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Ways to reduce the impact of the external environment in summer on the milk productivity of cows

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Abstract. One of the factors of efficient intensive milk production is the creation of comfortable conditions for keeping cows on a farm or complex. Highly productive cows are quite demanding of the indoor microclimate and conditions of keeping. It is believed that the productivity of animals by 10-30% depends on this. The purpose of the study was to examine the possibility of reducing the influence of high ambient temperature on the milk productivity of cows by different approaches to the organisation of their feeding technology. The paper uses analytical, diagnostic, physico-chemical, and statistical research methods. The main climate indicators were monitored during the summer period (June–August). It is established that the decrease in daily milk yield is a consequence of the negative influence of the temperature factor when the daily (from 11⁰⁰ to 17⁰⁰) air temperature in June–July is at the level of +26–30°C. At an air temperature



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of 26.5°C (about 14⁰⁰), the body temperature of cows rises from 37.5–37.8°C to 38.20–38.46°C. The proof of this is a decrease in the rate of decline in the level of milk productivity of cows of the experimental groups in August when the average daily air temperature dropped to +24–26°C. It is proved that the introduction of 1.5 kg of protein feed additive with protected TEP-mix protein into the diet of highly productive cows increases the productivity of experimental cows (in terms of basic milk) by 15.7% (4.3 kg). Modernisation of the diet of feeding highly productive cows by increasing the content of non-broken down protein in the rumen to normal during temperature stress contributed to better adaptation of animals in terms of productivity and quality indicators of milk: an increase in the mass fraction of fat by 0.67% and the mass fraction of protein by 0.26%, with the content of somatic cells of 285.06±81.0–409.3±134.3 thousand/cm³

Keywords: climatic conditions; dairy cows; milk productivity; temperature; protected protein

INTRODUCTION

Over the past decades, the trend of global warming has been observed around the world. According to the World Meteorological Organisation (WMO, 2022), the last seven years, from 2015 to 2021, were the warmest on record. Various climate change models predict a further 1.1–6.4°C increase in temperature by the end of this century. Such climate changes lead to the disruption of thermoneutral conditions, which are a key element of herd health and productivity. Over the past decades, researchers around the world have been modernising the conditions of keep, improving the food feeding strategy, and breeding heat-resistant livestock breeds, but the development of innovative methods to prevent and overcome the negative impact of heat stress on the body of highly productive livestock remains one of the crucial tasks for veterinary medicine.

According to Zotko (2018), a particularly substantial problem of livestock comfort is a substantial increase in ambient temperature in the summer, which leads to heat stress in animals. Researchers (Borshch, 2021; Almuhanha *et al.*, 2021; Schmeling *et al.*, 2022) agreed that high ambient temperatures primarily affect the productivity of dairy cows. Results of monitoring studies by Mylostiviy and Kryukova (2020) indicate that when the ambient temperature rises above +21°C, milk yields gradually decrease, and above +29°C – decrease sharply. Therewith, Iqbal *et al.* (2021) determined that in highly productive dairy cows, heat stress can occur already at an air temperature of +20°C, and the decrease in milk yields occurs directly in proportion to the increase in temperature.

Skliarov *et al.* (2022) by experimental studies proved that in ruminants, there is a close relationship between feeding and heat production: the metabolic heat generated during microbial fermentation of feed in the rumen accounts for 3 to 8% of the total heat production of cattle. A group of researchers led by Koshchavka *et al.* (2019) determined that the higher the proportion of coarse feed in the diet, the faster the portions of feed consumed decrease. Ivanov & Bezalychna (2018) claim that during the increase in the heat load of the environment, adaptive mechanisms are activated and the animal body tries to reduce the metabolic production of heat. That is why, in hot weather, cattle compensate

for the temperature effect, reducing portions of feed consumption. According to Becker *et al.* (2020), voluntary feed consumption by cows begins to decrease at an ambient temperature of +25–26°C. The researchers note that dry matter intake is reduced by 9.6–14.6 kg/animal, compared to thermoneutral cows.

The results obtained by Miller-Cushon *et al.* (2019) indicate that during the period of heat stress, animals more carefully sort food into fractions and consume, for the most part, small particles. In turn, Meneses *et al.* (2021) note that heat stress reduces dry matter intake by 16%. Osei-Amponsah *et al.* (2020) during the study of the productivity parameters of lactating cows of the Holstein Frisian breed, which were fed robotically, identified that with the increase in ambient temperature milk production decreased by 14%.

High ambient temperatures negatively affect not only the volume of milk but also its composition. Specialists (Pragna *et al.*, 2017) identified that changes in the composition of milk occur immediately after an increase in air temperature and even precede a decrease in milk yield. First of all, the number of somatic cells increases, indicating a decrease in the quality of milk produced.

The main goals of managing the feeding of dairy cows during heat stress are to reduce heat gain through digestive processes. Specialists (Koshchavka *et al.*, 2019; Mylostiviy *et al.*, 2021) propose changing the feeding time (not feeding cows during the hottest hours) and reducing the coarse feed proportion in the diet to reduce metabolic heat loads.

