on onions, 2019-2021*

Active ingredient	Consumption rate
Difenoconazole (250g/l)	0,5 l/ha
Azoxystrobin (250 g/l)	1.0 l/ha
Praklostrobin (67 g/kg) + boscalid (267 g/kg)	1.5 kg/ha
Ciprodinyl (375 g/l) + fludioxonil (250 g/l)	1.0 kg/ha
Fluoxastrobin (100 g/l) + prothioconazole (100 g/l)	1,25 l/ha
Floupiram (200 g/l) + tebuconazole (200 g/l)	0,75 l/ha

***Source:** developed by the authors based on (Letter from the State Customs Service of Ukraine No. 18/18-1159-EP, 2005)*

The effectiveness of the drugs under study was determined by the formula:

$$E = \frac{100 * (D_c - D\partial)}{D_c} \quad (3)$$

where D_c – indicator of the development of the disease in control; $D\partial$ – indicator of the development of the disease in the experimental version.

The obtained experimental data were processed using the variance analysis method.

RESULTS AND DISCUSSION

Onions are one of the most popular vegetable crops in Ukraine, with acreage ranging between 30-40 thousand hectares. The main volume of production is concentrated in the southern regions of Ukraine, where soil, climatic conditions, and modern cultivation technologies allow obtaining commercial bulbs during one growing season. The main problems with growing onions are diseases, insects, and adverse weather conditions. Leaf stemphiliosis, which is caused by *S. vesicarium*, is a relatively new onion disease in Ukraine, which is observed in onion fields from about mid-June to harvest and leads to substantial crop losses, requiring repeated use of fungicides (Fig. 1).

On the green parts isolated from Onion plantings, 8 species of mushrooms were identified, including various species of *Stemphylium* spp. (*Stemphylium*

vesicarium (Wallr.) Simm., *Stemphylium botryosum* Wallr., *Stemphylium herbarum* Simm.), which are pathogens of onion stemphiliosis and pathogens of other diseases: fusarium rot (*Fusarium oxysporum*), head powdery mildew or peronosporosis (*Peronospora destructor*), alternariosis (*Alternaria* spp.). The data of the study of the morphology features of fungal mycoflora of onions are summarised and presented in Table 2.

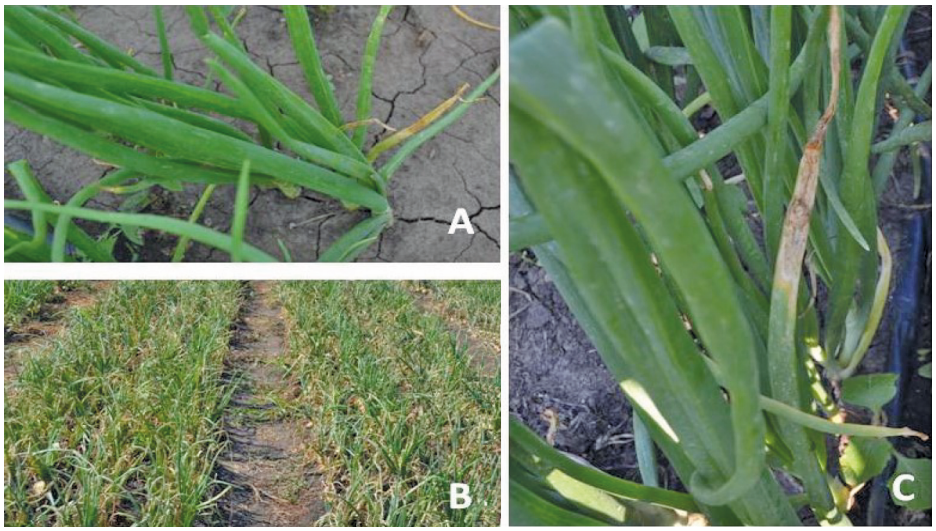

Figure 1. *Symptoms of stemphiliosis on onion plants – A – necrotic tips (onset of the disease); B – general appearance of the affected areas of onion plantings; C – necrotic lesions spreading upwards by leaves*
Source: *photo N.T. Mogyliuk, G.A. Horokhoryna*

Table 1. *Cultural features of onion fungal mycoflora (Ahrofirma "Petrodolynske", Odesa district, Odesa region, Banco variety)*

Pathogen	Cultural features of the colony	Morphology features
Stemphylium spp.	Dirty-white, light grey colour of colonies, subsequently changes from light brown to dark brown with white and brown stripes.	Conidia are olive-brown, oval to ovate, oblong on conidiophores. The length of conidia varies from 146 to 306 microns (μ). The width of conidia varies from 47 to 157 μ .
Fusarium oxysporum	Colonies range from white to pale lilac, and the airy mycelium ranges from almost absent to abundant and fluffy. In the central part of the colonies, abundant macroconidia are often formed, and sometimes brown, blue, or purple sclerotia are formed. It often emits a dark purple to dark crimson pigment.	Macroconidia are fusiform-sickle-shaped, slightly curved to almost straight, with 3–5 septa (mostly with 3). The upper cell is short, sometimes slightly hooked, and the lower cell with a pedicel or papilla.
Aspergillus niger Thieg.	The fungus forms a loose mycelium. The conidionic zone is black in colour.	Sterigmas, 20×7 μ, 7×3 μ Spherical conidia, 3 μ connected in chains.
Peronospora destructor	Colonies range from white to pale grey, and the airy mycelium is abundant and fluffy.	Asexual reproduction occurs with the formation of zoosporangia, which develop into a tube-like conidia. Dichotomically branched conidiophores are formed. Conidia always sprout hyphae.
Alternaria spp.	Grey-purple or olive colour of colonies, velvety coating of conidial sporulation of the fungus	Conidiophores are single 150×3.5 6.5 μ Pear-shaped spores are multicellular with septa, olive in colour, 150×3.5–6.5 μ
Penicillium Link.	Mycelium is yellow-green with a yellow-white border, on the surface with fine colourless speckling.	Conidiophores are smooth, 3–4 μ thicknesses that carry two-tiered brushes. Conidia are ellipsoidal, slightly narrowed at the end, 3-4×2.5–3.5 μ, small-warty.

Source: *MycoBank Database, 2022*

The frequency of spread in samples (intensity of spread, %) of isolated pathogens on average was: *Stemphylium* spp. – 13,9%, *Fusarium oxysporum* – 20,7%, *Aspergillus niger* – 18,6%, *Penicillium* – 19,4%, *Peronospora destructor* – 9,5%, *Alternaria* spp. – 17.9% (Fig. 2).

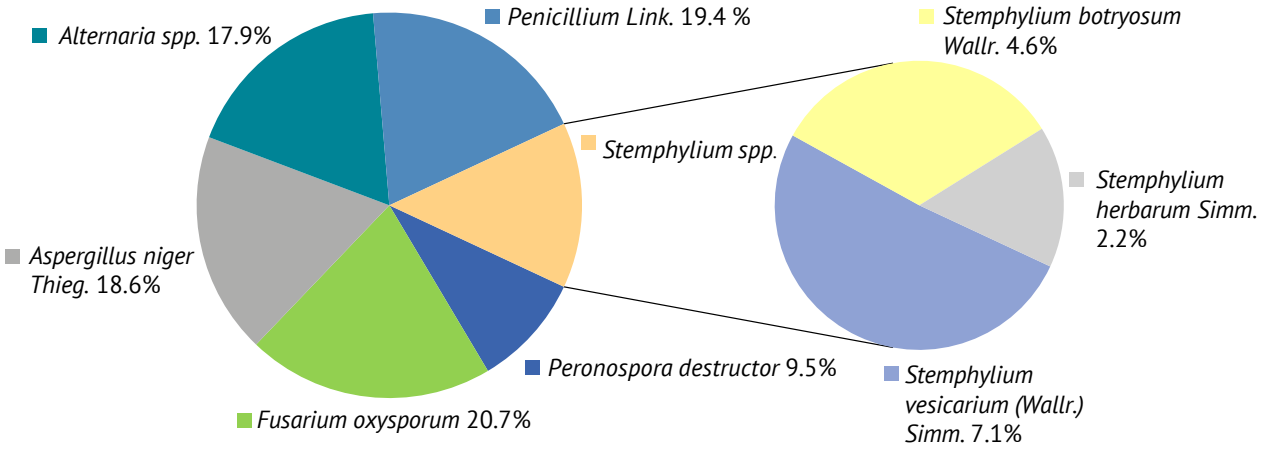

Figure 2. *Species composition of onion fungal mycoflora (% of the number of samples)*

Among the identified eight types of fungi, only *Alternaria* and *Stemphylium* are representatives of closely related species, so they need to be identified based on colony culture and conidia morphology (Fig. 3).

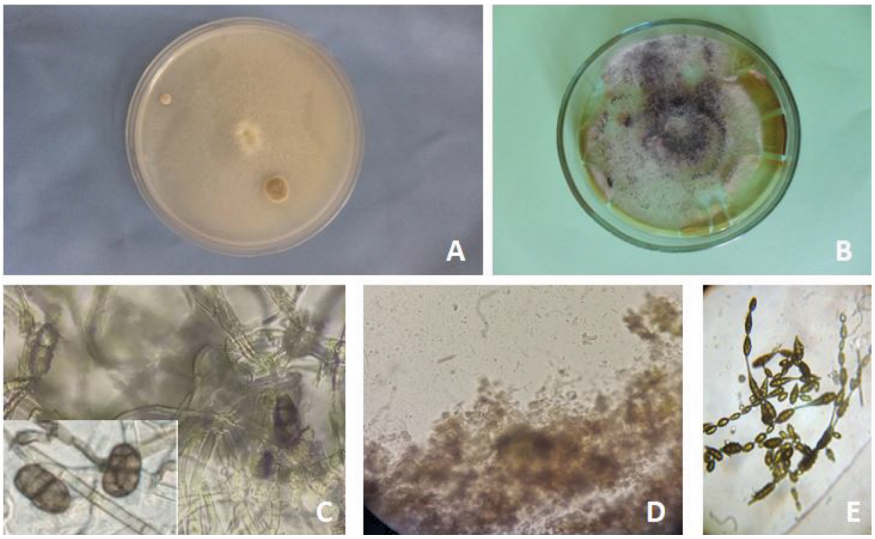

Figure 3. *Mycelial colonies on potato dextrose agar (PDA) (A) Stemphylium spp, (B) Alternaria spp; conidiophores with conidia (C) (D) Stemphylium spp, (E) Alternaria spp*

Source: *photo by K.A. Shmatkovska*

In the second stage, pathogens of onion stemphiliosis were identified from the spectrum of isolated fungi. Identification of members of the genus *Stemphylium* based on the cultural characteristics of the colony and the morphology of conidia showed the presence of three of its representatives in the samples: *Stemphylium vesicarium* (Wallr.) Simm., *Stemphylium botryosum* Wallr., *Stemphylium herbarum* Simm., which are similar in shape to conidia, but other characteristics, such as size, make them different.

Conidia *S. vesicarium* – oblong or oval with 1-5 transverse partitions, sometimes narrowed in the middle, one or three of the most central of them, with a full or almost complete row of longitudinal partitions. The size of conidia varies from 25 to 42 μ in length, 12-22 μ in width. *S. botryosum* has spores from subspherical to oblong in shape, strongly narrowed in the middle septum, 33-35 μ in length and width of 24-26 μ (Das *et al.*, 2019).

Culture *S. herbarum* was characterised by rapid growth on the medium, compared to the species described above. The colonies had a round shape, a fluffy texture, and the colour of the mycelium ranged from brown-orange to dark brown. *S. herbarum* produced unripe fruit bodies and many conidia. Spore size range: length – 20-30 μ; width – 10-15 μ (Das *et al.*, 2019). The micromycetes listed above also differed in the frequency of distribution in the samples – *Stemphylium vesicarium* (Wallr.) Simm. – 7,1%, *Stemphylium botryosum* Wallr. – 4,6%, *Stemphylium herbarum* Simm. – 2,2%.

Influence of weather conditions on the development of stemphiliosis. It is known from literary sources (Wright *et al.*, 2019) that the conditions of the year

affect, first of all, the causative agent of the disease, and the degree of this influence depends on its biological characteristics. The maximum infection of onion with stemphiliosis was observed in 2021 with warm and humid spring and summer periods. However, the weather conditions of the growing seasons of 2019 and 2020 were also favourable for the development of the disease.

In 2019, during the growing season, precipitation was 182.8 mm or 85.4% of the climatic norm (214 mm) (Fig. 4). The highest amount of precipitation was observed in the second decade of April (33 mm), the second decade of June (29 mm), and the first decade of August (63 mm). The average air temperature for the test period was 19.6°C, which is 2.4°C above the long-term average (17.2°C). Relative humidity averaged 65%, which was 4% lower than long-term data for this period (69%). In 2020, during the growing season, precipitation was 152.0 mm, which is 29% lower than the climatic norm. The highest amount of precipitation was observed in the third decade of May (58.0 mm) and the second decade of June (24.0 mm) in the form of heavy rains. The average air temperature for the test period was 18.7°C, which is 1.5°C above the long-term average. Relative humidity averaged 61.0%, which was 8% lower than long-term data for this period. In 2021, during the growing season, precipitation was 344.0 mm, which is 74.0% higher than the climatic norm. The highest amount of precipitation was observed in the second decade of May (29.0 mm), the first and second decades of June (45.0 and 52 mm), and in the first and third decades of July (39.0 and 60 mm) in the form of heavy rains. The average air temperature for the test period was 18.4°C, which is by 1.2°C above the long-term average. Relative humidity averaged 71.0%, which was 2.0% higher than long-term data for this period.

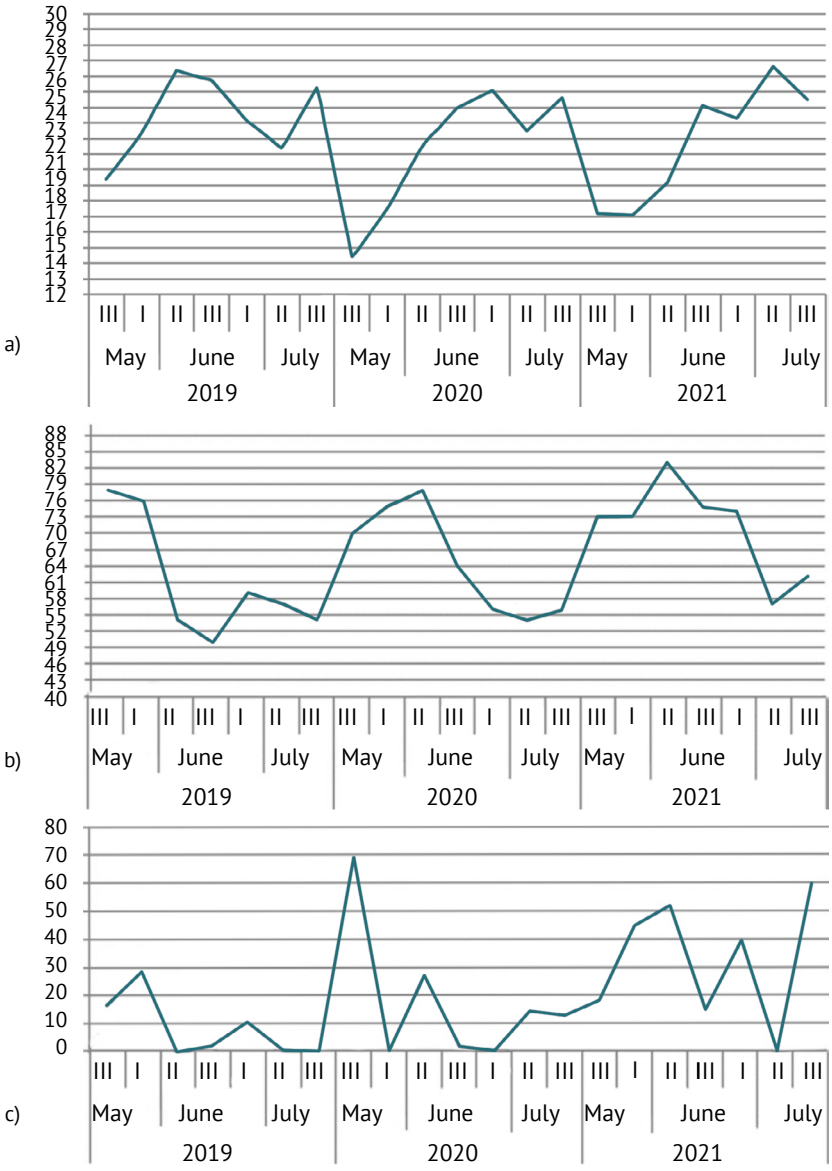

Figure 4. *Weather conditions of the onion growing season, 2019–2021 a) t, °C, b) relative humidity, %,c) precipitation, mm*

Evaluating the effectiveness of fungicides. Phytosanitary monitoring showed that stemphiliosis in the industrial conditions of the south of Ukraine is a fairly common and harmful disease of onions. In onion crops, the disease develops according to the following scheme: low incidence in June (<10%), followed by rapid growth in July. In late July and early August (in the onion phase of BBCH 43-45), the incidence can reach from 50 to 80% (Fig. 5).

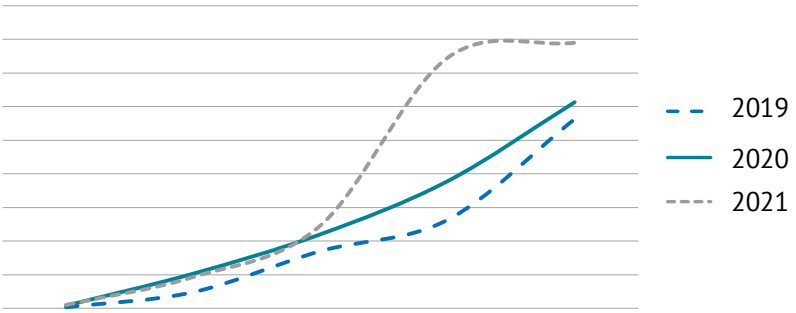

***Figure 4**. Development of stemphiliosis on onion plantings (2019-2021)*

Hay *et al.* (2021) note that at this time there is a rapid increase in the vegetative mass of plants, which contributes to a decrease in the movement of air between plants, an increase in its humidity and the further development of stemphiliosis. This is usually accompanied by necrosis of the tips and death of the outer leaves.

In 2019-2021, field studies were conducted to determine the most effective fungicides. During the growing season, five fungicide treatments were performed: difenoconazole (250 g/l), azoxystrobin (250 g/l), pyraclostrobin (67 g/kg) + boscalid (267 g/kg), cyprodinil (375 g/l) + fludioxonil (250 g/l), fluopyram (200 g/l)+ tebuconazole (200 g/l), and fluoxastrobin (100 g/l)+ prothioconazole (100 g/l). The first treatment was conducted to identify the first symptoms that were observed in the second decade of June in the onion phase of BBCH 13-14 in the form of single spots, the next – with an interval of 10-14 days, the last treatment was conducted at the stage of BBCH 47 (the beginning of feather lodging: up to 10% of plants died). The use of difenoconazole (250 g/l), azoxystrobin (250 g/l), pyraclostrobin (67 g/kg)+ boscalid (267 g/kg), cyprodinil (375 g/l)+ fludioxonil (250 g/l) was not effective enough. The fungicides fluopyram (200 g/l)+ tebuconazole (200 g/l) and fluoxastrobin (100 g/l)+ prothioconazole (100 g/l) were the most effective for disease control. Their use during the growing season reduced the infection of onion plants with stemphiliosis by 66.3-73.5% and 65.7-77.4%, respectively (Table 3).

***Table 3**. Effectiveness of fungicides to protect onions from stemphiliosis (2019-2021)*

Experiment option	Year	Effectiveness of fungicides by accounting period, %			
		2nd accounting	3rd accounting	4th accounting	Average
Difenoconazole (250g/l)	2019	57.9	70.6	69.5	66.0
	2020	56.1	67.1	68.9	64.0
	2021	56.8	44.4	48.0	49.7
Azoxystrobin (250 g/l)	2019	52.6	64.7	67.6	61.6
	2020	46.3	60.2	66.9	57.8
	2021	48.7	55.6	48.0	50.8
Pyraclostrobin (67 g/kg) + boscalid (267 g/kg)	2019	57.6	67.6	71.4	65.5
	2020	58.5	59.1	64.2	60.6
	2021	56.8	51.5	46.0	51.4
Ciprodinyl (375 g/l) + fludioxonil (250 g/l)	2019	52.6	69.1	70.5	64.1
	2020	63.4	64.8	68.9	65.7
	2021	56.8	51.5	46.0	51.4
Fluoxastrobin (100 g/l) + prothioconazole (100 g/l)	2019	68.4	75.0	77.1	73.5
	2020	70.7	73.9	72.9	72.5
	2021	70.3	61.6	67.1	66.3
Azoxystrobin 120 g/l + tebuconazole 200 g/l	2019	73.7	79.4	79.1	77.4
	2020	73.2	75.0	74.2	74.1
	2021	67.6	62.6	66.8	65.7

***Source:** developed by the authors based on the studies by N.T Mogyliuk, G.A. Horokhoryna (2019-2021)*

The effectiveness of fungicides in the third year (2021) of application decreased compared to 2019 and 2020, which may indicate the emergence of resistance to these drugs.

One of the serious reasons that hinder the cultivation of crops is the spread of diseases. Stemfilium is also known to cause premature ageing of the leaves, which makes the harvested onion crop more susceptible to post-harvest losses. The disease was detected on all onion plantings under study, which makes it epiphytotic, which is consistent with data from other researchers (Hay *et al.*, 2021; Khar *et al.*, 2022).

Pathogens of plant diseases – phytopathogenic micromycetes, cause damage to agriculture, thereby arousing the natural interest of researchers in the field of mycology and phytopathology. Separate information about the presence of micromycetes-pathogens of onion diseases can be identified in the studies by Rahul *et al.* (2022), which provide data on the detection of the composition of onion diseases in the fields of farms in the Tashkent region. As a result of investigating the composition of pathogens of fungal diseases of onions, only 57 species from 29 genera, 11 families, 7 orders, and 4 classes of fungi were identified, with different frequencies of occurrence.

Such papers confirm that the mycoflora of onions is extremely diverse. The *Stemphylium* genus is rich in species, has a wide range of hosts, and is pathogenic to over 43 plant genera worldwide. Morphologically *Stemphylium* genus can be distinguished from other related genera, such as *Alternaria*, using the cultural characteristics of colonies and morphological features. Recent studies on the definition of species of the *Stemphylium* genus demonstrated the match of morphological features, which makes it difficult to identify and describe species (Das *et al.*, 2019; Foster *et al.*, 2019; Sharma *et al.*, 2020).

A study was conducted to examine the features of fungal mycoflora of onions to identify pathogens that cause stemphiliosis. Identification of pathogens of stemphiliosis showed the presence of three of them with different frequencies of spread in the samples. The largest percentage of distribution in samples was identified in *Stemphylium vesicarium* (Wallr.) Simm. – 7,1%. Such results allow highlighting *Stemphylium vesicarium* as the main pathogen causing stemphiliosis in onion plantings of the Odesa region.

Studies showed that the maximum damage to onion stemphiliosis was observed in 2021, which was characterised by high humidity, heavy precipitation, and elevated air temperature. These results are consistent with previous experiments conducted by various authors using onion cultures (Wang *et al.*, 2021; Wright *et al.*, 2019). Gossen *et al.* (2021) identified that the first symptoms of onion stemphiliosis coincided with the appearance of a large number of conidia, precipitation, leaf moisture duration of ⩾8 hours, and days with an average daily temperature of ⩾18°C.

Agha (2022) and Hassan *et al.* (2020) investigated the effects of mineral salt – as an alternative to fungicides. The authors investigated the effect of salicylic acid, potassium dibasic phosphate, sodium bicarbonate salt, potassium carbonate, and sodium carbonate on reducing the incidence and severity of natural infection with stemphiliosis with improving the vegetative growth of onions. The authors concluded that the use of the above-mentioned treatments can be an economic and environmental alternative in controlling the spread and development of stemphiliosis.

Roylawar *et al.* (2021) identified that the root endophytic fungus *Piriformospora indica* (*Serendipita indica*) stimulates growth and the ability to induce resistance in a wide range of host plants. The effectiveness of biocontrol of *P. indica* was evaluated against stemphiliosis caused by the necrotrophic fungal pathogen *Stemphylium vesicarium*. The authors note that *P. indica* was also effective in reducing the severity of leaf stemphilium damage, which was evaluated in greenhouses and confirmed by field tests.

The possibility of controlling pathogens of stemphiliosis in onion plantations using fungicides was described by Mishra *et al.* (2017), Stricker *et al* (2021), Hausbeck *et al.* (2018), Hoepting *et al.* (2018). They note the appearance of resistance of pathogens of stemphiliosis to the fungicides under study.

Mishra *et al.* (2017) conducted a number of experiments on the effectiveness of fungicides in protecting onions from *Stemphylium vesicarium*. The combined substances azoxystrobin + flutriafol are highly effective in disease control. Wang *et al.* (2021) note the sensitivity of isolates *Stemphylium vesicarium* to difenoconazole. Recent research Hay *et al.* (2019) from Cornell University and the University of Guelph identified reduced sensitivity in laboratory and field studies to boscalid, fluopyram, and fluxapyroxad group fungicides.

There is growing evidence that the fungicides currently used by producers do not provide an economic level of suppression of stemphiliosis on onions. Mishra *et al.* (2017) note that high concentrations of mancozeb, azoxystrobin, propiconazole, and propineb in vitro inhibit the growth of *S. Vesicarium.* but practically did not affect stemphiliosis in the field

Among the ways to solve the problem of controlling stemphiliosis with fungicides, to overcome resistance to them, it is proposed to examine the effectiveness of the latest drugs regulated for use in onion plantings. These studies showed high efficiency of tank mixtures in the control of onion stemphiliosis. Fungicides with the active substance fluopyram (200 g/l) + tebuconazole (200 g/l) and fluoxastrobin (100 g/l) + prothioconazole (100 g/l) were the most effective for disease control.

Thus, according to the results of the conducted studies, the widespread fungal diseases of onions in the plantings of the Odesa region were established. The

most common and harmful is stemphiliosis, or black-and-grey onion spotting, which has recently become a serious obstacle to onion cultivation in major growing areas around the world.

CONCLUSIONS

The features of the fungal microflora of onions were examined in laboratories. Eight species of micromycetes belonging to different systematic groups were identified. The most common ones are *Peronospora destructor* – 9.5%, *Stemphylium vesicarium* (Wallr.) Simm. – 7.1%. They dominate in terms of development intensity *Fusarium oxysporum* – 20.7%, Aspergillus niger – 18.6%, *Penicillium* – 19.4%, *Alternaria* spp. – 17.9%.

Based on the cultural characteristics of the colony and the morphology of conidia, three pathogens of onion stemphiliosis were identified – *Stemphylium vesicarium* (Wallr.) Simm, *Stemphylium botryosum* Wallr, *Stemphylium herbarum* Simm. Meteorological conditions during the research years were characterised by the exceeding sum of active temperatures and the amount of precipitation that was higher than the climatic norm.

It was identified that the growing season of 2021 was the most favourable for stemphiliosis. The amount of precipitation and an increase in air temperature caused the maximum manifestation of the disease, the spread of which in onion plantings was 100%, and the development of the disease reached 79%. It was identified that fungicides with the active substance fluopyram (200 g/l) + tebuconazole (200 g/l) and fluoxastrobin (100 g/l) + prothioconazole (100 g/l) were the most effective in disease control in the field.

In this regard, to develop recommendations for controlling onion stemphiliosis, it is necessary to continue the study of the effectiveness of new fungicides in the field to warn manufacturers against using ineffective drugs.

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CONFLICT OF INTEREST

None.

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Анотація. Стемфіліоз цибулі є відносно новою хворобою в Україні, тому глибше вивчення *Stemphylium*, видового складу патоценозу, виділення та визначення видової належності збудників хвороби є актуальним. Метою роботи було вивчення видового складу патоценозу, біофенології збудника хвороби стемфіліозу, визначення ефективності фунгіцидів для подальшого контролювання стемфіліозу на посівах цибулі ріпчастої. Основними методами досліджень були: польовий – для визначення розповсюдження, розвитку і шкідливості стемфіліозу; лабораторний – для вивчення збудників хвороб цибулі ріпчастої; візуальний та математично-статистичний. В роботі було використано метод мікологічних посівів на картопляно-декстрозний агар (PDA). Польовими обстеженнями у 2019-2021 роках було встановлено поширення та розвиток стемфіліозу в посадках ріпчастої цибулі Одеського району Одеської області. Встановлено, що найбільш сприятливим для стемфіліозу був вегетаційний період 2021 року, коли на фоні високої вологості та високих температур повітря, поширення хвороби становило 100%, а розвиток хвороби досягав 79%. У посівах цибулі хвороба розвивалась нерівномірно, поширення її було низьким у червні, з швидким зростанням в липні. На початку серпня відсоток хвороби сягав 80 %. Виявлено та ідентифіковано вісім видів грибів, з яких *Stemphylium vesicarium (Wallr.) Simm, Stemphylium botryosum Wallr, Stemphylium herbarum Simm.*, – є збудниками стемфіліозу цибулі. Лабораторними дослідженнями встановлено частоту їх поширення у пробах. Доведено, що п'ятиразове обприскування фунгіцидами, сприяє зменшенню подальшого розвитку стемфіліозу в посадках цибулі ріпчастої. Для пригнічення розвитку спор збудників хвороби доведена висока ефективність застосування обприскувань рослин відповідними фунгіцидами, з діючою речовиною флуопірам (200 г/л) + тебуконазол (200 г/л) та флуоксастробін (100 г/л) + протиоконазол (100 г/л). Подальшого розвитку набули положення і висновки про фітосанітарний стан насаджень цибулі ріпчастої Одеської області. Результати досліджень можуть служити для розробки рекомендацій виробництву щодо ведення заходів захисту цибулі ріпчастої від стемфіліозу

Ключові слова: *Allium cepa* L.; моніторинг; грибна мікофлора; Stemphylium vesicarium; ефективність фунгіцидів

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Physiological and biochemical justification of second-crop potatoes (*Solanum tuberosum* L.)

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Abstract. The relevance of the conducted studies lies in the need to improve the technology of growing potatoes from freshly picked tubers in the conditions of summer planting to improve the quality of seed material. The purpose of the study was to determine the influence of the physiological and biochemical state and varietal characteristics of potato plants on the ability of freshly harvested tubers to form high-quality seed material for second-crop potatoes in the Forest-Steppe of Ukraine. Field, statistical, computational, analytical, and laboratory methods were used to conduct the study. It is identified that harvesting the first crop for planting with freshly picked tubers during the flowering phase and within two weeks after its completion is ineffective for some varieties. Therewith, the first crop averages 18.5 t/ha, and the second – 5.1 t/ha. Some varieties have a low germination rate from freshly picked tubers

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(from 4 to 76%) or are not formed at all. This is due to the accumulation of germination inhibitors (abscisic acid etc.) in maturing tubers, which causes deep natural dormancy of tubers. It is proposed to consider the activity of germination inhibitors in freshly harvested tubers using allelopathic testing, which allows for determining the optimal time for their collection and planting. This ensures germination rate at the level of 80-87%. Therewith, the first crop of tubers is from 10.1 to 15.0 t/ha, and the second – from 26.2 to 9.3 t/ha. The dependence of the content of abscisic acid with the accumulation of starch in tubers allows visually determining their suitability for germination by the chemical reaction of vegetable juice with an iodine solution. The practical value of the study lies in the possibility of obtaining two crops of seed potatoes per year, while the first crop is formed in 60-70 days, and the second – 90-100 days from planting. Despite the relatively low yield, the resulting seed material is physiologically young, free from diseases and has a high productivity potential. This allows for shortening the seed production scheme, increasing the reproduction rate of potatoes, and saving resources

Keywords: potatoes; seed production; freshly picked tubers; two crops; reproduction rate; allelopathic testing

INTRODUCTION

The need to research the possibility of forming high-quality potato seed material in the Forest-Steppe of Ukraine is justified by negative climate changes and the complication of the humanitarian crisis in the country. An increase in average daily air temperatures and uneven soil moisture supply in the region led to a substantial decrease in the yield of agricultural crops, in particular, potatoes, using conventional cultivation technology. The formation of seed material under these conditions becomes ineffective due to the intensive degeneration of plants during sequential reproduction. Seed material improved by biotechnological methods needs variety renewal after 3-5 years of reproduction in this region. Providing farmers with high-quality seed material of promising potato varieties is possible if the seed production technology is adapted to modern growing conditions.

R. Vozhehova *et al.* (2021) note that optimal conditions for the growth and development of potato plants are formed when the average daily air temperature is not higher than 18-21°C. Therewith, the soil moisture content should be at least 65-70% of the lowest moisture capacity. According to V. Pastukhov (2021), over the past 25 years, there has been a substantial increase in average daily air temperatures in the eastern Forest-Steppe region of Ukraine. In critical phases of plant development, which are the budding and flowering phases, temperature values exceed perennial values by 1.1-2.4°C. Therewith, precipitation has a heavy rain character, which leads to compaction and overheating of the soil. Under these conditions, the formation of tubers is inhibited. Their development is accompanied by physiological disorders. In addition, in July-August, plants are intensively re-infected with insects that carry viruses (aphids, cicadas, etc.). This leads to an acceleration of the degeneration of potato plants.

Climate researchers predict that an increase in CO_2 concentration will lead to an increase in the efficiency of using solar radiation, which can contribute to the growth of potential yields in some regions (George *et al.*, 2017; Rana *et al.*, 2020). However, increased heat and drought, which will be observed in areas with insufficient hydrological supply, will cause increased stress in plants and reduce their productivity (Yagiz *et al.*, 2020; Muhie, 2022).

The conventional scheme of potato seed production is based on the use of the material improved by the method of culture of apical meristems. Elite potatoes (base material) are obtained from the source material improved in this way for four years (Bondarchuk, 2010). However, due to changes in weather conditions in the region recently, it has not been possible to form a full-fledged seed material with high productive potential.

Under these weather conditions, the formation of potato seed material is possible with a second-crop culture. Similar technology, as evidenced by L. Boiarkina *et al.* (2020), is used in the south of Ukraine and avoids the negative impact of adverse conditions on the formation of potato seed tubers. Therewith, the first crop is harvested before the period of maximum air temperatures, and the second crop is formed at favourable temperatures in September-October. This technology allows for avoiding the re-infection of plants with virus-carrying insects and forming a crop of physiologically young tubers with high productive potential. The second-crop technology of obtaining seed material allows potato seed production on a two-year cycle.

The effectiveness of a second-crop culture largely depends on the suitability of potato varieties for the intensive formation of the first crop of tubers. According to K. Mori (2015) and J.P. Hyun (2021), it is most appropriate to use varieties that quickly form a developed vegetative mass that prevents overheating of the soil. The value of soil cover for the formation of the second tuber crop is slightly lower. More substantial is the duration of the dormant period, which is a varietal property. It is most appropriate in the conditions of eastern Ukraine to use early and medium-early varieties to obtain two potato crops. Among the 194 potato varieties zoned in Ukraine, 40 early-maturing and 25 medium-early varieties are recommended for the conditions of the Forest-Steppe region (State register of plant varieties suitable for dissemination in Ukraine in 2022, 2022).

However, the presence of varietal features in relation to the physiological and biochemical mechanism of the deep natural dormant period requires further research.

The purpose of this study is to determine the influence of the physiological and biochemical state and varietal characteristics of potato plants on the ability of freshly harvested tubers to form high-quality seed material for a second-crop culture in the Forest-Steppe of Ukraine.

MATERIALS AND METHODS

Field research in 2012-2018 was conducted in the soil and climatic conditions of the eastern Forest-Steppe of Ukraine in accordance with the "Methodical recommendations for conducting research with potatoes" (Kutsenko *et al.*, 2002).

During 2012-2014, methods for removing freshly picked tubers from dormancy were examined on potato varieties Serpanok and Skarbnytsia, which provided for their pricking, germination, chemical treatment with stimulants, and a combination of these operations.

In 2014-2015, potato varieties of Ukrainian selection Tyras, Skarbnytsia, Serpanok, Ivankivs'ka rannia, Strumok, Shchedryk, Partner, Povin', Hlazurna, Kimmeriia were examined. Spring planting was conducted in the third decade of April, summer planting of freshly picked tubers of the varieties under study – in the flowering phase.

In 2016-2018, laboratory studies were conducted on the activity of germination inhibitors in freshly picked tubers of the Tyras variety using the method of allelopathic testing. Therewith, white mustard seeds were sprouted in an extract from the vegetable juice of freshly harvested tubers of different harvesting periods (control – distilled water). The biotesting was conducted by analogy with laboratory studies on the allelopathic interaction of other vegetable plants (Harbovska *et al.*, 2020; Semenchenko *et al.*, 2020). Determination of starch content in freshly picked tubers was conducted according to the relevant state standard (DSTU 4953:2008, 2009). The presence of colouration of vegetable juice of tubers was determined by adding an iodine solution to it at a concentration not exceeding 5%. In the field, the first crop of Tyras tubers was harvested 60, 63, 66, 69, and 72 days after planting. A four-component chemical solution (thiourea – 1%, potassium rhodanide – 1%, gibberellin – 0.0005%, succinic acid – 0.002%) was used to inactivate the action of inhibitors (Bondarchuk, 2019). After processing, freshly picked tubers were planted to produce a second crop, which was harvested after 98, 95, 92, 89, and 86 days, respectively.

The weather conditions of 2012-2018 were substantially different, which is typical for this geographical area. This allows for assessing the suitability of the examined varieties for second-crop cultivation technology and investigating the physiological and biochemical state of potato plants depending on the time of harvesting the first crop. Notably, the temperature conditions of the growing season of the eastern Forest-Steppe of Ukraine, according to perennial data, are characterised by long hot periods, which causes the riskiness of potato growing in this region. According to the conventional technology of growing seed potatoes, its critical phases of development fall on the maximum increase in average daily air and soil temperatures, which negatively affects the processes of stolon and tuber formation (Archive of meteorological data, n.d.).

Analysis of meteorological data (according to the Merefa weather post) covering the growing season of potatoes with the first and second tuber crops indicates a tendency of daily increase in air temperatures during 2012-2018. Their increase compared to the perennial average values ranged from 0.1 to 2.9°C. Special attention is paid to the period from mid-June to the third decade of September when the hottest weather is observed. Freshly picked tubers during this period are just beginning active vegetation and the transition to autotrophic nutrition. The formation of tubers of the second crop occurs in relatively moderate conditions, starting from the third decade of September to the end of October (Fig. 1).