Min *et al.* (2019) note that adding dietary fats, fibre, microbial supplements, minerals, vitamins, metal ion buffers, plant extracts, and anti-stress additives to the main diet of lactating cows that are under the influence of heat stress contributes to the normalisation of digestive processes, reducing rectal temperature and body temperature, increasing milk yield. Fontoura *et al.* (2022) claim that the addition of dietary acids and plant extracts (25% citric acid, 16.7% sorbic acid, 1.7% thymol, 1.0% vanillin, 55.6% triglyceride) to the diet of cows at a dose of 75 mg/kg of body weight twice a day contributed to a decrease in body temperature, increased milk yield and the content of protein and lactose in milk.

Ribeiro *et al.* (2020) and Shan *et al.* (2020) proved that the addition of minerals to the main diet of cows, in particular, chromium, prevents an increase in body temperature under heat stress, but does not substantially affect the quantity and quality of milk. Shah *et al.* (2020) received positive results on the prevention of temperature stress in dairy cows due to the addition of 15 g of betaine per day to the diet. Du *et al.* (2022) obtained similar results for enriching the diet of Holstein cows by adding *Saccharomyces cerevisiae* culture in the quantity of 100 g/d.

Thus, hot weather and heat stress have a substantial negative impact on the well-being and health of dairy cows, the quantity and quality of milk, and cause substantial economic losses. In accordance with the regulations on animal welfare, considering the proven substantial negative impact of high temperatures on the health and productivity of livestock, this factor determines the need to develop and implement special measures for animal protection, one of which is the modernisation of feeding strategies.

The purpose of the study is to examine the possibility of reducing the impact of high ambient temperature on the milk productivity of cows with different approaches to the organisation of their feeding technology.

MATERIALS AND METHODS

The study was conducted as part of the implementation of a scientific research work 29.01.01.02.F (2021-2025) "Physiological Features of Highly Productive Cattle Under Various Feeding Systems Under Climate Change" (state registration number 0121U108647).

The possibility of reducing the negative impact of high temperature in summer on the manifestation of signs of animal productivity by using a protein feed additive with protected protein TEP-mix (Arnika Feed LLC, Ukraine) was investigated. A scientific-economic experiment was conducted in the conditions of the state enterprise "Experimental Farm "Hontarivka" of the Institute of animal science of the National Academy of Agrarian Sciences" Volchansky District of the Kharkiv region on the high-productive cows of the Ukrainian black-and-white dairy breed. Three groups of cows were formed – control and two experimental ones with 8 heads each.

The object of the study was the milk productivity of dairy cows. Experimental groups were formed by the method of matched pairs, considering the breed, milk productivity, lactation phase, and live weight (Vlizlo *et al.*, 2004). Duration of the experiment – 63 days. The conditions of keeping, feeding, and watering, microclimate parameters in all groups of experimental animals were the same and mostly corresponded to the technological standards. Keep on the farm in the summer – on pasture grounds with milking indoors.

Feed samples were taken in the amount of 1 kg, packed in plastic bags. Determination of the factual feed consumption – by conducting control feedings every 10

days according to (Viktorov & Menkin, 1991). Determination of the level of milk productivity of cows – by conducting control milkings with the subsequent sampling of milk to determine its quality.

Milk samples from each cow were taken using a probe, in proportion to milk yield in accordance with the requirements of DSTU ISO 707:2002 Milk and milk products, Guidance on sampling (ISO 707:1997, IDT). Samples were delivered to the laboratory with preserved Broad Spectrum Mikrotabs tablets (USA).

The analysis of milk was conducted by chemical composition, nutritional and energy value. Determination of physical and technological properties: mass fraction of true (tru) protein, fat (Fat), lactose (Lac), dry matter (Solids), solids-not-fat (SNF), total (total) protein was conducted according to DSTU 8396:2015 (2016) Cows milk. Determination of the mass fraction of fat, protein, lactose, dry matter – by infrared spectrometry (express method), freezing point (FPD) according to DSTU 7671:2014 (2015) Cows milk. Determination of the freezing point by the conductometric method (express method) – on the Bentley Combi 150 device (Bentley, USA). Nutritional and energy value is calculated based on the content of nutrients and their caloric coefficients. The content of somatic cells in milk – instrumentally according to DSTU 7672:2014 (2015) Cows milk. Determination of the number of somatic cells – by flow cytometry (express method) on the Bentley Somacaunt 150 device (Bentley, USA).

Methods of organising feeding of experimental animals. The diets of all experimental animals for all limited organic and mineral nutrients were balanced according to the current detailed feeding standards (Bogdanov *et al.*, 2012), considering the factual chemical composition and nutritional value of the feed.

Difference between the diets of the control and experimental groups – in the composition and structure of mixed feed – in the experimental groups, some of the concentrated feed was replaced with protected energy and protein supplement TEP-mix, which was distributed to cows individually. As part of the diet of the first experimental group, 1.5 kg of TEP-mix additive was used, and in the second experimental group – 1.0 kg of the same additive instead of part of the mixed feed. Moreover, despite the fact that different amounts of TEP-mix were introduced into the diets of the experimental groups, the ratio of protein broken down in the rumen (BP) to protein not broken down in the rumen (NBP) was always maintained at 40:60%.

In the diet of the control and experimental groups, the content of metabolic energy, energetic feed units, dry matter, and crude fibre was almost the same – the difference did not exceed 2.5%. For crude protein, the advantage of the first experimental group over the control group was 79 g or 2.46%, and the second experimental group – 32 g (1%). The diet of the first experimental group included 297 g or 41.4% more non-cleaved

protein than the control and the diet of the second experimental group – 189 g (26.3%). In terms of crude fat content, the control group was inferior to the first experimental group by 157 g or 24.6%, and to the second experimental group – 104 g or 16.3%. Therewith, in terms of starch content, the control group had higher indicators over the first experimental group by 559 g (13.8%) and the second experimental group – 375 g (9.2%).

Methods for determining climate indicators. The following parameters were examined: air temperature, °C; humidity, %; air velocity, m/s; they were measured at pasture sites with an interval of 3 hours: at 8, 11, 14, 17, 20.

Methods for determining cow body temperature indicators. Body surface temperature was measured twice a day – at 14 and 20, using a BOSH non-contact thermometer. The measurement points are shown in Figure 1.

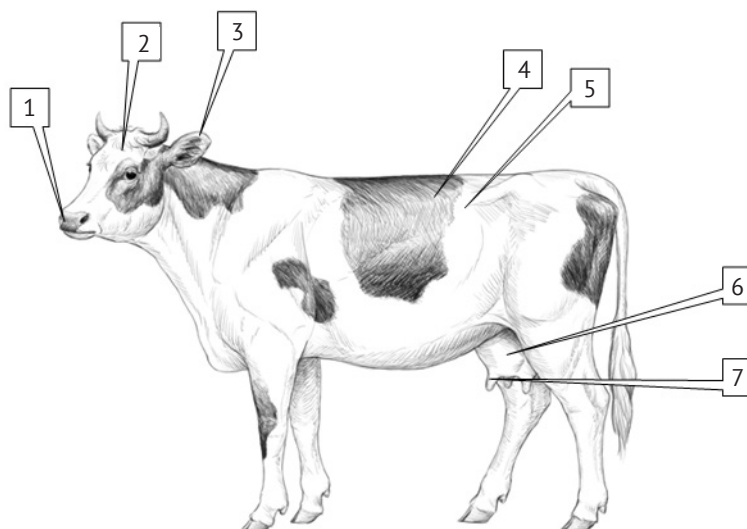


Figure 1. Temperature measurement points: 1 – nasal mirror; 2 – forehead; 3 – ear; 4 – black parts of the body; 5 – light parts of the body; 6 – udder; 7 – udder teats.

Source: compiled by the authors

Statistical analysis. The analysis of experimental studies was conducted using the Microsoft Excel 2010 programme. The results obtained in this study were statistically calculated using the Fisher-Student method, considering statistical errors, and the probability of the indicators compared. Indicators with a level above 95%.

All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). The keep of animals and all manipulations were conducted in accordance with the Order by the HCM of Ukraine No. 416/20729 on the "Approval of the Procedure of Animal Tests in Research Institutes's (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (European convention..., 1986).

RESULTS AND DISCUSSION

In connection with the integration of Ukraine into the European Union and the Joint Trade Organisation, there is a need to produce competitive and environmentally safe for the life and health of the population of dairy and meat products, which in turn puts forward new conditions for improving production technologies towards reducing the impact of negative factors on the

level of productivity of animals, their stress resistance to technological and natural factors and resistance to diseases (Betlii *et al.*, 2014; Rodionova *et al.*, 2020a; Rodionova *et al.*, 2020b).

Many researchers (Voitenko & Sydorenko, 2020; Gauly & Ammer, 2020) predicted that over the century, changes in the Earth's climate will continue, in particular, an increase in air temperature and a decrease in its humidity. During the summer period (June-August), the main climate indicators were monitored (Figure 2-4).