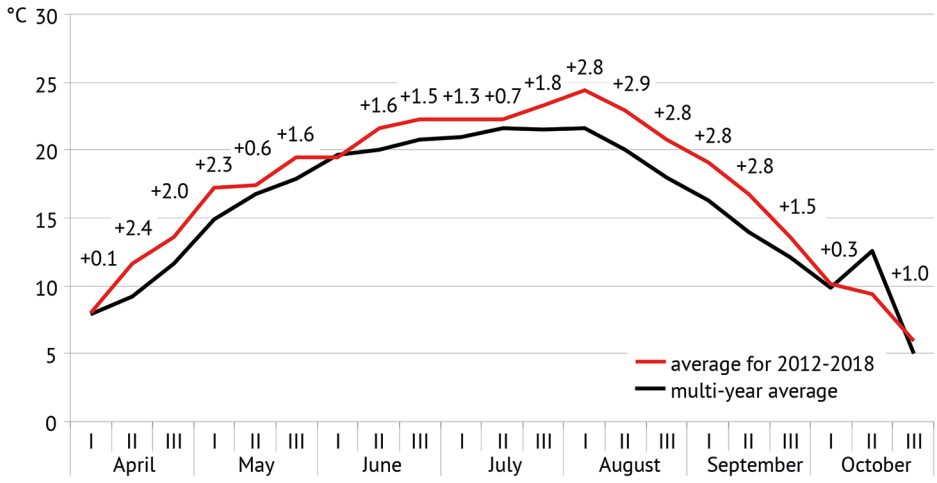

***Figure 1**. Average daily air temperature during the potato growing season, 2012-2018*
***Source:** compiled by the authors*

The increase in maximum and average daily air temperatures was mostly due to a reduction and uneven precipitation over time. This led to dry periods during the potato growing season (Fig. 2).

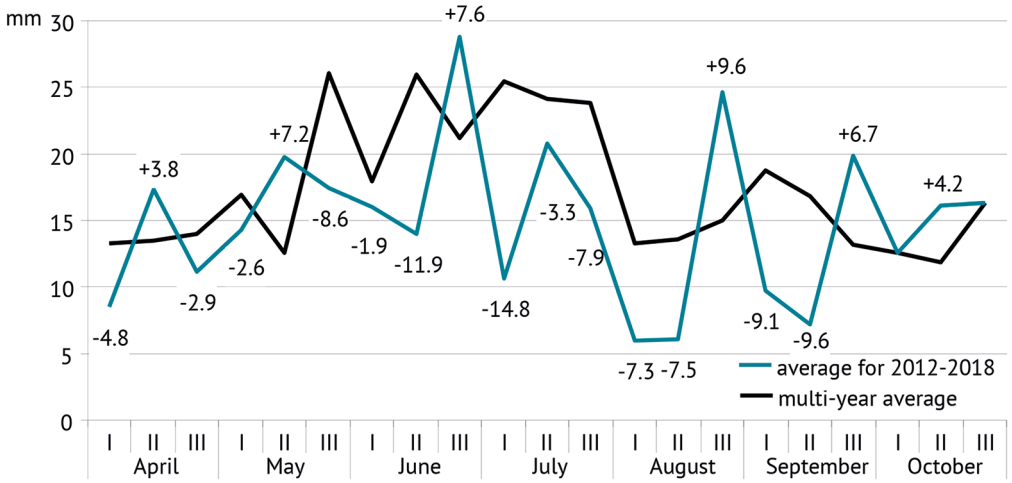

***Figure 2**. Precipitation dynamics during the potato growing season, 2012-2018*
***Source:** compiled by the authors*

For the period from 2012 to 2018, the amount of precipitation during the growing season averaged 313.0 mm, which is 53.1 mm less than the perennial value. Special attention should be paid to the progressive decrease in precipitation in the period from the beginning of July to mid-August, when there was a decrease in the amount of precipitation by 40.8 mm. The small amount of precipitation that was observed during the growing season was mainly heavy rain and was not productively absorbed by plants. The general deterioration of the hydrothermal regime in relation to the biological requirements of potatoes confirmed global trends in climate change and expected forecasts for Ukraine.

RESULTS AND DISCUSSION

The main problems of second-crop technology are the intensity of tuber crop formation and the ability of freshly harvested tubers to come out of dormancy. Harvesting of the first crop of tubers is recommended to be conducted during mass -flowering and within two weeks after its completion (Osypchuk *et al.*, 2012). Only certain varieties, mainly early-maturing and medium-early, can form a full-fledged crop of seed tubers in such a short period of time in the conditions of the eastern Forest-Steppe of Ukraine. According to the results obtained, the yield above average (18.5 t/ha) at the time of flowering is formed by the varieties Tyras (19.4 t/ha), Skarbnitsa (22.5 t/ha), Shchedryk (19.4 t/ha), and Ivankivs'ka rannia (27.0 t/ha). The harvest from summer planting with freshly picked tubers was formed only by the varieties Tyras, Skarbnitsa, Serpanok, Ivankivs'ka rannia, and Strumok. Their average yield was 10.2 t/ha. The highest yield (14.5 t/ha) was provided by the Tyras, Skarbnitsa (11.0 t/ha), and Serpanok (10.8 t/ha) varieties. Other varieties, due to uneven germination, had a decrease in the second crop of seed potatoes. For the Ivankivs'ka rannia variety, it was 7.9 t/ha, and for the Strumok variety – 6.7 t/ha. Such varieties as Shchedryk, Partner, Povin', Hlazurna, and Kimmeriia did not form shoots for harvesting tubers during the mass flowering of plants and for two weeks after its completion (Fig. 3).

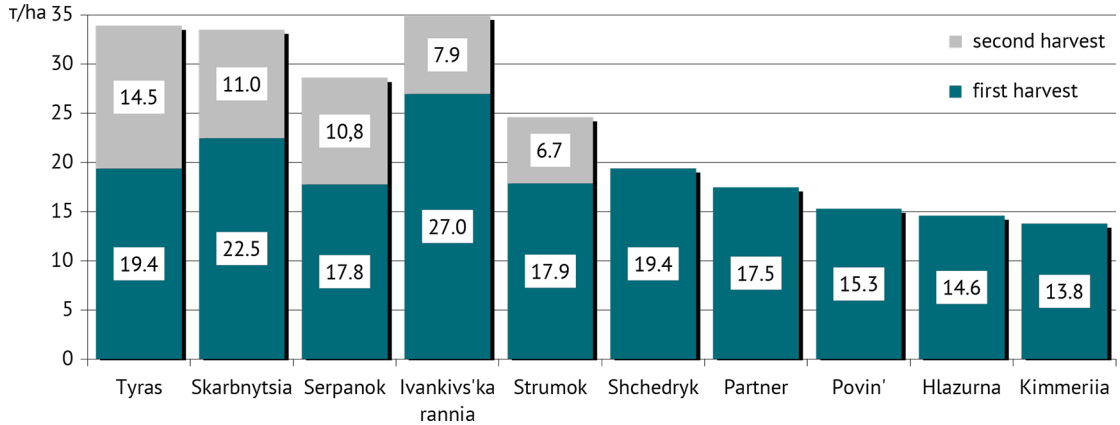

***Figure 3**. Potato yield for a second-crop culture, depending on the variety, average for 2014-2015, t/ha*
***Source:** compiled by the authors*

The reaction of the potato varieties under study to growing in a second-crop culture allows them to be divided into three groups: varieties that react well; varieties that react poorly; varieties that almost do not react. It is worth paying attention to the fact that such a division is conditional and applies only to cultivation according to the method that involves harvesting the first crop of tubers at the onset of the flowering phase.

Tubers of the first crop gradually accumulate inhibitors (abscisic acid, caffeic acid, cinnamon, scopoletin, coumarins) during growth and development, which cause tubers to enter a state of deep natural dormancy (Gemeda, 2017). Therewith, the shoots of freshly picked tubers are delayed or not formed. Thus, the germination rate of the examined varieties ranged from 4 to 76%, depending on the variety (Table 1).

***Table 1**. The germination rate of freshly picked tubers during summer potato planting, depending on the variety, average for 2014-2015*

No.	Variety	Similarity, %
1	Tyras	76
2	Skarbnytsia	67
3	Serpanok	48
4	Ivankivs'ka rannia	69
5	Strumok	66
6	Shchedryk	5
7	Partner	14
8	Povin'	18
9	Hlazurna	23
10	Kimmeriia	4

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

Low germination caused the thinning out of most of the varieties under study. As a result, this did not allow getting a second harvest of seed material of the Povin', Partner, Hlazurna, Kimmeriia, and Shchedryk varieties. This study suggests that when determining the timing of harvesting the first crop of tubers, it is necessary to consider the physiological and biochemical state of each variety. This is due to the fact that a certain part of the varieties in the flowering phase already forms tubers, which begin to enter a dormant state and almost do not form shoots. Therewith, a certain part of the varieties still continues to form stolons, from which tubers have not yet formed. It is advisable to determine the timing of harvesting freshly harvested tubers not by the onset of the phenological phase of flowering, but by the accumulation of germination inhibitors in maturing tubers. Therewith, harvesting of the first crop is proposed to be conducted when a sufficient number of tubers of the seed fraction have formed. This allows economically justifying the first terms of harvesting and determining in a timely manner the last terms at which seedlings can still be obtained.

Regardless of the growing region, the accumulation of germination inhibitors in maturing tubers largely depends on varietal characteristics. In accordance with the duration of the tuber formation period of each individual variety, the optimal time for harvesting and planting freshly picked tubers is individual (Haider, 2021). Weather conditions have a substantial impact on the physiological and biochemical state of potato plants. All factors that accelerate the maturation of tubers contribute to the accumulation of germination inhibitors (abscisic acid, cinnamon, scopoletin, caffeic acid, coumarins, etc.).

The suitability of freshly picked tubers for planting can be visually determined based on the condition of the peel. In physiologically young tubers that are still able to form shoots, the periderm layer is very thin and easily torn off. Therefore, these tubers should be planted immediately after harvesting, before they lose their turgor or rot. Therewith, before treatment with a solution of stimulants, it is advisable to make 10-20 pricks over the entire surface of tubers to the depth of the vascular ring. This technique also increases the germination rate of tubers by 6-13% (Table 2). Short-term germination of these tubers is ineffective, even when combined with chemical treatment with stimulants and pricking.

Field studies were conducted on the Tyras variety, which responds best to second-crop cultivation technology to determine the effect of the physiological and biochemical state of plants on the ability of freshly harvested tubers to form seedlings. The condition of freshly harvested tubers, depending on the time of harvesting, is shown in the figure (Fig. 4).

***Table 2**. Germination rate of freshly picked tubers depending on the method of pre-planting preparation and varietal characteristics, %, average for 2012-2014*

No.	Pre-planting treatment options	Variety	
		Serpanok	Skarbnytsia
1	Chemical treatment (control)	55	68
2	Chemical treatment + germination	27	30
3	Chemical treatment + pricking	68	74
4	Chemical treatment + germination + pricking	21	36

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

***Figure 4**. Freshly picked potato tubers of the Tyras variety after 60, 63, 66, 69, and 72 days of vegetation*
***Source:** compiled by the authors*

When harvesting the first crop 60 days after planting, the Tyras variety forms 25% of the tubers of the seed fraction suitable for planting. In the future, their share gradually continues to grow to 62%. In this case, the yield was determined by both the number and average weight of tubers. Its growth over 12 days was 4.9 t/ha (from 10.1 to 15.0 t/ha) (Table 3).

***Table 3**. Productivity of the first potato crop of the Tyras variety, depending on the time of harvesting, is average for 2016-2018*

No.	Duration of vegetation, days	Number of tubers, pcs./bush	Average weight of tubers, g	Seed fraction, %	Yield, t/ha
1	60	4.2	43	25	10.1
2	63	4.5	42	29	10.7
3	66	4.7	47	35	12.1
4	69	5.1	49	46	13.6
5	72	5.4	50	62	15.0

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

After pricking and short-term immersion in a four-component solution of stimulants, the tubers were immediately planted in the ground on the day of harvesting. Therewith, the activity of germination inhibitors in freshly picked tubers, namely in the eyes, was determined using biotesting. It is at the growth points that the main physiological and biochemical activity of maturing tubers is observed. Using other parts of the plant (tuber pulp or stem) to produce water extraction is less effective, presumably due to the low concentration of inhibitors in them and the presence of other chemicals. The difference in the amount of white mustard seeds sprouted on the extract in relation to those sprouted on distilled water indicates an increase in the content of inhibitors and their effect on growth processes (Fig. 5).

Figure 5. *Germination of white mustard seeds on extract from the juice of freshly picked tubers*
Source: *compiled by the authors*

Starting from the 60th day of vegetation, the number of germination inhibitors gradually increases in maturing tubers. According to the results of allelopathic testing, the activity of these inhibitors increases from 36 to 66% within 12 days. In turn, this leads to a decrease in the germination rate of freshly picked tubers of the examined variety from 87 to 38% (Table 4).

Table 4. *Physiological and biochemical state of freshly picked potato tubers depending on the harvesting period, %*

No.	Activity of germination inhibitors, %	Germination of freshly picked tubers, %	Starch content in tubers, %	Presence of cell juice staining in reaction with iodine solution
1	36	87	6.2	No
2	42	80	6.3	No
3	52	59	6.4	No
4	57	50	6.8	No
5	66	38	6.9	Yes

Source: *compiled by the authors*

In maturing tubers, the peel parenchyma gradually accumulates storage substances, in particular, starch. There is evidence of a relationship between its content and the concentration of abscisic acid, which is an auxin antagonist and accelerates the maturation and entry of tubers into a natural state of deep dormancy (Tkashuk & Shevchuk, 2018). When harvesting, every three days there is a tendency to increase the starch content in freshly picked tubers from 6.2 to 6.9%. Therewith, the reaction of vegetable juice with an iodine solution can be observed by its intense colour in black and purple (Fig. 6). This allows determining the starch concentration in freshly picked tubers, at which abscisic acid and other inhibitors accumulate in an amount at which they begin to enter a state of deep natural dormancy and field germination sharply decreases.

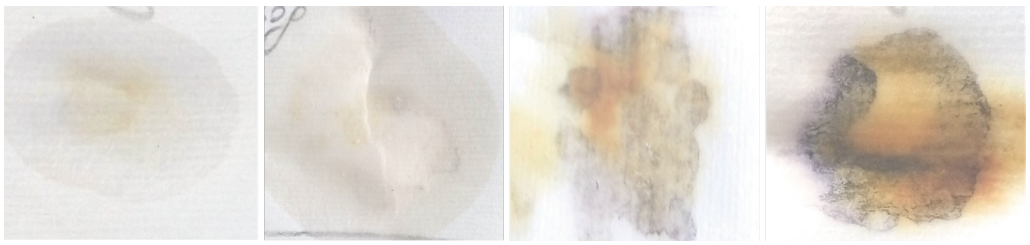

Figure 6. *Discolouration of vegetable juice from freshly picked tubers by chemical reaction with iodine solution depending on the starch content and harvesting time*
Source: *compiled by the authors*

Therewith, the yield from summer planting with freshly picked tubers is maximum during the first planting period (26.2 t/ha), and then decreases to 9.3 t/ha (Table 5). This is mostly due to a decrease in plant density due to a deterioration in germination, and a reduction in the growing season, which is limited by the onset of autumn frosts.

***Table 5**. Productivity of the second potato crop of the Tyras variety, depending on the time of harvesting, average for 2016-2018*

No.	Duration of vegetation, days	Number of tubers, pcs./bush	Average weight of tubers, g	Seed fraction, %	Yield, t/ha
1	98	7.0	77	54	26.2
2	95	7.0	80	49	25.2
3	92	7.0	67	41	15.0
4	89	6.3	74	50	14.1
5	86	5.0	67	38	9.3

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

Damage to the vegetative mass of plants by minor frosts on the soil surface occurs mainly in early October. In the future, a drop in air temperature at night to -3°C leads to substantial damage to the vegetative mass and causes a stop in the vegetation of plants (Fig. 7).

***Figure 7**. Condition of potato plants and their frost damage in October*
***Source:** compiled by the authors*

The second potato crop consists of physiologically young tubers, the vast majority of which are seed fraction. However, this material has a formed periderm and is suitable for perennial storage (Fig. 8).

***Figure 7**. Condition of potato plants and their frost damage in October*
***Source:** compiled by the authors*

Depending on the duration of the growing season, when the first and second crops of seed potatoes are formed, substantial changes are observed in the number of tubers formed. The largest number of tubers in the first crop was formed by plants after 72 days of vegetation (5.4 pcs./bush). However, in the second crop, the maximum number of tubers (7.0 pcs./bush) is formed during the first term of planting freshly picked tubers. This affects the value of the reproduction coefficient, which is the main indicator of the effectiveness of second-crop technology for growing seed potatoes. Depending on the experiment variant, it ranges from 1:26 to 1:10 (Table 6).

***Table 6**. Seed productivity of Tyras potatoes with a second-crop culture depending on the time of harvesting, t/ha, 2016–2018*

No.	Number of tubers in the crop, pcs./bush		Reproduction rate
	first crop	second crop	
1	4.2	7.0	1:26
2	4.5	7.0	1:25
3	4.7	7.0	1:19
4	5.1	6.3	1:16
5	5.4	5.0	1:10

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

Therewith, it is determined not only by the number of tubers that the plant formed by a certain harvesting period but also by the number of plants that formed shoots during summer planting with freshly picked tubers of the first crop. That is why there is a high reproduction rate for the sequential propagation of seed potatoes in variants with the highest germination of freshly picked tubers.

Similar studies were conducted by Balashova *et al*. (2020) in the southern part of Ukraine. According to their results, the growing conditions of the region do not correspond to the biological requirements of the crop. According to this data, a substantial negative impact of climatic factors on the formation of potato seed material is a violation of the development of tubers and intensive degeneration of seed material. A corresponding scheme of potato seed production has been developed, which provides for a second-crop cycle of its cultivation. Therewith, harvesting of the first crop is proposed to be conducted during the flowering phase and within two weeks after it, and freshly picked tubers after appropriate preparation should be planted to obtain a second crop in autumn. The trend towards meteorological changes observed over the past 20-25 years in the Forest-Steppe of Ukraine creates conditions for the emergence of similar problems with the cultivation of seed potatoes in this region. The presented results confirmed the possibility of obtaining seed potatoes in a second-crop culture with a certain improvement in this technology.

Chernychenko (2012), Boyarkina (2019), and Vozhehova (2021) also note the need to adapt the technology of growing seed potatoes to climate change. They analysed the influence of meteorological conditions on the formation of the first and second potato crops and investigated the effectiveness of technological methods for planting dates, the fractional composition of tubers, irrigation, fertilisation, and the use of biologically active substances. The data obtained by researchers confirm the need to stimulate planting material to accelerate the emergence of seedlings, intensify the development of vegetative mass, and activate stolon and tuberous formation. They pay special attention to the varietal reaction of potatoes to second-crop cultivation technology. The potato varieties of Ukrainian selection proposed by Osypchuk (2012) allow forming stable yields of seed material in the soil and climatic conditions of southern Ukraine. However, according to the data of this study, these recommendations on the suitability of varieties require certain changes for use in the conditions of the Forest-Steppe of Ukraine, in particular, in its eastern part.

The influence of varietal characteristics on the ability of freshly picked tubers to come out of dormancy is noted by Balashova (2021). The results of this study confirm the data obtained by the researcher on the accumulation of germination inhibitors in tubers of the first crop and the need for the use of growth stimulants. The high efficiency of a four-component solution for interrupting the dormancy period has been proven: 10 g/l of thiourea +10 g/l of potassium rhodanide +20 mg/l of succinic acid +5 mg/l of gibberellin.

According to Semenchenko (2020), treatment of freshly picked tubers with a solution of fumar with gibberellin leads to an increase in the yield of the Dutch Impala variety by 1.8-1.9 t/ha, and solutions of bioglobin and reastim with gibberellin – the Ukrainian Zahadka variety. However, in this study, there is no high effect on the germination of freshly picked tubers, which can be explained by the physiological and biochemical features of the examined varieties.

Deligios (2020) notes a substantial effect of gibberellic acid on the release of tubers from dormancy.

Therewith, there is an increase in the effect of cutting tubers in half, which is confirmed by the results of this study on mechanical pricking them to the depth of the vascular ring. According to Gemeda (2017), the use of gibberellic acid to disrupt the dormancy of tubers also contributes to an increase in yield by 23-92% and an improvement in potato quality.

Haider (2021) draws attention to the physiological changes in tubers that accompany their dormant state. Of particular importance is the ratio between abscisic acid and cytokinin and between abscisic acid and gibberellic acid. The author also notes the inhibition of catalase and the accumulation of soluble carbohydrates. Therewith, Bajji *et al*. (2007) state about rapid and synchronous germination of tubers treated with thiourea (catalase inhibitor) or exogenous hydrogen peroxide. This confirms the data of this study on the accumulation of germination inhibitors in tubers (in particular, abscisic acid), the possibility of exposure to them by chemical methods, and information on the relationship with changes in carbohydrates (starch, etc.).

Thus, the results of the conducted studies largely confirm the previously obtained data on the substantial influence of the physiological and biochemical state and the varietal reaction of plants on the effectiveness of potato seed formation in the conditions of the Forest-Steppe of Ukraine using second-crop cultivation technology. Therewith, it is proposed to determine the activity of germination inhibitors of freshly harvested tubers based on the results of allelopathic testing and plan the number and timing of harvesting the first crop based on the iodine reaction with the cell juice of these tubers. In the future, this allows for getting full shoots and forming a second crop of high-quality seed potatoes.

CONCLUSIONS

During the study, it was identified that the second-crop technology of growing seed potatoes in the conditions of climate changes observed in the eastern Forest-Steppe of Ukraine allows obtaining seed material twice during one season. This allows for maintaining high seed quality and shortening the seed production scheme. In addition to the use of chemicals, to stimulate freshly harvested tubers of the first crop, it is advisable to prick their surface to the depth of the vascular ring. This improves germination by 8-13%, depending on the variety.

However, as the study showed, not all potato varieties are able to form the first crop of tubers before the flowering phase, which form shoots during summer planting. The germination rate of freshly picked tubers at the level of 48-76% was identified in the varieties Serpanok, Tyras, Skarbnitsa, Strumok, and Ivankivs'ka rannia. Therewith, the first crop is 17.8-27.0 t/ha, the second – 6.7-14.5 t/ha. According to the reaction to the second-crop cultivation technology, the examined varieties can be divided into three groups: varieties that react well; varieties that react poorly; varieties that almost do not react.

Harvesting of the first potato crop of the Tyras variety, depending on the physiological and biochemical state of the plants, allowed obtaining the germination rate of freshly harvested tubers at the level of 87 to 38%. This is largely determined by the activity of germination inhibitors, which gradually accumulate in the tubers of the first crop. The dependence of the content of abscisic acid, which is the main inhibitor of germination, with the concentration of starch in tubers allows using a chemical reaction with an iodine solution to visually determine the suitability of freshly picked tubers for summer planting. When harvesting the first crop of tubers of the Tyras variety, 60 and 63 days after planting, the maximum germination rate of freshly harvested tubers is observed, and the highest density of crops is formed. The reproduction rate is 1:26 and 1:25, respectively.

Further research on the mechanism of accumulation of germination inhibitors in the process of maturation of tubers will attract promising potato varieties to the process of seed production using second-crop technology in the soil and climatic conditions of the Forest-Steppe of Ukraine, which will halve the four-year seed production scheme and increase the reproduction rate.

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CONFLICT OF INTEREST

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Фізіолого-біохімічне обґрунтування двоврожайної культури картоплі (*Solanum tuberosum* L.)

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Анотація. Актуальність проведених досліджень полягає у необхідності вдосконаленні технології вирощування картоплі зі свіжозібраних бульб за умов літнього садіння для покращання якості насіннєвого матеріалу. Метою досліджень було визначення впливу фізіолого-біохімічного стану та сортових особливостей рослин картоплі на здатність свіжозібраних бульб формувати якісний насіннєвий матеріал за двоурожайної культури в умовах Лісостепу України. Для проведення досліджень використовувалися польові, статистичні, розрахунково-аналітичні та лабораторні методи. Встановлено, що збирання першого врожаю для садіння свіжозібраними бульбами у фазу цвітіння та впродовж двох тижнів після його завершення для деяких сортів є неефективними. При цьому, перший урожай складає в середньому 18,5 т/га, а другий – 5,1 т/га. Деякі сорти мають низьку схожість зі свіжозібраних бульб (від 4 до 76 %) або взагалі їх не утворюють. Це пояснюється накопиченням у дозріваючих бульбах інгібіторів проростання (абсцизової кислоти та інших), що спричиняє глибокий природний спокій бульб. Пропонуємо враховувати активність інгібіторів проростання у свіжозібраних бульбах за допомогою алелопатичного тестування, що дозволяє встановити оптимальні строки їх збирання та садіння. Це забезпечує схожість на рівні 80-87%. При цьому перший урожай бульб складає від 10,1 до 15,0 т/га, а другий – від 26,2 до 9,3 т/га. Залежність вмісту абсцизової кислоти з накопиченням у бульбах крохмалю дозволяє візуально визначити придатність їх до проростання за хімічною реакцією рослинного соку з розчином йоду. Практична цінність роботи полягає у можливості отримання двох врожаїв насіннєвої картоплі на рік, при цьому перший врожай формується за 60-70 діб, а другий – 90-100 діб від садіння. Не зважаючи на порівняно невисоку врожайність, отриманий насіннєвий матеріал є фізіологічно молодим, вільним від хвороб і має високий потенціал продуктивності. Це дозволяє скоротити схему насінництва, підвищити коефіцієнт розмноження картоплі та заощадити ресурси

Ключові слова: картопля; насінництво; свіжозібрані бульби; два врожаї; коефіцієнт розмноження; алелопатичне тестування

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Formation of grain yield and quality indicators of soybeans under the influence of fungicidal protection

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Abstract. Soybean diseases reduce the energy of seed germination, dilute crops, reduce the photosynthetic surface and productivity of cultivated plants, and worsen quality indicators. The purpose of the study was to determine the effect of fungicidal protection on the yield and quality of soybean grain. The following methods were used to achieve it: field, chemical (to determine the quality indicators of soybean grain), and statistical (to assess the reliability of data). The study was conducted in 2021-2022 in the conditions of TOV Savarske, Obukhiv district, Kyiv region. Soybean varieties Amadea and Aurelina and 10 variants of fungicidal protection were examined. It was identified that the increase in soybean grain yield when using fungicides is 0.41-0.72 t/ha, compared to the control. The highest yield in the experiment was obtained on the variants Celest top 312.5 FS, TH (1 l/t) + Abacus (2 l/ha) and Standak Top

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(2 l/t) + Abacus (2 l/ha) – 3.31 and 3.37 t/ha and 3.06 and 3.13 t/ha, respectively, in the varieties Amadea and Aurelina. There was no effect of the fungicides under study on the moisture content of soybean grains and the fat content of soybean seeds. There is an increase in protein content by 0.3-1.8% in variants with the use of fungicidal protection, compared to the control. The highest fat and protein content was obtained on the variant Standak Top (2 l/t) + Abacus (2 l/ha) and Celest top 312.5 FS, TH (1 l/t) + Abacus (2 l/ha) – 21.9 and 21.7% and 38.5 and 42.4%, respectively, in the varieties Amadea and Aurelina. The results of the conducted studies can be used in production conditions to improve the protection of soybean crops from diseases and increase the yield and quality of grain of this crop

Keywords: soy; fungicides; productivity; grain quality; pre-sowing seed treatment

INTRODUCTION

Soybeans are one of the most profitable crops in Ukraine, and its global acreage increases every year. Therewith, the yield of this crop is unstable and changes under the influence of many factors, one of which is the infection of soybean seedlings and the leaf apparatus by fungal diseases. The use of plant protection products is required to level or reduce the impact of fungal diseases on soybean plants, one of the most effective of which are fungicides. Due to the emergence of new fungicidal preparations, it becomes expedient to examine their effect on the yield and quality of soybean grain.

The studies (Baysal-Gurel, 2018; Kots, 2021) note that high economic and food losses from damage to soybean plants by phytopathogens cause the need for crop protection. Modern fungicides are effective compounds that act on specific biochemical processes of pathogen growth and development and stimulate the protective mechanisms of cultivated plants. However, there are problems using synthetic fungicides, which include hazards to human health, damage to aquatic ecosystems, reduction of the number of beneficial microorganisms in the soil, and even damage to the ozone layer. According to Christopher (2010), frequent and indiscriminate use of fungicides can promote the development of fungicide resistance.

The study by Bandara *et al*. (2020) identified a substantial and positive association between soybean yield and fungicide use in most years of the study. According to the data obtained by Kandel *et al*. (2021), mixtures of fungicides from several groups of active ingredients (two or three ingredients) increase soybean yield by 3.0% compared to the control. Therewith, the average yield increase over the years of observation (2005-2018) is 2.7%. As noted in the study by Bluck (2015), the absence of fungicides in the soybean cultivation system reduced grain yields in 5 out of 13 years of the experiment (2000-2013) by 0.21-0.79 t/ha, and their use increased yields by an average of 0.47 t/ha.

According to the results of the study conducted with the fungicides Triazole (tebuconazole) and Strobilurine (pyraclostrobin) by Swoboda (2009), it was identified that their separate and combined use in soybean crops did not result in a substantial effect on grain yield. In this study, fungicides were used in the absence of fungal diseases and had no non-fungicidal physiological effect on soybean plants.

Hanna (2008) and Mourtzinis (2017) think that the phase of crop development in which the fungicide is used substantially affects its effectiveness and ability to suppress diseases. In addition, there is a decrease in the effectiveness of fungicides due to unfavourable environmental conditions and their use on soybean varieties that are resistant to diseases. According to Bestor (2011) and Chanda (2014), there is no clear understanding of the correct period of application of fungicides. In many soybean-producing countries, the use of fungicides for disease control is based on a fixed stage of crop growth, usually between R3 and R5. This phenology-based criterion is widely accepted because of its ease of implementation, as it does not require disease detection or diagnosis (Carmona, 2015).

According to Pavlishche *et al*. (2017), soybean seed treatment had a negative impact on nodulation processes, nodule nitrogen-fixing activity, photosynthetic intensity, and leaf transpiration. Therewith, the degree of manifestation of the effect depended on the drug and the method of treatment. Early, two weeks before sowing, seed treatment had less effect on the symbiotic apparatus compared to etching together with inoculation on the day of sowing, but it had a stronger effect on the physiological state of the plant itself, in particular, on photosynthesis and transpiration. Rybachenko (2021) studies showed that the fungicides Fever and Standak Top slightly inhibit the nodulation activity of rhizobia in the phase of 2 true leaves of soybean. Therewith, in the phase of 3 true leaves and budding, these drugs activate the processes of nodule formation and fixation of molecular nitrogen. Therewith, the results of field experiments by Omelchuk (2019) show that the use of Acanto Plus fungicide contributed to a more complete realisation of the productive capacity of soy-rhizobial symbiosis of soybeans and an increase in seed weight by 21% compared to the control.

Mostovyak & Kravchenko (2018) note that in the conditions of the Forest-Steppe of Ukraine, the use of fungicides Acanto Plus 28 KS (1.0 l/ha), Amistar Extra 280 SC (0.75 l/ha), Bumper Super 490 SE (1.5 l/ha),

Impact K, KC (0.8 L/ha), Coronet 300 SC KS (0.8 L/ha) in crops soy leads to intensive passage of growth and photosynthetic processes in plants, accompanied by an increase of 20-48% of the leaf surface area, 58-79% of the amount of chlorophylls A and B in the leaves, and 7-9% of the net productivity of photosynthesis of crops.

According to Kandel *et al*. (2016) and Bradley (2008), fungicides can be used for preventive purposes to increase soybean yields, but their use was profitable in about 14% of cases based on the average market price of soybeans in 2008-2014. According to Orlowski (2016), the use of fungicides is profitable even in the absence of diseases. In addition, as noted by Bergman *et al*. (2020), it is necessary to adhere to the principles of Integrated disease control and use fungicides only if they are known or highly likely to occur. A similar opinion is shared by Swoboda *et al*. (2009), which indicates that environmental conditions and disease assessment should be used as a reference for foliar application of fungicides on soybeans.

A review of literature sources indicates a lack of consensus on the type of fungicides, the period of their application, and their impact on the growth processes, productivity, and quality indicators of soybeans. Therefore, the purpose of these studies was to identify the features of the formation of productivity and quality of soybean grain depending on fungicidal protection.

MATERIALS AND METHODS

The study was conducted in 2021-2022 in the conditions of TOV Savarske, Obukhiv district, Kyiv region. The scheme of the experiment is shown in Table 1.

Table 1. *Experiment scheme*

Soybean varieties (factor A)	Fungicides (Factor B)
Amadea	Control
	Maxim Advance (1.25 l/t)
	Vibrance (1 l/t)
	Celest top (1 l/t)
	Standak Top (2 l/t)
Aurelina	Abacus (2 l/ha)
	Maxim Advance (1.25 l/t) + Abacus (2 l/ha)
	Vibrance (1 l/t) + Abacus (2 l/ha)
	Celest top (1 l/t) + Abacus (2 l/ha)
	Standak Top (2 l/t) + Abacus (2 l/ha)

Source: *compiled by the authors*

Seed treatment with fungicides was conducted before sowing and spraying of crops during the growing season (before the budding phase) by applying a working solution (250 l/ha) in experimental plots. On the control variants, seeds were treated, and crops were sprayed with water at the rate of 250 l/ha during the period when fungicides were applied.

The total area of the basic plot is 144 m^2, accounting – 120 m^2. The experiment is repeated three times. Soil of experimental plots – typical medium-loamy loamy chernozem. The content of humus is 2.56%, easily hydrolysed nitrogen – 145 mg/kg, mobile phosphorus – 167 mg/kg, exchange potassium – 178 mg/kg. The degree of soil pH acidity – 6.1.

In 2021, the weather conditions were favourable for the growth, development, and formation of soybean productivity. In some months (May and July), there was 63 and 78% more precipitation compared to the long-term average. In 2022, air and soil droughts were observed in May and June, and there was an excess of precipitation only in September (112.6 mm), which did not affect soybean productivity. That is, this year was unfavourable for soybeans in terms of climate indicators.

Yield accounting was conducted separately by the method of continuous threshing of each plot, followed by recalculation for 100% purity and standard humidity. The protein content was determined by the Kjeldahl method, and the fat content was determined by the extraction of the suspension with ethyl ether in the Soxlet apparatus according to DSTU 4964:2008 (2010). The analysis of the obtained data was conducted using the methods of dispersion and variation analysis using Microsoft Excel and Statistics 12.0 computer programmes.

RESULTS AND DISCUSSION

Based on the results of the conducted studies, it was identified that the yield of the soybean varieties under study depended both on the hydrothermal conditions of the year of research and the use of fungicides (Table 2).

***Table 2**. Effect of fungicides on soybean grain yield, t/ha*

Experiment variant	2021	2022	Average	Increase compared with control
Amadea				
Control	2.98	2.03	2.50	–
Maxim Advance (1.25 l/t)	3.50	2.34	2.92	0.42
Vibrance (1 l/t)	3.52	2.35	2.94	0.44
Celest top (1 l/t)	3.78	2.58	3.18	0.68
Standak Top (2 l/t)	3.84	2.64	3.24	0.74
Abacus (2 l/ha)	3.42	2.28	2.85	0.35
Maxim Advance (1.25 l/t) + Abacus (2 l/ha)	3.63	2.51	3.07	0.57
Vibrance (1 l/t) + Abacus (2 l/ha)	3.66	2.52	3.09	0.59
Celest top (1 l/t) + Abacus (2 l/ha)	3.93	2.69	3.31	0.81
Standak Top (2 l/t) + Abacus (2 l/ha)	4.00	2.74	3.37	0.87
Aurelina				
Control	3.03	1.84	2.43	–
Maxim Advance (1.25 l/t)	3.27	2.20	2.73	0.30
Vibrance (1 l/t)	3.30	2.21	2.75	0.32
Celest top (1 l/t)	3.50	2.41	2.95	0.52
Standak Top (2 l/t)	3.52	2.46	2.99	0.55
Abacus (2 l/ha)	3.20	2.18	2.69	0.26
Maxim Advance (1.25 l/t) + Abacus (2 l/ha)	3.42	2.36	2.89	0.46
Vibrance (1 l/t) + Abacus (2 l/ha)	3.44	2.38	2.91	0.48
Celest top (1 l/t) + Abacus (2 l/ha)	3.59	2.54	3.06	0.63
Standak Top (2 l/t) + Abacus (2 l/ha)	3.67	2.60	3.13	0.70
HIP_{05}	0.11	0.09	0.12	

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

The weather conditions of 2022 were unfavourable for soybeans, which affected the growth and development of plants and the level of crop yield in general. Depending on the factors under study, it ranged from 1.84 (Aurelina variety, control) to 2.74 t/ha (Amadea variety, Standak Top (2 l/t) + Abacus (2 l/ha)). In 2021, the hydrothermal regime during the growing season of soybeans contributed to the maximum realisation of the genetic potential of soybean varieties, which allowed obtaining grain yields from 2.98 (Amadea variety, control) to 4.00 t/ha (Amadea variety, Standak Top (2 l/t) + Abacus (2 l/ha)). The decrease in yield in 2022 was 28.2-33.4% compared to the previous year.

The use of fungicides had a positive effect on increasing the yield of soybeans of both varieties during the years of research. Thus, under the influence of this technological measure, the yield increase was 0.42-0.87 t/ha for the Amadea variety and 0.30-0.70 t/ha for the Aurelina variety, compared to the control. The difference between the fungicide protection options was greater in 2022. On average, for two years, the most effective option was pre-sowing seed treatment with Standak Top (2 l/t) and spraying plants during the growing season with Abacus (2 l/ha). The grain yield was 3.37 and 3.13 t/ha, respectively, in the varieties Amadea and Aurelina. Notably, in both varieties there was no substantial difference between this option and the use of Celest top (1 l/t) + Abacus (2 l/ha), which was within the error range of the experiment (HIP05 in 2021 – 0.11, in 2022 – 0.09 t/ha). There is also no substantial difference between the use of Maxim Advance (1.25 l/t) + Abacus (2 l/ha) and Vaibrans (1 l/t) + Abacus (2 l/ha), Maxim Advance (1.25 l/t) and Vaibrans (1 l/t), and Celest top (1 l/t) and Standak Top (2 l/t). This is due to the similar mechanism of action of the examined drugs, especially in the initial period, on pathogens.

In general, options with the combined use of pre-sowing seed treatment and the introduction of fungicides on vegetative soybean plants were more effective. Therewith, in areas with pre-sowing treatment of seeds with Maxim Advance (1.25 l/t), the grain yield was 0.4-0.7 t/ha higher than with post-emergence application of Abacus (2 l/ha). On average over the years of the study, the grain yield of the Amadea variety was 2.7-7.7% higher than the Aurelina variety. The yield of the Amadea variety was in the range of 2.03-3.70 t/ha and the Aurelina variety – 1.84-3.43 t/ha (Fig. 1).