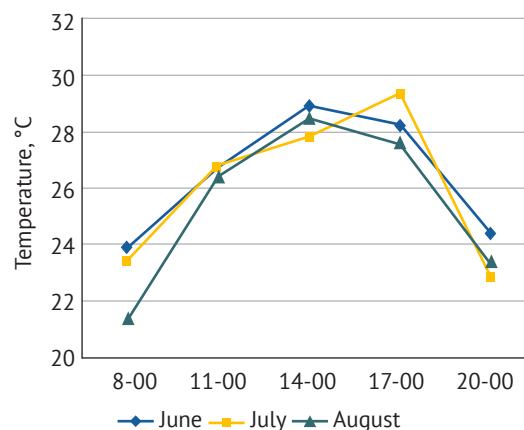


Figure 2. Dynamics of daytime temperature

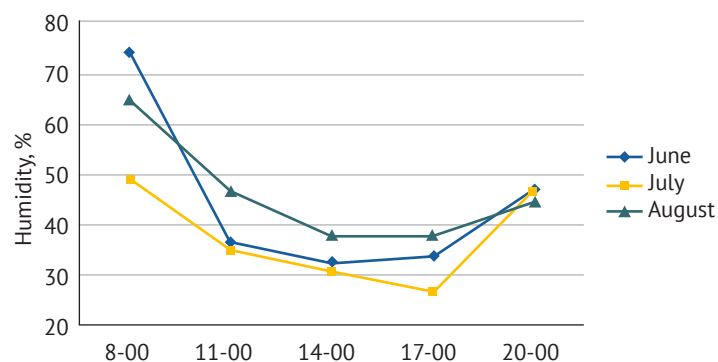


Figure 3. Dynamics of air humidity during the day

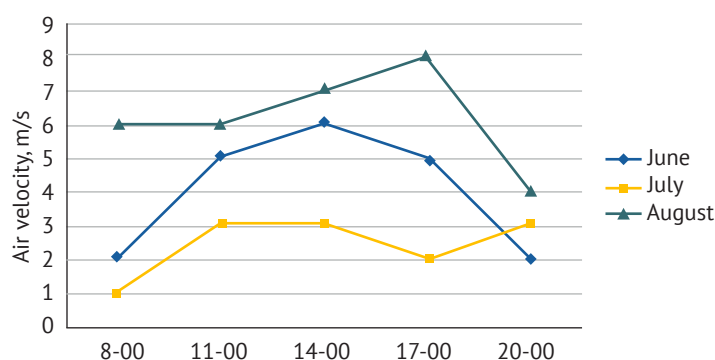


Figure 4. Dynamics of air velocity during the day

Source: compiled by the authors

As for the reaction of dairy cows to high temperature and low humidity, it was identified that the body temperature of cows and the temperature of their skin in hot times of the day substantially differed than under comfortable conditions of keep. The study was conducted on 5 animals from each group. Thus, at an air temperature of 26.5°C

at 14 o'clock, the body temperature of cows ranged from 38.20°C to 38.46°C, and the temperature of individual parts of the body and skin had slightly lower indicators (°C): forehead – 35.6–36.2; nasal mirror – 33.9–34.3; ears – 36.7–36.9; black parts of the body – 35.8–36.2, light – 35.1–35.5; udder – 36.4–36.6; udder teats – 35.4–35.6 (Table 1).

Table 1. Indicators of the temperature of individual parts of the body of experimental cows in the summer at 14⁰⁰, on average by group, °C, ($M \pm m$), $n = 5$

Group	Body temperature	Forehead	Nasal mirror	Ear	White spot	Black spot	Udder	Teat
June								
control	38.40±0.08	35.64±0.05	34.02±0.08	36.66±0.05	35.12±0.05	35.84±0.04	36.50±0.05	35.52±0.04
First experimental	38.30±0.12	35.76±0.05	34.04±0.04	36.72±0.04	35.22±0.04	35.88±0.06	36.54±0.04	35.54±0.05
Second experimental	38.38±0.11	35.66±0.04	33.92±0.06	36.88±0.07	35.26±0.05	35.84±0.07	36.54±0.05	35.52±0.04
July								
control	38.40±0.16	36.18±0.11	34.28±0.07	36.86±0.04	35.52±0.04	36.28±0.07	36.54±0.07	35.5±0.05
First experimental	38.20±0.11	35.90±0.04	34.18±0.07	36.82±0.06	35.44±0.07	36.22±0.07	36.60±0.07	35.54±0.02
Second experimental	38.44±0.09	36.02±0.07	34.06±0.05	36.94±0.05	35.42±0.10	36.28±0.05	36.60±0.04	35.58±0.04
August								
control	38.36±0.12	35.88±0.04	33.94±0.05	36.7±0.05	35.08±0.06	35.86±0.05	36.50±0.05	35.38±0.04

Table 1, Continued

Group	Body temperature	Forehead	Nasal mirror	Ear	White spot	Black spot	Udder	Teat
First experimental	38.26±0.10	35.86±0.07	34.14±0.06	36.76±0.07	35.32±0.06	35.94±0.05	36.50±0.04	35.50±0.04
Second experimental	38.46±0.06	35.76±0.02	34.12±0.06	36.86±0.06	35.30±0.03	36.04±0.05	36.40±0.05	35.36±0.04

Source: compiled by the authors

Therewith, in the evening, when the air temperature dropped to comfortable conditions, the temperature of the skin and individual parts of the body changed accordingly (Table 2).

Table 2. Indicators of the temperature of individual parts of the body of experimental cows in the summer period at 20⁰⁰, on average by group, °C, (M±m), n=5

Group	Body temperature	Forehead	Nasal mirror	Ear	White spot	Black spot	Udder	Teat
June								
control	38.10±0.07	35.32±0.06	33.48±0.09	36.34±0.04	34.42±0.06	35.32±0.04	36.32±0.04	35.12±0.04
First experimental	38.12±0.06	35.32±0.04	33.92±0.06	36.28±0.04	35.06±0.05	35.44±0.07	36.32±0.04	32.56±0.04
Second experimental	38.08±0.11	35.28±0.04	33.54±0.04	36.50±0.08	34.98±0.08	35.36±0.07	36.20±0.05	35.20±0.05
July								
control	38.26±0.10	35.42±0.09	33.60±0.07	36.42±0.06	34.66±0.06	35.54±0.06	36.44±0.05	35.14±0.04
First experimental	38.10±0.08	35.34±0.05	34.00±0.04	36.38±0.05	35.20±0.07	35.8±0.06	36.30±0.05	35.26±0.02
Second experimental	38.44±0.09	36.02±0.07	34.06±0.05	36.94±0.05	35.42±0.10	36.28±0.05	36.60±0.04	35.58±0.04
August								
control	38.14±0.09	35.88±0.04	33.94±0.05	36.66±0.05	35.12±0.05	35.86±0.05	36.50±0.05	35.52±0.04
First experimental	38.12±0.07	35.30±0.04	34.00±0.04	36.38±0.06	35.14±0.05	35.50±0.09	36.20±0.03	35.22±0.05
Second experimental	38.06±0.12	35.28±0.04	33.80±0.04	36.56±0.09	34.96±0.09	35.66±0.05	36.16±0.07	35.08±0.04