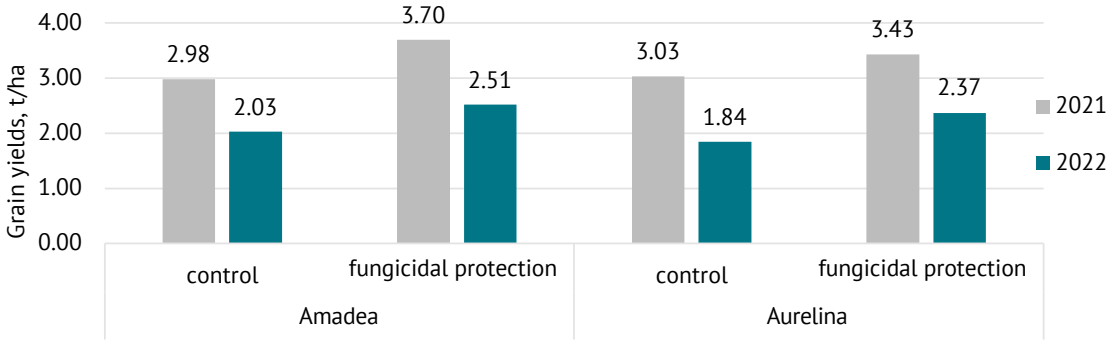

***Figure 1**. Yield of soybean varieties depending on the application of fungicidal protection, t/ha*
***Source:** compiled by the authors*

The use of fungicides provides an increase in the yield of soybean grain in the range of 0.41-0.72 t/ha, compared to the control. The above-mentioned increases in the yield level indicate a high efficiency of using fungicides. Based on the results of the variance analysis of data for the years of research, the share of involvement of the factors under study and their interaction in the formation of grain yield of soybean varieties Amadea and Aurelina was established (Table 3).

***Table 3**. Variance analysis of soybean yield in 2021-2022*

Factor	MS	p	Involvement part, %	Substantiality
Variety (A)	3.288	<0.001	17.1	*
Fungicides (B)	2.404	<0.001	12.5	*
Year (Y)	12.519	<0.001	65.1	*
A x B	0.808	<0.001	4.3	*
B x Y	0.154	<0.001	0.8	*
Other interactions	<0,01	>0.05	0.2	ns

***Note:** p≤0.05; ns – not substantial, p>0.05*
***Source:** compiled by the authors*

Weather conditions (year) had the greatest impact (65.1%) on the formation of soybean yields. The genotypic effect (variety) was at the level of 17.1% and the share of fungicides in the formation of soybean yield was 12.5%. The interaction "variety – fungicidal protection" was substantial (4.3%), and the interaction "fungicides – weather conditions (year)" was insubstantial. A direct high relationship was established between the yield and precipitation for the soybean growing season (r=0.85 in 2021 and r=0.92 in 2022) and the sum of effective temperatures for the growing season (r=0.88 in 2021, r=0.96 in 2022).

According to Podpryatov (2014), the moisture content of soybean grain during harvesting should be 14-16%, because at values of 11-12%, beans crack, cracks form in the seeds, through which pathogens enter, leading to substantial grain losses. When the grain moisture content is over 20%, the seeds are deformed, the embryo is damaged and cannot be completely grounded from the beans.

There was no effect of the fungicides under study on the moisture content of soybean grain, this indicator depended on the weather conditions of the year and varietal characteristics (Table 4). The highest indicators of grain moisture were in 2022 – 8.9-9.6% and 8.4-9.2% and lower in 2021 – 7.8-8.6% and 7.8-8.4%, respectively, in the varieties Amadea and Aurelina. The Amadea Variety had a 0.2-0.7% higher grain moisture content compared to the Aurelina variety.

***Table 4**. Effect of fungicides on grain moisture of soybean varieties, %*

Experiment variant	2021	2022	Average
	Amadea		
Control	8.1	9.4	8.8
Maxim Advance (1.25 l/t)	8.4	9.0	8.7
Vibrance (1 l/t)	8.3	8.9	8.6
Celest top (1 l/t)	7.9	9.1	8.5
Standak Top (2 l/t)	8.2	9.4	8.8

Table 4, Continued

Experiment variant	2021	2022	Average
Amadea			
Abacus (2 l/ha)	7.8	9.6	8.7
Maxim Advance (1.25 l/t) + Abacus (2 l/ha)	8.0	9.3	8.7
Vibrance (1 l/t) + Abacus (2 l/ha)	8.6	9.3	9.0
Celest top (1 l/t) + Abacus (2 l/ha)	8.5	9.0	8.8
Standak Top (2 l/t) + Abacus (2 l/ha)	7.9	9.5	8.7
Aurelina			
Control	8.3	8.8	8.6
Maxim Advance (1.25 l/t)	7.8	8.7	8.3
Vibrance (1 l/t)	8.6	9.2	8.9
Celest top (1 l/t)	7.9	8.7	8.3
Standak Top (2 l/t)	8.0	8.9	8.5
Abacus (2 l/ha)	7.8	9.0	8.4
Maxim Advance (1.25 l/t) + Abacus (2 l/ha)	8.4	8.5	8.5
Vibrance (1 l/t) + Abacus (2 l/ha)	7.9	8.6	8.3
Celest top (1 l/t) + Abacus (2 l/ha)	7.8	8.7	8.3
Standak Top (2 l/t) + Abacus (2 l/ha)	7.8	8.4	8.1
HIP_{05}	0.1	0.2	0.2

Source: *compiled by the authors*

The fat content of soybean seeds depended on the genotypic characteristics of the studied varieties. There was no substantial effect of fungicides on fat accumulation in soybean grain, there was only a tendency to increase it by 0.1-0.4% in the experimental areas with their use, compared to the control. In the Amadea variety, on average for two years, this indicator was higher than in the Aurelina variety by 0.1-0.4% and varied in the range of 21.3-21.7%, and in the Aurelina variety, it was 21.0-21.6% (Fig. 2).

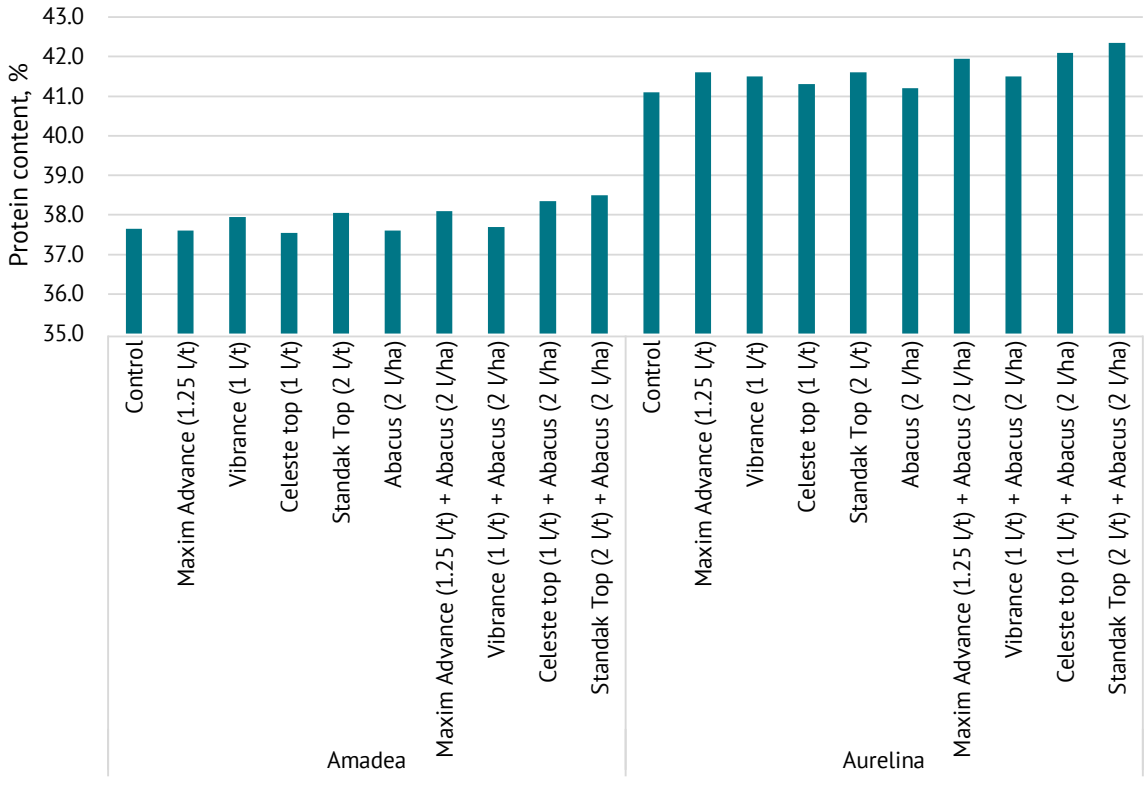

Figure 2*. Soybean grain fat content (average for 2021-2022), %*

Source: *compiled by the authors*

The protein content in soybean grains varied between 37.5-38.5% in the Amadea variety and 40.6-42.4% in the Aurelina variety (Fig. 3). In the Amadea variety, the protein content in the grain was 3.1-3.9% lower compared to the Aurelina variety. In the variants using fungicidal protection, the protein content increased in the varieties Amadea and Aurelina by 0.3-1.0% and 0.7-1.8%, compared to the control. The highest protein content in both varieties was obtained using Celest top (1 l/t) + Abacus (2 l/ha) – 38.4 and 42.1 % and Standak Top (2 l/t) + Abacus (2 l/ha) – 38.5 and 42.4%, respectively, in the varieties Amadea and Aurelina.

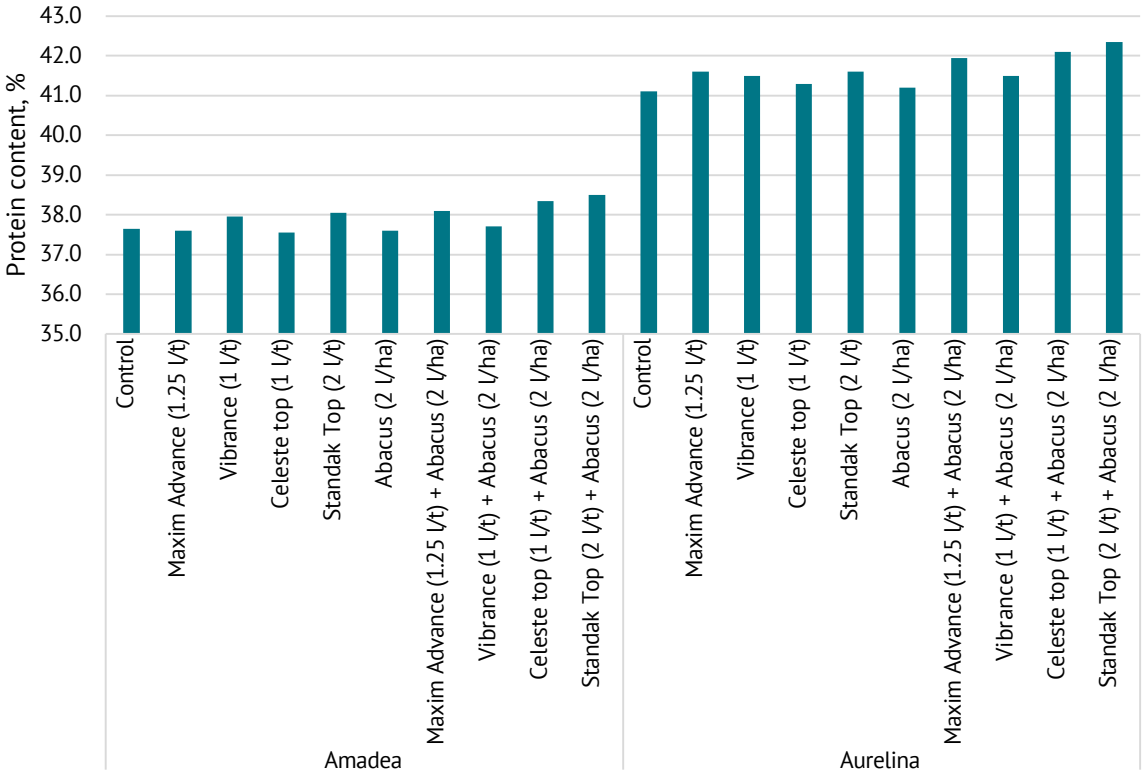

***Figure 3**. Protein content in soybean grains (average for 2021-2022), %*
***Source:** compiled by the authors*

Consequently, an increase in soybean grain yield was identified in the range from 0.41 to 0.72 t/ha and protein content from 0.3 to 1.8%, on variants using fungicides, compared with the control. The effect of the fungicides under study on the moisture content of soybean grains and the fat content of soybean seeds was not established. The highest yield of soybeans in the experiment, in the varieties Amadea and Aurelina, was obtained on the variants Celest top 312.5 FS, TH (1 l/t) + Abacus (2 l/ha) and Standak Top (2 l/t) + Abacus (2 l/ha) – 3.31 and 3.37 t/ha and 3.06 and 3.13 t/ha.

According to the results of the conducted studies, a substantial increase in the yield of soybean grain on variants using fungicides was established. This is consistent with the data of other researchers. Thus, Kosylovych & Golyachuk (2020) identified that the highest soybean yield was obtained when applying fungicides Aliette, 80% WP (1.5 kg/ha), Propulse, 25% SE (0.8 l/ha) – 37.5 cwt/ha, which was 11.0 cwt/ha in addition to the control. Shendryk (2018), in the conditions of the Bila Tserkiva experimental breeding station, the high efficiency of the fungicide Propulse 250 SE against a complex of soybean diseases and an increase in soybean yield by 1.0-1.5 t/ha, compared to the control, was established. As noted by Shcherbachuk (2015), double application of fungicides Coronet (0.6 l/ha) and Abacus (1.5 l/ha) provides the highest yield of soybeans – 2.70 t/ha and the highest protein content – 37.8%.

Kolisnyk (2020) identifyed that pre-sowing seed treatment with Rhizoactive + Maxim XL 035 FS in combination with Abacus fungicide contributed to an increase in soybean seed yield to 2.65 t/ha. According to Ng (2018), fungicide treatment of soybean seeds and crops increased yields in 4 out of 12 years of testing compared to the control. The use of a separate fungicide, insecticide, or a mixture of both did not improve yields in the absence of harmful entomofauna or phytopathogens at threshold levels on soybean plants. In the studies by Mostovyak (2019), soybean grain yields increased by 11-15% when using fungicides. Other researchers also note the positive effect of fungicides on soybean productivity (Kolisnyk, 2020; Grassini, 2015; Vann, 2021). Some researchers (Swoboda & Pedersen, 2009; Ng, 2018) emphasise the importance of regulated

use of fungicides in soybean cultivation. As noted, (Bergman, 2020; Junqueira, 2021; Bestor, 2011) fungicides should only be used if certain diseases are present or highly likely to occur in soybean crops.

According To Rotundo (2009), high air temperatures and low precipitation during seed formation and reproductive growth lead to higher protein concentrations in soybean seeds. The increase in protein synthesis depends on the time and degree of environmental stress. This increase in protein content may be the reason for the low correlation of protein content with grain yield.

According to the results obtained, the protein content depended on varietal characteristics and did not change substantially over the years of the study. The authors did not calculate the correlation between grain yield and protein content. An increase in protein content of 0.3-1.8% was identified in variants using fungicidal protection, compared with the control. This is consistent with the data obtained by Hryhor'eva (2020) and Hadzovsky (2020).

According to the data obtained, the use of fungicides did not cause substantial differences in changes in the fat content in soybean grains, which is confirmed by other researchers (Kosylovych, 2020; Procházka, 2017; Ghahari, 2017). However, based on the results obtained by Siddiqui (2006) with an increase in the dose of fungicides, the protein and fat content in soybean grains decreased. The insufficient number of studies to examine the effect of fungicides on the quality indicators of soybean grain is notable. That is, the question of the effect of fungicides on protein and fat content requires further study.

CONCLUSIONS

Based on the results of the conducted studies, the influence of pre-sowing seed treatment and post-emergence use of fungicides on the productivity of soybean varieties was established. On average, the increase in soybean grain yield is 0.41-0.72 t/ha, compared to the control. The highest yield in the experiment was obtained on the following variants: Celest top 312.5 FS, TH (1 l/t) + Abacus (2 l/ha) and Standak Top (2 l/t) + Abacus (2 l/ha) – 3.31 and 3.37 t/ha and 3.06 and 3.13 t/ha, respectively, in the varieties Amadea and Aurelina. The grain yield in the Amadea variety was 2.7-7.7% higher than in the Aurelina variety.

Soybean productivity depended on the hydrothermal conditions of the year. Thus, in the best in terms of precipitation year of 2021, the yield of Amadea and Aurelina varieties, depending on the fungicidal protection, was 2.98-4.00 and 3.03-3.67 t/ha, respectively. And in the unfavourable climatic year 2022, the yield was 2.03-2.74 and 1.84-2.60 t/ha, respectively. The decrease in yield in 2022 was 28.2-33.4% compared to the previous year.

The effect of the fungicides under study on the moisture content of soybean grains and the fat content of soybean seeds was not established. An increase in protein content by 0.3-1.8% was identified in variants using fungicidal protection, compared with the control. The highest fat and protein content is obtained when using fungicides Standak Top (2 l/t) + Abacus (2 l/ha) – 21.9 and 21.7% and 38.5 and 42.4%, respectively, in the varieties Amadea and Aurelin. The high efficiency of the examined fungicides is explained by their effect on pathogens in the initial period of soybean plant ontogenesis and the development of fungal diseases during the growing season. Therewith, it requires further research to determine the effectiveness of fungicides as preventive drugs, justify the economic feasibility of their use, and their impact on the quality indicators of soybean grain.

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CONFLICT OF INTEREST

None.

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Формування урожайності зерна та якісних показників сої під впливом фунгіцидного захисту

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Анотація. Хвороби сої знижують енергію проростання насіння та його схожість, зріджують посіви, зменшують фотосинтетичну поверхню й продуктивність культурних рослин, погіршують якісні показники. Метою досліджень було визначення впливу фунгіцидного захисту на урожайність та якість зерна сортів сої. У процесі виконання досліджень використовували наступні методи: польовий, хімічний (для визначення якісних показників зерна сої) та статистичний (для оцінки достовірності даних). Дослідження проводилися в 2021-2022 рр. в умовах ТОВ «Саварське» Обухівського району Київської області. Вивчали сорти сої Амадеа та Ауреліна та 10 варіантів фунгіцидного захисту. Виявлено, що приріст врожайності зерна сої при застосуванні фунгіцидів становить 0,41-0,72 т/га, порівняно з контролем. Найвища урожайність в досліді отримана на варіантах Селест топ 312.5 FS, ТН (1 л/т) + Абакус (2 л/га) і Стандак Топ (2 л/т) + Абакус (2 л/га) – 3,31 і 3,37 т/га та 3,06 і 3,13 т/га, відповідно у сортів Амадеа та Ауреліна. Не відмічено впливу досліджуваних фунгіцидів на вологість зерна сої та вміст жиру в насінні сої. Спостерігається зростання вмісту білку на 0,3–1,8 % на варіантах із застосуванням фунгіцидного захисту, порівняно з контролем. Найвищий вміст жиру та білка отримано на варіантах Стандак Топ (2 л/т) + Абакус (2 л/га) і Селест топ 312.5 FS, ТН (1 л/т) + Абакус (2 л/га) – 21,9 і 21,7 % та 38,5 і 42,4 %, відповідно у сортів Амадеа та Ауреліна. Результати проведених досліджень можуть бути використанні в виробничих умовах для покращення захисту посівів сої від хвороб та підвищення урожайності та якості зерна цієї культури

Ключові слова: соя; фунгіциди; продуктивність; якість зерна; передпосівна обробка насіння

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Mineral composition of alfalfa, alfalfa-cereal, and cereal feed agrophytocenoses biomass

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Abstract. The relevance of the results of these studies lies in the fact that until recently, changes in the mineral composition of different types of meadow agrophytocenoses under the influence of symbiotic alfalfa and mineral nitrogen in the content of macro- and microelements, heavy metals, and nitrates in feed biomass have not yet been sufficiently investigated, which hinders the development and implementation of feed production findings in agricultural production. The purpose of the study is to establish changes in the accumulation of various meadow agrophytocenoses in dry feed biomass on various agricultural zones of mineral elements during cultivation on dark grey soils of the Right-Bank Forest-Steppe. During this study, field and laboratory methods were used, and an analytical method was used to determine the mineral composition of dry feed biomass. The results of studies on the accumulation of alfalfa,

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alfalfa-cereals, and cereal stands in in dry feed mass on various backgrounds of fertilisation and liming of raw ash, macro- and microelements, heavy metals, and nitrate nitrogen are presented. It is shown that under the action of symbiotic nitrogen in alfalfa and alfalfa cereal stands, compared with cereals in the dry mass of feed, raw ash accumulates more macroelements, trace elements, and heavy metals by 0.6-0.8%, the ratio of calcium to phosphorus increases by 0.11-0.26, and potassium to the sum of calcium and magnesium decreases by 0.11-0.26. Under the action of mineral nitrogen in the case of the introduction of N90 in the cereal stand, the content of nitrates increases from 0.02 to 0.04%, zinc – from 9.1-9.2 to 12.4-12.6 or by 3.2-3.5 mg/kg, copper – from 3.4-3.7 to 5.3-5.5 mg/kg, as well as manganese, lead, nickel, cadmium in the dry mass of the feed of the cereal stand. It is proved that the content of macro- and microelements in the dry mass of feed corresponds to zootechnical standards for feeding cattle, and nitrates and heavy metals do not exceed the maximum permissible concentrations. The results of these studies can be used in the development of recommendations on technologies for growing perennial cereals for feed purposes and in the educational process

Keywords: heavy metals; zootechnical norm; macro- and microelements; nitrates; raw ash; dry mass; cereal feed

INTRODUCTION

The effective functioning of animal husbandry largely depends on providing this branch of agriculture with cheap cereal feed. Hayfields, pastures, and crops of perennial cereals are their main source. One of the ways of environmentally safe intensification of feed production and meadow culture is the creation of feed agrophytocenoses with a high content of legumes. Due to symbiotic nitrogen fixation, they not only increase the productivity of forage lands but also improve the quality of feed, in particular, their mineral composition. Therefore, the results of researching the mineral composition of different types of meadow agrophytocenoses are certainly relevant.

Analysis of the studies (Dziubailo *et al.*, 2020; Kovtun *et al.*, 2020; Kamalongo & Cannon, 2020) shows that replacing mineral nitrogen in the cultivation of perennial cereals with symbiotically fixed nitrogen of perennial legumes for growing them in a single-species crop or mixed with cereals substantially reduces the energy costs of growing forage agrophytocenoses. Ultimately, the nitrogen of mineral fertilisers, used for the cultivation of highly productive cereal stands, can account for half or more of all total costs.

Due to the substantial increase in mineral nitrogen, increasing the use of perennial legumes as a source of symbiotic nitrogen in meadow culture and feed production is an important component of the programme for introducing energy-saving technologies abroad, including for organic agricultural production (Hannaway *et al.*, 2018; Kim *et al.*, 2019; Karbivska *et al.*, 2020).

The studies (Bo *et al.*, 2022; Odzijewicz *et al.*, 2023) identified that symbiotic nitrogen of perennial legumes both in legume-cereal mixtures and in single-species crops improves the chemical composition of feed. In particular, it helps to increase the content of crude protein, protein, macroelements of calcium and magnesium in the dry mass, improve the digestibility of feed, the nutritional content of feed units and energy intensity in the content of metabolic energy, and reduce the amount of nitrogen-free extractives, crude fibre, and potassium.

Authors (Bogovin & Ptashnyk, 2020; Tamahina & Turabov, 2021; Kurgak & Karbovskaya, 2020) also established that the quality of feed of cereal phytocenoses is positively affected by nitrogen mineral fertilisers. When it is applied, the content of crude protein and protein in herbs increases, the content of nitrogen-free extractive substances and, in particular, their component part – hydrocarbons, including water-soluble or sugars, decreases. However, it should be noted that the increase in the content of crude protein in herbs under the influence of nitrogen fertilisers in different conditions occurs at different rates.

It is known that the mineral composition of the feed, in particular, the content of macro- and microelements, is important in feeding animals. The content of mineral elements in the biomass of perennial phytocenoses depends on their species composition, fertiliser system, timing and frequency of harvesting, and other technological measures of cultivation (Nilsdotter-Linde *et al.*, 2016; Kurhak *et al.*, 2020; Martsinko *et al.*, 2021).

In the studies (Monti *et al.*, 2008; Demidas & Galushko, 2020) it is noted that a substantial danger to animals may arise from mineral fertilisers due to the introduction of increased doses of nitrogen and the accumulation of nitrate nitrogen ($N\text{-}NO_3$), which as part of crude protein accumulates in the biomass of herbs, in such cereal feed. It is also highlighted that in the early phases of vegetation (tillering of cereals and shoot formation of legumes), the nitrate content is substantially higher than in optimal periods of harvesting cereal stands (earing of cereals budding or flowering of legumes). It is also proved that the accumulation of $N\text{-}NO_3$ over 0.07% of the dry mass of feed is harmful, 0.07-0.2% can lead to poisoning, and over 0.25% can be fatal for cattle. According to DSTU 8528:2015 (2017), the maximum permissible concentration (MPC) of $N\text{-}NO_3$ which is safe for cattle is considered to be 500.0 mg/kg of dry weight or 0.05%.

All of the above indicates the need to apply such fertilisers and other agrotechnical measures that increase

not only the productivity of forage lands but also contribute to obtaining high-quality feed in terms of mineral composition. Therefore, it is important to use such doses of nitrogen fertilisers that would not increase the accumulation of toxic elements (nitrates and heavy metals) in the feed over the maximum permissible concentration.

However, until recently, changes in the mineral composition of different types of meadow agrophytocenoses under the influence of symbiotic alfalfa and mineral nitrogen in terms of the content of macro- and microelements and heavy metals and nitrates in feed biomass have not yet been sufficiently examined and highlighted in open print, which hinders the introduction of feed production findings in agricultural production. The purpose of this study was to investigate these issues, the results of which are presented in the paper.

The purpose of the study is to establish changes in the accumulation of feed in the dry mass from various meadow agrophytocenoses macro-and microelements and heavy metals and nitrates on various agricultural backgrounds for growing on dark grey soils of the Right-Bank Forest-Steppe.

MATERIALS AND METHODS

The study of the mineral composition of the dry mass of alfalfa, alfalfa-cereals, and cereals of perennial forage agrophytocenoses was conducted during 2019-2021. Plant samples for determining the mineral composition of feed were selected, according to research programmes, in the National Scientific Centre "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine" on dark grey podzolic large-dusty-light-loamy soil of the Forest-Steppe of Ukraine (Chabany village, Kyiv region) in a three-factor experiment, which was conducted according to the following scheme (Table 1):

Table 1. *Scheme of the conducted experiment*

Herbage factor (types of cereals, their mixtures, and seeding rates, kg/ha)	Liming factor (lime doses, t/ha)	Fertiliser factor (nutrients and doses, kg/ha)
Alfalfa, 18	Without liming	Without fertilisers
Alfalfa, 10 + smooth brome, 15	1.5 t/ha	$P_{45}K_{90}$
Alfalfa, 10 + smooth brome, 14 + eastern fescue, 8		
Smooth brome, 15 + eastern fescue, 14		
Smooth brome, 15 + eastern fescue, 14 + $N_{90\ (30+30+30)}$		

Source: *compiled by the authors*

In a 0-20 cm layer of soil, the humus content was at the level of 2.4%; pH (salt) – 5.2; the content of easily hydrolysed nitrogen – 13.1, mobile phosphorus – 17.1, and exchange potassium – 12.9 mg per 100 g of soil. Lime was applied once in pre-sowing tillage during alkalinisation in the spring of 2019. Mineral fertilisers, according to the scheme of the experiment, were applied annually. Phosphorous and potash fertilisers were applied in the spring, and nitrogen fertilisers in the cereal stand – in equal parts for each harvest.

The repetition rate of the experiment is fourfold with an area of the sown plot of 16 m^2, accounting – 10 m^2. Perennial herbs in the experiment were grown according to the generally accepted technology in the region, with the exception of the factors under study. Zoned varieties of perennial cereals were used in the experiment: alfalfa – the Narechena Pivnochi variety, smooth brome – Vizant, and eastern fescue – Domenika, mainly selected by the NSC of the Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine. Field studies were performed in accordance with generally accepted methods in feed production (Babich, 1994).

The content of crude ash and macroelements of phosphorus and potassium in dry plant samples was determined by infrared spectroscopy in accordance with DSTU 4117:2007 (2008). The content of macroelements (calcium and magnesium), trace elements (copper, zinc, manganese, iron), and heavy metals (lead, nickel, cadmium) was determined by atomic absorption spectrometry on the AAS-30 device. Nitrate nitrogen concentration ($N\text{-}NO_3$) calculated for the dry mass was determined by the ionometric method.

The analysis of the results was conducted by comparing changes in the mineral composition of the feed, which were obtained on different variants of the field experiment. Evaluation of the results was also conducted by comparing the content of macro- and microelements with zootechnical standards for feeding cattle, and safety indicators for the content of heavy metals and nitrates – with the maximum permissible concentrations (MPC). Zootechnical standards for the content of mineral elements according to citation (Demidas & Galushko, 2020) and the MPC according to DSTU 8528:2015 (2017) are shown in the tables of the following section, where the results are presented.

Agrochemical indicators of the soil were determined before laying a field experiment in a 0-20 cm layer of soil according to the following generally accepted methods: humus – according to Tyurin, easily hydrolysed nitrogen – according to Cornfield, mobile phosphorus and potassium – according to Chirikov, pH (salt) – potentiometrically.

Mathematical processing of the reliability of the obtained experimental data on the content of mineral elements and nitrate nitrogen in the dry mass of feed in the studies was conducted by the method of dispersion analysis according to the indicators of the smallest substantial difference (HIP_{05}) (Ermantraut, 2007).

RESULTS AND DISCUSSION

The results of the study on average for 2019-2021 of the content of crude ash, macroelements, and their ratio in the biomass of alfalfa alfalfa-cereal, and cereal mixtures are shown in Table 2. These data indicate that on all fertiliser backgrounds, the highest content in the dry mass of raw ash (9.0-9.5%), calcium (0.56-0.63%), magnesium (0.13-0.18%), phosphorus (0.40-0.45%), and the lowest content of potassium (2.35-2.58%) was in the dry mass of alfalfa and its mixtures with cereals, respectively 0.6-0.8%, 0.13-0.16%, 0.07-0.08%, 0.03-0.04% more and 0.13-0.21% less than in dry feed biomass of cereal stand.

***Table 2**. The content of raw ash and macroelements and their ratio in the dry mass of alfalfa, alfalfa-cereals, and cereal stands in (average for 2019-2021), %*

Herbage (types of cereals and seeding rate, kg/ha)	Liming*	Fertiliser	Raw ash	P	K	Ca	Mg	K:(Ca+Mg)	Ca:P
Alfalfa, 18	–	Without fertilisers	9.4	0.44	2.35	0.60	0.17	3.05	1.36
		$P_{45}K_{90}$	9.5	0.45	2.40	0.61	0.18	3.04	1.36
	+	Without fertilisers	9.4	0.41	2.45	0.62	0.17	3.10	1.51
		$P_{45}K_{90}$	9.5	0.43	2.53	0.63	0.18	3.12	1.47
Alfalfa, 10 + smooth brome, 15	–	Without fertilisers	9.1	0.41	2.50	0.56	0.15	3.52	1.37
		$P_{45}K_{90}$	9.3	0.43	2.58	0.57	0.15	3.58	1.32
	+	Without fertilisers	9.0	0.41	2.40	0.58	0.14	3.33	1.41
		$P_{45}K_{90}$	9.2	0.43	2.48	0.59	0.13	3.44	1.37
Alfalfa, 10 + smooth brome, 8 + eastern fescue, 6	–	Without fertilisers	9.0	0.41	2.50	0.56	0.15	3.52	1.37
		$P_{45}K_{90}$	9.2	0.43	2.58	0.57	0.15	3.58	1.33
	+	Without fertilisers	9.1	0.40	2.45	0.58	0.15	3.56	1.45
		$P_{45}K_{90}$	9.2	0.43	2.53	0.60	0.14	3.42	1.40
Smooth brome, 15 + eastern fescue, 14	–	Without fertilisers	8.3	0.37	2.67	0.41	0.11	5.13	1.11
		$P_{45}K_{90}$	8.4	0.39	2.68	0.43	0.11	4.96	1.10
	+	Without fertilisers	8.3	0.41	2.60	0.48	0.11	4.41	1.17
		$P_{45}K_{90}$	8.4	0.43	2.58	0.47	0.11	4.45	1.09
	–	N_{90}	8.7	0.36	2.60	0.45	0.10	4.73	1.25
		$N_{90}P_{45}K_{90}$	8.8	0.37	2.65	0.45	0.10	4.82	1.22
	+	N_{90}	8.7	0.36	2.60	0.47	0.10	4.56	1.31
		$N_{90}P_{45}K_{90}$	8.8	0.37	2.65	0.48	0.10	4.57	1.30
Zootechnical norm				0.2–0.35	1.0–3.0	0.3–0.6	0.12–0.26	2.5–5.5	0.7–2.5
HIP_{05}, %			0.4	0.02	0.12	0.03	0.01		

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

In the dry mass of herbage with alfalfa in comparison with cereal herbage, the content of crude ash, calcium, and magnesium was correspondingly higher by 0.3-0.6%, 0.06-0.10%, 0.01-0.06%, and the content of potassium was less by 0.04-0.12%. Notably, the advantage of the alfalfa stands in comparison with the

cereal stands in terms of the content of raw ash and the above-mentioned mineral elements was substantially greater than the advantage of alfalfa-cereal stands.

According to the data listed in Table 2 on the background of all fertilisers, a higher ratio of calcium to phosphorus Ca:P (in the range of 1.33-1.51) and a lower ratio of potassium to the sum of calcium and magnesium (K:(Ca+Mg)) (in the range of 3.04-3.58) were in the dry mass of alfalfa and alfalfa-cereal mixtures, which, respectively, is 0.11-0.26 units more and 0.83-2.08 units less than in dry feed biomass cereal stand. Similar patterns regarding the effect of nitrogen symbiotic fixation on changes in the ratio of these macroelements in the dry mass of feed were observed by other researchers (Karbivska 2019; Demidas & Galushko, 2020; Kurhak *et al.*, 2020).

Comparison of the content of macroelements indicated in Table 2 in the dry mass of feed from different types of herbage with zootechnical standards for feeding cattle showed that it mainly corresponded to them. However, in these studies the following deviations were noted: a slight excess of the zootechnical norm (0.2-0.35%) in the content of phosphorus in the dry mass of alfalfa feed and its mixtures with cereals, which is positive, and a decrease from the norm (0.12-0.26%) of magnesium, which is negative.

However, both the ratio of K:(Ca+Mg) and the ratio of Ca:P did not go beyond the limits of zootechnical standards for cattle. This indicates that the biomass for the production of cereal feed from the examined cereal stands is quite suitable for feeding cattle. Analysis of these studies showed that phosphorous and potash fertilisers had little effect on the mineral composition of the feed and on the ratio of mineral elements. However, under the influence of nitrogen application at a dose of N90 in the cereal stand, an increase in the content of crude ash, a decrease in the content of phosphorus and potassium, and an increase in the Ca:P ratio, were observed.

According to the data (Table 3), nitrate content ($N\text{-}NO_3$) in the dry mass of alfalfa, alfalfa-cereal mixtures, and cereal stand on different backgrounds, the average use of fertiliser for 2019-2021 ranged between 0.0-0.04% and did not go beyond the maximum permissible concentration (0.07%). Experimental data indicate that the content of nitrates ($N\text{-}NO_3$) in the dry mass of feed when eaten by animals is not harmful to animal health.

Table 3. *Nitrate concentration (N-NO3) in the dry mass of alfalfa, alfalfa-cereals, and cereal stands in on different backgrounds of fertiliser and liming, % (2019-2020)*

Herbage (types of cereals and seeding rate, kg/ha)	Liming*	Fertiliser	Years of life			Average for three years
			1st	2nd	3rd	
Alfalfa, 18	–	Without fertilisers	0.04	0.02	0.02	0.03
		$P_{45}K_{60}$	0.04	0.03	0.02	0.03
	+	Without fertilisers	0.04	0.03	0.02	0.03
		$P_{45}K_{60}$	0.04	0.03	0.02	0.03
Alfalfa, 10 + smooth brome, 15	–	Without fertilisers	0.04	0.02	0.02	0.03
		$P_{45}K_{60}$	0.04	0.02	0.02	0.03
	+	Without fertilisers	0.04	0.02	0.02	0.03
		$P_{45}K_{60}$	0.04	0.03	0.02	0.03
Alfalfa, 10 + smooth brome, 8 + eastern fescue, 6	–	Without fertilisers	0.04	0.02	0.02	0.03
		$P_{45}K_{60}$	0.04	0.02	0.02	0.03
	+	Without fertilisers	0.04	0.02	0.02	0.03
		$P_{45}K_{60}$	0.04	0.03	0.02	0.03
Smooth brome, 15 + eastern fescue, 14	–	Without fertilisers	0.03	0.01	0.01	0.02
		$P_{45}K_{60}$	0.03	0.01	0.01	0.02
	+	Without fertilisers	0.03	0.02	0.01	0.02
		$P_{45}K_{60}$	0.03	0.02	0.01	0.02
	–	$N_{90\ (30+30+30)}$	0.05	0.03	0.03	0.04
		$N_{90}P_{45}K_{60}$	0.05	0.03	0.03	0.04
	+	N_{90}	0.05	0.04	0.03	0.04
		$N_{90}P_{45}K_{60}$	0.05	0.04	0.03	0.04
		HIP_{05}, %	0.005	0.005	0.005	0.005
		MPC, %			0.05	

Source: *compiled by the authors*

In the dry mass of alfalfa and alfalfa-cereal stands in comparison with cereal ones on the same fertiliser backgrounds (options without fertilisers and application of $P_{45}K_{60}$) on average, 0.01% more nitrates accumulated over the years of research. When applying nitrogen fertilisers at a dose of N_{90} (variants N_{90} and $N_{90}P_{45}K_{90}$), the content of nitrates in the dry mass of cereal stands on average for 2019-2021 increased by 0.02%. Thus, introducing mineral nitrogen at a dose of N90 affects the accumulation of $N\text{-}NO_3$ more than the use of symbiotic nitrogen of alfalfa both in single-species sowing and alfalfa-cereal mixtures.

In the analysis of $N\text{-}NO_3$ accumulation over the years of use, it was identified that the nitrate content also changed noticeably. In the 1st year of life and use of herbage (2019), 0.01-0.02% more $N\text{-}NO_3$ was accumulated than in 2020 and 2021. However, patterns of changes in $N\text{-}NO_3$ accumulation under the influence of symbiotic nitrogen, alfalfa, and mineral nitrogen were preserved on the cereal stand for all years. In all years of research, the content of $N\text{-}NO_3$ did not exceed the maximum permissible concentration (0.05% in the dry mass of the feed).

It is known that both under the influence of mineral nitrogen in fertilisers and under the influence of nitrogen symbiotic fixation of perennial legumes, the microelement composition of feed biomass also changes substantially.