Source: compiled by the authors

The prevalence of heat stress in animals is expected to increase in frequency, duration, and severity. This will have a big negative impact on the health, reproductive capacity, and productivity of farm animals, that is, it will lead to a decrease in the volume of milk and meat production because due to heat stress, livestock consumes less feed. (Vaculíková *et al.*, 2017; Shan *et al.*, 2018; Kim *et al.*, 2018).

Since the creation of comfortable environmental conditions is very relevant for a highly productive herd, fluctuations in temperature and humidity can lead to a decrease in the dairy productivity of cows and product quality. During the summer period, the temperature of atmospheric air had a substantial negative impact on high-productive cows of the second half of lactation kept on pasture grounds (Table 3).

Table 3. Indicators of milk productivity of cows of the second half of lactation and milk quality in the summer period (M±m), n=8

Parameter	Duration of the study		
	June	July	August
Daily milk yield, kg:			
Control group	21.6±1.19	22.7±1.52	18.8±1.04
First experimental	30.9±0.87	22.5±0.57	20.7±0.99
Second experimental	28.1±1.93	26.4±1.81	20.3±1.57

Table 3, Continued

Parameter	Duration of the study		
	June	July	August
Mass fraction of fat in milk, %:			
Control group	3.96±0.09	3.94±0.04	3.79±0.06
First experimental	3.67±0.04	4.75±0.06	4.34±0.07
Second experimental	4.05±0.10	4.05±0.06	4.07±0.10
Daily milk yield of basic fat content, kg:			
Control group	25.2±1.72	26.4±1.81	21.0±1.46
First experimental	40.0±1.42	29.0±0.78	26.4±1.21
Second experimental	33.4±2.35	31.4±2.27	24.3±1.96
Mass fraction of protein in milk, %:			
Control group	2.90±0.03	2.87±0.03	2.70±0.06
First experimental	3.03±0.06	3.13±0.07	3.30±0.09
Second experimental	2.98±0.08	2.97±0.08	3.22±0.11
Somatic cell content, thousand/cm ³ :			
Control group	460.0±148.6	815.0±326.8	616.8±160.4
First experimental	285.06±81.0	488.0±196.3	409.3±134.3
Second experimental	278.0±69.7	309.6±85.9	444.4±84.4

Source: compiled by the authors

It was identified that in the period from June to August, the dairy productivity of animals of the control group decreased by 13.1%. Therewith, in cows of the experimental groups, the average daily milk yield decreased by 33.1% in the first and by 27.5% in the second. However, due to the increase in the content of bypass protein to the norm, the productivity of cows in the experimental groups remained still higher compared to the control by 1.9 kg and 1.5 kg, and in terms of basic milk – by 5.4 kg (25.7%) and 4.3 kg (15.7%), respectively.

This decrease in daily milk yields is a consequence of the negative influence of the temperature factor when the daily (from 11⁰⁰ up to 17⁰⁰ hours) air temperature in June-July was at the level of +26–30°C. The proof of this is a decrease in the rate of decline in the level of milk productivity of cows of the experimental groups in August, when the average daily air temperature dropped to +24–26°C.

Therewith, it was identified that during the summer period in experimental cows had an increase in the mass fraction of fat in milk compared to the previous level – in the first experimental group – by 0.67%, and in the second – by 0.02%; protein – by 0.26% and 0.24%, respectively. The fact that the content of somatic cells in the milk of cows of the first and second experimental groups was lower than in the control group and met the requirements of the grades extra, top, or first for this indicator according to DSTU 3662:2018 Raw cow milk. Technical specifications.

It is known that in hot weather, the consumption of feed by cows during the daytime decreases. The authors observed that most of the diet was eaten by experimental

animals in the evening, after evening milking, and in the morning – before morning milking. In addition, cows tried to stay in the shade under canopies and drink water more often. That is, if the air temperature was not hot in June and July, then the curve of decreasing milk production would have a different shape, and milk production in this period in general would be larger. Consequently, the use of the proposed intake during temperature stress contributed to better adaptation of animals in relation to the quality indicators of milk.

Changes in the eating behaviour of animals lead to a disruption of the energy balance and, as a result, a decrease in productivity. However, the data on the exact relationship between air temperature and milk yield varies. Petrusha and Dibirov (2014) report that when the air temperature rises to +28°C, the milk yield decreases by 2.16%, +32°C – 10.7%, +34°C – 20.14%, +36°C – 22.3%, +40°C – 29.5%, respectively. Lees *et al.* (2019) note that an increase in the ambient temperature to +29°C reduces milk yield by 23%. Therewith, another group of researchers (Molina Benavides *et al.*, 2018; Chung *et al.*, 2020; Polishchuk *et al.*, 2021) calculated that during hot days, milk productivity losses can reach 20%.