The studies (Table 4) also indicate that both when using nitrogen symbiotic fixation of alfalfa in feed agrophytocenoses with it, and mineral nitrogen fertilisers on perennial cereal stands substantially changed the microelement composition of cereal feed and the accumulation of heavy metals in it. Thus, in particular, in the dry mass of alfalfa and alfalfa-cereal stands with various cereal components, in comparison with cereal stands on nitrogen-free fertiliser backgrounds (variants without fertilisers and $P_{45}K_{90}$), zinc content increased from 9.0-9.2 to 12.3-14.8 mg/kg or by 3.3-5.6 mg, copper – from 3.3-3.7 to 4.4-4.7 or by 1.0-1.1 mg/kg, iron – from 54.6-62.7 to 58.3-72.1 or by 3.7-9.4 mg/kg, lead – from 1.4-1.5 to 2.0-2.2 mg or by 0.6-0.7 mg, nickel – from 1.-1.2 to 1.8 mg/kg, cadmium – from 0.1 to 0.2 mg/kg of dry mass.

***Table 4**. Content of trace elements and heavy metals in the dry mass of alfalfa, alfalfa-cereal, and cereal stands, depending on the fertiliser and liming systems (average for 2019-2021), mg/kg*

Herbage (types of cereals and seeding rate, kg/ha)	Liming*	Fertiliser	Microelements				Heavy metals		
			Zn	Cu	Mn	Fe	Pb	Ni	Cd
Alfalfa, 18	–	Without fertilisers	13.9	4.4	44.6	65.9	2.2	1.8	0.2
		$P_{45}K_{90}$	14.7	4.5	46.2	72.1	2.2	1.8	0.2
	+	Without fertilisers	14.3	4.6	44.8	65.9	2.2	1.8	0.2
		$P_{45}K_{90}$	14.8	4.7	46.4	72.1	2.2	1.8	0.2
Alfalfa, 10 + smooth brome, 15	–	Without fertilisers	13.5	4.4	43.3	66.9	2.0	1.8	0.2
		$P_{45}K_{90}$	14.5	4.5	45.5	71.0	2.0	1.8	0.2
	+	Without fertilisers	13.8	4.5	43.5	66.9	2.0	1.8	0.2
		$P_{45}K_{90}$	14.7	4.6	45.8	71.0	2.0	1.8	0.2
Alfalfa, 10 + smooth brome, 8 + eastern fescue, 6	–	Without fertilisers	12.3	4.4	38.9	59.0	2.0	1.8	0.2
		$P_{45}K_{90}$	12.9	4.5	43.9	58.3	2.0	1.8	0.2
	+	Without fertilisers	12.5	4.5	39.3	59.0	2.0	1.8	0.2
		$P_{45}K_{90}$	13.2	4.6	44.2	58.3	2.0	1.8	0.2
Smooth brome, 15 + eastern fescue, 14	–	Without fertilisers	9.0	3.3	45.2	54.6	1.4	1.1	0.1
		$P_{45}K_{90}$	9.2	3.7	54.3	62.5	1.5	1.2	0.1
	+	Without fertilisers	9.0	3.4	45.4	54.6	1.5	1.1	0.1
		$P_{45}K_{90}$	9.1	3.7	54.3	62.7	1.5	1.2	0.1
	–	N_{90}	12.4	5.3	65.9	58.2	1.7	1.3	0.2
		$N_{90}P_{45}K_{90}$	12.6	5.5	66.4	58.3	1.8	1.3	0.2
	+	N_{90}	12.5	5.4	65.6	58.5	1.8	1.4	0.2
		$N_{90}P_{45}K_{90}$	12.6	5.5	66.2	58.7	1.8	1.4	0.2

Table 4, Continued

Herbage (types of cereals and seeding rate, kg/ha)	Liming*	Fertiliser	Microelements				Heavy metals		
			Zn	Cu	Mn	Fe	Pb	Ni	Cd
Zootechnical norm			20–50	4–10	250	200	–	–	–
MPC			50.0	30.0	–	–	2–3	2.0	0.3
HIP_{05}, %			0.6	0.2	2.2	3.2	0.1	0.1	0.01

Note: *trace elements in high concentrations exceeding MPC are also toxic elements, like heavy metals, and are harmful to animal health*
Source: *compiled by the authors*

On the cereal stand under the influence of introducing N_{90} on two backgrounds (without fertilisers and applying $P_{45}K_{90}$) in comparison with non-nitrogen backgrounds, the content of zinc in the dry mass increased from 9.1-9.2 to 12.4-12.6 mg/kg or by 3.2-3.5 mg, copper – from 3.4-3.7 to 5.3-5.5 or by 1.9 mg, manganese – from 45.2-54.3 to 65.6-66.4 mg, lead – from 1.4-1.5 to 1.7-1.8 mg, nickel – from 1.1-1.2 to 1.3-1.4 mg, and cadmium – from 0.1 to 0.2 mg/kg or by 0.1 mg/kg of dry mass.

The analysis of the studies showed that the content of zinc, copper, manganese, and iron in the dry mass of feed from alfalfa, alfalfa-cereals, and cereal perennial stands on various backgrounds of fertilisation and liming, with the exception of minor deviations, did not go beyond the zootechnical standards, which are given in Table 3. Indicators of the content of heavy metals (lead, nickel, cadmium) in the dry mass of feed of these cereal stands, as evidenced by these studies, did not exceed the maximum permissible concentrations (Table 4). This gives grounds to assert that such feed is quite safe for cattle.

The results of the studies on the mineral composition of feed obtained from the biomass of alfalfa, alfalfa-cereals, and cereal perennial stands, depending on fertiliser, are confirmed by experimental data from other researchers. In the studies (Kotyash *et al.*, 2019; Demidas & Galushko, 2020; Martsinko *et al.*, 2021), as in this one, it was shown that under the action of symbiotic nitrogen in alfalfa and alfalfa-cereal stands, compared with cereals among mineral elements, to the greatest extent increased the content of calcium and magnesium in the dry mass of feed (respectively, to 0.86-1.07% and to 0.21-0.35%), and the content of potassium decreased.

Kurhak *et al.* (2020) in their study identified that when applying high doses of nitrogen fertilisers to a perennial cereal stand, the nitrate content increases in the aboveground biomass of cereals in an amount that may exceed the maximum permissible concentration. When applying moderate doses of nitrogen fertilisers, as a rule, despite the fact that the accumulation of nitrates in the dry mass of feed increases, it does not exceed the MPC and is not harmful to animals, which confirms this and similar studies.

Most of the experimental data presented in the studies (Demidas & Galushko, 2020; Kurhak *et al.*, 2020) concerns changes in the microelement composition of feed from perennial cereals under the influence of nitrogen and mineral fertilisers. In particular, it was identified that under its influence, the copper content in the feed biomass of perennial cereals depends on its presence in the soil. On turf soils that are poor in copper, an increase in the dose of nitrogen, due to the formation of complex copper-ammonia compounds, reduces its content in cereals, while against the background of copper fertilisers and copper-rich soils, it increases.

The studies (Prorochenko, 2020) show that both under the influence of symbiotic nitrogen of perennial legumes, and under the influence of moderate doses of mineral nitrogen in the dry mass of feed, there is an increase in the content of trace elements (zinc, copper, iron) within zootechnical standards and without exceeding the maximum permissible concentrations of heavy metals (lead, nickel, cadmium)

Thus, the analysis of literature sources showed that both under the influence of nitrogen of mineral fertilisers and biological, in particular, symbiotic nitrogen, which is fixed by perennial legumes, the concentration of trace elements in the feed biomass of perennial cereals can also change substantially, with similar patterns obtained in this study.

CONCLUSIONS

As a result of the study, it was established, that in the dry mass of feed obtained from alfalfa and alfalfa-cereal stands, there is a higher accumulation of raw ash by 0.6-0.8%, macroelements of calcium – 0.13-0.16%, magnesium – 0.07-0.08%, phosphorus – 0.03-0.04%, nitrate nitrogen – 0.01%, and 0.04-0.12% lower accumulation of potassium than in the feed of perennial cereal stands. The ratio of calcium to phosphorus is higher – by 0.11-0.26 and the ratio of potassium to the sum of calcium and magnesium is lower – by 0.11-0.26. Therewith, in the dry mass of feed made from cereal stands with alfalfa, the accumulation of the following elements is higher: zinc – by 3.3-5.6 mg/kg, copper – 1.0-1.1 mg/kg, iron – 3.7-9.4 mg/kg, and heavy metals of lead – 0.6-0.7 mg/kg, as well as nickel and cadmium, compared to cereal stands.

The chemical composition of cereal feed made from cereal stands is most affected by the mineral composition of the applied nitrogen fertilisers. In the

dry mass of feed produced with the application of N90, the content of nitrate nitrogen increases from 0.02 to 0.04%, trace elements of zinc – from 9.1-9.2 to 12.4-12.6 mg/kg or by 3.2-3.5 mg/kg, copper – from 3.4-3.7 to 5.3-5.5 mg/kg, as well as manganese, heavy metals of lead, nickel, cadmium.

The content of these macro- and microelements in the dry mass of feed is within the limits of zootechnical standards for feeding cattle, and the content of feed safety indicators, in particular, nitrates and heavy metals, does not exceed the maximum permissible concentrations. The prospects for further research are to investigate the cultivation technologies and features of perennial cereals used for feed purposes.

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CONFLICT OF INTEREST

None.

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Мінеральний склад біомаси люцернового, люцерно-злакових і злакового кормових агрофітоценозів

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Анотація. Актуальність наведених результатів досліджень полягає в тому, що до останнього часу зміни мінерального складу різнотипних лучних агрофітоценозів під впливом симбіотичного люцерни посівної і мінерального азоту за вмістом у кормовій біомасі макро- і мікроелементів та важких металів і нітратів ще не достатньо вивчено, що стримує розроблення і впровадження розробок з кормовиробництва у сільськогосподарське виробництво. Мета досліджень полягає в установленні зміни з нагромадження в сухій кормовій біомасі різних лучних агрофітоценозів на різних агрофонах мінеральних елементів за вирощування на темно-сірих ґрунтах Правобережного Лісостепу. Для досліджень використано польовий і лабораторний методи, а для визначення мінерального складу сухої кормової біомаси – аналітичний. Наведено результати досліджень з накопичення у сухій кормовій масі люцернового, люцерно-злакових і злакового травостоїв на різних фонах удобрення і вапнування сирої золи, макро- та мікроелементів, важких металів і нітратного азоту. Показано, що під дією симбіотичного азоту в люцерновому та люцерно-злакових травостоях порівняно зі злаковим в сухій масі корму більше нагромаджується сирої золи на 0,6-0,8 %, макроелементів, мікроелементів та важких металів, відношення кальцію до фосфору збільшується на 0,11-0,26, а калію до суми кальцію і магнію зменшується – на 0,11-0,26. Під дією мінерального азоту за внесення N_{90} на злаковий травостій в сухій масі корму злакового травостою збільшується вміст нітратів від 0,02 до 0,04 %, цинку – від 9,1-9,2 до 12,4-12,6 або на 3,2-3,5 мг/кг, міді – від 3,4-3,7 до 5,3-5,5 мг/кг, а також марганцю, свинцю, нікелю, кадмію. Доведено, що показники вмісту макро- та мікроелементів в сухій масі корму відповідають зоотехнічним нормам для годівлі великої рогатої худоби, а нітратів і важких металів – не виходять за межі гранично допустимих концентрацій. Результати цих досліджень можуть бути використані при розробленні рекомендацій щодо технологій вирощування багаторічних трав на кормові цілі та годівлі тварин, а також у навчальному процесі

Ключові слова: важкі метали; зоотехнічна норма; макро- та мікроелементи; нітрати; сира зола; суха маса; трав'яний корм

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Forecasting the adaptability of heat-loving crops to climate change in Ukraine

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Abstract. Ukraine has a developed agricultural sector of the economy, where agriculture accounts for 10.4% of the gross domestic product. The relevance of the subject is due to the fact that agricultural production, which is of strategic importance for the country, is very sensitive to ongoing climate changes. Therewith, the crop industry is already undergoing a process of adaptation to the consequences of climate change and agrometeorological factors, which is manifested in the expansion of the range of cultivated crops. The purpose of this study was to predict the adaptability of heat-loving agricultural crops by their yield in various natural and climatic zones of Ukraine. In the course of the research, such methods as analysis, synthesis, factor analysis, correlation-regression, and mathematical-statistical were used. Based on the results of the conducted studies, the expediency of considering climate change

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to obtain high yields of both conventional agricultural crops and heat-loving ones, which were not typical for Polissia and Forest-Steppe, is proved. Based on the analysis of the dynamics of crop yields, it is identified that it is advisable to reorient agricultural production to the cultivation of heat-loving crops – corn, sunflower, soy, and rapeseed in the Forest-Steppe, which in recent years give the same or slightly higher yields than in the south of Ukraine. Growing these crops in the Polissia zone is unprofitable – the yield is quite low, so in these regions, it is worth continuing to grow conventional crops (cereals, legumes, vegetables, potatoes). The established dependences of crop yields on climatic and agrometeorological factors allowed identifying a complex of factors that play a major role in the formation of the yield of specific crops. The developed crop yield models based on multiple correlation allow for predicting it. The results of the study can be useful in planning and optimising the activities of agricultural enterprises, and agriculture in general, in various natural and climatic zones of Ukraine, as a strategic branch of the economy

Keywords: climate change; agricultural adaptability; heat-loving crops; abiotic factors; agroecosystems

INTRODUCTION

Timely adaptation of the agro-industrial complex of Ukraine to climate change is an urgent environmental, scientific, and industrial problem. The development of a strategy for the sustainable development of agricultural production in Ukraine should provide for adaptation measures considering climatic conditions. There are about 20 predictive models of climate change at the global level developed by researchers from different countries of the world (Adamenko, 2019).

According to the results of such studies, by the end of the 21st century, there may be an increase in temperature by 2-4°C throughout Ukraine (Yatsyuk *et al.*, 2021; Christidis & Stott, 2021). Climate change trends are characterised by an upward vector of growth in the average annual atmospheric temperature, and therefore, in the next 20 years, there is a high potential risk of factual loss of arable land for intensive farming not only in the Steppe zone of Ukraine but also over half of the area of agricultural land throughout the country (FAO, 2022).

Therewith, Ukraine has all the prerequisites for effective management and further development of agriculture, including: fertile soils, favourable agroclimatic conditions, established historical traditions of agricultural activities, sufficient availability of labour resources, etc. Thus, in 2021, the total share of exports of corn, barley, rapeseed, and sunflower oil on the world export market from Ukraine amounted to almost 63% (Chumak *et al.*, 2012; Mirzoeva, 2022).

Changing climatic conditions in Ukraine cause the shift of the boundaries of agroclimatic zones from south to north and northwest, causing the development of unfavourable agrometeorological phenomena, which are manifested in a lack of moisture and increased temperatures of atmospheric air and soil. Based on the current situation, Howden *et al.* (2007), Romaschenko *et al.* (2003) proposed areas of scientific research aimed at adapting agricultural production to climate change in Ukraine and at the planetary level in general. According to O.G. Tarariko *et al.* (2016), the most important task of the agro-industrial complex of Ukraine, given the inertial nature of agricultural production, is its timely adaptation to climate change. Therewith, the scientific justification of approaches to more efficient use of heat as additional agricultural resource potential, and minimising possible risks manifested by all sorts of extreme phenomena that can substantially worsen both the ecological state of agricultural landscapes and substantially reduce the productivity of agroecosystems themselves is necessary. Muller (2009) considers the transition to organic farming to be the most effective way to adapt agriculture to changing climatic conditions.

In addition to the problematic consequences, climate change also has positive aspects. Thus, Stefanovska and Pidlisniuk (2010) consider the lengthening of the growing season, the shift to the north of the area of cultivation of heat-loving agricultural crops, the improvement of the physiological state of fruit crops in winter, and the increase in grain yields under the influence of an increase in the concentration of CO_2 in the atmosphere as positive. Pisarenko and Khlebnikova (2015) believe that high crop yields can be caused, among other things, by an increase in solar activity. As a result of climate change, it became possible to grow heat-loving industrial crops – corn, rapeseed, sunflower, and soybeans in the Polissia and Forest-Steppe zones. This was also facilitated by the pricing policy, agricultural market conditions and the orientation of agricultural producers to high yields and substantial profits at low costs. Every year, the volume of production of these crops is growing, and that of the agricultural crops typical for growing in these agroclimatic conditions is decreasing (Klymenko *et al.*, 2021). In recent years, there has been a tendency to increase the area under heat-loving crops, violate their cultivation technologies, and, as a result, an increase in the area of depleted and degraded soils. Thus, agricultural production in the Steppe zone is already substantially affected by the effects of climate change, intensive and extensive farming, and existing imbalances in the structure of crops. For example, climate changes that manifest themselves in the form of abnormal droughts, frosts, and dust storms in recent years have caused substantial

yield losses in all southern regions of Ukraine (Mirzoeva, 2022; Pichura *et al.*, 2022).

The purpose of the study is to examine the features of adaptation and expediency of growing agricultural crops in new agroecological conditions in various natural and climatic zones of Ukraine.

MATERIALS AND METHODS

The research period was from 2010 to 2021. The analysis of climate changes was conducted according to meteorological (annual average air temperature, maximum and minimum soil surface temperatures, average temperature of the arable soil layer and precipitation during the growing season) and agrometeorological (sum of effective and positive temperatures, reserves of productive moisture in the arable soil layer, and hydrothermal coefficient for the growing season) indicators. Technical agricultural crops were selected to examine the issue of adaptation to new agroecological conditions – corn, sunflower, soy, rapeseed (they are more resistant to climate change) – their yield in different natural zones of Ukraine (in Polissia, in the Forest-Steppe, and Steppe).

The information database for the research was the materials of the State Statistics Service of Ukraine; the Main Department of Statistics in Rivne, Volyn, Zhytomyr, Vinnytsia, Poltava, Kirovohrad, Kherson, Mykolaiv, Odesa, and Zaporizhia regions; the Departments of Agro-Industrial Development and Departments of Ecology and Natural Resources of the above-mentioned regions; materials of meteorological observations of regional centres of Ukraine on hydrometeorology and weather stations; papers of Ukrainian and foreign researchers, periodicals.

The study was conducted using the following general scientific, specific scientific, and special methods of scientific knowledge:

– analysis and synthesis – for collecting and analysing statistical information on meteorological, agrometeorological data and indicators of agricultural production; for assessing the factual state, dynamics, and trends in the development of crop production in the Polissia, Forest-Steppe, and Steppe zones of Ukraine;

– factor analysis – for detailed analysis of natural and anthropogenic factors influencing the productivity indicators of agricultural production of crop products;

– correlation-regression analysis – establishing the dependence of the yield of corn, sunflower, soy, and rapeseed on climatic and agrometeorological indicators separately performed based on the values of correlation coefficients and determination, complex action – using the multiple correlation function (R), which characterises the degree of tightness of the relationship between the dependent variable (yield) and several independent variables (climatic and agrometeorological indicators). These coefficients were determined using mathematical-statistical methods, namely regression analysis, using Microsoft Excel software tools, which allowed forming mathematical models for predicting the adaptability of agricultural crops (by yield indicator) from climatic and agrometeorological factors. The statistical reliability of regression models with a small sample of data was checked using the *F*- criterion (Fischer's criterion).

RESULTS AND DISCUSSION

The natural-climatic conditions in the territory of Ukraine are quite favourable for the development of agricultural production. Therewith, its further intensification has certain negative consequences. Thus, due to the increase in the level of anthropogenic load in Ukraine in 2018, for the first time since 1990, the issue of carbon dioxide in the atmospheric air from agricultural activities exceeded the volume, which can be accumulated by forests. Therewith, there is a decrease in the absorption of greenhouse gases by forests by about 20%. Depending on management practices and weather conditions, the flow of greenhouse gases into the atmosphere from arable land and pastures varies substantially. Thus, in the early 90s, the introduction of substantial amounts of organic and mineral fertilisers provided sufficient absorption of greenhouse gases. Modern organic application rates have substantially decreased compared to 1990 and amount to only 5%, while mineral fertilisers – approximately 88%. In addition, due to changes in the ratio between industrial and oil crops, the overall structure of agricultural land has also been transformed. Thus, the share of industrial crops (hemp, sugar beet, flax) decreased from 35% to 10%, and the share of oilseeds (soybeans, sunflower, rapeseed) increased from 7 to 30%. This radically changed the trend of carbon dioxide absorption in the range of 5 million tonnes-eq of CO_2 to the emission at the level of 48 million tonnes-eq of CO_2FAO. STAT., 2022). All this makes it necessary to control the structure of agricultural land and crop rotations.

Notably, withan increase in the anthropogenic load on agroecosystems intensifies the consequences of uncontrolled manifestations of climate change. It is established that in the Polissia and Forest-Steppe zones of Ukraine, the average annual air temperature increased by 0.8-1.0°C over the centuries and by about 0.5°C – in the Steppe, while the number of natural phenomena increased by 7-15% (Adamenko, 2019; Klymenko *et al.*, 2021). Therewith, according to the Ukrainian hydrometeorological centre, over the past 30 years, the average annual air temperature in the whole country has already increased by 1.2°C. The same trend is established based on the results of statistical studies, the data of which are presented on the official FAO website (Fig. 1) (Ministry of EEP of Ukraine, 2020).

The increase in air temperature from November to March averages 1.3°C, and from April to October – 1.1°C. Notably, in the entire history of instrumental meteorological observations on the territory of Ukraine, the deviation from the normal air temperature for the

period of 1989-2019 was the largest. In each subsequent decade, since 1991, the air temperature has increased by: 0.5°C in 1991-2000, 1.2°C in 2001-2010, and 1.7°C in 2011-2019. Analysis of regional warming rates for 1975-2019 indicates a substantial rate of increase in atmospheric air temperature in the region – by 0.61-0.82°C/10 years, while in neighbouring countries – 0.47-0.59°C/10 years (Adamenko, 2019).

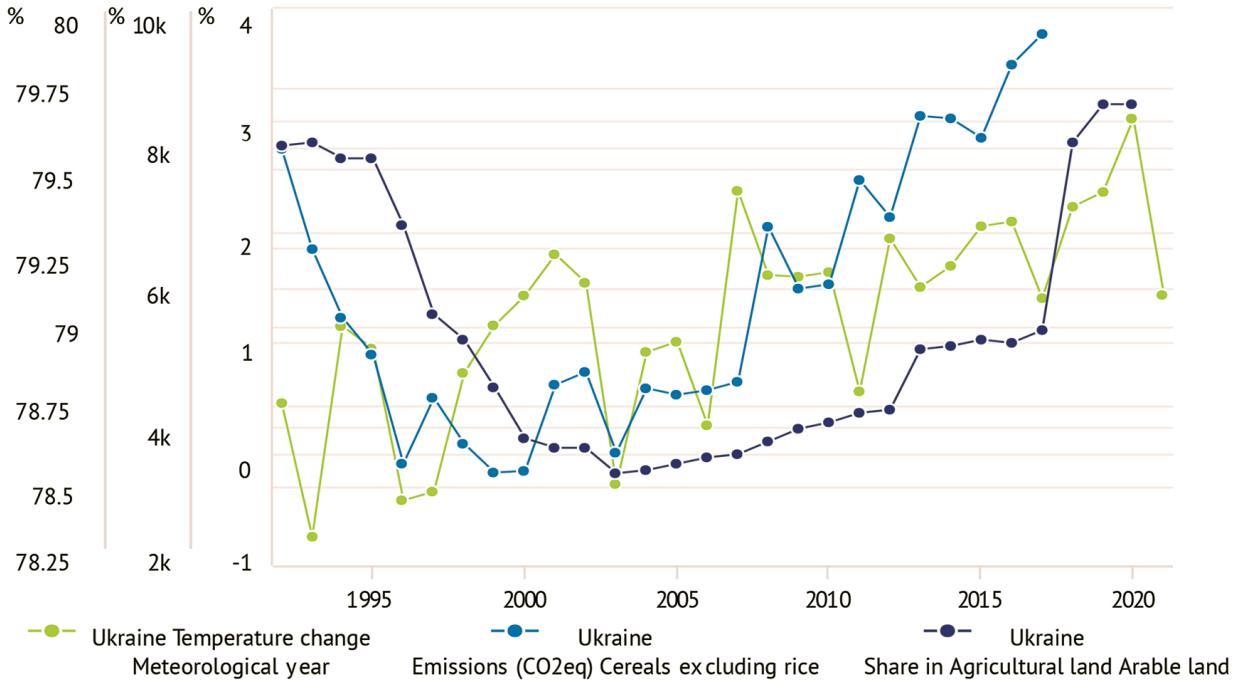

Figure 1. *Dynamics of average annual atmospheric air temperature, CO_2 emissions into the atmospheric air, and the share of arable land in the structure of agricultural landscapes for 1990-2021*

Source: *FAO. STAT., 2022*

According to the results of joint study by researchers of the Chinese Academy of Agricultural Sciences (CAAS) Meng Fanhua and Zhou Chian and researchers of Sumy National Agrarian University, due to the manifestation of adverse weather conditions caused by climate change, the cultivation of winter wheat is accompanied by substantial yield instability (Bakumenko *et al.*, 2019). There is a negative trend in the correlation between the yield of the main crops and the values of the average maximum and minimum temperatures during the growing season. The development of such a situation may lead to the need for irrigation and those crops that have not previously required it (Tao *et al.*, 2006). In accordance with potential changes in climatic factors, farmers are forced to change the range of crops grown to those that are more economically feasible. However, the adaptation of the crop industry to climate change and shifting climate zones may have substantial promising trends (Kussul *et al.*, 2020).

Considering the actual climate changes on the territory of Ukraine, the dynamics of meteorological (average air temperature, maximum and minimum soil surface temperature, average temperature of the arable soil layer, the amount of precipitation) and agrometeorological (sums of positive and effective temperatures, reserves of productive moisture of the arable soil layer, hydrothermal coefficient) factors were analysed (Klymenko *et al.*, 2021) for the period 2010-2021 in the Polissia, Forest-Steppe, and Steppe zones.

In Polissia and the Forest-Steppe, the average air temperature during the growing season is almost the same and ranges from 13-14°C during the study period. In the Steppe zone, this indicator is 1.4 times higher and is in the range of 18-20°C. Changes in the temperature regime during the warm period of the year affected the thermal resources of Ukraine. The indicator of the sum of active air temperatures above +10°C accumulated during the warm period was used to evaluate them. Analysis of the dynamics of these amounts for different periods allowed recording their increase by an average of 200-400°C. In the far south, a thermal zone has formed, where the sum of temperatures exceeds 3400-3700°C – these are the southern districts of Kherson, Mykolaiv, Odesa, and Zaporizhia regions, where there is quite enough heat for very heat-loving crops. In addition, in the previous decade, the heat supply of the Vinnytsia, Poltava, Kharkiv, and Kirovohrad regions in the period 2010-2019 was the same as that of the Kherson region. Thus, the regions of the Northern Steppe and Southern Forest-Steppe of Ukraine are already close to the conditions of the Southern Steppe. However, it is noted that the increase in the amount of heat is more rapid in the

northern regions (indicated in parentheses in Table 1), for example, the increase in active temperatures over the past decade for the Steppe zone was +150°C, Forest-Steppe – +200°C, Polissia – +220°C (Adamenko, 2019).

Table 1. *Sums of active air temperatures above +10°C in agroclimatic zones of Ukraine for different periods*

Agroclimatic zone	Periods		
	1961–1990	1991–2009	2010–2019
Steppe	3145	3400 *(+255)*	3550 *(+150)*
Forest-Steppe	2705	2950 *(+245)*	3150 (+200)
Polissia	2500	2770 *(+200)*	2950 *(+220)*

Source: *Adamenko, 2019*

The sums of positive and effective temperatures of 10°C and above for the Steppe zone range from 4030-4353°C and 2805-3198°C, respectively (Fig. 2). For the Polissia and Forest-Steppe zones, the values of these indicators are the same, changes occurred in the range of 2805-3245°C and 1190-1350°C, respectively, which is 1.4 and 2.1 times less than the indicators of the Steppe zone.

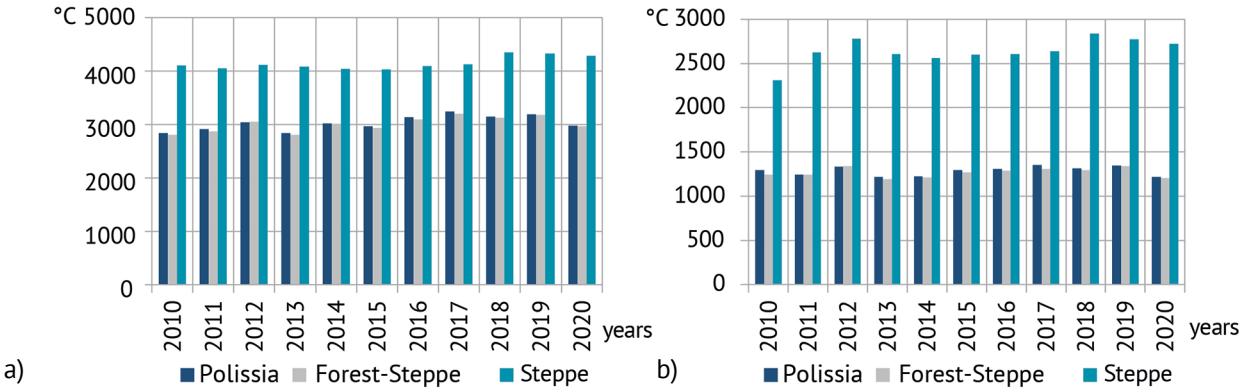

Figure 2. *Dynamics of the sum of positive (a) and effective (b) temperatures of 10°Cand above during the growing season*
Source: *compiled by the authors*

The maximum soil surface temperature is slightly higher in the Steppe than in Polissia and Forest-Steppe (Fig. 3), but in percentage terms, it does not exceed an average of 8 and 14%. The values of this indicator for the study period range from 56-64°C in Polissia, 55-61°C in the Forest-Steppe, and 62-66°C in the Steppe. It should also be noted that the Forest-Steppe and Polissia zones are more characterised by extreme temperatures of the minimum soil surface.

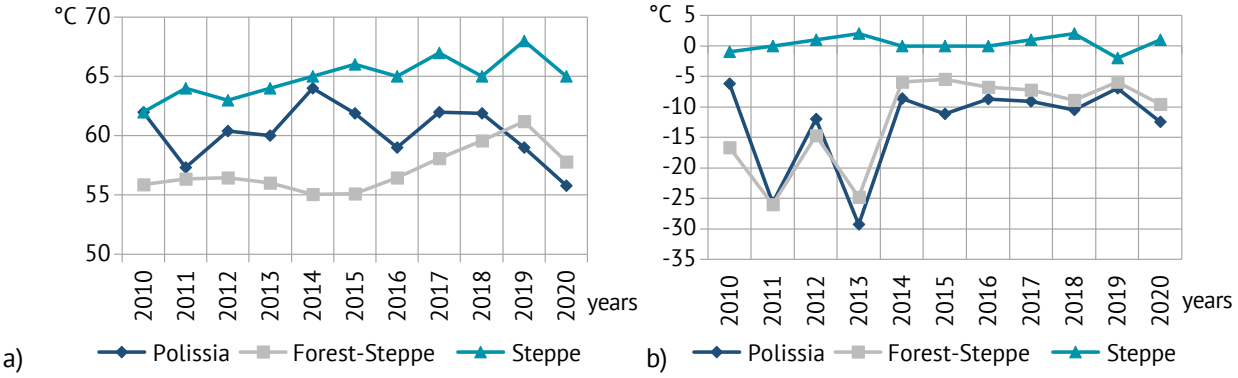

Figure 3. *Dynamics of maximum (a) and minimum (b) soil surface temperatures during the growing season*
Source: *compiled by the authors*

As shown in Figure 3 (b), the minimum soil surface temperature is substantially higher in the Steppe area and varies within -2...+2°C. Therewith, in Polissia and in the Forest-Steppe zone, this indicator is almost the same

and ranges from -6...-29°C and -6...-25°C, respectively. Notably, since 2014, the minimum soil surface temperature in the examined zones of Polissia and Forest-Steppe has not lowered below -13°C and -10°C, respectively.

The average temperature of the arable layer (0-20 cm) of soil during the growing season (Fig. 4) in the Steppe zone is 28% and 19% higher relative to the same indicator in the Polissia and Forest-Steppe zones, respectively. In general, the value of the average temperature of the arable soil layer for the study period varied in the range of 11-17°C in Polissia, 14-17°C in the Forest-Steppe, and 17-20°C in the Steppe.

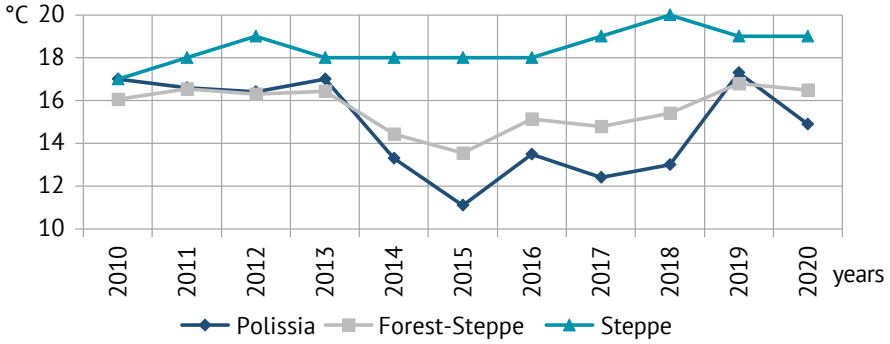

Figure 4. *Dynamics of the average temperature of the arable soil layer (0-20 cm) during the growing season of 2010-2021*
Source: *compiled by the authors*

Almost all areas of agricultural crops in Ukraine are in the zone of risky farming, that is, in areas with a natural lack of precipitation, where in an excessively dry year there is a constant risk of loss of harvest volumes or in a too rainy year – loss of harvest quality, while global climate change factors only increase such risks.

Depending on the level of natural moisture, the territory of Ukraine is divided into six typical zones: excessively humid (4.5% of the territory), humid (30%), insufficiently humid (16%), arid (20%), dry (22%), and extremely dry (7.5%). During the period of 1991-2015, compared to 1961-1990, the area of territories with a substantial water supply deficit increased by 7% and already covers almost a third (29.5%) of the area of Ukraine or 11.6 million ha (37%) of arable land. The area of the territory with excessive and sufficient atmospheric moisture decreased by 10% and amounts to 22.5%, including 7.6 million ha of arable land. According to the medium-term forecast until 2050, the temperature regime is expected to continue to increase by 1.24°C-1.48°C compared to the current period. Given this, it can be assumed that the area with insufficient moisture will increase by 56% and only 28% of the territory will have humid and excessively humid conditions (Yatsyuk *et al.*, 2021).

In the agroclimatic zones of Polissia and Forest-Steppe, the amount of precipitation is 2.1-2.2 times higher compared to the Steppe zone. The total amount of precipitation for the study period of 2010-2021 varied in the range of 326-627 mm/year in Polissia, 326-598 mm/year in the Forest-Steppe, and 134-297 mm/year in the Steppe (Fig. 5). Considering the fact that the norm of this indicator for sustainable agriculture is 700 mm/year or more (Adamenko, 2019), today a moisture deficit of 100-150 mm/year is already determined for the Polissia and Forest-Steppe zones.

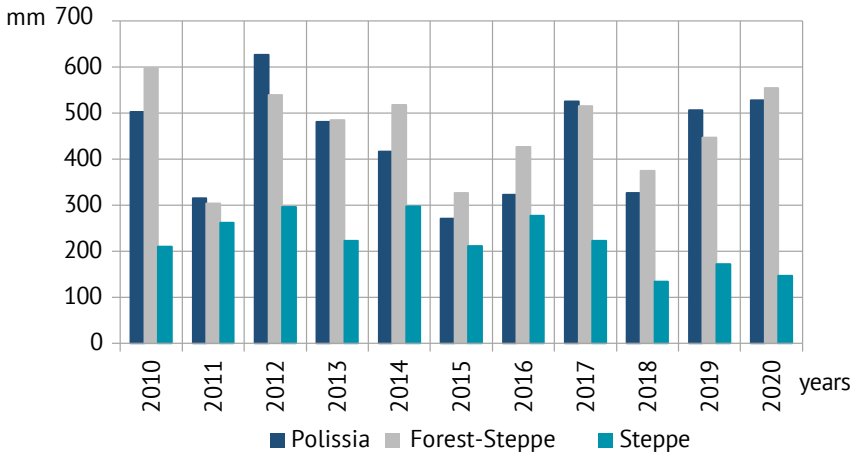

Figure 5. *Dynamics of precipitation during the growing season for 2010-2021, mm*
Source: *compiled by the authors*

In accordance with one of the climate scenarios, which considers the increase in atmospheric air temperature by 1.5°C, the total climatic balance of the territory of Ukraine by 2050 will decrease by 45-115 mm, and its deficit in the Steppe zone is projected to be ⩾560 mm, the percentage of territories with insufficient moisture will increase to 56%. The forecast model for 2100 indicates a lack of water supply in the southern, central, and eastern regions – 400-470 mm, and this corresponds to the current conditions of the Steppe zone of Ukraine. The percentage of territories with insufficient moisture can reach 71%, and those with sufficient moisture will not exceed 12% (Fig. 6) (Yatsyuk *et al.*, 2021).

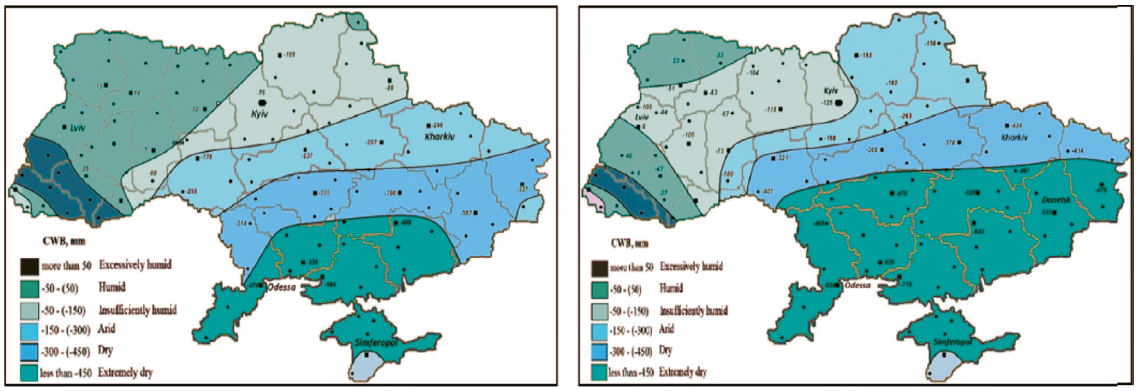

***Figure 6**. Forecast models of the natural water supply of the territory of Ukraine, considering potential climate changes*
***Source:** Yatsyuk et al. (2021)*

Another substantial factor that negatively affects the yield is the lack of soil moisture during the growing season, the main source of which is precipitation or irrigation systems of irrigation agriculture. It is the amount of precipitation that determines the level of soil moisture supply. As shown in Figure 7, the reserves of productive moisture of the arable soil layer on the territory of the Forest-Steppe are higher and during the period under study varied in the range of 25-36 mm, which is 1.6 times more than in Polissia (15-26 mm), and 1.7 times more than in the Steppe zone (15-21 mm).