These data correlate with the results of this study, which once again confirm that the increase in ambient temperature associated with climate change is the main factor that negatively affects the productivity of highly productive dairy cows and milk quality. It was identified that in the summer period (June-August), the dairy productivity of experimental animals decreases by 24.56%.

Now the processing industry puts forward increased requirements for the quality of milk. The main

indicators that determine its quality are protein and fat content, acidity, the number of somatic cells, etc. (Bogatko *et al.*, 2018; 2019). The studies of recent years (Hall *et al.*, 2018; Sejian *et al.*, 2018; Hou *et al.*, 2021) indicate that due to heat stress, the content of milk fat, protein, solids-not-fat, total nitrogen, and lactose decreases, while the content of non-protein nitrogen, palmitic and stearic acids, on the contrary, increases. A substantial increase in the content of somatic cells in milk was also recorded.

This hypothesis is also confirmed by the conducted scientific experiments. Due to heat stress, high-productive cows in the control group showed a decrease in the mass fraction of fat from $3.96 \pm 0.09\%$ in June to $3.79 \pm 0.06\%$ in August and the mass fraction of protein from $2.90 \pm 0.03\%$ to $2.70 \pm 0.06\%$, respectively. There-with, the number of somatic cells increased by 34.09%, reaching the highest levels in August – 616.8 ± 160.4 thousand/cm³.

Feeding is a factor that determines the vital activity of animals. The level of productivity, reproductive qualities, health, and, ultimately, the economic and breeding value of livestock directly depend on the level and usefulness of feeding (Riznychuk *et al.*, 2021). Farms need to create comfortable conditions for keeping animals (Kravchenko *et al.*, 2019; Mylostyvyi *et al.*, 2021; Lutnicki *et al.*, 2021), organise synchronous feeding, develop and use optimised diets for feeding using a variety of innovative feed additives that can increase the absorption of nutrients to reduce the impact of heat stress (Min *et al.*, 2017; Bondarenko & Dvorska, 2015).

Researchers (Dunshea *et al.*, 2019; Hmelovskyi, 2020; Suprun & Kurylenko, 2022) investigate and substantiate the feasibility of using various energy feed additives (betaine, glycerin, propylene glycol, ENERGY-TOP, etc.), buffering additives (sodium bicarbonate), probiotic yeast additives and antioxidants (beta-carotene, vitamin E, selenium) in diets to normalise the pH of the rumen and compensate for possible mineral and vitamin deficiencies.

Lees *et al.* (2019) note that there is substantial variability in the success of feeding correction methods during heat load, and further research is needed to verify the appropriateness of dietary supplements as a means of reducing heat load. A number of researchers Gonzalez-Rivas *et al.*, 2018 Polsky & Von Keyserlingk, 2017) prove that for the same purpose, it is advisable to use high-energy diets with reduced protein and fibre content and increased fat content in feeding highly productive cows. However, the conducted study confirms the opposite.

Testing of protein feed additive with protected protein TEP-mix (LLC Arnika feed, Ukraine) in the conditions of an experimental farm against the background of heat stress in animals in the summer season has a positive effect on the productivity of high-performance dairy cows and milk quality. It was experimentally proved that due to the modernisation of the animal

diet, the preservation of milk productivity at the level of 20.5 ± 0.08 kg was achieved, which is almost 2 kg higher than the control. Besides, the use of the proposed measure during temperature stress contributed to better adaptation of animals in relation to the quality indicators of milk.

The obtained data correlates with the results obtained by other researchers. Thus, Kaufman *et al.* (2017) identified that an increase in the BP:NBP ratio in diets contributed to a decrease in daily milk yield and milk fat, protein, and lactose content under prolonged temperature stress. This suggests that milk fat and protein precursors were reduced and limited cow productivity. Gonzalez-Rivas *et al.* (2018), managed to reduce the effect of temperature stress on the milk productivity of cows by reducing heat increase during digestion by using processed end feeds.

According to Garner *et al.* (2022), cows receiving concentrated feed with a reduced starch fermentation rate as part of the diet recovered milk productivity faster after exposure to temperature stress, while having higher protein, fat, and lactose yields.

An increase in ambient temperature in summer causes heat stress in highly productive dairy cows and, as a result, negatively affects their productivity and milk quality. Testing of the food strategy for introducing a protein feed additive with protected TEP-mix protein into the diet of experimental animals during temperature stress contributed to the normalisation of productivity and improvement of milk quality indicators.

CONCLUSIONS

According to the results of monitoring studies of climate indicators, it was established that in the summer period (June-August), the daytime ambient temperature was $+26-30^{\circ}\text{C}$. The hottest month is July when daytime air temperature (from 14^{00} to 17^{00}) reached $+29-30^{\circ}\text{C}$.

It was proved that such climatic conditions (high temperature and low humidity) negatively affect the milk productivity of cows: in the period from June to August, the milk productivity of animals of the control group decreased by 13.1%. Due to heat stress in cows, the mass fraction of fat in milk and the mass fraction of protein decreased by 0.2%, while the somatic cell content increased by 55.6%. Due to the use of a protein feed additive with protected protein TEP-mix, the productivity of experimental cows is higher compared to the control by 1.9 kg (first group) and 1.5 kg (second group), and in terms of basic milk – by 5.4 kg (25.7%) and 4.3 kg (15.7%), respectively.

The introduction of 1.5 kg of TEP-mix supplement into the diet during temperature stress is optimal, which contributes to better adaptation of animals to the quality indicators of milk: an increase in the mass fraction of fat by 0.67% and the mass fraction of protein by 0.26%, with the content of somatic cells of $285.06 \pm 81.0-409.3 \pm 134.3$ thousand/cm³.

The prospect of further research is to develop a strategy to reduce the long-term impact of temperature stress in the cultivation of rearing animals and heifers through the use of feed additives with protein and starch protected from being broken down in the rumen.

None.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Шляхи зниження впливу зовнішнього середовища в літній період на молочну продуктивність корів

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Анотація. Одним з чинників ефективного виробництва молока за інтенсивного ведення галузі є створення комфортних умов утримання корів на фермі або комплексі. Високопродуктивні корови доволі вибагливі до мікроклімату в приміщенні та умов утримання. Вважається, що продуктивність тварин на 10-30 % залежить від цього. Метою дослідження є вивчення можливості зниження впливу високої температури зовнішнього середовища на молочну продуктивність корів за різних підходів до організації технології їх годівлі. В роботі використано аналітичні, діагностичні, фізико-хімічні та статистичні методи дослідження. Було проведено моніторинг основних кліматичних показників впродовж літнього періоду (червень-серпень). Встановлено, що зниження добового надою є наслідком негативного впливу температурного фактору, коли денна (з 11⁰⁰ до 17⁰⁰ години) температура повітря у червні-липні місяці була на рівні +26...30 °С. За температури повітря 26,5 °С (о 14⁰⁰ годині) температура тіла корів підвищується з 37,5...37,8 °С до 38,20...38,46 °С. Доказом цього є зниження швидкості падіння рівня молочної продуктивності корів дослідних груп у серпні місяці, коли середня денна температура повітря знизилася до +24...26 °С. Доведено, що введення у склад раціону високопродуктивних корів 1,5 кг білкової кормової добавки з захищеним протеїном ТЕП-мікс сприяє підвищенню продуктивності дослідних корів (у перерахунку на базисне молоко) на 15,7 % (4,3 кг). Модернізація раціону годівлі високоудійних корів за рахунок підвищення вмісту нерозщеплюваного протеїну у рубці до норми під час температурного стресу сприяло кращій адаптації тварин щодо продуктивності та якісних показників молока: більшення масової частки жиру на 0,67 % та масової частки білка на 0,26 %, при вмісті соматичних клітин 285,06±81,0...409,3±134,3 тис/см³

Ключові слова: кліматичні умови; дійні корови; молочна продуктивність; температура; захищений протеїн



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Growth energy and quality of beef from bulls of Maine-Anjou, Chianina, and Santa Gertrudis breeds grown in Ukraine

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Abstract. Zonal genotypes have already been created using imported breeds to increase the number of meat cattle in Ukraine, but not enough studies related to the specific features of breeding and feeding imported genotypes in the Steppe zone of Ukraine have been conducted, which is relevant. The purpose of the study is to examine the productive and slaughter indicators of bulls of imported meat breeds of various ecological and genetic origins in the climatic conditions of the steppe zone of Ukraine. Zootechnical, morphometric, biometric, and statistical methods were used in the research. The results of an analysis of the meat productivity of bulls of imported meat breeds of Maine-Anjou, Chianina, and Santa Gertrudis in the age aspect in the conditions of the steppe of the Dnieper region of Ukraine are presented. It was identified that



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when slaughtering experimental animals at the age of 18 months, the mass of paired carcasses of Maine-Anjou and Chianina was quite high and amounted to 324.2 and 311.3 kg, respectively, and the Santa Gertrudis – 233.3 kg, which is 1.39 and 1.33 times less than the young animals of Maine-Anjou and Chianina, respectively. It is proved that to use livestock more efficiently and obtain high-quality beef to improve the supply of meat to the population, it is advisable to grow them up to 18-24 months of age. Maine-Anjou animals dominate in terms of growth energy, age of reaching live weight during key growing periods, and feed conversion. In addition, due to the pronounced massiveness and habit of the body, have a larger carcass mass, the amount of internal fat, offal, as a result of which, the slaughter yield is higher. Based on the conducted studies, the possibility of effective breeding of Maine-Anjou bulls up to 12 months of age is proved, since during this period they reach a live weight of 400 kg and are characterised by the high production rate of lean beef, and for Chianina breed – up to 18 months of age and bigger weight conditions

Keywords: meat cattle; imported genotypes; young animals; live weight; slaughter indicators; beef

INTRODUCTION

Meat production and quality occupy a special place in ensuring food security. A substantial reserve for solving this problem is specialised meat cattle breeding. This is due to the fact that beef is the main source of high-value proteins in the human diet. The effectiveness of meat cattle breeding largely depends on the scientifically based choice of breeds for breeding (Kozyr *et al.*, 2018; Prudnikov *et al.*, 2019).