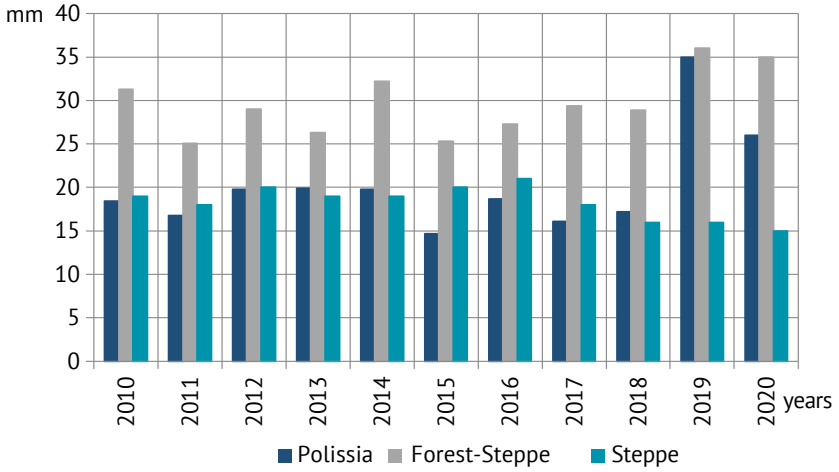

***Figure 7**. Dynamics of the productive moisture reserve of the arable soil layer (0-20 cm) during the growing season in 2010-2021, mm*

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

The hydrothermal coefficient (HTC), which is an indicator of the moisture content of the territory during the growing season, is determined. The amount of precipitation for the period in which the average daily air temperature is above 10°C and the sum of active temperatures for the same period during 2010-2021 were considered (Fig. 8).

On the territory of Polissia and Forest-Steppe, the HTC was almost the same, its value ranged from 0.8, which is typical for dry conditions, to 1.8 – conditions of excessive moisture. In the Steppe zone, it ranged from 0.2-1 (extremely dry conditions – satisfactory moisture). The average value of the HTC for the period under review was 1.3 for Polissia and Forest-Steppe and 0.5 – for Steppe.

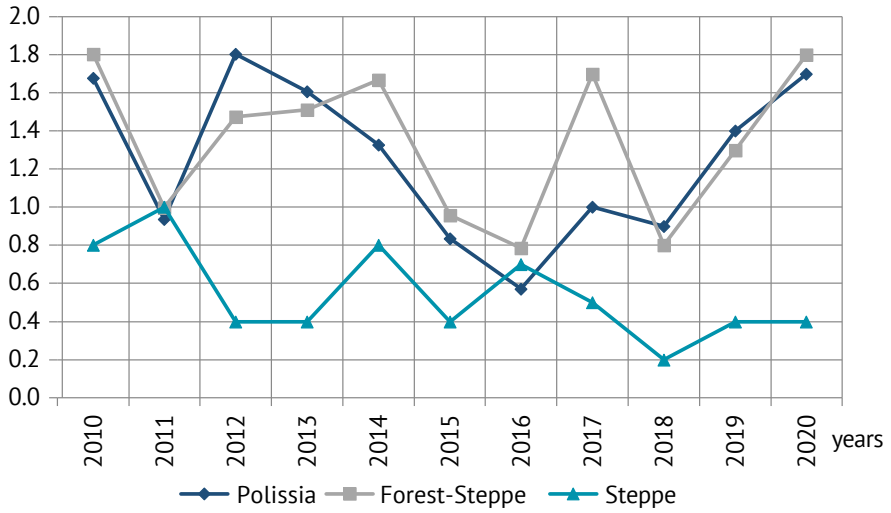

***Figure 8**. Dynamics of the hydrothermal coefficient for the growing season in 2010-2021*
***Source:** compiled by the authors*

The yield of agricultural crops is determined by natural-climatic conditions and organisational-economic capabilities, depends on many factors, and therefore can act as a qualitative complex indicator. During the study, the yield of heat-loving agricultural crops in the Polissia, Forest-Steppe, and Steppe zones was analysed. Figure 9 shows the dynamics of corn yield for 2010-2021.

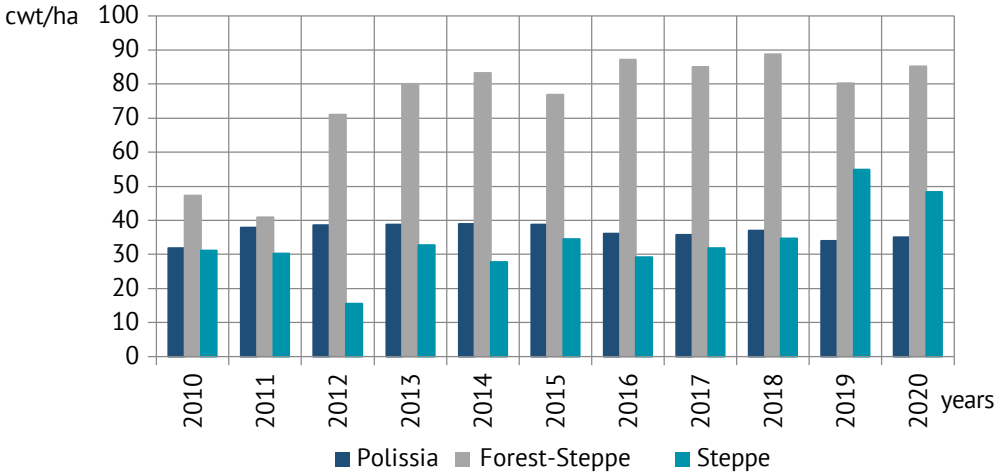

***Figure 9**. Dynamics of corn yield for 2010-2021., cwt/ha*
***Source:** compiled by the authors*

Analysis of the dynamics of corn yield in different natural and climatic zones allows concluding that the most favourable conditions for growing corn were formed in the Forest-Steppe zone, with an average yield of 2.1 and 2.4 times higher than in Polissia and Steppe, respectively (with the exception of 2021). In general, for the period 2010-2021, the yield of corn varied in the range of 32-39 cwt/ha in Polissia, 41-89 cwt/ha in the Forest-Steppe, and 16-75 cwt/ha in the Steppe.

For both corn and sunflower, the Forest-Steppe zone was identified to be more suitable for cultivation (Fig. 10). Sunflower yields are on average 3.5 and 1.4 times higher than in Polissia and Steppe, respectively. In general, for the period 2010-2021, the yield of sunflower varied from 1.7 to 13.2 cwt/ha in Polissia, 11.3-28.3 cwt/ha in the Forest-Steppe, and 12.6-20 cwt/ha in the Steppe. Consequently, it is unprofitable to cultivate sunflower in the Polissia zone, but there is a tendency to increase its yield in the Forest-Steppe zone and instability in obtaining high yields in the Steppe.

For agricultural enterprises located in the Steppe zone, for many years in a row, the practice of managing with substantial violations of sunflower cultivation technology has been inherent, which consists in insufficient consideration of its biological characteristics and possible impact on the yield of subsequent crops. As a result, an unreasonably high share of this crop in the structure of acreage, which exceeds 15%, causes drying of the upper and lower layers of the soil, which, in turn, will negatively affect the yield of 2-3 harvest following it (Mirzoeva, 2022).

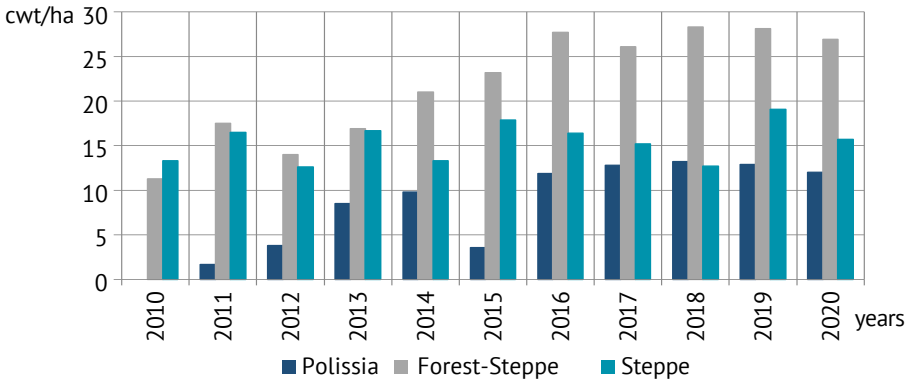

***Figure 10**. Dynamics of sunflower yield for 2010-2021, cwt/ha*
***Source:** compiled by the authors*

The Steppe zone is more suitable for growing soybean (Fig. 11) since its yield is 2.3 and 1.3 times higher than in the Polissia and Forest-Steppe zones, respectively. During the period under study, there was an increase in soybean yield from North to South in all the examined zones, indicators fluctuated in the Polissia zone in the range of 7-21 cwt/ha, in the Forest-Steppe zone – 11-29 cwt/ha, and 18-36 cwt/ha in the Steppe.

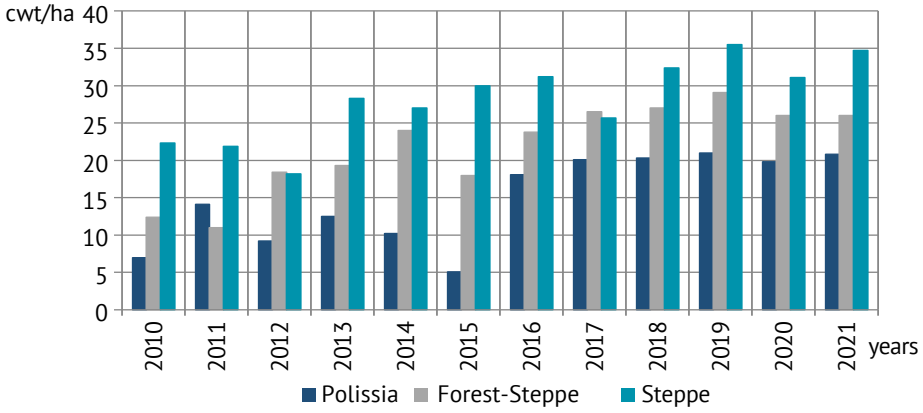

***Figure 11**. Dynamics of soybean yield for 2010-2021, cwt/ha*
***Source:** compiled by the authors*

The yield of rapeseed is substantially higher in the Forest-Steppe compared to Polissia, and slightly higher or close to the yield in the Steppe zone. However, as Figure 12 shows, from 2014 to 2015, there was a decrease in rapeseed yield by 1.7 times in the Forest-Steppe zone and by 15 times in the Polissia zone. In the Steppe, on the contrary, there is some stability in the yield of this agricultural crop. In general, rapeseed yield during the study period was in the range of 0.5-15.1 cwt/ha in Polissia, 20.1-34 cwt/ha in the Forest-Steppe, and 12.7-24.6 cwt/ha in the Steppe.

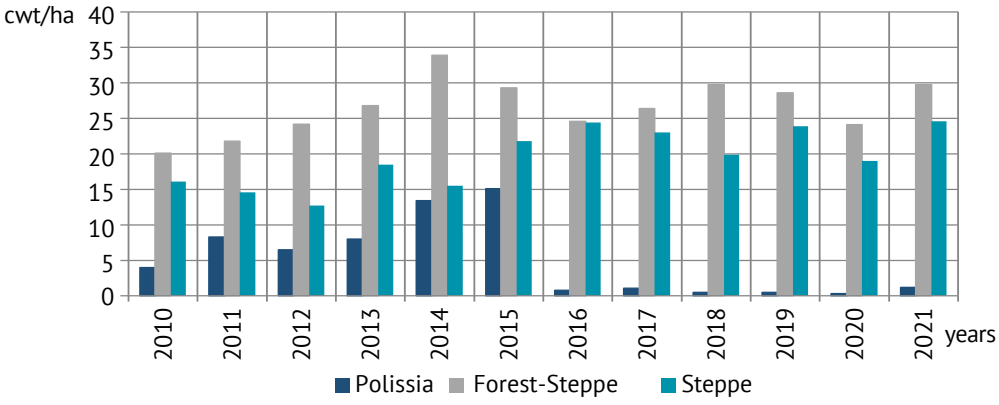

***Figure 12**. Dynamics of rapeseed yield in 2010-2021, cwt/ha*
***Source:** compiled by the authors*

Based on the above information, the influence of meteorological and agrometeorological factors on the yield of heat-loving agricultural crops in Polissia, Forest-Steppe, and Steppe of Ukraine for the period 2010-2021 is analysed. Results of calculation of correlation coefficient values are presented in Table 2.

***Table 2**. Results of the correlation coefficient calculation*

Name of the culture	Indicators								
	meteorological					agrometeorological			
	average air temperature	maximum soil surface temperature	minimum soil surface temperature	average temperature of the arable layer	amount of precipitation	sum of effective temperatures	sum of positive temperatures	productive moisture reserves	HTC
Polissia									
corn	-0.20	0.18	-0.50	-0.32	-0.29	-0.33	-0.11	-0.40	-0.19
sunflower	0.36	0.07	0.50	-0.16	0.18	0.22	0.65	0.42	-0.06
soybean	0.23	-0.43	0.09	-0.01	0.07	0.23	0.68	0.45	-0.23
rapeseed	-0.29	0.42	-0.28	-0.22	-0.33	-0.42	-0.51	-0.42	-0.02
Forest-Steppe									
corn	0.42	0.32	0.68	-0.34	0.09	0.14	0.62	0.26	-0.08
sunflower	0.46	0.60	0.69	-0.24	-0.32	0.27	0.73	0.28	-0.38
soybean	0.57	0.66	0.72	-0.11	0.13	0.30	0.80	0.56	0.00
rapeseed	0.38	0.10	0.56	-0.54	-0.20	0.01	0.41	0.14	-0.14
Steppe									
corn	0.00	0.65	0.29	0.27	-0.07	-0.06	0.19	0.61	0.06
sunflower	-0.18	0.22	0.05	0.07	-0.45	0.02	0.02	-0.03	-0.27
soybean	0.29	0.54	0.06	0.60	-0.25	0.18	0.02	0.49	-0.35
rapeseed	0.28	0.47	0.59	-0.29	-0.24	0.31	0.54	0.11	-0.33

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

Analysis of the results of calculating the correlation coefficient shown in Table 2 allows concluding that each individual factor taken from the examined factors does not have a substantial importance in the formation of crop yields. This is confirmed by the results of correlation analysis – in most cases, an insubstantial relationship was established (r<0.7). Therewith, the results obtained allowed for establishing limiting factors of influence on the yield of heat-loving industrial crops. These include the average temperature value, the sum of positive temperatures, and the soil surface temperature (r=0.57-0.80).

A mathematical analysis of the data was performed using the multiple correlation coefficient to confirm the overall effect of the limiting factors established as a result of the study on crop yields. The results of calculation are presented in Table 3.

***Table 3**. Results of the multiple correlation coefficient calculation*

Name of the culture	Factors		
	meteorological	agrometeorological	meteorological and agrometeorological
Polissia			
corn	0.819	0.573	0.997
sunflower	0.568	0.862	1
soybean	0.634	0.817	0.997
rapeseed	0.699	0.617	0.968
Forest-Steppe			
corn	0.739	0.782	0.927

Table 3, Continued

Name of the culture	Factors		
	meteorological	agrometeorological	meteorological and agrometeorological
Forest-Steppe			
sunflower	0.933	0.925	0.998
soybean	0.891	0.934	0.975
rapeseed	0.658	0.637	0.813
Steppe			
corn	0.942	0.766	0.999
sunflower	0.823	0.153	0.967
soybean	1	0.979	1
rapeseed	0.84	0.452	0.992

Source: *developed by the authors (Klymenko et al., 2021; Sobko et al., 2021)*

The results of calculating the multiple correlation coefficient (Table 3) give grounds to assert that it is the combined effect of meteorological and agrometeorological factors that has a substantial impact on the yield of the considered agricultural crops in the territories of the examined agroclimatic zones. The greatest dependence of yield on the group of meteorological factors was identified for corn in Polissia (R=0.819), sunflower in the Forest-Steppe (R=0.933), soybeans in the Steppe (R=1); on agrometeorological factors – in Polissia for sunflower (R=0.862), soybeans in the Forest-Steppe (R=0.934) and Steppe (R=0.979); on meteorological and agrometeorological factors together – for sunflower in Polissia (R=1) and Forest-Steppe (R=0.998), soybeans in the Steppe (R=1).

Regression models are proposed (Table 4), which consider meteorological and agrometeorological factors characteristic of the Polissia, Forest-Steppe, and Steppe zones of Ukraine to predict the yield of the considered agricultural crops.

Table 4*. Regression models of crop yields*

Name of the cultural tour	Group of factors	Regression models	F-criterion	
			P≤0.05	F_{calc}
1	2	3	4	5
POLISSIA				
corn	climatic	$y=2.86*x_1+0.23*x_2-0.36*x_3-0.53*x_4+0.002*x_5-14.02$	3.2	3.05
	agrometeorological	$y=-0.03*x_6+0.01*x_7-0.2*x_8+0.25*x_9+52.27$	3.36	1.15
	climatic and agrometeorological	$y=18.53*x_1-0.07*x_2-0.66*x_3-0.61*x_4+0.01*x_5-0.05*x_6-0.02*x_7+0.13*x_8-2.32*x_9-97.87$	2.9	24.75
sunflower	climatic	$y=-5.79*x_1+0.04*x_2+0.58*x_3+0.17*x_4+00.04*x_5+89.86$	3.33	0.59
	agrometeorological	$y=-0.07*x_6+0.05*x_7+0.14*x_8+0.44*x_9-41.58$	3.48	5.69
	climatic and agrometeorological	$y=-182.73*x_1+3.19*x_2+7.33*x_3+9.45*x_4-0.11*x_5+0.5*x_6+0.12*x_7-2.91*x_8+27.92*x_9+1357.24$	3.02	12.38
soybean	climatic	$y=9.36*x_1-1.57*x_2-0.19*x_3-0.4*x_4+0.004*x_5-17.97$	3.2	1
	agrometeorological	$y=-0.05*x_6+0.04*x_7+0.34*x_8-1.55*x_9-38.51$	3.36	4.74
	climatic and agrometeorological	$y=-32.17*x_1-0.59*x_2+0.61*x_3+1.1*x_4-0.05*x_5+0.04*x_6+0.11*x_7-0.46*x_8+16.18*x_9+111.01$	2.9	24.75
rapeseed	climatic	$y=-5.37*x_1+1.3*x_2-0.15*x_3-0.31*x_4-0.01*x_5+6.55$	3.2	1.44
	agrometeorological	$y=-0.02*x_6-0.02*x_7-0.25*x_8-1.59*x_9+79.79$	3.36	1.43
	climatic and agrometeorological	$y=37.75*x_1+0.95*x_2-1.01*x_3-1.68*x_4+0.05*x_5-0.09*x_6-0.1*x_7+0.82*x_8-18.28*x_9-161.39$	2.9	3.92

Table 4, Continued

1	2	3	4	5
		FOREST-STEPPE		
corn	climatic	$y=-15.77*x_1+3.61*x_2+1.51*x_3-4.05*x_4+0.02*x_5+154.94$	3.2	1.83
	agrometeorological	$y=-0.23*x_6+0.14*x_7-0.33*x_8-1.91*x_9-30.61$	3.36	3.65
	climatic and agrometeorological	$y=32.48*x_1+6.07*x_2+4.97*x_3+24.01*x_4+0.05*x_5-0.48*x_6+0.02*x_7-10.6*x_8+23.27*x_9-224.35$	2.9	1.54
sunflower	climatic	$y=-8.4*x_1+1.66*x_2+0.85*x_3+0.43*x_4-0.02*x_5+56.25$	3.2	10.04
	agrometeorological	$y=-0.09*x_6+0.05*x_7+0.45*x_8-8.6*x_9-10.66$	3.36	14.33
	climatic and agrometeorological	$y=-3.76*x_1+1.32*x_2+1.28*x_3+4.94*x_4-0.02*x_5-0.08*x_6+0.02*x_7-1.49*x_8+3.35*x_9+15.11$	2.9	24.75
soybean	climatic	$y=-4.68*x_1+2.07*x_2+0.57*x_3-0.57*x_4+0.01*x_5-21.16$	3.2	5.64
	agrometeorological	$y=-0.07*x_6+0.05*x_7+0.47*x_8-1.92*x_9-47.46$	3.36	15.62
	climatic and agrometeorological	$y=4.11*x_1+1.84*x_2+0.91*x_3+4.02*x_4+0.01*x_5-0.11*x_6+0.02*x_7-1.54*x_8+3.65*x_9-91.25$	2.9	4.75
rapeseed	climatic	$y=-1.15*x_1+0.62*x_2+0.14*x_3-1.99*x_4+40.72$	3.2	1.13
	agrometeorological	$y=-0.06*x_6+0.03*x_7-0.03*x_8-1.91*x_9+22.63$	3.36	1.62
	climatic and agrometeorological	$y=8.64*x_1+0.58*x_2-0.34*x_3-2.8*x_4-0.01*x_5-0.08*x_6+0.01*x_7+0.3*x_8-0.24*x_9-26.82$	2.9	0.49
		STEPPE		
corn	climatic	$y=-4.34*x_1+1.28*x_2-4.26*x_3+3.3*x_4-0.13*x_5+2.03$	3.2	12.14
	agrometeorological	$y=-0.02*x_6+0.02*x_7-3.41*x_8-4.17*x_9+60.55$	3.36	3.5
	climatic and agrometeorological	$y=-10.1*x_1+0.59*x_2-5.3*x_3+0.12*x_4+0.06*x_5-0.02*x_6+0.06*x_7-3.08*x_8-33.06*x_9+50.38$	2.9	24.75
sunflower	climatic	$y=-1.24*x_1+0.73*x_2-0.53*x_3-0.07*x_4-0.01*x_5-5.64$	3.2	3.19
	agrometeorological	$y=-0.01*x_7-0.29*x_8-0.49*x_9+38.39$	3.36	0.05
	climatic and agrometeorological	$y=2.46*x_1+1.73*x_2+1.65*x_3-9.85*x_4-0.05*x_5+0.04*x_6+0.32*x_8+8.3*x_9-53.59$	2.9	3.92
soybean	climatic	$y=5.32*x_1-2.49*x_2-2.17*x_3-3.15*x_4-0.02*x_5+157.69$	4.39	24.75
	agrometeorological	$y=-0.26*x_6+0.23*x_7+5.29*x_8-57.3*x_9-317.82$	4.53	16
	climatic and agrometeorological	$y=-1.87*x_2-2.85*x_3+0.04*x_6-0.01*x_7+95.35$	4.1	-37.13
rapeseed	climatic	$y=1.17*x_1+2.42*x_2+1.08*x_3-3.49*x_4-0.02*x_5-91.13$	3.2	3.67
	agrometeorological	$y=-0.01*x_6+0.02*x_7+0.77*x_8-4.22*x_9-60.37$	3.36	0.58
	climatic and agrometeorological	$y=-4.34*x_1+1.45*x_2-0.88*x_3+4.95*x_4-0.02*x_6+0.04*x_7+2.44*x_8-4.53*x_9-238.62$	2.9	12.25
Note	x_1 – average air temperature for the growing season, °C; x_2 – maximum soil surface temperature during the growing season, °C; x_3 – minimum soil surface temperature during the growing season, °C; x_4 – average temperature of the arable soil layer (20 cm) during the growing season, °C; x_5 – the amount of precipitation during the growing season, mm; x_6 – the sum of effective temperatures of 10°C and above for the growing season, °C; x_7 – the sum of positive temperatures of 10°C and above for the growing season, °C; x_8 – reserves of productive moisture in the arable soil layer (0-20 cm) during the growing season, mm; x_9 – hydrothermal coefficient (HTC) for the growing season. – the regression model is statistically substantial P≤0.05 (condition $F_{calc} > F_{table}$ is observed**)** **(**Klymenko *et al.*, 2021**)**		

Source: *compiled by the authors*

The trends established as a result of the study are confirmed by a number of researchers. Thus, researchers of the Scientific Centre for Aerospace Research of the Earth of the National Academy of Sciences of Ukraine (Lyalko *et al.*, 2020) established that according to the average annual indicators of gross primary productivity of vegetation cover, the most highly productive territories include the western regions (with the exception of Khmelnitska and Ternopil) and Zhytomyr region using MOD17 A3 satellite images. Most of Podillia (Vinnytsia, Ternopil, Khmelnytska

regions), the remaining northern regions and the Cherkasy region form a normally productive part of the territory of Ukraine. Other administrative regions belong to a moderately productive part of the territory of the state.

The examination of the trend in the dynamics of yield of heat-loving crops is confirmed by the results of the study by O.S. Budziak, (2022). Due to the increase in the sum of effective temperatures, favourable conditions have emerged In the Western Forest-Steppe zone for growing heat-loving crops such as sunflower, corn for grain, soybeans, etc. The area under them is constantly growing, which causes changes in the structure of both acreage and agricultural landscapes. In 2000-2021, the area of crops increased rapidly – under soybeans (20 times), rapeseed (5 times), corn for grain (4 times), and sunflower (2 times). The change in land use management practices from grain-feed to grain-technical was also caused by an economic factor (Budziak *et al.*, 2022).

Poliovyi (2019) notes that the total amount of precipitation for the year and for the growing season cannot be a reliable initial criterion for assessing the real moisture supply of agricultural crops during the growing season. The data obtained by the researcher indicate that the processes caused by global warming have substantially worsened the supply of moisture to plants. It was identified that the reserves of productive moisture under winter wheat in the soil layer of 0-100 cm, with almost the same amount of precipitation in June-July of 2013-2018, were half as much as in 1985-1990. There is a gradual aridisation of the territory. Although due to an increase in the amount of winter precipitation and its better assimilation by the soil if it freezes slightly early spring moisture reserves somewhat increase, in summer there are clearly pronounced downward trends.

An increase in air and soil temperature during the growing season of agricultural crops, combined with increased winds and a decrease in relative humidity, substantially increases the evaporation of moisture, which leads to a worse moisture supply for plants, even if the amount of precipitation does not decrease (Poliovyi *et al.*, 2019). The hydrothermal coefficient established in the course of the study, which is an indicator of the moisture content of the territory during the growing season, confirms this trend.

In the modern agricultural production of Ukraine, a special place is occupied by corn, which is characterised by high potential productivity compared to other grain crops. Since 1998, the area under corn and sunflower crops in Polissia has substantially increased. Previously, agroclimatic conditions were not favourable for growing these heat-loving crops in the Polissia zone, since they did not have time to ripen at insufficient temperatures. However, due to climate change, this has become attainable, and in some areas, it is now possible to get even two harvests from one field per season (Liu *et al.*, 2021; Johnston & Chiotti, 2000). Over the past 20 years, the acreage under corn in the Polissia zone has increased by 98,843 hectares, and sunflower – by 126,963 hectares, while in the Steppe zone these areas are 361,551 hectares for corn and 473,044 hectares for sunflower. Over the past decade, the area of corn crops in Ukraine has increased more than 2 times and amounts to about 5 million tonnes despite the fact that according to scientific recommendations, the optimal area of corn sowing for grain and silage in Ukraine should be within 3 million hectares (FAO, 2022).

Corn yields in Ukraine almost doubled from 2000 to 2021 – from 27 cwt/ha (2000) to 50 cwt/ha (2021). The maximum yield of corn in individual agricultural enterprises located in the Forest-Steppe zone, under the conditions of production intensification, reached 170-180 cwt/ha (Tkachuk & Bondarenko, 2022).

Notably, the cultivation of not only conventional agricultural crops but also heat-loving ones forms a tendency to intensify the development of degradation processes of the soil cover, which in turn causes an increase in the area of degraded and depleted soils. This is due to a violation of the technology of agricultural production when growing heat-loving crops on unreasonably large areas. A study by V.S. Chumak *et al.* (2012) allowed establishing that "with one ton of the main product of rapeseed, 65 kg of nitrogen, 24 kg of phosphorus, and 42 kg of potassium are removed from the soil, sunflower – 43 kg, 17 kg, and 10 kg, respectively, corn 24 kg, 9 kg, and 22 kg, respectively". Thus, a negative balance of nutrients in the soil is formed, which can only be partially compensated by the introduction of mineral and organic fertilisers. Due to this, in the conditions of intensive farming, there is a decrease in soil fertility, which leads to a decrease in yield (Stepanenko *et al.*, 2011; Klymenko *et al.*, 2021).

It is necessary that climatic and agrometeorological indicators are within certain optimal limits to obtain the planned yield of agricultural crops (Hanson *et al.*, 2007; Khudaverdiyeva, 2022), which is confirmed by the environmental laws of J. Liebig (the law of the minimum) and V. Shelford (the law of tolerance). The processes taking place in the agricultural sector due to climate change are ambiguous. Fast and excessive heat accumulation caused by them can lead to a reduction in the growing season, premature ripening of crops, and a decrease in yield (Petersen, 2008; Nelson *et al.*, 2014).

T.I. Adamenko (2019) states that there is a high probability of the transition of Polissia and Western Forest-Steppe from a zone of sufficient moisture to a zone of unstable and insufficient moisture. This is due to the fact that in the coming years not only an increase in air temperature is to be expected, but also a decrease in precipitation. This trend requires attention and further research.

CONCLUSIONS

This study confirmed that climate changes take an active part in the complex process of forming the productivity of agroecosystems of Polissia, the Forest-Steppe, and

the Steppe of Ukraine, considering which will allow agricultural enterprises to obtain high yields of both conventional agricultural crops and heat-loving ones. Crop yields are largely determined, along with other factors, by climatic and agrometeorological factors. The obtained results of correlation analysis allowed establishing limiting factors of influence on the yield of corn, sunflower, soy, and rapeseed, namely: the average value of air temperature, the sum of positive temperatures and soil surface temperature (r=0.57-0.80). The complex effect of meteorological and agrometeorological factors has a more substantial impact on the yield of the considered agricultural crops in the territories of the examined agroclimatic zones (R>0.7). The greatest dependence of yield on the group of meteorological factors was identified for corn in Polissia (R=0.819), sunflower in the Forest-Steppe (R=0.933), soybeans in the Steppe (R=1); on agrometeorological factors – in Polissia for sunflower (R=0.862), soybeans in the Forest-Steppe (R=0.934) and Steppe (R=0.979); on meteorological and agrometeorological factors together – for sunflower in Polissia (R=1) and Forest-Steppe (R=0.998), soybeans in the Steppe (R=1).

Considering the forecasts of further increase in air temperature, which leads to substantial changes in climatic and agrometeorological factors, there is an urgent need to quickly adapt to the variability of natural conditions and search for optimal methods of agricultural activity. Following the strategy of sustainable development, in the post-war period, it will be necessary for Ukraine, as an independent state with strong agricultural potential, to restore agricultural production with high crop yields, considering the potential risks of natural and anthropogenic origin. It is suggested to forecast the adaptability of agricultural crops in different natural and climatic zones of Ukraine by yield indicator using the developed regression models, most of which are statistically reliable with an error level of no over 5% ($P \leq 0.05$) to solve this problem. Further research will be aimed at investigating the possibility of introducing other agricultural crops into crop rotations, their adaptation to new agroecological conditions, and the possible consequences of such actions for agroecosystems.

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CONFLICT OF INTEREST

None.

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Прогнозування адаптивності теплолюбних культур до змін клімату в умовах України

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Анотація. Україна має розвинутий аграрний сектор економіки, де 10,4 % валового внутрішнього продукту припадає на сільське господарство. Актуальність теми обумовлена тим, що сільськогосподарське виробництво, яке має стратегічне значення для країни, дуже чутливе до кліматичних змін, що відбуваються. При цьому вже проходить процес адаптації рослинницької галузі до наслідків зміни клімату та агрометеорологічних факторів, що проявляється у розширенні спектру вирощуваних сільськогосподарських культур. Метою даного дослідження було прогнозування адаптивності теплолюбних сільськогосподарських культур за їх врожайністю в різних природно-кліматичних зонах України. У процесі досліджень було використано такі методи, як: аналіз, синтез, факторний аналіз, кореляційно-регресійний, математико-статистичний. За результатами проведених досліджень доведено доцільність врахування кліматичних змін для отримання високих врожаїв як традиційних сільськогосподарських культур, так і теплолюбних, які не були типовими для Полісся та Лісостепу. На підставі аналізу динаміки врожайності сільськогосподарських культур було встановлено, що на території Лісостепу доцільно здійснювати переорієнтацію сільськогосподарського виробництва на вирощування теплолюбних культур – кукурудзи, соняшника, сої, ріпаку, які в останні роки дають такі ж або й дещо вищі врожаї ніж на півдні України. Вирощування ж цих культур у Поліській зоні є збитковим – врожайність досить низька, тому в цих регіонах варто продовжувати вирощувати традиційні культури (зернові, зернобобові, овочеві культури, картоплю). Встановлені залежності врожайності сільськогосподарських культур від кліматичних і агрометеорологічних чинників дозволили виявити комплекс факторів, що відіграють головну роль у формуванні врожаю конкретних культур. Розроблені моделі врожайності сільськогосподарських культур на основі множинної кореляції дозволяють здійснювати її прогнозування. Результати дослідження можуть бути корисними при плануванні та оптимізації діяльності сільськогосподарських підприємств, і в цілому сільського господарства, в різних природно-кліматичних зонах України, як стратегічної галузі економіки

Ключові слова: зміна клімату; адаптивність сільського господарства; теплолюбні культури; абіотичні фактори; агроекосистеми

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Ecological factors affecting the spread of class Chilopoda of the group Myriapoda

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Abstract. Recently, the problem of preserving biodiversity on the planet has become increasingly relevant. Therefore, research on the ecological characteristics of organisms that play an important role in the functioning of biogeocoenoses is especially relevant. Chilipoda millipedes are one of these groups. Currently, many questions on the ecology of Chilopods, especially in the territory of Albania, remain unresolved. This motivates researchers to seek answers to these issues. The primary research aim is to analyse the specific features of the ecology of the Chilipoda millipedes inhabiting Vlora. The material used for the study was the author's collections of centipedes. Manual collection and soil sampling methods were used in the research. Determination of the taxonomic affiliation of centipedes was performed by examining the morphological features of centipedes under a stereoscopic microscope and further determining specimens with the help of determination keys. In the field under investigation, the Chilipoda fauna is represented by 6 species from 4 orders, 6 genera, and 5 families. Temperature and humidity have been shown to have a significant influence on the geographical distribution of chilopods: thus, the occurrence of centipedes in litter and the upper soil layer decreases significantly with the onset of drought. The character of flora plays a secondary role in the distribution of centipedes. It was established that soils with high content of humus and nitrogen are a favourable habitat for centipedes. The paper presents, for the first time for the Vlora region, data on the vertical distribution of *S. coleoptrata* along the soil profile. Scootigers preferred litter and did not migrate into the soil. Other representatives of Chilipoda were mainly found in the uppermost soil layer (0-10 cm), moreover Chilipoda were concentrated in the litter, and only a small part of them descended to a depth of 20 cm. The obtained results contribute to the knowledge of the ecological features of chilopods

Keywords: centipedes; soil profile; climatic conditions; biotope, Albania

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INTRODUCTION

In recent decades, the problem of preserving the planet's biodiversity was of substantial relevance. This is mainly caused by the detrimental human impact on natural communities: the destruction of habitats of living organisms, extreme exploitation of biological resources, and pollution of the environment. This problem is especially relevant in insufficiently studied regions subject to increasing anthropogenic impact, such as southern Albania. Therefore, studies of the ecological features of different living organism groups that play an important role in the functioning of biogeocoenoses are of particular importance.

One of these groups is the class Chilipoda or centipedes. This is one of the largest classes of terrestrial arthropods. The world fauna of chilopods includes more than 3,000 species, although Sombke & Harzsch (2015) and Vujić *et al.* (2022) suggest that only a fraction of the species has been currently described, while about 8,000 species may exist worldwide.

Chilipods live a hidden life, avoiding daylight and dry locations. Most often they can be found under rocks, in broken trees, and in other covers. Centipedes are typical polyphagous predators. They inhabit the topsoil layer and litter and play an important role in regulating populations of soil invertebrates. They feed on insects, including pests of important crops, their larvae, earthworms, spiders, and several other animals. E. Iorio *et al.* (2020) and Yahata *et al.* (2018) showed the importance of chilopodans as a reliable indicator for determining the level of anthropogenic pressure on the environment. Although representatives of the Chilipoda class are present in many landscape zones, except deserts, little attention has been paid to the study of the ecological factors influencing the distribution of centipedes in Albania.

Thus, P. Stoev (1996) published the first research on Chilipoda in Albania in 35 years. In this paper, the main attention is devoted to the Chilipoda fauna. The author highlighted 21 species of chilopods, six of which were mentioned in Albanian fauna for the first time. The second part of the research (Stoev, 2000) was published, in which the author demonstrated data on 27 species of Chilipoda collected in Albania, including a complete checklist (58 species and subspecies) and gave a brief zoogeographical description of the Albanian centipedes. H. Kicaj (2018) presented a zoogeographic analysis of the Chilipoda fauna in Vlora, southern Albania.

Researchers have not given much attention to the ecological features of chilopods in Albania. A study by H. Kicaj and M. Qirjo (2014) and Cassar & Zapparoli (2021) is devoted to the distribution of centipedes over the soil profile in Vlora. However, many issues on the ecology of the centipedes remain uncovered. Overall, the insufficient study of the centipede ecology in southern Albania is evident and requires further research.

The purpose of the study is to investigate the specific features of the centipede ecology of the Vlora, southern Albania. To reach the purpose, the following objectives were set: to analyse the species composition of Chilipoda in Vlora, southern Albania; evaluate the influence of climatic factors on the geographical distribution of centipedes in the study area; characterise the features of the biotopic distribution of chilopods; analyse the specific features of the vertical distribution of chilopods along the soil profile.

MATERIALS AND METHODS

The material for the research was based on the author's collections of centipedes in Vlora, southern Albania. Manual collection and soil sampling methods were used in the research. The sample size was at least 25 m^2 (50 cm by 50 cm). Four experimental samples were established in each plot, from which material was selected randomly. Within the boundaries of the selected one, leaf litter was carefully moved on the polyethylene prepared in advance. Then, it was thoroughly hand-picked over, noting all detected chilopods.

To assess the influence of climatic factors on the geographical distribution of chilopods, specimens were collected in spring, summer, and autumn under rocks, tree leaves, and mosses, in tree hollows, or the upper soil layer. The study covered areas at different altitudes; in some cases, the soil sampling method was used. To determine the period of drought in the research region, an ombrothermic diagram was constructed, showing changes in such indicators as temperature and amount of precipitation within each month throughout the year. Such a diagram was first constructed by Kamińska *et al.* (2016) to determine drought periods in the Mediterranean environment.

To research the biotopic distribution of chilopods, two stationary collection points were selected from which material was collected during the spring, summer, and fall using the soil sampling method. Biotope 1 is located 10-50 m above sea level. In this biotope, the vegetation is represented by deciduous trees (lemon, plum), reed, and other plants, which play an important role in agriculture. Biotope 2 is a coniferous forest at 900-950 meters above sea level. A total of 18 samples were collected and analysed. Biotope monitoring continued during the winter months, but no centipedes were collected at this time.

The vertical distribution of centipedes over the soil profile was also analysed in one in Vlora. In this case, excavation and disassembly of samples were conducted separately in two layers, each 10 cm deep. The centipedes were collected and recorded separately from each sample and layer. A total of about 680 specimens of Chilipoda were collected. The detected specimens were placed in tubes with 80% ethyl alcohol with the addition of a few drops of ether to preserve the natural coloration of the specimens. Each sample was labelled conventionally with complete information.

Determination of the taxonomic affiliation of centipedes was performed by addressing such morphological characteristics as body size and shape, number of segments and pairs of legs, presence of gonopods, body coloration, placement of the tergal plates, etc. These characters were examined under a stereoscopic microscope EMZ13TR, Trinocular Zoom with a magnification of 10 to 70 times. Identification of specimens was also carried out using identification keys for class Chilipoda species developed by P. Stoev (1996; 2000).

RESULTS

The characteristic of the entire class Chilopoda. Like representatives of other groups of centipedes, Chilipoda is associated with the soil and leads mainly a hidden life, hiding most of the time under rocks, tree bark, on the forest floor, and in cracks of rocks and soil. As a rule, Chilipoda comes out to hunt at night.

The characteristic of the entire class Chilopoda is that the legs of the first body segment are converted to jawfoot, with venomous gland ducts opening at the ends of the claws, which are used by these centipedes to strike prey and defend themselves.

Within the class Chyloroda, there are 5 currently living types (Zapparoli, 2016). These groups represent separate branches of evolution with traces of one or another specialisation:

Geophilomorphs (Geophilomorpha): The body is worm-shaped, with 27-191 pairs of legs, usually coloured in yellow and brown tones. The size of centipedes in this group does not exceed 22 cm. They can migrate into the soil to a depth of 70 cm. Most often, centipedes of this group settle under tree roots, in ants' nests, and sometimes they occupy mouse burrows (Shear & Krejca, 2019). More than 1,000 species from 246 types have been described.

Scolopendromorpha: The body of the scolopendra is broad and dense, dorsoventrally flattened, with 21-23 pairs of legs, coloured yellow or brown. The body is subdivided into the head and torso. The size of centipedes in this group varies from 1.2 cm to 27 cm. The head bears a pair of well-defined antennae, a pair of mandibles, and two pairs of maxillae. Around 100 species from 132 types have been described.

Scutigeromorpha: The body is short, consisting of 15 segments and the same number of legs. Hind legs are twice as big as walking legs. Segments of the body are covered by 8 tergal plates. Currently, more than 540 species of 132 types are known to science.

Common British centipede (*Lithobiomorpha*): The common British centipede body is divided into head and body and consists of 19 segments with 15 pairs of walking legs. The body length can reach up to 5 cm. At the front, on the sides of the head, there are 13-100 membered antennae and simple eyes in varying numbers, which may be absent in some species. More than 130 species of 30 types have been described.

Craterostigmomorpha: The body consists of 21 tergites. This group is also characterised by 15 pairs of walking legs. The body length varies from 3.7 cm to 5 cm. There are 17-18 membered antennae on the sides of the head in front. Science knows 2 species of the same type.

The chilopod species composition in Vlora. Under our observations, 6 species of centipedes from 4 orders, 6 types, and 5 families were found in the region under study.

Table 1. *Class Chilipoda*

Order	Family	Genus	Discoverer
Geophilomorpha	*Dignathodontidae*	*Dignathodon*	Meinert, 1870
		Dignathodon microcephalus	Lucas, 1860
		Henia	Koch, 1847
		Heniaillyrica	Meinert, 1870
	Geophilidae	*Clinopodes*	Latreille, 1817
		Clinopodesflavidus	Koch, 1847
Scolopendromorpha	*Scolopendridae*	*Scolopendra*	Linnaeus, 1758
		Scolopendracingulata	Latreille, 1892
Schutigeromorpha	*Schutigeridae*	*Schutigera*	Lamark, 1801
		Schutigeracoleoptrata	Linneaus, 1758
Lithobiomorpha	*Lithobiidae*	*Lithobius*	Leach, 1814
		Lithobiuslapidicola	Meinert, 1872

Source: *compiled by the author*

Influence of climatic factors on the geographical distribution of centipedes. Southern Albania has a mild Mediterranean climate. The region can be divided into several climatic subzones. The average January temperature varies from -3°C to 10°C, while the average July temperature ranges from 17°C to 26°C. The average daily temperature does not fall below 10°C for 156 days a year. The average precipitation is 1,480 mm per year. (Ivask *et al.*, 2019). Table 2 shows data for each month on the precipitation and air temperature collected over several years in Vlora (Rost-Roszkowska *et al.*, 2020), according to which the average rainfall is about 953.8 mm.

***Table 2**. Average air temperature and precipitation in Vlora*

	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Temperature, °C	9.2	10	11.4	14.4	18.3	22	24.1	24.2	21.6	17.9	14.1	10.8
Precipitation, mm	126	99.5	83.5	69.6	53.5	22.8	16.7	29	57.9	111.5	148.4	136.3

***Source:** Rost-Roszkowska et al. (2020)*

However, in southern Albania, the geographical distribution of precipitation is uneven: the western areas, facing the bringing cyclones, are more humid than the leeward eastern ones. This situation causes dry summers and often in other seasons as well as rainy winters. Nevertheless, Table 2 shows that the driest month in Vlora is July. Currently, the average air temperature is 24.2°C, and the amount of precipitation decreases to 16.7 mm. These results are confirmed by the data in the ombrothermic diagram (Fig. 1), showing the change of such indicators as temperature and precipitation within each month throughout the year.

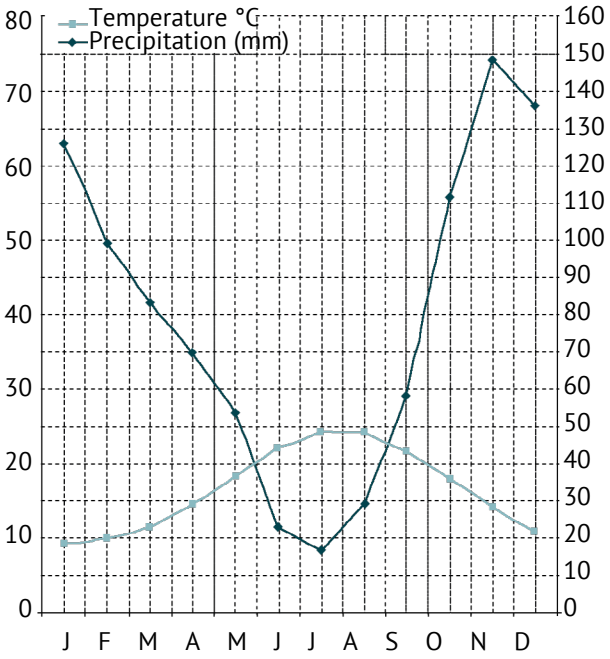

***Figure 1**. Ombrothermic diagram for Vlora*

***Source:** H. Kicaj (2012)*

The issue of the influence of climatic factors on the geographical distribution of centipedes is insufficiently covered. The results of the studies are presented in Table 3. According to the data obtained, only a representative of the Scolopendra species, *S. cingulata*, was observed in summer. This group of centipedes was also registered in other seasons of the year. As seen from Table 3, members of the Geophilomorpha species were found in spring and fall, while centipedes of the Schutigeromorpha species were noted only in spring, and a representative of the *L. lapidicola* – only in autumn.

***Table 3**. Seasonal changes in the occurrence of centipedes in Vlora*

	Spring	Summer	Autumn
Geophilomorpha	+		+
Scolopendromorpha	+	+	+
Schutigeromorpha	+		
Lithobiomorpha			+

***Source:** completed by the author based on author's researchers' data*

Seasonal changes in the occurrence of centipedes in VloraPeculiarities of the topic distribution of chilopods. The study of their biotopical variability is necessary to comprehend the influence of ecological factors on centipedes. When assessing the biotopic distribution of the Chilipoda class members in Vlora, only specimens collected by soil sampling were considered. Biotope 1 was 10-50 m above sea level. Vegetation was represented by trees such as plums, lemons, etc., and reeds. In addition, grass vegetation was completely absent in this biotope (ASH, 1975; 1989; 1991).

Soil chemical composition: humus – 56%; nitrogen – 92 mg/100g soil; phosphorus – 66 mg/100g soil.

Biotope 2 was a coniferous forest located 900-950 m above sea level. This biotope is dominated by conifers *Pinus heldreichii, Pinus nigra, Abies borisii-regis*. Soil is low in humus and nitrogen. In Biotope 1, where deciduous trees predominated, inhabited by representatives of all 4 species of the class Chilipoda, while in biotope 2, where coniferous trees mainly grew, representatives of the order Schutigeromorpha were absent.

Table 4 shows that *S. cingulata* was the most frequent species among all centipedes in both biotopes studied: the occurrence of this species was 48% and 58% for deciduous trees and coniferous forests, respectively. Density and occurrence rates for another genus of centipedes, Geophilomorpha, were about the same in both cases. All found specimens were found at a depth of more than 30 cm. It is also interesting to note the fact that during the collection of soil samples, specimens of *Henia illyrica* and *Clinopodes flavidus* were found in both biotopes. Table 4 shows that the total population density of centipedes is higher in the biotope dominated by deciduous trees than in the coniferous forest. However, the occurrence of chilopods is influenced more by temperature and moisture, soil chemical composition, than by the species composition of litter. First of all, this is because Diplopoda are predators, so, on the one hand, their occurrence is not associated with vegetation, but, on the other hand, the species composition of plants affects the chemical composition of the landscape soil.

***Table 4**. Seasonal changes in the appearance of centipedes in Vlora*

	Geophilomorpha	Scolopendromorpha	Schutigeromorpha	Lithobiomorpha
Biotop 1				
Occurrence, %	35	48	5	12
Density, species/m^2	2.3	3.2	0.3	0.8
Overall density, species/m^2		6.6		
Biotop 2				
Occurrence, %	34	58	-	8
Density, species/m^2	1.8	2.7	-	0.5
Overall density, species/m^2		6		

***Source:** compiled by the author based on the own research data*

Peculiarities of the vertical distribution of Chilipoda along the soil profile in Vlora. In the region under study, most specimens of chilopods were found at a depth of 0-10 cm (Fig. 2). No centipedes were found at depths greater than 30 cm. The vertical distribution of centipedes is influenced by a complex of biotic and abiotic factors. As can be seen in Figure 2, *S. coleoptrata*, a representative of the order Schutigeromorpha, everywhere prefers litter, whereas *S. cingulata* (Scolopendromorphaspecies) is widely distributed not only in a litter but also in the upper soil horizon, and also these millipedes migrate to soil depth in small numbers.

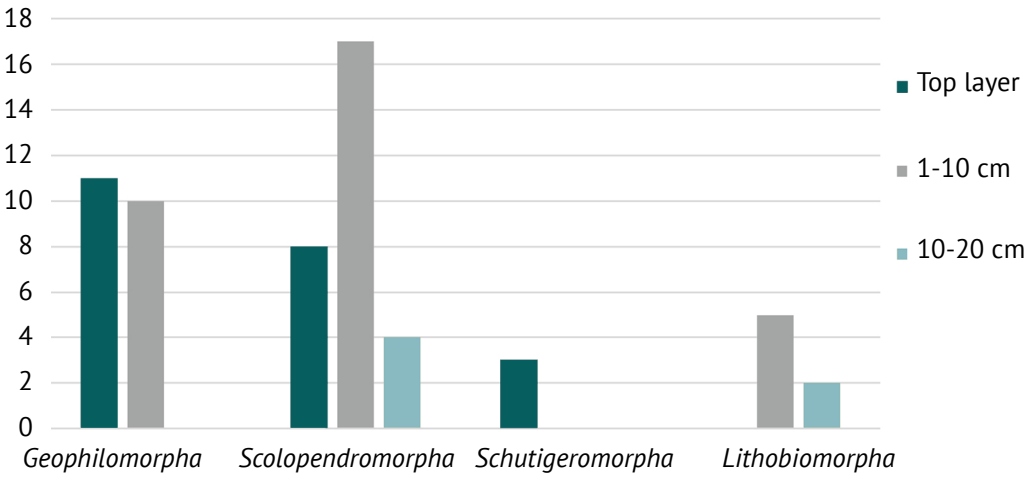

Figure 2. *Distribution of Chilipoda along the soil profile in Vlora*

Following the obtained results, *L. lapidicola* descended into the soil 10 cm and lower and was not found in the litter. Since members of Lithobiomorpha prefer dark habitats with high humidity, therefore, they are not often found in open areas. Geophilomorpha species were almost equally distributed between the litter and the top soil layer up to 10 cm and were absent in deeper soil layers. The centipedes of this group are widespread in places characterised by high humidity.

DISCUSSION

The research area is inhabited by centipedes from 4 species of the class Chilipoda. The most numerous are representatives of Geophila and Scolopendra. The obtained results coincide with the data presented in the literature. It is worth noting that two Geophilomorpha species: *Henia illyrica* and *Clinopodes flavidus* have been recorded in the Vlora fauna relatively recently (Kicaj, 2018). During the study, members of these two species were observed both in coniferous forests and in deciduous tree stands, which may indicate a wider distribution of *H. illyrica* and *C. flavidus* recently in southern Albania. Climatic factors play a significant role in the geographical distribution of centipedes.

There has been insufficient attention devoted to this issue, especially within the territory under study. In this connection, the study by H. Kicaj (2012; 2018) should be highlighted, which analysed the effect of temperature and humidity on the distribution of representatives of the family Glomeridae belonging to the class Diplopoda. Glomeridae belongs to another class of centipedes – Diplopoda. The researcher noted that the smallest number of diplopods was found in July-August since this period of the year is the driest (Kicaj, 2012).

For members of the class Chilipoda, such data are absent, which determines the need for this study. The obtained data fully coincides with the observations of H. Kicaj (2012; 2018): the smallest number of chilopods was observed in summer. Only *S. cingulata*, a representative of the Scolopendra species, was found (Table 3). This may indicate a wide ecological tolerance of this species. The centipedes burrowed into deeper soil layers with the onset of drought. The period of drought in southern Albania occurs in July and August when high air temperatures and the least amount of precipitation become characteristic of the climate in Vlora. There are known cases when during drought, centipedes migrated to a depth of 1.5 meters, where they were nourished by worms that migrated deeper into the soil due to high air temperatures and lack of precipitation (Poloczek *et al.*, 2016).

Members of the *Lithobiomorpha* species were observed only in the fall. Since lapidomorphs can be active and mobile at lower temperatures, they can remain for longer periods in the upper soil layers, unlike other centipedes. The species *L. lapidicola* found in the research area can easily deal, for example, with leafminer caterpillars that were inaccessible to it in the warm season (Poloczek *et al.*, 2016). Thus, during drought, the occurrence of centipedes significantly decreases in the region, and such climatic factors as temperature and humidity influence the geographical distribution of chilopods.

Recent researches show that, in addition to climatic factors, the distribution of centipedes is influenced by vegetation and hydrothermal soil composition (de Oliveira *et al.*, 2019; Bouzan *et al.*, 2022; de Almeida *et al.*, 2022). However, similar data for chilopods in Albania are practically absent. Observations show that in Biotope 1, where deciduous trees dominated and herbaceous vegetation was absent, representatives of all 4 species of the Chilipoda class were present, whereas, in Biotope 2, where coniferous trees were growing, centipedes from the type *Schutigeromorpha* were absent.

It can be assumed that this is conditioned by the chemical composition of the soil, especially the lower content of humus and nitrogen in the pine plantations. Whereas in the soil of Biotope 1, which was characterised by a higher content of humus and nitrogen, Scutiger was found. In addition, *S. coleoptrata* leads a synanthropic lifestyle (Shear & Edgecombe, 2010; Mitić *et al*, 2022), so its presence in a human-altered landscape is quite reasonable.

S. cingulate, a representative of the *Scolopendromorpha* type, was found most often among the chilopods. This may indicate the resistance of this species to the chemical composition of soils. The occurrence and density of *Geophilomorpha* were approximately the same in both habitats, although the density of Geophiles in the coniferous forest was slightly lower compared to this indicator in Biotope 1 (Table 4). This can be explained by the fact that the soil in pine forests is dense and it is difficult for centipedes to move in it.

In turn, the occurrence and density of knucklegrass were higher in Biotope 1. It can be assumed that the presence of leaf litter is a favourable factor for *Lithobiomorpha*. In Biotope 1, where vegetation is represented by trees such as plum, lemon, etc., and reed, the total density of centipedes was 1.3 times higher than in the coniferous forest (Table 4). Thus, soil with high content of humus and nitrogen acts as a more favourable habitat for chilopods. However, the data obtained indicate that vegetation and soil chemistry has little influence on this group of centipedes.

In studying the ecological characteristics of centipedes, their vertical distribution in the soil profile is an important parameter. Most centipedes migrate between different soil layers. They migrate to survive under unfavourable environmental factors. For example, representatives of the type *Geophilomorpha* during the tropical rainy season are most often found in the upper soil layer up to 7 m, and with the onset of drought, they migrate to a depth of up to 14 cm (Cabanillas and Robla, 2022; Anselmo and Selvaggi, 2022). Regarding the region under study, H. Kicaj and M. Qirjo (2014) made a comparative study of the vertical distribution of centipedes from the Diplopoda and Chilipoda Geophilomorpha classes in Vlora. In their study, the authors noted that chilopods burrow deeper than centipedes. They attributed this feature to the faster movement of centipedes at the time of collection.

However, *Diplopoda* is saprophagous, actively destroying leaf litter, so they are more often found in forest litter and on the soil surface. In comparison with *Diplopoda* centipedes, they are more tolerant to low humidity. Moreover, for the Vlora region, the researchers found representatives of 3 groups of centipedes: *Geophilomorpha*, *Scolopendromorpha* and *Lithobiomorpha*, and analysed the features of their distribution in the soil profile. Most of the centipedes lived in the litter and at a depth of 0-10 cm, while only 18% of the chilopods and diplopods migrated to a depth of 10-20 cm. (Kicaj and Qirjo, 2014).

The results of this research coincide with the data obtained by H. Kicaj and M. Qirjo (2014). In addition, the vertical distribution of *S. coleoptrata* in the soil profile of southern Albania was shown for the first time in this work. *S. coleoptrata*, a representative of the Schutigeromorpha type, universally prefer litter and does not occur in soil (Fig. 2). On the contrary, *L. lapidicola* migrated mainly to a depth of up to 10 cm.

As indicated by many authors studying the ecology of the common British centipede, most of these insects prefer dark and moist habitats, most often found in litter and upper soil layers (Tuf, 2015; Netto *et al.*, 2021), also representatives of this group of centipedes in small numbers were found in deeper soil layers up to 20 cm (Fig. 2). Geophytes inhabited mainly litter and the top 0-10 cm soil layer, and they did not descend to a depth of more than 10 cm at all. Most often, the depth at which the centipedes descended depended on the hydrothermal conditions of the soil.

Thus, the greatest number of Chilipoda was found in the uppermost soil layer (0-10 cm), the centipedes were also concentrated in the litter, and only a small part of them migrated to the depth. However, the maximum depth of Chilipoda migration did not exceed 20 cm.

CONCLUSIONS

The results reveal that there are four groups of centipedes in the Vlora fauna. The most numerous are representatives of the Geophilomorpha and Scolopendromorpha types. Air temperature and humidity have a paramount influence on the geographical distribution of chilopods. Only one species of centipedes, *S. cingulata*, was recorded during the aridest period, which may indicate a wide ecological tolerance of this species. This statement is supported by the fact that it was found more often than other chilopods in two different biotopes, which may also testify to the loyalty of ringed scolopendra to the chemical composition of the soil. Vegetation plays an insignificant role in the distribution of centipedes. But the soil with high humus and nitrogen content is a favourable factor for the habitat of these invertebrates.

During the research, specimens of *H. illyrica* and *C. flavidus*, relatively recently described for the Vlora fauna, were noted both in the coniferous forest and among deciduous trees, which may indicate a wider recent distribution of these in southern Albania. The study of the vertical distribution of Chilipoda along the soil profile showed that the greatest number of centipedes was found in the uppermost layer of soil (0-10 cm), also Chilipoda were concentrated in the litter, and only a small part of them migrated to a depth of 20 cm. It is worth noting the following features of the vertical distribution of *S. coleoptrata*: the centipedes preferred litter and did not migrate into the soil. These data were obtained for the first time in southern Albania.

The problem of the ecological peculiarities of centipedes in Albania is a complex and multifaceted one. The present research forms prerequisites for a more comprehensive study of this issue. The main prospects for further studies are related to the analysis of the sex and age structure of chilopods in Albania and the investigation of their locomotor activity. Thus, the ecological features of centipedes of the class Chilipoda in Vlora, southern Albania, were studied.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Екологічні фактори, що впливають на поширення класу Chilopoda групи Myriapoda

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Анотація. Останнім часом проблема збереження біорізноманіття на планеті набуває все більшої актуальності. Тому дослідження екологічних особливостей організмів, які відіграють важливу роль у функціонуванні біогеоценозів, є особливо актуальними. Багатоніжки Chilipoda є однією з таких груп. Наразі багато питань з екології хілопод, особливо на території Албанії, залишаються невирішеними. Це спонукає дослідників шукати відповіді на ці питання. Основна мета дослідження – проаналізувати особливості екології багатоніжок Chilipoda, що мешкають на території Влори. Матеріалом дослідження слугували власні колекції багатоніжок. У дослідженнях використовували методи ручного збору та відбору проб ґрунту. Визначення таксономічної належності багатоніжок проводили шляхом вивчення морфологічних ознак багатоніжок під стереоскопічним мікроскопом та подальшого визначення екземплярів за допомогою визначників. На досліджуваній території фауна Chilipoda представлена 6 видами з 4 рядів, 6 родів і 5 родин. Показано, що температура і вологість мають значний вплив на географічний розподіл губок: так, з настанням посухи значно зменшується кількість стоног у підстилці та верхньому шарі ґрунту. Характер флори відіграє другорядну роль у розподілі стоніг. Встановлено, що ґрунти з високим вмістом гумусу та азоту є сприятливим середовищем існування для багатоніжок. У роботі вперше для регіону Влора наведено дані про вертикальний розподіл *S. coleoptrata* по ґрунтовому профілю. Скунси надавали перевагу підстилці і не мігрували в ґрунт. Інші представники Chilipoda були виявлені переважно у верхньому шарі ґрунту (0-10 см), також скутери концентрувалися в підстилці, і лише незначна їх частина спускалася на глибину до 20 см. Отримані результати є внеском у пізнання екологічних особливостей губчастих багатоніжок

Ключові слова: багатоніжки; ґрунтовий профіль; кліматичні умови; біотоп, Албанія

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Analysis of physical economic theory implementation efficiency in the economic activity of Azerbaijan

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Abstract. The physical and economic theory is under-investigated and has no clear definition of its determinants. The main goal of the economic activity of any country is the generation of capital and progress. Azerbaijan is characterised by economic growth, which is accompanied by the country's material resource usage and production of goods by using energy resources and a labour force. The rational use of material resources is quite important, which is the basis for the formation of the country's profitability and the introduction of innovations. That is why the issue of physical economic theory implementation in the economic activity of Azerbaijan is relevant. Establishing the effective use of physical economics in the functioning of the country will help identify the main flaws and develop the main ways to improve the economic activity of Azerbaijan. That is why the study aims to investigate and generalise the aspects of physical economic theory implementation in the economic activity of Azerbaijan. By using the induction method, the determinants of the physical economy were established, which include indicators of industry, energy, trade, and human capital. The analytical method determined that although the economy of Azerbaijan employs a physical economy efficiently, there are problems with the development of production, energy consumption, and labour force. As such, it was determined that the main ways to improve the efficiency of the physical economic theory implementation in the economic activity of Azerbaijan should be: the development and implementation of measures to increase the efficiency of beverage and tobacco, mineral fuel, lubricant, and related material production and employment of measures to reduce energy consumption in the production of non-metallic minerals, iron and steel, chemical and petrochemical products, non-ferrous metals through the introduction of innovative technologies. At the same time, the number of jobs should be increased, the skills of workers should be developed, and the quality of education in Azerbaijan should be improved following international standards. As such, the practical value of the research is predetermined by the characterisation of the main determinants of the physical economy of the country, which can be used in further scientific research to analyse the effectiveness of the physical economic theory implementation in the economic activity of countries

Keywords: industry; energetics; trade balance; human capital; wealth; progress

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INTRODUCTION

With the development of economic science, the concept of physical economic theory was introduced. The modern economic activity of Azerbaijan is based on the use of physical economic theory. The effectiveness of this theory usage is an important issue in the aspect of the development of Azerbaijan's economic stability. It is important to establish the definition and origin of "physical economy" as this term is a new concept that requires a detailed study and personification. Currently, there is no single defined approach to the interpretation of this concept and the corresponding theory. The first to address the concept of "physical economy" was L. Larush (1997), who interpreted this concept as an economy based on the exact natural sciences. The basis of this theory is that the mathematical form of economic laws coincides with the mathematical form of several physical laws. L.F. Vasilevich and M.L. Vasilevich (2013) and Hasanov & Huseynov (2013) considered the nature of physical economics and added the word "fuzzy" to this term, explaining that in economics not all quantities can be measured as in physics, so the authors consider it appropriate to set some of the indicators in the form of fuzzy data, and the theory is called "fuzzy physical economics". Researchers have established that the basic principle of fuzzy physical economy is an optimal approach for the main categories of economics, which include information, risk, and cost. When making economic decisions, the one that is available under the condition of acceptable risk, minimum time, and provides the maximum value per information required is accepted. D.A. Nayko and O.F. Shevchuk (2011) and Magalhães *et al*. (2019) consider the physical economy as a system of measures to build the economy on the model of natural sciences (physics) using mathematical modelling. The physical economy is viewed by researchers based on three principles. First, human actions are formed based on behavioural reactions formalised in the form of supply, demand, income, and expenditure functions. Secondly, although market stability is ensured by the balance of supply and demand, and costs and revenues, these functions are variable due to the development of science and technology, which is why equilibrium never occurs, although the system is constantly moving towards it. Thirdly, physical economy according to scientists should be based on the theory of systems. E. Jonathan (2022) explains physical economics as a theory of physics and economics whose main goal is to establish a connection between financial currency and the use of energy as the most reliable method of enrichment and progress. Wealth and progress are also investigated in this theory. Physical economics is not considered by the researcher as an ideology. According to the author, the physical economy is that humanity is the main factor of progress and wealth, following the current level. That is, the world is predetermined to progress. Progress in terms of physical economic theory is seen as an increase in the amount of energy that humanity converts from one form to another. S. Gierlinger and F. Krausman (2012) and Raupova *et al*. (2014) interpreted the concept of physical economy as the evolution of the use of materials and energy. That is, the authors define material intensity as the main indicator of physical economic theory. The main indicators of the physical economy of a country are domestic production, imports, and exports; domestic consumption of materials, physical trade balance, and material intensity, which is the inverse of material productivity. The researchers also call the level of material and energy consumption per capita the metabolic rate. P. Richmond, J. Mimkes and S. Hutzler (2013) considered the physical economy based on the approach based on two-dimensional numbers and a model that defines the production process as a cycle.

As such, the physical economy should be considered as a set of economic processes that have specific patterns, derive from the cycle of production created by mankind, and can be explained by mathematical modelling. As for Azerbaijan, the physical economy is gaining momentum, accompanied by the significant economic growth of the country in the world markets. The purpose of this study is to analyse the aspects of implementation of physical and economic theory in the economic activity of Azerbaijan.

MATERIALS AND METHODS

The theory and methodology of the study are based on the main expert and scientific research on physical economic theory from Azerbaijan, the European Union, France, Ukraine, and the United States of America. The following methods were used in the study. The analysis was used to establish the specific features of the meaning of the category "physical economy", to define the essence of physical economic theory, and to establish the main determinants of physical economy.

The analysis was used to determine the features of the physical economic theory implementation in the economic activity of Azerbaijan during 2017-2021. This method was also used to systematise the data on the determinants of the physical economy industry of Azerbaijan in terms of the structure and production of food and live animals, beverages and tobacco, raw materials, inedible, except for fuel, mineral fuels, lubricants, and related materials, animal and vegetable oils, fats and waxes, chemicals and related products, industrial goods classified mainly by material, machinery and transport equipment, various industrial products, and other goods. This method was used to analyse the determinants of energy in the physical economy of Azerbaijan and to consider the indicators of GDP at purchasing power parity in 2017, final energy consumption, energy capacity, total energy supply, energy intensity, and GDP produced as a result of energy consumption per unit, and to determine the amount of energy consumed

for the production of iron and steel, chemical and petrochemical products, non-ferrous metals, non-metallic minerals, transport equipment, machinery, food, and tobacco. The analysis was also used to highlight the determinants of physical economy trade in Azerbaijan and to identify the main trends in the development of exports, imports, trade turnover, and trade balance of the country under study. This method was used in the analysis of human capital determinants of the physical economy efficiency in the country's economic activity and was employed in the consideration of indicators of the average annual population, the number of the economically active population, the number of employed, including by ownership, the number of unemployed persons, the number of those who received the status of unemployed in the state employment service and those receiving unemployment benefits, the number of employed women, the number of employees.

By using the induction method on the preliminary analysis of the state of physical economy indicators, the ways of improving the efficiency of the application of physical economic theory in the economic activity of Azerbaijan were developed and the main areas of improvement of industry, energy, and human capital development were characterised.

The research information is based on the studies by researchers from Azerbaijan, the European Union, Ukraine, France, and the United States of America on the effectiveness of the application of physical economic theory in the economic activity of the country. For characterising the determinants of the effectiveness of the implementation of physical economic theory in the economic activity of Azerbaijan, the data of the State Statistics Committee of Azerbaijan (2021) on the metrics of industrial production, energy consumption, the trade balance of the country, and the labour market was used.

RESULTS

The issue of analysing the effectiveness of the physical economic theory in the economic activity of the country has not been previously considered in the scientific literature. Nowadays, physical economic theory is quite vague and does not have a clearly defined approach. It is only established that the physical economy is based on the use of material resources and energy and their transformation into wealth by a person, which, in turn, entails certain laws and can be mathematically modelled (Richmond *et al.*, 2013). However, there are no specifics as to which indicators of the country's activity should be attributed to the physical economy in the scientific literature today. That is why the study identified the determinants of the physical economy and divided them into indicators of industrial, energy, trade, and human capital development (Fig. 1).

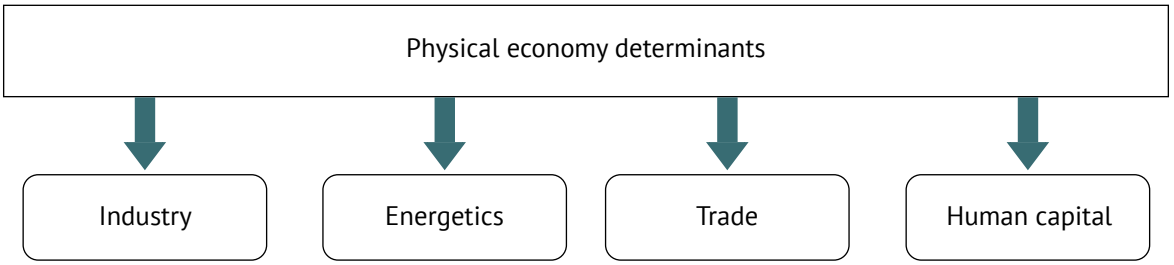

Figure 1. *Physical economy determinants relative to the economic activity of the country*
Source: *compiled by the author*

Determinants of the physical economy industry concerning the economic activity of the country reflect the specific features of the state of production results. That is, they facilitate the analysis of the production of the goods by using the country's resources. This is where the law of physical economy is used when one energy is transformed into another. Energy indicators in the aspect of the physical economy should be considered as the consumption of energy resources for production. The use of energy allows changing the form of materials from one to another. Meanwhile, foreign trade, mainly exports and imports, is also a determinant of the physical economy. The trade balance of the country reflects the physical economic activity of the state in international markets. Human capital is integral for the circulation and interaction of the above determinants of the physical economy. After all, it is the person who is the basis of the economic and physical development of the country. In this aspect, it is advisable to consider the saturation of the country's labour market, which allows the introduction of the latest technologies and innovations in the country. In general, a set of industrial, energy, and trade determinants in interaction with human capital form the physical economy of the country.

During further research in order to analyse the effectiveness of the physical economic theory in the economic activity of Azerbaijan, the features of the development of certain determinants of the physical economy are considered. First, the analysis was carried out and the growth rates of the determinants of the industry of the physical economy of Azerbaijan were determined. The main indicators are the volume of production in the country by industry (Table 1).

***Table 1**. Industrial physical economic determinant dynamics of Azerbaijan according to the industry sphere, thousand USD, 2017-2021*

Sections of commodities	2017	2018	2019	2020	2021	Growth rate. %
Total	8.783.301	11.465.915	13.667.475	10.732.039	11.705.787	33.27
Food and live animals	1.282.743	1.270.899	1.558.029	1.553.766	1.768.186	37.84
Beverages and tobacco	231.804	250.314	182.630	143.657	165.614	-28.55
Raw and inedible materials (except fuels)	231.128	313.645	362.083	271.888	323.304	39.88
Mineral fuels. lubricants, and related materials	378.811	723.720	827.328	280.263	333.637	-11.93
Animal and vegetable products, fats, and waxes	125.217	114.043	115.474	137.930	188.839	50.81
Chemicals and related products, not specified elsewhere	1.040.095	1.192.782	1.313.403	1.347.707	1.520.877	46.22
Manufactured goods classified primarily by material	1.684.695	2.173.823	2.140.640	2.002.315	2.148.879	27.55
Machinery and transport equipment	2.933.283	3.481.462	3.876.177	4.033.988	4.054.860	38.24
Miscellaneous manufactured articles	860.019	1.124.657	1.161.676	959.591	1.102.344	28.18
Commodities not classified elsewhere in SITC	15.507	820.570	2.130.037	934	99.248	540.00

***Source:** The State Statistical Committee of the Republic of Azerbaijan (2021)*

Table 1 shows that in general, production in the industry of Azerbaijan tended to grow by 33.27%, which indicates an increase in the level of efficiency of the physical economic theory application in the country's economic activity. At the same time, during 2017-2021, there was an increase in the production of food products, raw inedible materials (except fuel), animal and vegetable oils, fats and waxes, chemicals and related products, industrial goods (classified mainly by material), machinery and transport equipment, various industrial products. Goods that are not classified to the rest have experienced significant growth in the industry. At the same time, the volume of industrial production in Azerbaijan of beverages and tobacco, mineral fuels, lubricants, and related materials decreased. Industrial production structure in the span of the analysed period had the following nature (Table 2).

***Table 2**. Dynamics of the industrial physical economic determinant dynamics of Azerbaijan according to the industry sphere, % from 2017 to 2021*

Sections of commodities	2017	2018	2019	2020	2021
Total	100.0	100.0	100.0	100.0	100.0
Food and live animals	14.6	11.1	11.4	14.5	15.1
Beverages and tobacco	2.6	2.2	1.3	1.3	1.4
Raw inedible materials (except fuels)	2.6	2.7	2.6	2.5	2.8
Mineral fuels, lubricants, and related materials	4.3	6.3	6.1	2.6	2.9
Animal and vegetable products, fats, and waxes	1.4	1.0	0.8	1.3	1.6
Chemicals and related products, not specified elsewhere	11.8	10.4	9.6	12.6	13.0
Manufactured goods classified primarily by material	19.2	19.0	15.7	18.7	18.4
Machinery and transport equipment	33.4	30.4	28.4	37.6	34.6
Miscellaneous manufactured articles	9.8	9.8	8.5	8.9	9.4
Commodities not classified elsewhere in SITC	0.3	7.1	15.6	0.0	0.8

***Source:** The State Statistical Committee of the Republic of Azerbaijan (2021)*

Table 2 shows that the most significant determinants of the industrial efficiency of the physical economy of Azerbaijan during 2017-2021 were industrial goods, categorised mainly by material, machinery, transport equipment, and food. The production in these industries in general during the analysed period took about half of the country's production. At the same time, a significant impact on the performance of the physical economy of the country's economic activity was made by the production of various industrial products and chemicals and related products. Beverages and tobacco, raw materials, inedibles, mineral fuels, lubricants, and related materials, animal and vegetable oils, fats and waxes were completely insignificant in the structure of industrial production of Azerbaijan. It can be concluded that due to the growth of production of the main structural elements of the country's industry, the effectiveness of the application of physical economic theory in the economic activity of Azerbaijan has a positive trend.

Further research attention is focused on the development of physical economy energy determinants of Azerbaijan. Firstly, the specific features of energy generation in the country will be analysed (Table 3).

***Table 3**. Physical economy energy determinants dynamics in the context of Azerbaijan's energy intensity trends during 2017-2021*

Energy capacity (GDP. PPP) *)	2017	2018	2019	2020	2021	Growth rate. %
GDP by purchasing power parity prices of 2017, million USD	139.152.8	141.240.1	144.771.1	138.545.9	146.304.6	5.14
Energy final consumption – total. thousand TOE	9.361.2	9.894.3	11.348.5	11.264.1	12.053.7	28.76
Energy capacity (conversion to the final consumption of total energy), thousand TOE /thousand USD	67.3	70.1	78.4	81.3	82.4	22.47
Total energy supply, thousand TOE	15.506.8	15.590.7	17.085.6	16.642.8	17.566.6	13.28
Energy capacity (in conversion to total energy consumption). thousand TOE / thousand USD	111.4	110.4	118.0	120.1	120.1	7.75
GDP produced per unit of energy consumption. 1 USD/ thousand TOE	9.0	9.1	8.5	8.3	8.3	-7.19

***Source:** The State Statistical Committee of the Republic of Azerbaijan (2021)*

Table 3 shows that almost all energy intensity indicators of Azerbaijan during the analysed period tended to increase, which indicates both the growth of energy efficiency and the effectiveness of the application of physical economic theory in the country's economic activity. GDP at purchasing power parity in 2017 increased by 5% during 2017-2021, and such low growth rates were characterised by the energy intensity indicator (in terms of total energy consumption). The indicators of final energy consumption and energy capacity were relatively better developed in the energy sector of Azerbaijan. Although at the same time, there is a decrease in the GDP produced as a result of energy consumption per unit, which can be explained by economic changes in the country, such as inflation and rising prices, which has nothing to do with the efficiency of the use of physical economic theory. Thus, the increase in production in the country is accompanied by an increase in energy consumption, which is another postulate of physical economic theory. Therefore, it is necessary to analyse the dynamics of the volume of energy consumed to produce the respective product (Table 4).

***Table 4**. The volume of energy products consumed to produce a product in the amount of 1 AZN (at current prices) in the industrial sectors, kg of oil equivalent/AZN during 2017-2021*

Industry	2017	2018	2019	2020	2021	Growth rate, %
Industry	0.139	0.118	0.153	0.149	0.121	-13.22
Iron and steel	0.203	0.170	0.184	0.167	0.143	-29.65
Chemical and petrochemical	0.369	0.365	0.729	0.772	0.287	-22.31
Non-ferrous metal	0.325	0.290	0.302	0.328	0.235	-27.57
Non-metallic minerals	0.470	0.375	0.395	0.550	0.520	10.58
Transport equipment	0.117	0.118	0.005	0.006	0.006	-95.06
Machinery	0.039	0.034	0.045	0.040	0.033	-15.76

Table 4, Continued

Industry	2017	2018	2019	2020	2021	Growth rate, %
Food and tobacco	0.067	0.051	0.071	0.039	0.038	-43.00
Paper, pulp, and printing	0.032	0.031	0.043	0.039	0.041	27.42
Wood and wood products	0.077	0.050	0.060	0.067	0.055	-28.51
Textile and leather	0.072	0.063	0.064	0.055	0.046	-36.20
Non specified	0.048	0.036	0.043	0.026	0.029	-38.88

Source: *The State Statistical Committee of the Republic of Azerbaijan (2021)*

Table 4 shows that the highest volume of energy was used to produce non-metallic minerals. A significant amount of energy consumption in Azerbaijan during 2017-2021 was also required to produce iron and steel, chemical, and petrochemical products, and non-ferrous metals. Relatively small amounts of energy were consumed in the production of transport equipment, machinery, food and tobacco, paper, pulp and printing, wood and wood products, textiles and leather, and other unspecified products. Moreover, in general, during the period there is a general decrease in energy consumption, which can be explained by the effectiveness of the application of physical economic theory in the economic activity of Azerbaijan as there is an expansion of production using fewer energy resources due to the introduction of new technologies. The specific features of the development of physical economy trade determinants in Azerbaijan were further investigated (Table 5).

Table 5*. Dynamics of physical economy trade determinants of Azerbaijan during 2017-2021*

Indicator		2017	2018	2019	2020	2021	Growth rate, %
In million US dollars	trade turnover	24,103.3	30,955	33,302.7	24,464.6	33,912.5	40.7
	imports	8,783.3	11,465.9	13,667.5	10,732	11,705.8	33.3
	exports	15,320	19,489.1	19,635.2	13,732.6	22,206.7	45.0
	balance	6,536.7	8,023.2	5,967.7	3,000.6	10,500.9	60.6
Actual prices as a percent of the previous year*	trade turnover	85.2	96.1	96.8	72.7	87.2	2.3
	imports	83.8	100.2	93.5	64	90	7.4
	exports	86.1	93.8	98.8	78.8	85	-1.3

Source: *The State Statistical Committee of the Republic of Azerbaijan (2021)*

Table 5 shows that the determinants of trade in the analysed country during 2017-2021 had growth trends, which indicates an increase in the efficiency of the use of physical economic theory in the economic activity of Azerbaijan. During the analysed period, trade turnover increased by 40.7%, imports increased by 33.3%, and exports – by 45%. Accordingly, the trade balance had a positive trend and increased by 60.6%, which indicates the high productivity of production in the country. That is, Azerbaijan produces much more products than is purchased in other countries. Such trends indicate that economic activity is focused on the use of physical economic theory as the basis of economic activity in Azerbaijan is the production of products from materials, i.e., transformation from one form to another. At the same time, the actual prices as a percentage of the previous year's turnover and imports in the study period increased and decreased relative to exports, which indicates a high quantitative physical and positive trade balance. During the further study, the features of the creation of one of the significant determinants of Azerbaijan's physical economy are analysed. Such a metric is human capital as without a person no processes would take place in the country.

Table 6*. Dynamics of physical economy trade determinants of Azerbaijan during 2017-2021*

Main social-economic indicators of the labour market	2017	2018	2019	2020	2021	Growth rate, %
Average annual number of populations – thsd. persons	9.854.0	9.939.8	10.024.3	10.093.1	10.137.8	2.9
Number of the economically active population, thsd. persons	5.073.8	5.133.1	5.190.1	5.252.5	5.303.9	4.5

Table 6, Continued

Main social-economic indicators of the labour market	2017	2018	2019	2020	2021	Growth rate, %
Number of employed persons, thsd. persons	4.822.1	4.879.3	4.938.5	4.876.6	4.988.2	3.4
including by property forms:						
State	1.158.4	1.154.9	1.156.8	1.123.2	1.115.3	-3.7
Non-state	3.663.7	3.724.4	3.781.7	3.753.4	3.872.9	5.7
Number of unemployed persons, thsd. persons	251.7	253.8	251.6	375.9	315.7	25.4
Persons received unemployment status in a state employment agency, person	38.481	20.088	812.724	...	...	2,012.0
of which receiving benefits as unemployed	6974	1117[5)]	540[5)]	7275	...	4.3
Number of employed women – thsd. persons	2.319.3	2.349.9	2,381.7	2.351.5	2.408.1	3.8
Number of employees[2)] – thsd. persons	1.525.0	1.551.7	1.646.6	1.698.7	1.709.1	12.1
Average monthly nominal wages and salaries of employees – manat	528.5	544.6	635.1	707.7	732.1	38.5
Professional training of staff – person	4502	5,629	5.130	3.478	3.713	-17.5
Number of officials and specialists who improved qualifications – person	11.499	17.676	26.037	14.122	14.604	27.0
Costs spent on upgrading of professional level of the staff, training new qualifications, and improving the professional skills, mln AZN	9.5	11.6	11.6	5.8	9.2	-3.2
Special weight of costs incurred the increase the vocational training of employees in the total labour costs, percent	0.08	0.10	0.08	0.04	0.05	-39.1

Source: *The State Statistical Committee of the Republic of Azerbaijan (2021)*

Table 6 shows that the average annual population during the study period in Azerbaijan increased by 2.9%, the number of economically active population increased by 4.5%, and the number of employed also increased by 3.4% due to employment in non-state structures. The increase in the number of unemployment had a rather high growth trend during 2017-2021, as their number increased by 25.4%. That is, the efficiency of the physical economy is slowing down due to the irrational use of labour in the country. At the same time, the number of people who received the status of unemployed in the state employment service increased significantly, and the number of people receiving unemployment benefits was insignificant to the total and had insignificant growth trends. The low level of unemployment benefits and the high number of unemployed are followed by the migration of the population, i.e., the loss of the main components of building an effective physical economy in the country. The number of employed women and the total number of employees is also increasing, which is caused by a significant increase in the average monthly nominal wage of employees (The State Statistical Committee..., 2021). Professional training of personnel relative to the number of people in Azerbaijan during the period under review tended to decrease, although the number of officials and specialists who improved their qualifications increased. Moreover, the number of expenditures spent on raising the professional level of staff, training new qualifications, and improving professional skills decreased. At the same time, the share of expenditures on the professional development of employees in total labour costs also decreased. This trend reflects the concentration of the improvement of the determinants of human capital in Azerbaijan only on officials, which in the future may be accompanied by a decrease in the level of efficiency of the application of physical economic theory in the economic activity of the country (Mammadov, 2021).

Following the analysis of the physical economic theory implementation efficiency in the economic activity of Azerbaijan, it is possible to identify the following ways of its improvement (Fig. 2).

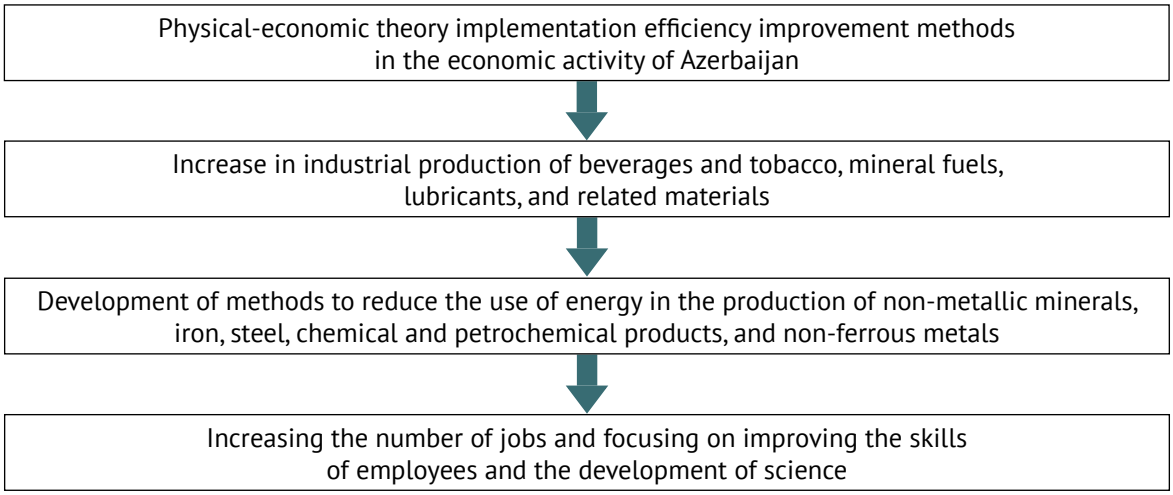

***Figure 2**. Methods of physical economic theory implementation efficiency improvement in the economic activity of Azerbaijan*

***Source:** compiled by the author*

To improve the efficiency of the physical economic theory implementation in the economic activity of Azerbaijan, it is necessary to expand the production of beverages and tobacco, mineral fuels, lubricants, and related materials, which will increase the determinants of the physical economy of the country's industry. The decrease in the production of these products is caused by a decrease in demand based on higher prices for these goods (Mammadov & Vali, 2020). Therefore, the authorities should take measures to slow down the inflation rate. At the same time, it is important to take measures to introduce newer technologies that would help to reduce energy consumption in the production of non-metallic minerals, iron, steel, chemical and petrochemical products, and non-ferrous metals. It is also important to improve the state of human capital in the labour market of Azerbaijan. After all, human development and qualification are the basis of the efficiency of the physical economy. The country's authorities should focus on the development and introduction of new jobs for the population (Integrated Country Strategy, 2022). For example, one such measure can be support for small and medium-sized businesses in the country, reducing the tax burden on the private sector of Azerbaijan. It is also important to develop a quality education system, which should be guided by international standards and technological progress. At the same time, it is important to eradicate corruption from the education system and conduct a qualitative assessment of the knowledge of future specialists. It is also recommended to establish requirements for the country's enterprises to develop and introduce separate departments in firms, which should be engaged in the motivation and professional training of workers and carry out measures to improve the skills of the company's employees (Asian Development Bank, 2022). All the above-mentioned measures will help increase the efficiency of human actions towards increasing wealth and progress in the country through the transformation of energy and matter from one form to another, which is the main principle of the application of physical economic theory in the economic activity of the country.

DISCUSSION

The issue of the physical economic theory implementation effectiveness in economic activity today is ambiguous and has no consistent approach. In addition, the problem of the physical economic theory of employment effectiveness in Azerbaijan has not been studied before.

L.F. Vasilevich and M.L. Vasilevich (2013) in their study only generalised the essentials and principles of physical economic theory. It was determined that from the central principle of fuzzy physical economics, the law of capital interaction and the law of the duration of economic cycles are derived, the mathematical form of which coincides with the form of the thermodynamic law. The researchers suggest that the duration of economic cycles is determined by the critical degree of capital concentration. The argument of the thermodynamic approach in these laws is determined by a fuzzy set of the economic environment, the characteristics of which cannot be clearly defined. Based on the general approach of fuzzy physical economics and the law of the duration of economic cycles, the authors suggest a hypothesis that the power of economic crises coincides in form with the thermodynamic law of Stefan-Boltzmann (Gilberto *et al.*, 2022). Accordingly, from the central principle and law of fuzzy physical economics identified by the researchers, it is established in the paper that economic crises will be observed more often, and their negative impact will be even greater. Therefore, the researchers recommend a transition from a market economy to a regulatory market economy and consider it necessary to reproduce a rational ratio of these two

regulators. Although, the researcher notes that it is no longer possible to change the speed of the process of capital concentration, which is the main factor of crises, only by changing the economic environment without changes in the person (Vasilevich & Vasilevich, 2013).

Temel *et al*. (2003) in his study reviewed the literature of previous researchers on this issue and summarised these materials mainly from a philosophical point of view. The author noted that in terms of physical economy, the wealth of a nation or state is equal to the amount of energy that can be converted from one form to another, which is also the most important indicator of progress. The researcher determined that energy cannot be created or destroyed because it is only transformed from one form to another. This is what humanity creates, that is, from the simplest biological functions to the most advanced technologies, it is a man who transforms energy and matter from one form to another. The author noted that there is a limited amount of energy in the universe, which is why there is a consistent standard by which the economy can be measured. Physical economic theory, according to the scientist, allows one to determine the value of the economy by establishing the amount of energy converted from one form to another in this economy. It is important to develop an indicator or measurement that should be clear and constant to measure the efficiency of the physical economy. The researcher emphasises that such an area will require the joint work of physicists and economists and a lot of time. At the same time, he recommends first formulating the goal of the physical economy based on establishing a link between financial currency and the use of energy as a means of the most reliable and consistent creation of wealth and progress. Such a goal of physical economy, according to the author, would contribute to the unification of science, economics, and philosophy.

E. Jonathan (2022) and Nasibov (2018) noted that physical economics does not provide religious security and is not an ideology, because it is only the best theory of wealth and progress that is available according to the current level of knowledge. That is, the author resorted to philosophy and determined that this view may constitute the logical core of the worldview, but it is not necessarily a worldview, because the choice is always up to the individual.

The literature review included the paper by S. Gierlinger and F. Krausman (2012), which is based on the consideration of the physical economy of the United States of America. This study is more analytical than theoretical and is based on the consideration of indicators of the physical economy concerning the United States. The physical economy of the country was considered in the aspect of resource use. To compile a comprehensive database of physical economy development metrics in the country, an array of data on trends in the development of material and energy flows in the U.S. economy was formed and standard methods of general economic accounting of material flows were used, and the used production, imports, and exports were quantified. The study provided indicators of the main groups of materials: biomass, fossil energy, ores, and non-metallic minerals. The work of these researchers has established that the development of the US physical economy over the past century reflects a characteristic pattern of sociometabolism and transition, as there has been a significant increase in both the production and trade of materials, a transition from the dominance of renewable biomass to fossil and mineral materials, as well as an increase in the reproduction rate.

Wang *et al*. (2022) and Polimeni and Polimeni (2007) established that the analysis of flows showed that population growth plays a significant role in this aspect. The authors also found that the US economy is characterised by a disproportionately large share of global resource use. Indeed, the per capita consumption of materials in the US is higher than in other developed countries. The study also shows that decisions on the spatial organisation of the economy and infrastructure have a long-term impact on resource use. At the same time, the exact interaction of the main factors that contribute to the use of materials is not fully understood and requires further research.

L. Freeman (2022) in his study recommended that African citizens develop the physical economy. The researcher explained that the basis of the physical economic theory is that wealth is not formed based on the financial system, but its base is a person and what they produce. The author suggests that it is possible to improve the development of Africa through science and technology because the human mind is the only known force in the world that can discover new physical principles. Discoveries of physical principles are accompanied by the creation of new technologies that allow producing more wealth with the same or less effort. Scientist suggests that the African continent's desire to spread nuclear energy in its economies will not only increase energy production but also the growth of the entire physical economy. Such trends will contribute to raising the level of education, skilled labour, development of scientific centres, and modernisation of the economy. According to the researcher, the development of the physical economy will help to improve the infrastructure of this contingent, because the introduction of the latest technologies increases the productivity of workers. Improvement and development of the physical economy contribute not only to the expansion of production but also increase the level of influence of each citizen and increase the standard of living of the population. That is if most of the population does not participate in the production itself, but at the same time develops technologies and scientific potential of the country and participates in the economic development of the country (Freeman, 2022). Human development and quality organisation of social activity are the main factors of efficiency of the physical economy.

As for Azerbaijan, there are studies and reviews of the general state of the economy (Nuri Aras & Suleymanov, 2016; McNerney *et al.*, 2021). The most detailed among the latest studies on the development of the Azerbaijani economy is the study by E. Mammadov (2021). The researcher found that according to the results of 2021, the economy recovers after the pandemic, but the risks remain high, which is explained by the rising inflation rate in the country. The increase in nominal income and wages is relative to the price level, as inflation arose due to higher prices for imported goods. As a result of such trends, the Central Bank of Azerbaijan raised the discount rate, referring to the growth of inflationary pressures from outside and inside the country. Although the primary task should be to prevent price increases. The researcher noted that the exchange rate dynamics remained stable due to the massive inflow of foreign currencies. Moreover, despite the positive signs of growth in non-oil production, the economic recovery mainly lasted until 2021, because the country's dependence on hydrocarbons continues to be higher, which necessitates further strengthening of the market-oriented economic structure, and diversification of the economy (Quality of life indicators, 2021).

As such, the conducted study of the research papers on the analysis of the efficiency of physical economic theory implementation has shown that the researchers have not previously identified these aspects concerning the Azerbaijan region, and in most papers, there is no clear separation of indicators that characterise the physical economy of the country. The study conducted by the author allows including the shortcomings of the previous ones and considering the specific features of the determinants of the physical economy, with the help of which it is possible to analyse the effectiveness of the use of this theory in the country and to establish further ways to improve the efficiency of the application of physical economic theory in the economic activity of Azerbaijan.

CONCLUSIONS

As such, the study of physical economic theory established that its nature is human actions to increase wealth and development progress in the country through the transformation of energy and matter from one form to another. That is, the physical economy considers material production, energy use, and increasing human potential as the main means of enriching the country and its progress. The study also identified the main determinants of the physical economy, which include industry, energy, trade, and human capital. Accordingly, while analysing the effectiveness of the application of physical economic theory in the economic activity of Azerbaijan, it was found that the country's industry was characterised by an increase in production in all sectors, except for the creation of beverages and tobacco, mineral fuels, lubricants, and related materials. At the same time, the analysis of energy determinants reflected the presence of expansion of production using fewer energy resources due to the introduction of new technologies in Azerbaijan. The study of the state of trade determinants in the country showed that there is a high level of productivity in the country, as Azerbaijan produces much more products than purchased in other countries and there is a high quantitative physical and positive trade balance. The analysis of the determinants of human capital showed that the unemployment rate in the country is growing, the degree of professional training of workers is decreasing, and the level of qualification of employees is decreasing, which is accompanied by the migration of the population. According to the analysis of the determinants of the physical economy of Azerbaijan, the ways to improve the efficiency of the application of physical economic theory in the economic activity of the country were identified, the main of which was to increase the efficiency of industrial production, reduce energy consumption and increase the potential of the country's labour force.

Further research of the physical and economic theory in the economic activity of Azerbaijan should be based on the development of measures to increase the productivity of production of beverages and tobacco, mineral fuels, lubricants, and related materials, implementation of measures to reduce energy consumption in the production of non-metallic minerals, iron and steel, chemical and petrochemical products, non-ferrous metals and the development of methods aimed at expanding jobs, raising the qualification of workers, improving the quality of life, and improving the efficiency of the economy.

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CONFLICT OF INTEREST

None.

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Аналіз ефективності впровадження фізико-економічної теорії в економічну діяльність Азербайджану

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Анотація. Фізико-економічна теорія є недостатньо дослідженою темою і не має чіткого визначення її детермінант. Основною метою економічної діяльності будь-якої країни є формування капіталу та прогресу. Для Азербайджану характерне економічне зростання, яке супроводжується використанням матеріальних ресурсів країни і виробництвом товарів за допомогою енергетичних ресурсів і робочої сили. Досить важливим є раціональне використання матеріальних ресурсів, що є основою для формування прибутковості країни та впровадження інновацій. Саме тому питання імплементації фізико-економічної теорії в господарську діяльність Азербайджану є актуальним. Встановлення ефективного використання фізичної економії у функціонуванні країни допоможе виявити основні недоліки та встановити основні шляхи вдосконалення економічної діяльності Азербайджану. Саме тому метою роботи є дослідження та узагальнення аспектів впровадження фізико-економічної теорії в економічну діяльність Азербайджану. За допомогою методу індукції встановлено детермінанти фізичної економіки, до яких віднесено показники промисловості, енергетики, торгівлі та людського капіталу. За допомогою аналітичного методу визначено, що хоча економіка Азербайджану ефективно використовує фізичну економіку, існують проблеми з розвитком виробництва, споживанням енергії та робочої сили. У зв'язку з цим було визначено, що основними шляхами підвищення ефективності впровадження фізико-економічної теорії в господарську діяльність Азербайджану мають стати: розробка та реалізація заходів щодо підвищення ефективності виробництва напоїв та тютюнових виробів, мінерального палива, мастильних матеріалів та пов'язаних з ними матеріальних виробництв, а також застосування заходів щодо зниження енергоспоживання у виробництві неметалевих корисних копалин, чавуну та сталі, хімічної та нафтохімічної продукції, кольорових металів за рахунок запровадження інноваційних технологій. Одночасно має бути збільшена кількість робочих місць, підвищена кваліфікація робітників та покращена якість освіти в Азербайджані відповідно до міжнародних стандартів. Таким чином, практична цінність дослідження зумовлена характеристикою основних детермінант фізичної економіки країни, які можуть бути використані в подальших наукових дослідженнях для аналізу ефективності впровадження фізико-економічної теорії в господарську діяльність країн

Ключові слова: промисловість; енергетика; торговельний баланс; людський капітал; багатство, прогрес

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Institutional aspects of transactional spending accounting demonstration in agricultural organizations

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Abstract. Agricultural organisations in Ukrainian market play an important role. In 2022, during the worsening economic crisis and war on the territory of the entire country, the stable functioning of an agricultural sphere is a topical issue. The demonstration of "transactional spending" is somewhat unclear at the current stage. Thus, the purpose of the study is to investigate the field and generalisation of institutional aspects of the demonstration of transactional spending in agricultural organisations. With the employment of analysis and scientific research systematisation methods, it was noted that transactional spending of an agricultural organisation includes spending on information regarding the market functioning gathering, legal expenses, quality control, and property security. During the research, a demonstration of transactional spending of agricultural organisation subaccounts is unclear and requires the development of a unified approach

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to the spending regulation. The main ways of transactional spending accounting of agricultural organisations were determined. Practical aspects of transactional spending accounting in agricultural organisations of Ukraine were also denoted. A model of transactional spending accounting was developed, which is based on a creation of a new account 99 "Transactional spendings". A new transactional spending accounting system was developed, which sorts transactional spending according to the classification in the new account subaccounts. These changes in accounting may be used to create new financial statement systems for agricultural organisations. The proposed transactional spending accounting system includes every possible risk of payment duplication or payment not being included in the statement. It may be employed not only by agricultural organisations but also used for the standards of bookkeeping practice

Keywords: analytical accounting; synthetic accounting; specification spendings; business spendings; legal spendings; monitoring spendings; value for money

INTRODUCTION

With the development of agricultural organisations, the competitiveness of these companies is determined by the success of bookkeeping practice. A demonstration of transactional spending in accounting is currently an unresolved question. Due to the substantial meaning of transactional spending in the agricultural sphere, their proper demonstration is key to the effectiveness of the agricultural functionality. The notion of "transactional spending" is a scientific neo-institutional postulate, which has fully studied the matter. However, the results of these spending accounting research have shown no distinctive and clear notions determined. Many opinions regarding transactional spending exist, which complicates the research and information collection by the agricultural organisation of respective level, amount, and spending size.

Researcher D.O. Lyudovenko (2020) has proposed to implement a whole new class of transactional spending in the Account Bookkeeping Plan (2022). The author also recommended renaming the 8th account class. I. Prykhodko *et al.* (2014) suggest the creation of a new synthetic account in 9 classes of accounts with place for respective subaccounts for agricultural accounting bookkeeping. Suggested Account 99 "Transactional spendings" (n.d.) is deemed active. V.S. Lytvynenko and V.V. Tolstonoh (2015) denote "transactional spendings" with overhead expenses with an explanation, that these spendings ensure the interaction of an organisation with an outside world with intention of transacting and include the information gathering expenses, negotiation expenses, contract compilation, and performance. Therefore, the researchers recommend dedicating a whole chapter to transactional spending in bookkeeping while focusing on the spending classification approach variety. A.Yu. Zelinskyy (2015) and Struk & Shevchuk (2018) in the study on transactional spending, has also focused on the lack of dedicated transactional spending creation in financial accounting and management. Therefore, the researcher has suggested a quantitative analysis of transactional spending on basis of their average percentage. H.V. Holovchak and O.B. Yurchenko (2018), in their research, suggested accounting transactional spending on subaccount 978 under the types of transactional spending, which are to be determined by the Accounting Policy of the Enterprise (2021). Researchers also stated that transactional spending is to be noted in line 2180 "Other Operational Spendings" (2021) of the Overall Income Statement.

It is possible to conclude after the review of scientists' opinions, that the unified approach to the problem was not defined. It is important to properly classify and sort the transactional spending accounting to prevent duplicating of expenses. Incorrect distribution of transactional spending may result in inefficient spending overall and in the deformation of the structure, which will lead to incorrect management decision-making. Duplication of expenses in transactional spending during bookkeeping is a common problem, which leads to a lowered level of agricultural organisation profitableness. Incorrect financial statement of the company is not only an outer risk (having to pay fines during examinations) but also an inner risk (false directors' and employers' depiction of business profitability and spending structure). This is why it was necessary to create a classification of transactional spending of agricultural organisations and, on its basis, to develop aspects of its accounting, which should calculate the main notions of book keeping standards.

The purpose of the study is to explore the field and summarise the institutional aspects of the demonstration of transaction costs for agricultural organisations.

MATERIALS AND METHODS

The theory and methods of the research are based on the main regulations of bookkeeping standards. The following methods were used in the research. The systemic approach was utilised to define the "transactional spending" category of the agricultural organisation, to instate a notion of agricultural organisation spendings bookkeeping, to determine the specific features of demonstration of business keeping spending, legal spending, monitoring spending, registration and licensing spending, partner search spendings, potential client information gathering spendings, quality assurance

spendings, property security spendings, transaction negotiation spendings. The analysis method was employed to analyse the agricultural organisation transactional spending bookkeeping, to analyse recent studies on the agricultural organisation transactional spending accounting, and to classify the specific features of agricultural organisation transactional spending. Specific features of legal spending accounting, monitoring spending, partner search spending, potential client information gathering spending, quality assurance spending, property security spending, transaction negotiation spending, and business keeping spending were analysed.

The subjective and objective approach was also used to determine the issues of agricultural organisation transactional spending accounting. This method was used to determine an agricultural organisation's transactional spending division according to the expenses. The subjective and objective approach determined the specific features of reflecting transaction costs on sub-accounts of agricultural organisations. A conceptual approach was also used to indicate areas of agricultural organisation transactional spending accounting improvement. To analyse the transactional spending accounting features, a bookkeeping and economical diagnostic method was employed. The formalisation method was used to simulate transactional spending accounting systems, while the program-target method and integrative approach were used to develop a new transactional spending accounting system. The informational basis of the study is the International Financial Reporting Standards (2011), International Accounting Standards (2017), the law and legislative acts of transactional spending of Ukraine, and publications in periodic journals about transactional spending in agricultural organisations.

The basis of the agricultural organisation transactional spending accounting research was a series of financial reports of "Agroprodservice" (2021) private agro-industrial enterprise (PAE), where transactional spending was concentrated on selling and other operational expenses. Moreover, during the study, the financial statements of one of the leading agricultural companies of the limited liability company (LLC) "KERNEL-TRADE" (2021) were considered, where accounting policy regarding transactional spending is in their demonstration in administrative and operational expenses, while other selling expenses are still present. A study of the financial statements of the private joint-stock company (PJSC) "Agricultural Production Firm "Agroton" (2020) has shown that inter-stock expenses of the company are demonstrated in other operational expenses. Overall, the analysis of agricultural organisation financial reporting has shown that the inter-stock expenses accounting system is relatively variative and unclear.

RESULTS

Inter-stock expenses accounting is currently insufficiently analysed. During the agricultural organisation inter-stock expense accounting, it is worth denoting the term "inter-stock expense" of the organisation. The notion itself is denoted as those, related to the coordination and interaction of organisation subjects, usually expenses, which occur during the business process. Therefore, during the agricultural organisation activity, a series of required expenses occur, such as information gathering expenses, agreement compilation expenses, quality assurance expenses, and property security expenses are all integral elements of each company's functioning. After researching the term "transactional expenses" and their accounting features (Makalyuk, 2013; Ishchenko, 2020), it is apparent, that their notion and accounting on an agricultural organisation heavily depend on their classification. Transactional expenses classifications vary and, as such, their features affect the expenses accounting. Thus, study suggests using the following classification of transactional expenses in agricultural organisations (Fig. 1).

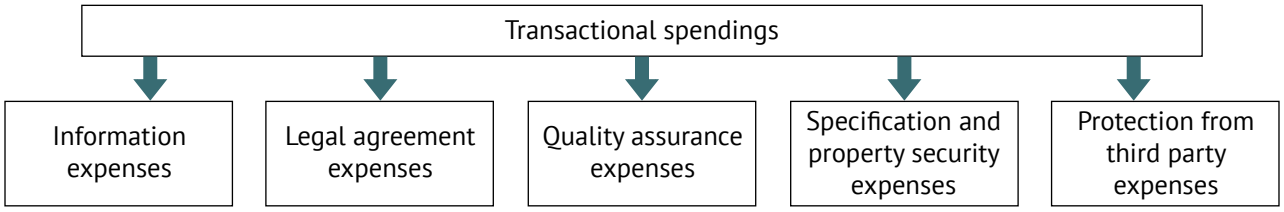

***Figure 1**. Classification of transactional expenses in agricultural organisation*
***Source:** compiled by the authors based on I. Paska (2015)*

Information spendings, in an aspect of transactional expenses, are followed in agricultural organisations by gathering information regarding agricultural market state, new customer or trader search, and expenses on collecting aforementioned information. Insufficient and incomplete information support cause new expenses to arise, which are followed by much more expensive goods acquisition and much less profitable goods selling. Marketing expenses, sales team expenses, and fair participation expenses, commission trading expenses, and agricultural organisation informational database functioning expenses are all to be included in the information expenses. Legal agreement expenses are denoted as expenses for the development of the agreement and negotiation process. Legal agreement expedition, notarial attestation of the agreement, communication

expenses, and like are also to be included in this type of expense. Legal control and expedition expenses are also to be included in the category. As for the quality assurance transactional expenses aspect, the agricultural product quality assurance services are to be categorised into the category. Amongst those are quality assurance technical expenses, standardisation expenses, warranty repair and maintenance expenses, and measuring during goods transportation expenses. Specification and property security transactional expenses are the agricultural organisation patents expenses, license acquisition expenses, and court proceedings expenses.

Protection from third-party transactional expenses is the risks insurance expenses, protection from a third party, and others, who are not stated in the agreement, expenses. Thus, transactional spending of an agricultural organisation is formed based on spending on information regarding the market functioning gathering, legal expenses, quality control, and property security. During the research of transactional expenses in agricultural organisations accounting demonstration institutional aspects, it is worth investigating the specific features of transactional expenses demonstration in bookkeeping. The authors will investigate the specifics of transactional spending on information gathering (Zakharchyn, 2009). As such, marketing expenses, advertisement expenses, sales expenses, and commission trading expenses are all demonstrated in account 93 "Selling expenses". Moreover, the show and fair expenses, and information database functioning expenses of the agricultural organisation are all demonstrated in accounts 92 "Administrative expenses" (2019) and 93 "Selling expenses" (2019).

As for the legal expenses accounting, the transactional expenses on legal negotiation expenses, agreement expenses, notarial attestation expenses, representational expenses, and communication expenses are categorised, according to the rules of bookkeeping, to account 92 "Administrative expenses" (2019). Transactional quality assurance expenses are demonstrated by various accounts (Yushchak & Melnyk, 2009). As such, goods measuring during goods loading expenses and warranty maintenance and repair expenses are demonstrated by account 93 "Selling expenses" (2019). While quality assurance team expenses are demonstrated by account 91 "General production expenses". Specification and property security transactional expenses are also demonstrated by various bookkeeping accounts. Transactional expenses of patent acquisition and court proceedings expenses are demonstrated by account 92 "Administrative expenses" (2019). As for the protection from third-party expenses accounting, the responsibilities of expedition expenses are demonstrated by account 94 "Other operational activity expenses" (2019), while risks insurance is demonstrated by accounts 91, 92, and 93 (2019).

From the concluded research, it may be stated, that transactional expense accounting is done on various accounts. This accounting system is ambiguous and has certain contradictions, which may cause false demonstration of expenses. To investigate specific features of transactional spending accounting in agricultural organisations, the authors will analyse the main accounting notions on an example of several agricultural market leaders: PAE "Agroprodservice" (2021), "KERNEL-TRADE" LLC (2021), PJSC "Agricultural Production Firm "Agroton" (2020) (Table 1).

***Table 1**. Features of agricultural organisation transactional expenses accounting*

Expenses account	Transactional spendings		
	PAE "Agroprodservice"	**"KERNEL-TRADE" LLC**	**PJSC "Agricultural Production Firm "Agroton"**
91 "General-production expenses"	-	-	-
92 "Administrative expenses"	Legal expenses, product certification expenses	Marketing team payment expenses, business trips expenses, representational expenses, professional services (notary and legal) expenses	Agreement compilation and performance expenses
93 "Selling expenses"	Marketing expenses, advertisement expenses, marketing team business trips expenses, product certification expenses, packing material expenses	Final product preparation and transportation expenses	Marketing and advertisement expenses
94 "Other operational activity expenses"	Periodic publishing expenses, exchange rate difference expenses	Exchange rate expenses, license and patents expenses, insurance expenses, agreement compilation expenses, negotiation expenses, information expenses	Final product packing and shipment expenses, trade and marketing agents expenses, insurance expenses.
95 "Financial expenses"	-	-	-
97 "Other expenses"	-	Financial investment implementation expenses	-

***Source:** PAE "Agroprodservice", 2021; "KERNEL-TRADE" LLC, 2021; PJSC "Agricultural Production Firm "Agroton", 2020*

Table 1 shows that agricultural organisation transactional expense categorisation is ambiguous, as each company categorises the same spending on different accounts, For example, in the case of account 91 "General-production expenses" (2019), it was not used for any on the transactional expenses even though, according to the results of researchers, it could be used for quality assurance spendings. In this case, PAE "Agroprodservice" has categorised product certification services on account 92 (2019), while LLC "KERNEL-TRADE" categorises these expenses on account 94 (2019). Table 1 shows the ambiguity in the categorisation of sales team payment expenses. LLC "KERNEL-TRADE", during the transactional expenses accounting, has categorised marketing team payments expenses to account 92 "Administrative expenses" (2019), which is logical, because this category accounts for all the employee payments, according to the bookkeeping standards. PAE "Agroprodservice" has demonstrated the same expenses on account 93 "Selling expenses" (2019), as marketing team payment is closely tied to the sales of the agricultural organisation goods, which also proves the logic of the categorisation. Meanwhile, the PJSC "Agricultural Production Firm "Agroton" categorises the sales and marketing agent payments to account 94 "Other operational activity expenses" (2019), which may be explained due to the temporary nature of these employees. During the analysis of the agricultural organisation transactional expenses bookkeeping, authors noted, that goods packing, and transportation expenses are mostly categorised to account 93 "Selling expenses" (2019), while PJSC "Agrotron" categorised those to account 94 (2019). The same case can be seen in the legal expenses on agreement compilation. PAE "Agroprodservice", and PJSC "Agrotron" demonstrate their transactional expenses on account 92 "Administrative expenses", while LLC "KERNEL-TRADE" – on account 94 (2019).

In general, from the results of agricultural organisation transactional spending analysis, it may be concluded, that there is no valid system. This causes, several problems regarding transactional expense accounting system validity. The lack of a unified transactional spending accounting system causes expense duplication, which distorts the organisation's expense information. Incorrect division of transactional expenses to accounts may cause a false demonstration of the expense structure, which may later cause inefficient management decision-making on expense optimisation. Accordingly, in the global plane, improper categorisation of transactional spending during financial report formation will cause the efficiency of the agricultural organisation to drop as overestimated or underestimated spending in reports causes further destructive management actions. These actions bear a negative effect on the financial result and, in the future, cause more harm. With intentions of avoiding further false agricultural organisation financial reporting, it is worth using a unified system of transactional expenses accounting, which may later be used as a standard bookkeeping practice. A suggested transactional expense accounting system is mainly a creation of a new account 99 "Transactional expenses" (2019). These include marketing and advertisements, client base employment and expansion, information gathering, processing, and storage (Table 2).

***Table 2**. Features of agricultural organisation transactional expense accounting in the aspect of account 99 "Transactional expenses" implementation*

Transactional expense subaccount	Transactional expense name	Transactional expenses, which are categorised to this account
991	Information expenses	Marketing expenses, advertisement expenses, sales team functioning expenses, fair and show participation expenses, commission trading expenses, agricultural organisation client base creation and development expenses
992.	Legal agreement expenses	Representational expenses, professional legal services to perform an agreement expense, negotiation expenses, agreement compilation expenses, agreement conditions performance and expedition expenses, communication services expenses, agreement notarial attestation expenses, responsibilities performance
993	Quality assurance expenses	Quality assurance expenses, goods measuring during loading expenses, warranty maintenance and repairs expenses
994	Specification and property security expenses	Patent acquisition expenses, license acquisition expenses, court proceeding expenses
995	Protection from third party expenses	Risk insurance expenses, agricultural information protection expenses

***Source:** compiled by the authors based on Recommendations of the Transfer Pricing Forum (2021), Technical Line (2022)*

Transactional expenses on subaccount 991 (2019) should indicate spendings on agreement performance – agreement signing negotiations, agreement development, and its fulfilment expenses. Quality assurance expenses are demonstrated by account 993 (2019) and are related to quality control features, goods loading,

and warranty repairs and maintenance. Subaccount 992 (2019) is to demonstrate patent, license, and certificate acquisition expenses and court proceeding expenses. The worthy benefit of transactional expenses is that they do not add up to the product manufacturing cost and to the gross profit of the organisation or even contribute to the gross earnings. The suggested bookkeeping system would allow demonstrating transactional expenses based on their classification, which would allow avoiding transactional spending duplications on accounts and will enhance the expense structure demonstration in bookkeeping. It is important to note, that account 99 (2019) should remain active. Moreover, this agricultural organisation's transactional spending accounting system will ensure its control. Bookkeeping practice requires immediate additions regarding transactional expense accounting. The suggested accounting system will allow categorising transactional expenses to respective subaccounts according to their classification, will avoid any duplication, and will ensure expense demonstration.

DISCUSSION

Several researchers have focused their attention on the problem of a unified transactional expenses system and have suggested various accounting systems. The ideas of most scientists are closely tied to the research, as they are suggesting the creation of a new account system, which would be dedicated to transactional expenses. Zh.M. Yushchak and S.I. Melnyk (2009) suggests creating an additional subaccount of class 9, related to the transactional expenses. These researchers also suggest dividing transactional spending into information search, negotiation and agreement compilation, calculations, and ownership rights defence expenses. However, those researchers do not indicate a need for quality control expenses, which is one of the key elements of agricultural organisation transactional spending. Lack of quality control transactional expenses demonstration will lead to false financial reporting. As a result, these researchers have not found a solution for transactional expense accounting. Researchers N. Lokhanova (2012) and Ye. Bozhko (2019), during the research of animal husbandry agricultural organisation transactional expenses accounting and information sphere main problematics, has described only the transactional expense demonstration in bookkeeping. The scientist only reviews the approaches of other researchers on transactional expenses accounting and agrees with an opinion, that suggests the addition of a whole new account with its subaccount to the bookkeeping practice, which will be an important notion in economic theory enhancement.

V.S. Lytvynenko (2013), V.V. Bonarev (2017) and N.O. Pacheva (2018) during their research of housing and public facilities transactional expenses accounting features, have simulated the creation of transactional expense accounting, which consisted of 5 steps. At the initial stage, the scientists recommend developing a list of transactional expenses and to develop a concept of their accounting and reporting. At the next stage, researchers suggest the creation of an accounting policy in parts of transactional expenses accounting on subaccounts 978 per their expense types. At the third stage, researchers recommend commencing a development procedure to control transactional expenses demonstration. At the next stage, they recommend developing a registry of transactional expenses accounting and reporting. And, at the last stage, researchers recommend making changes to the National provisions (standards) of accounting 1, with intentions of transactional expenses demonstration in article 2180 "Other operational expenses" (2021) in their overall income report. These recommendations, while logical, will not allow for transactional expense bookkeeping following their content and classification. O.V. Palchuk (2012), A. Nygaard (2018), O.O. Boyko and D.O. Norets (2021) during the research of transactional expenses accounting features, have categorised the spending content according to the bookkeeping practice. At the beginning of the research, the researchers separated the transactional expenses classification, which is based on dividing transactional expense types into single, conditionally consistent, and conditionally variable. Then, the study (Horstmeyer *et al.*, 2022) recommends separating transactional expense contents following the existing articles of bookkeeping practice.

D. Lundenberg (2016), S. Shahab (2018), A. Petraki (2020), in their research, have developed an algorithm for the creation of transactional expense accounting methods. In the first stage, scientists recommended building a new conception of their accounting, then – concluding a reconstruction of the bookkeeping methodology with a transactional and institutional approach in mind. At the third stage, researchers recommend refining the organisation's transactional expense demonstration and its expense control mechanisms. Then researchers recommended developing methodical recommendations on rebuilding the expense accounting with the transactional component in mind. And, at the last stage, researchers recommended changing the methodological basis of expense information demonstration in financial reporting. While researchers investigate the bookkeeping practice changes, they do not determine the clear distinction between transactional expense subaccounts, which does not improve the transactional expense accounting system. S. Anderson and H. Dekker (2009), N. Plotnikova and N. Gorodnova (2015), Y. Chou (2022) have analysed the transactional expense forming specifics per transaction procedure stages in the organisation. The researchers have highlighted, that at the stage of organisation registration, transactional spending of specification takes place (organisation registration expenses, license acquisition

expenses, back account expenses). Then, during the potential partner information gathering, the organisation concludes the information gathering and processing expenses and suffers from losses due to its lacking. During the partner search on organisation transactions, production, goods, and service quality assurance, which are the grounds for the ownership rights transfer, is commenced. During the agreement preparations, negotiation expenses, ownership security expenses, and opportunist behaviour avoidance expenses occur. In an agreement development stage, legal expenses occur. At the last stage, during further agreement fulfilment control, agreement performance monitor expenses, and responsibility insurance expenses occur.

M. Daferner (2017), Siegert *et al.* (2019), T. Reitsam (2021), during their study of transactional expenses' influence on the effectiveness of organisation sales, have highlighted, that transactional spending should be denoted through two methods. The first method is an apparent method, which is based on transactional spending financial report data. The second method should be non-apparent, which is the losses due to changes in the market environment or lost opportunity. The authors also recommended using a new Transaction expenses registry during the systematic detection and collection of transactional expenses. The researchers recommended dividing the registry according to the classification of transactional expenses into groups of external, internal, and lost profit expenses. The authors (Bentkowska, 2019; Adryjanek, 2022) noted that in bookkeeping, transactional expenses are not separated on some accounts and their share is demonstrated on account 92 "Administrative expenses" and other parts on account 93 "Selling expenses". However, during bookkeeping practice, lost opportunity expenses are not demonstrated at all, as this variable can only be determined by calculation through expert questioning.

The suggested system of transactional spending accounting is mostly similar to those of W. Pizło (2009), M. Polasik (2015), K. Kowalska (2021), where authors also suggest implementing account 99 "Transactional spendings" (2019). However, the researchers have denoted 3 subaccounts of transactional expenses, which is abundant due to their overlapping. As such, the above-mentioned scientists have determined subaccounts 991 "Information gathering expenses" (2019), 992 "Representative expenses" (2019), 993 "Ownership rights protection and professional services expenses" (2019). As such, expenses on account 993 "Ownership rights protection and professional services expenses" (2019) may overlap with account 992 "Representative expenses" (2019) as both subaccounts cover regulation of agreement conditions. It was suggested not to determine a series of a subaccount, but to categorise, according to the classification, a subaccount 991 "Information gathering expenses" (2019), which would include all the organisation expenses, related to agreement development and fulfilment.

W. Rembisz and S. Stańko (2007), D. Puciato (2018) have noted that a variety of problems with transactional expenses are present during the organisation takeover or absorption. It is related to the unique accounting policy of each organisation, in which transactional spending is categorised differently. As such, during the takeover or absorption of companies, equal transactional expenses articles, duplication, or removal of those from accounting reports take place. Researchers suggested the development of a transactional spending accounting system through the separation of transactional spending in a new article 9 "Transactional spendings". J. Plichta (2019) has reviewed transactional expense accounting features during the evaluation of the planning policy. The researcher highlighted, that classification of transactional expenses has to be made following the expense planning sequence. Per this, he noted, that transactional spending can be divided into ex-ante, which are formed on a stage of expense planning, constant expenses, which are created during sales monitoring, and post-factum expenses, which are formed during expense plan evaluation. This provides clarification of the transactional spending classification, yet it does not fully resolve the question of transactional spending demonstration in bookkeeping. Chotkowski (2010), Przenajkowska and Polasik (2018), in their researches of the transactional expenses' notion, have noted, that the balance demonstration of transactional expenses according to the bookkeeping standards of the USA mostly corresponds with Accounting policy of the enterprise (2021), even though there are certain differences in expense accounting and demonstration on obligation commissions, which were covered by the credit lines. As such, in comparison of acquired results of results with previous postulates on transactional spending accounting, it is possible to conclude, that a developed system of accounting will enable more precise transactional spending of the agricultural organisation by its demonstration with accordance to the classification.

CONCLUSIONS

The conducted analysis of transactional spending institutional aspects has shown, that there is no unified expenses accounting system present. Transactional spending during the compilation of financial reports is demonstrated on various accounts. Those mostly are targeted for account 92 "Administrative expenses", account 93 "Selling expenses", and account 94 "Other operational activity expenses". In practice, other accounts are also used. Moreover, the lack of a unified transactional spending classification approach and the lack of account categorisation during the development of financial report compilation cause a series of problems. The main problem is the duplication of transactional expenses during their categorisation by account, which causes improper financial reports of the company and the deformation of the agricultural organisation's payment

structure. False structure data and amounts of expenses may cause non-effective management decision-making in the future, which, in turn, will cause the lowering of agricultural organisation profitability. This is why authors suggest the creation of account 99 "Transactional spendings" with the aim of enhancement of transactional spending accounting. An important aspect during the inclusion of this account is the addition of subaccounts, which would utilise the classification of transactional expenses. A classification category and a subaccount "Information expenses" will allow systemising of all transactional spending, which was aimed at information expansion, employment, and keeping. Expenses on development and fulfilment of agreements will include all the expenses on negotiations, contract compilation, and control expenses, which would allow clearly stating the expenses on the subaccount in accordance with the agreement.

Subaccount, where quality assurance expenses are demonstrated, will allow unifying the agricultural organisation's expenses on support, control, and research of the product quality features. Subaccount for specification and property security expenses will allow systemising the transactional spending on the license, parent and allowance acquisition, and other similar expenses. Protection from third-party expenses – is an intermediate subaccount, created during the company activity. The suggested classification of transactional expenses will allow differentiating these expenses from the specifics of their origin, which will ensure the further validity of their categorisation during the accounting. The suggested transactional expense accounting system makes any duplications or absence from reports impossible and may be used by agricultural organisations in practice. Further research in the agricultural organisation transactional expense accounting is to be based on the study of the expense division features and development of the unified transactional expense classification system, which is to be used in the future as a basis to form an expense accounting system.

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CONFLICT OF INTEREST

None.

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Інституційні аспекти демонстрації обліку трансакційних витрат в сільськогосподарських організаціях

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Анотація. Сільськогосподарські організації на ринку України відіграють важливу роль. У 2022 році, під час загострення економічної кризи та війни на території всієї країни, стабільне функціонування аграрної сфери є актуальним питанням. Прояв "трансакційних витрат" є дещо незрозумілим на поточному етапі. Таким чином, метою дослідження є вивчення та узагальнення інституційних аспектів прояву трансакційних витрат в сільськогосподарських організаціях. За допомогою методів аналізу та систематизації наукових досліджень було виявлено, що трансакційні витрати сільськогосподарської організації включають витрати на збір інформації щодо функціонування ринку, юридичні витрати, контроль якості та охорону власності. В ході дослідження виявлено, що відображення трансакційних витрат на субрахунках бухгалтерського обліку сільськогосподарських організацій є нечітким і потребує розробки єдиного підходу до регулювання витрат. Визначено основні способи обліку трансакційних витрат сільськогосподарських організацій. Окреслено практичні аспекти обліку трансакційних витрат в сільськогосподарських організаціях України. Розроблено модель обліку трансакційних витрат, яка базується на створенні нового рахунку 99 "Трансакційні витрати". Розроблено нову систему обліку трансакційних витрат, яка сортує трансакційні витрати відповідно до класифікації на субрахунках нового рахунку. Ці зміни в обліку можуть бути використані для створення нових систем фінансової звітності для сільськогосподарських організацій. Запропонована система обліку трансакційних витрат враховує всі можливі ризики дублювання платежів або не включення платежів у звітність. Вона може бути використана не тільки сільськогосподарськими організаціями, але й для стандартів бухгалтерської практики

Ключові слова: аналітичний облік; синтетичний облік; специфікація витрат; господарські витрати; легальні витрати; моніторинг витрат; співвідношення ціни та якості

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Energy and environmental security of the European Union in the context of russia's unstable military and economic policy

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Abstract. The countries of the European Union are experiencing the first real global energy crisis in history, bearing in mind that reliability and the possibility of receiving the required amount of energy resources are the basis of full functioning and further sustainable social and economic development of countries. The purpose of the study is to analyse European Union energy and environmental security regulatory measures in terms of unpredictable actions of the main supplier of energy resources. A set of general scientific and special methods of scientific cognition was used: the historical method with a systematic analysis of energy law; the structural and functional method; synthesis; deduction and induction. As a result of the conducted study, the main areas of increasing energy security in the European Union were determined based on scientific programmes using renewable energy sources, which gradually reduce the demand for organic

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fossil fuels (natural gas, oil, coal, peat, oil shale). The situation of dependence of EU states on the export of russian energy resources was also characterised and the process of changing the EU energy policy was illustrated. This research contains an analysis of the ecological aspect of the change in the situation with energy security in the EU, and forecasts regarding the situation on the international energy market of russia. The primary theoretical principles, conclusions, and practical recommendations in the industry of the energy market would help accelerate the diversification of the natural gas market in Ukraine in terms of joining the European Union energy market

Keywords: environmental risks; energy carriers; renewable energy; international security; energy market; environmental policy

INTRODUCTION

Energy security is determined by the technical ability of energy industries to provide appropriate services at a reasonable price and to meet the current and prospective needs of energy consumers. The armed aggression of the russian federation against Ukraine has violated the global energy system and entails security risks due to high energy prices and excessive dependence on gas, oil, and coal imports. The russian federation remains one of the three largest worldwide producers of natural gas and oil, competing for first place with Saudi Arabia and the United States of America (USA). Two products the russian federation depends on income from are natural gas and oil. It could be seen from the 2021 budget report, that these two items represent 45% of GDP (gross domestic product). S. Ghaderi (2022) states that the scarcity of availability to robust and sustainable energy in the European Union (EU) is an obvious threat to the security of the entire European continent. According to data from the European Commission, the energy consumption of russian electricity by EU member states was the biggest in the year of 2021. EU countries` energy dependence on supply from the russian federation became an additional impetus to the further search for ways, forms and means of diversifying the supply of liquefied natural gas (LNG) to the EU countries to maintain the reliability of natural gas delivery and energy security in general. With the beginning of the conflict, the EU began to conclude short-term agreements for the LNG supply to compensate for the sharp decrease in supplies through russian pipelines (Fit for 55..., 2022).

According to G. Sgaravatti *et al.* (2022), the export of natural non-renewable energy resources to EU countries allows balancing the needs of the economy in energy resources in the winter period. Competition for LNG supplies and a decrease in russian gas pipeline supplies have led to increase in prices on energy markets. In combination with increase in prices for food products, prices for other non-energy goods increased, and increase in prices for imported fuel led to a sharp increase in general consumer prices in many European countries and inflation reached double digits. In response, governments have taken a number of short-term actions to facilitate the pressure of rising prices on energy carriers for utilities and businesses. J.L. Iriarte Ángel *et al.* (2022) proves that since energy prices are expected to continue to increase, and financial support will increase with a decrease in total national income, the development of cost-effective support policies will be a key policy task in EU countries.

In addition to the political situation, issues regarding the deterioration of the environmental situation in the world and the issue of transition from renewable energy sources (oil, coal, gas) to renewable energy sources (RES) remained relevant. According to forecasts of J.D. Hughes (2014), in the 21st century, the reserves of hydrocarbon resources will be significantly depleted, and including the growth of the Earth's population, the level of energy consumption will increase.

Increase in prices on energy markets and the threat of instability in the energy resources supply led to a more active implementation of planned measures to ensure climate neutrality. What was previously planned for environmental concerns with the increase in energy prices, has gained economic advisability. Considering the challenges facing the global community and individual countries in connection with climate change (in particular, the summer drought in Europe), the issue of energy security is becoming increasingly relevant. And although it is difficult to deny the importance of transitioning to more ecological energy sources as soon as possible, states actually have to perform a difficult dual task: on the one hand, reducing the harmful influence on the climate, and on the other hand, continuously providing their countries with sufficient amounts of energy carriers and their maximum supply.

The main purpose of the study is to analyse the regulatory measures of the European Union energy system security in terms of unpredictable actions of the main supplier of energy resources.

POSSIBILITIES AND RISKS OF EUROPEAN ENERGY AND ENVIRONMENTAL SECURITY

Energy security should be understood as the ability of the state represented by its governing bodies to provide end consumers with energy in the necessary amount and appropriate quality under normal conditions, including during the action of destabilising factors (emergency situations) of an internal or external nature within the guaranteed coverage of the minimum amount of the country's most important needs, its individual districts,

cities, villages or objects in fuel and power resources. The European energy security system is based on categories of availability and acceptable level of prices for energy resources. M. Stetsyuk (2021) suggests that the dependence on russian energy could be reduced by diversifying energy carriers into alternative ways of supplying liquefied gas imported from Egypt, Israel and the countries of the Middle East and that are the components of energy security, such as consumption and supply. According to Z. Kovacic and L.J. Di Felice (2019), it is almost impossible to form a relevant picture of energy security based only on the analysis of scientific publications and documents. That is why the found data cannot be re-approved at the legislative level or agreed upon without partial loss of valuable information.

Based on the theory of resource dependence presented by J. Colgan (2013), the russian-Ukrainian war from the perspective of energy and energy markets began as early as 2014. It was the deployment of hostilities on the territory of Ukraine and the annexation of the Crimean Peninsula by russia that caused the energy confrontation. According to J. Johannesson and D. Clowes (2022), one cannot deny russia's extreme dependence on profits from the export of energy products to Europe, and Ukrainian energy pipeline systems are a direct potential and competitive threat to russian energy exports. V.S. Herindrasti (2022) suggests that at this stage of the transition of the EU countries from the usual energy resources to alternative ones, there is an emergence of inequality in the speed of transformation of energy systems. This phenomenon may leave a negative mark on the energy security of the European Union. The world population is constantly growing, leading to a rise in the global energy use carriers, according to G. Cotella and S. Crivello (2016), in the long-term perspective until around 2050, the growth of the world demand for energy is predicted by another 100%.

Trends in the global environmental situation are worsening, according to H. Ritchie *et al*. (2020), carbon dioxide emissions increased from 1.95 billion tonnes in 1900 to 36.44 billion tonnes in 2019. As of 2019, the largest emissions volumes were registered in the People's Republic of China – 10.17 billion tonnes, the USA – 5.28 billion tonnes, and also in the EU countries – 2.92 billion tonnes. P. Bórawski *et al*. (2022) notes that a comprehensive approach explains the need for legal regulation in conditions of limited resources, as well as the importance of introducing certain global management parameters to prevent conflict situations in achieving energy security of the EU countries. P. Kivimaa (2022), in the framework of studying the guarantee of energy security in the EU states, also considered the process of balancing between, on the one hand, new energy sources, and, on the other hand, the growing demand of consumers due to their imports. As R. Sakwa (2022) states in their publications, natural gas reserves in EU countries continue to grow and currently their amount are about 75%.

In accordance with the conditions of the Renewable Energy Directive (2009), the diversification of resources of energy is planned in the EU until 2030, which involves the use of a combination of different energy sources, fuel cycles, energy resources types, relying not only on natural gas and nuclear energy, but also on coal, oil, sun, wind, biomass, geothermal energy sources, etc. T. Walde (1995) provides an evaluation of the Green Paper – A European Strategy for Sustainable, Competitive and Secure Energy (2006), which can accelerate the current situation, therefore, the European Commission introduced political support for an alternative energy transition aimed at building a climate-neutral continent in EU countries. The cooperation of the International Energy Agency (IEA) (2022) and the International Renewable Energy Agency (2022) will develop a global energy security, which would resolve the issue of gas and oil market dissonance, mitigate geopolitical tension and uncertainty to achieve reliability and availability energy in the context of environmental challenges. The activation of investment in alternative energy sources and the introduction of energy saving at the national level will be a logical result of the increase in the price of non-renewable types of energy. Meanwhile, the rise of the price of natural gas may trigger a switch to coal. An increase in tariffs for carbon emissions may also be applied to regulate the environmental situation at enterprises. However, global fossil fuel prices will decrease in the future. Renewable energy sources (RES) (solar, wind, marine, geothermal, and bioenergy) are considered as a "critical point" in interstate energy relations and are completely changing the landscape of international relations. The process of transition from one dominant type of energy to another is revealed in the most exciting way in the view of geopolitics in the global dimension. The fact is that fossil fuels will end one way or another, and then the question of using renewable types of energy will arise. Energy emphasis will be transferred from one country to another as soon as traditional types of energy are replaced by alternative ones. This process will also have an impact on the strategies and models of concluded energy relations between the countries (Ari *et al.*, 2022).

CURRENT SITUATION OF DEPENDENCE OF EU COUNTRIES ON rUSSIAN GAS

Today, the Southern Gas Corridor is the main project for the diversification of European energy security. The project will enable the countries of Central Asia and the Middle East to export such an important resource as natural gas to the member countries of the European Union. Statistics for 2022 from the International Energy Agency (2022) show that it is known that the Middle East has the largest share of natural gas reserves of more than 40%. In the recent 20 years, consumption of natural gas and oil reserves in the region has increased by 30%, mainly with the help of the discovery of new

fields in Qatar and Iran. The CIS countries rank second in terms of the volume of deposits, their share is more than 30% of the global stocks of natural gas, and the share of the russian federation is more than 20%. However, over the past two decades, the russian federation gas reserves have increased by 13% and reached 37.6 trillion m3 compared to Iran's reserves of 32.1 trillion m^3 and Qatar of 24.7 trillion m^3. The volume of deposits of the United States of America is 12.6 trillion m^3, and Turkmenistan is 13.6 trillion m^3. Other countries in the world do not have large deposits, the largest, for example, in Norway, but the main European gas producer has reserves of only 1.5 trillion m^3. At the same time, natural gas reserves in the EU amount 0.4 trillion m^3 or only 0.2% of the global (EU gas storage..., 2022). According to the President of the European Commission, Ursula von der Leyen, due to the gradual rejection of russian raw materials, the supply of liquefied natural gas from the USA to Europe increased by 75% compared to 2021.

Measures are being taken against the russian federation in the form of an antimonopoly process against Gazprom to eliminate obstacles in the natural gas flow to EU countries. According to EU statistics, an average of 43% of all gas brought to the European Union in 2020 came from the russian federation. However, as of mid-2022, the EU countries most dependent on pipeline gas supplies from the russian federation are: Germany, Italy, Poland, Bulgaria, and Austria (Khattak *et al.*, 2018). First, the countries that are members of the European Union plan to significantly reduce (by a third) the consumption of russian gas by the end of 2022. In August 2022, an unusually rapid reduction in gas flows could be observed. Some of them were reduced by the states, others were stopped by Gazprom. It is worth noting that some countries of the European Union have completely abandoned the consumption of electricity from russia. Among such countries are Estonia, Lithuania, and Latvia, which completely cut off the supply of russian gas in April. Bulgaria, Poland, and the Netherlands also announced their lack of intention to extend gas supplies from russia. In total, due to the refusal of countries to cooperate in energy or due to the cessation of supplies to the russian federation, Finland, Denmark, the Netherlands, Bulgaria, and Poland stopped energy consumption from Gazprom. As for the decisions made by Gazprom, in June-July 2022, gas supplies by the company to Italy were reduced by 15% and to Germany by 60%. The situation with gas supplies to Moldova remains unclear. Slovakia also supported the initiative to reduce the consumption of russian gas, reducing supplies in 2022 by 66%. The supply of energy resources is used by russia as a weapon to punish the European Union for imposing sanctions and to put more pressure on European countries. Data for August 2022 show that gas consumption from russia by EU countries decreased by 42% (Table 1) EU gas storage..., 2022).

***Table 1**. Features of agricultural organisation transactional expenses accounting*

Countries	russian federation' gas import in 2020, in TJ	russian federation' gas production in 2020, in billion m^3	EU countries dependence on russian energy carriers, %	EU countries dependence on the russian federation' gas in 2020, in billion m^3	Stopped in 04-08, 2022 (in relation to 2020)
Austria	305.616	8.0	76	6.1	
Belgium	633.872	16.6	8	1.3	
Bulgaria	102.234	2.7	73	2.0	2.7
Greece	206.346	5.4	39	2.1	
Denmark	86.828	2.3	-	0	2.3
Estonia	14.376	0.4	46	0.2	0.4
Iceland	190.695	5.0	-	0	
Spain	1.168.586	30.6	11	3.23	
Italy	2,448,407	64.0	41	26.2	54.4
Latvia	38.111	1.0	100	1.0	1.0
Lithuania	82.553	2.2	50	1.1	2.2
Luxembourg	26.011	0.7	25	0.2	
Malta	12.820	0.3	-	0	
Netherlands	1.316.248	34.4	36	13.36	34.3
Germany	3.118.859	81.6	46	37.3	32.6
Cyprus	-	0	0	0	
Poland	715.468	18.7	46	8.69	18.7
Portugal	216.612	5.7	10	0.55	
Romania	382.802	10.0	9	0.86	

Table 1, Continued

Slovakia	170.552	4.5	88	3.94	2.0
Slovenia	30.795	0.8	12	0.09	
Hungary	366.421	9.6	111	10.6	
Finland	87.792	2.3	68	1.6	2.3
France	1.463.842	38.2	20	7.7	
Croatia	100.733	2.6	0	0	
Czech Republic	304.646	8.0	86	6.9	
Sweden	52.459	1.4	14	0.19	
Total		356.9		139.9	152.9

Source: *EU gas storage and LNG capacity as responses to the war in Ukraine (2022)*

Compared to the average norms for the supply of natural gas to the EU from russia in 2021 (3 billion m^3 per week), at the beginning of August 2022, there was a positive trend in reducing imports of energy resources (1 billion m^3 per week). Moreover, the supply of RUSSIAn gas through the Yamal-Europe pipeline was completely stopped. Because of this, russia used only 40% of the transit capacity of the Ukrainian transit system, which was previously paid for and reserved. In addition, russia completely stopped the supply through "Nord Stream-1". Gas prices have more than tripled since the start of 2022, with serious consequences for commercial and retail customers. The reduction in supplies has significantly raised the European gas price. To increase the reliability of energy supply in the EU, its member states agreed on July 26, 2022 to voluntarily reduce gas consumption by at least 15% (drawing a parallel with the average amount of consumption over the past five years). The established changes entered into force from August 1, 2022 to March 31, 2023 (Member states commit…, 2022).

Germany, seeking to contribute to global climate change, has implemented a strategy of refusal of nuclear energy and coal by 2022, so as of August 13, 2022, it was particularly dependent on RUSSIAn natural gas inflows. However, at the national level, Energy Security Act press release called for a 20% reduction in natural gas consumption to prevent gas shortages in winter. Specific energy-saving measures were indicated: lowering the minimum heating temperature in work places, population, administrations and companies to 19ºC. In addition, gas suppliers and landlords should inform customers and tenants of their expected gas consumption and associated with is costs from the perspective of potential savings. Specific energy-saving measures were suggested: a ban on heating private swimming pools, aesthetic lighting of residential buildings, shops and advertising at night. Germany will additionally need to purchase about 10 GW of liquefied gas from the USA to compensate for the missing supplies from the russian federation.

Italy's strategy to reduce dependence on the russian federation is based on efforts to replace non-renewable energy resources and gradually abandon the import of russian natural gas. In particular, the Italian government plans to reduce the volume of gas imports from the russian federation from 40% to 25%, respectively. It is also necessary to accelerate investments in renewable energy sources without specifying unforeseen circumstances, plans to increase the storage level of this energy. Moreover, Italy introduced certain measures in May that relate to the temperature in public buildings. Compared to Italy and Germany, France's dependence on gas supplies from russia is much less. For this reason, France presented an "energy sobriety" plan, according to which the country will achieve energy savings of more than 10% in 2 years (compared to 2019). Spain, which is even less dependent on russian supplies, has already adopted a number of measures, such as limiting the temperature of cooling, heating, and electric lighting in public places. Implementation of the programme to promote investments in alternative kinds of energy and energy savings would lead towards 7% of the total energy savings by March 2023.

Exports of russian oil and energy raw materials to Europe, the United States of America, Japan, and South Korea have decreased since the beginning of the war, but losses in production have been reduced due to the diversion of flows from other countries like India, China, and Turkey, and domestic demand in russia itself. In July, oil production in russia was just 3% of pre-war levels, and oil exports also fell by less than 2%. Income from russian oil exports decreased from USD 21 billion to 19 USD billion in June 2018. However, according to russian customs, the total amount of 10 incomes for the full year of 2021 is USD 111 billion. Oil exports were also reduced inertially, by 115,000 barrels per day (BPD), to 7.4 million BPD.

The International Energy Agency (2022) notes that Western sanctions have so far had only a limited impact on russian oil production: an embargo on sea imports of russian crude oil (about 90% of oil imports into the EU), a ban on the import of oil products, except for pipeline oil. Temporary measures on the consumption of oil and petroleum products were provided for contracts

execution on global market and existing contracts, six months for marine crude oil and eight months for petroleum products, which are not expected to take full effect until December 2022 and February 2023, respectively. A further reduction in the supply of russian oil is the desired result of the EU ban on its imports from the russian federation. It is associated because the russian federation will definitely have to find new sales markets for 1 million barrels per day of oil products and 1.3 million barrels per day of crude oil (Table 2).

***Table 2**. russian oil export, mbpd*

Oil consuming states	08. 2021	01. 2022	02. 2022	03. 2022	04. 2022	05. 2022	06. 2022
EU oil	2.1	2.3	2.4	2.1	2.1	2.0	1.8
EU petroleum products	1.3	1.5	1.6	1.3	1.4	1.3	1.1
USA + Great Britain	0.7	0.6	0.9	0.2	0.1	0	0
China	1.6	1.7	1.6	1.8	1.8	2.0	1.8
India	0.1	0.1	0.1	0.5	1.0	1.0	0.8
Turkey	0.2	0.2	0.2	0.4	0.4	0.3	0.4
Central Asian countries	0.4	0.4	0.3	0.3	0.3	0	0.1
Other states	1.2	1.1	0.9	1.0	0.9	1.0	1.4
Total	7.5	8.0	7.9	7.7	7.9	7.6	7.4

***Source:** National Policies to Shield Consumers from Rising Energy Prices (2022)*

The lowest level of crude oil exports in the russian federation fell on August 2021. Then the total volume of external supplies amounted to 7.4 million barrels per day, which is 250,000 barrels less than usual. However, in the case of the export of petroleum products, the situation remained stable: 2.4 million barrels of products were exported per day. Meanwhile, export income increased by USD 700,000 per day up to USD 20.4 billion per month, which is 40% higher than the previous year's average due to increasing crude oil prices (International Energy Agency, 2022).

Low level of taxation of the oil and gas sector: the russian budget for July underestimated additional tax income from this economical sector by RUB 74.7 billion (USD ~1.3 billion) (that is, the actual tax income turned out to be lower than expected by the Ministry of Finance). According to the Ministry of Finance, total income from the oil and gas sector in July amounted to RUB 770.5 billion, down 22.5% compared to July 21. For example, revenue from export duties was down by a third compared to the previous year. Oil and gas income in June amounted to RUB 138.9 billion (USD ~2.4 billion), higher than the forecast of the Ministry of Finance. Oil and gas income in May amounted to RUB 263.7 billion (USD ~4.2 billion), higher than the forecast of the Ministry of Finance. In April, the russian budget showed that tax income amounted to RUB 1.3-3.1 billion. In the russian budget as of March, tax income from the oil and gas economical field were short-received by RUB 302 billion (USD ~2.9 billion) In the russian budget as of February, tax income from the oil and gas sector were short-received by RUB 216.4 billion (USD ~2.8 billion), but for January income were short-received by RUB 74.8 billion (USD ~1 billion) deficit (Energy Security: Reliable..., 2022). The diversification of the energy supply sources of the EU countries can be determined both by the consequences of energy cooperation and by various political aspects. In the context of business relationships the states of the European Union with russia, it is necessary to focus on the following directions: military aggression of the russian federation against Ukraine, which endangers the reliability of the energy security system in EU countries; ensuring stable energy supplies; reducing the energy dependence of the European Union on russia through cooperation with third countries; diversification of transport routes, suppliers; RES.

DYNAMICS OF DEVELOPMENT ENERGY SYSTEM IN EU COUNTRIES

Currently, the most progressive in the advance of alternative energy are the USA and the countries of the EU. Their mission is to minimise the number of pollutions from energy enterprises. In the event of minimising Europe's energy dependence on russian resources, the issue of guaranteeing the EU's energy security system can be solved. Decreasing consumption of energy and rising the overall level of energy efficiency can also have a positive effect. Implementation of the plans is possible with the use of RES that have sufficient potential to ensure the energy consumption of the European Union countries.

Therefore, in the course of the study, it was established that EU countries operate in two dimensions of energy security: external and internal. The internal dimension takes place in the EU itself and includes the implementation of energy security measures between

member states, regulated by the Lisbon Convention standards. As for the external dimension, it includes the relations normalisation in the area of energy security between the EU and partner countries. Legal regulation of these relations is also carried out in accordance with the security criteria of supply, secondary legal criteria set forth in proposals, agreements with third countries participating in the energy supply chain. Providing energy security suggests that the EU member states implement a coordinated policy in the foreign policy arena. The European plan to ensure sustainable, competitive and secure energy system is defined by general instruments of foreign energy policy. However, T. Lan *et al*. (2022) suggest a quick resumption of work in accordance with the Green Book of the European Commission, which includes partnership relations with manufacturers, countries of transit, and other international entities.

Currently, the International Energy Agency (2022) community ensures around 75% of the worldwide energy requirement for more than 5 billion users. On August 11, 2022, the IEA published the "Oil Market Report", which applies to the switching between gas and oil as well as to the rising usage of oil demand to produce more electricity. In July 2022, oil supplies reached their post-pandemic high, so the IEA revised its forecast for global oil supply towards higher consumption, indicating that the decrease in russian supplies is more limited than previously expected. Recently, a bilateral Declaration of Association was signed between Ukraine and the IEA that will allow participation in the summits of the permanent groups and committees of the IEA, as well as in personal ministers meetings.

Analysis of the EU energy security structure allows stating the need to use a wide range of energy resources, such as: nuclear energy, natural gas, crude oil, coal, hydropower, biomass and waste, wind, solar radiation, geothermal energy, tidal energy, etc. Scientific progress based on the decarbonisation of the energy economy and the minimisation of harmful effects on the environment will allow the formation of the latest RES. This step will dramatically decrease the intake of fossil fuels within the European Union. Among the leading factors of the further alternative energy development within ensuring the energy security of the EU member states could be called: the ability to provide states with independence from the import of energy carriers and to positively influence global economic processes by establishing stable pricing.

The change of course in the energy security system of the EU member states due to the supply of liquefied natural gas, oil and coal, and the further course towards the RES development and the replacement of natural gas with other types of energy (for example, electricity) deserves special attention. In particular, for this purpose, Austria is introducing restrictions on electricity prices for the period from December 2022 to June 2024. I.V. Perevozova *et al.* (2022) emphasise the increase in LNG supplies as of June 2022, where the USA delivered more LNG to the EU by tankers than was delivered by pipelines from the russian federation during the same period of time, but access to LNG requires the EU states to build special import terminals and integrate them to their gas networks.

In the area of energy security, an external dimension has been suggested between the relations of Ukraine and the EU, because Ukraine is taking all necessary measures before becoming a member of the EU. This is evidenced by the agreement signed on December 18, 2009, after which Ukraine became a full member of the Energy Community. Crises encourage the EU countries to take the discourse towards ensuring energy security more intensively. For example, during the previous energy crisis between Ukraine on the one hand and russia on the other, the EU states were concerned about ensuring that russian gas supplies were as intense as before. R. Kłaczyński (2022) suggests that the EU countries insist that gas transit from russia should still take place through Ukraine as an important transit territory.

Renewable energy, which has huge potential in the EU countries, is gaining high popularity. The EU is building mechanisms aimed at developing an algorithm for the implementation of alternative energy sources. In addition, environmental and climate problems regarding CO emissions from burning natural gas are growing. European societies are ready for the transition from the generally accepted use of energy resources to "green" energy. The economy of the EU countries is energy-consuming, because electricity production, gas and water supply alone account for a third of total energy consumption. The implementation of big new investments in RES projects, exploration of new oil and gas deposits, construction of pipelines, new nuclear reactors is an urgent line of EU energy security. I.V. Yakovyuk and K.V. Tsypyshchuk (2021) emphasise that, on the one hand, energy carriers from the russian federation solve in the long term the problems of outdated equipment and low energy and economic efficiency, and on the other hand, 60% of equipment is outdated, and in oil refining 80% of capacities are at a disappointing age from 30 to 60 years.

The EU states really depend on the gas of the russian federation. For this reason, one way or another, part of the system of energy security in the Europe is the stability of the supply of energy products from the russian federation. For example, russia has positioned the South Stream 1 and Nord Stream 2 projects as options for strengthening energy security in European countries. However, with the beginning of russia's aggression against Ukraine, the "REPowerEU" energy security plan was approved, which should reduce the EU's energy dependence on russian gas to zero by 2027.

By limiting the EU's dependence on russian oil and gas, the russian federation will lose its market, which will force it to export resources to China and other Asian

countries. According to L. Tichý (2020), it is established that from the supply side of oil and gas fields in Western siberia, consumption there will definitely decrease. Thus, in the future, the energy sector of the russian federation should move to Eastern siberia and the Arctic, requiring new infrastructure, the development and application of advanced technologies to strengthen the dependence of the russian federation on commercial partners from outside. The studied issues of energy security in the EU countries somehow collide with the russian energy sector, and it will not be without negative consequences. The discussion of the consequences depends primarily on how far the russian federation will continue to monopolise the energy sector, without competition from private and foreign holdings. An important and urgent task of Ukraine today is to explore the relevant mechanisms of energy security and determine the EU strategy, as an import-dependent country to ensure resistance to possible energy shocks, interruptions in the supply of energy carriers in the short term, and to reduce dependence on specific fuel types.

CONCLUSIONS

As part of this study, it was found that in order to ensure the energy security of the EU and reduce dependence on the russia`s sources of energy, the values and standards of energy security are used. In order to successfully build new energy sectors in the EU countries, it is necessary to establish public and private ownership balance in the energy sector. In the case of energy security determination, it is not the problem of unifying approaches to defining its content that is much more important the formation of an effective mechanism to ensure the security of the energy sector. One of the stages of Ukraine's integration process is the improvement of the regulatory framework for regulating the energy sector. Therefore, it is necessary to agree on the positions of researchers and adopt important acts in this area, considering the conclusions of researchers. The study also determined that with the loss of russia's permanent exporters of gas and oil products, the situation in the energy market of the russian federation may begin to develop towards the East, selling energy resources to China and other Asian countries. From the perspective of improving energy security in the European Union, it is important for countries to switch from non-renewable types of energy to alternative ones, as well as to reduce the total volume of energy consumption.

The price crisis in the energy market has shown that the EU is too dependent on carbon fuels. In the mid-term, biomethane and hydrogen will be the basis for decarbonisation in a wide range of sectors and increase EU autonomy through domestic production. According to experts' forecasts, in the future until 2040, there will be further steady growth of renewable energy. The course taken by the European states towards the alternative energy sources development of was once again confirmed by the dramatically changed circumstances in the energy area with the onset of the energy crisis in 2022, which was provoked by the russia war aggression against Ukraine. Despite the fact that currently the studied issues are in a state of rapid dynamics, the methods and solutions determined during the study will not lose their relevance.

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CONFLICT OF INTEREST

None.

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Енергетична та екологічна безпека Європейського Союзу в умовах нестабільної військової та економічної політики росії

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Анотація. Країни Європейського Союзу переживають першу в історії справжню глобальну енергетичну кризу, маючи на увазі, що надійність та можливість отримання необхідної кількості енергоресурсів є основою повноцінного функціонування та подальшого сталого соціально-економічного розвитку країн. Метою дослідження є аналіз заходів регулювання енергетичної та екологічної безпеки Європейського Союзу в умовах непередбачуваних дій основного постачальника енергоресурсів. Використано комплекс загальнонаукових та спеціальних методів наукового пізнання: історичний метод із системним аналізом енергетичного права; структурно-функціональний метод; синтез; дедукція та індукція. У результаті проведеного дослідження визначено основні напрями підвищення енергетичної безпеки Європейського Союзу на основі наукових програм з використанням відновлюваних джерел енергії, які поступово зменшують попит на органічні викопні види палива (природний газ, нафта, вугілля, торф, горючі сланці). Також охарактеризовано ситуацію залежності країн ЄС від експорту російських енергоресурсів та проілюстровано процес зміни енергетичної політики ЄС. Дослідження містить аналіз екологічного аспекту зміни ситуації з енергетичною безпекою в ЄС, а також прогнози щодо ситуації на міжнародному енергетичному ринку росії. Основні теоретичні положення, висновки та практичні рекомендації в галузі енергетичного ринку сприятимуть прискоренню диверсифікації ринку природного газу в Україні в умовах приєднання до енергетичного ринку Європейського Союзу

Ключові слова: екологічні ризики; енергоносії; відновлювальна енергетика; міжнародна безпека; енергетичний ринок; екологічна політика

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