However, today in Ukraine the number of specialised meat cattle remains extremely low, and beef is produced mainly at the expense of dairy cattle breeding. S.P. Pankiev (2019) notes that the quality of meat obtained from culled livestock and over-rearing dairy breeds does not meet the standards and has lower taste qualities compared to the beef of specialised meat breeds. The meat cattle industry is also attractive from the standpoint that it is less labour-intensive since it does not require complex machines and equipment, unlike dairy cattle breeding, and most importantly – there is a possibility of using resource-saving technologies. In addition, with the development of meat cattle breeding in Ukraine, the possibility of using land areas not involved in agricultural production increases (Kozyr & Petrenko, 2021).

As a result of painstaking work, a number of Ukrainian meat breeds of livestock were created in Ukraine. Imported livestock, including those of American, French, and Italian origin, was widely used in the breeding process. The ability of imported animals to adapt to new environmental conditions without reducing their productivity indicators allows for determining expediency of their use in the further breeding process in new conditions of existence (McAllister *et al.*, 2020). Such studies in the ecological and climatic zone of the Dnieper Steppe have not been conducted enough, and therefore they are of important interest, both from a scientific and practical standpoint.

The choice of growth technology for the farm must necessarily be based on the most efficient use of resources in each link of the technological process in relation to specific zonal natural and climatic conditions. An important source of increasing beef production

is grazing and fattening cattle. J. Soulat *et al.* (2018) concluded that where there is a sufficient number of pastures, grazing of animals should be conducted. For 4-5 months of the pasture period, the mass of adult cattle can be increased by 26-30%, young animals – by 60-75%. With an increase in the mass of animals, the yield of slaughter products increases sharply. In addition, beef obtained during grazing is characterised by a lower fat content.

On the way to solving the problem of sustainable development of the meat cattle industry, it is important to increase the efficiency of breeding work with the gene pool of cattle and improve the quality components of livestock products. The import of high-quality genetic material of meat cattle is usually accompanied by the transfer of new technologies, including methods for predicting the quality of meat. Modern breeding methods in the 21st century are based on the comparison of molecular genetic markers that interact with economically useful traits. At its core, this is an integrated approach that closely links genotype to phenotype, enabling the identification of valuable genetic material for targeted use in practical breeding. According to C. Berri *et al.* (2019), individual selection of animals, collection of information on breeding value, accounting for productivity, growth, development, use of modern molecular genetic, statistical methods, and computer technologies allow identifying outstanding animals in the shortest possible time.

The purpose of the study was to determine the productive qualities of animals of imported breeds of various ecological and genetic origins, considering the specific features of soil and climatic conditions, and the technology of keeping and feeding in the conditions of the Steppe of the Dnieper region.

MATERIALS AND METHODS

The study used generally accepted research methods: analytical (analysis of special literature, analysis and generalisation of the results), zootechnical (formation and introduction of groups of animals for the experiment, assessment of live weight, exterior measurements,

body structure indices, determination of growth energy, control slaughter), morphometric (physical-chemical composition of carcasses), biometric, statistical.

The experimental part of the study was conducted in the experimental farm "Polyvanovka" of the state institution "Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine" in the period from 2018 to 2021. Three groups of 15 heads of newborn bulls of the Ukrainian generation of Maine-Anjou, Chianina, and Santa Gertrudis breeds were formed to examine the influence of the natural-climatic conditions of the Dnipropetrovsk region on the technological processes and productivity of meat cattle.

When forming experimental groups, the origin, age, and body weight of animals were considered. Young animals of experimental groups after weaning from cows were raised according to the same feeding scheme, which met the optimal detailed standards of animal feeding (Ibatullin *et al.*, 2016).

All animals during the study period were clinically healthy and kept loose in the same climatic and technological conditions. During the experiments, the growth of young animals was considered, changes in linear measurements of animals were determined, and absolute, average daily, and relative weight gains were calculated (Antoniuk, 2013). Live mass was determined by individual weighing.

Linear growth of young animals was examined by taking basic measurements in the corresponding age periods (height at the withers, height at the sacrum, oblique trunk length, chest width behind the shoulder blades, chest depth, width in the hook bones and hip joints, chest circumference behind the shoulder blades, metacarpal circumference). The following body structure indices were calculated based on measurements to determine the harmony of body development in young animals: long-legged, stretched, pelvic, thoracic, overgrowth, bony, and meaty (Huziev, 2003).

A control slaughter of young animals at 18, 24, and 30 months of age of 3 heads was performed to assess the meat qualities of the examined cattle. The assessment was conducted according to the method of V. Prudnikov *et al.* (2018) in the Dnipropetrovsk State Regional Diagnostic Veterinary Laboratory

The morphological composition of carcasses was determined by deboning three right half-carcasses from each group, cooled for 48 hours. Based on the data obtained during deboning, the absolute and relative content of bones, tendons, and meat parts and the yield of meat per 1 kg of bones, were determined. Samples of the muscles of the limbs, chest, and back were taken to examine the chemical composition of meat.

All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). The keep of animals and all manipulations were conducted in accordance with the provisions of the procedure for conducting experiments and experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (European convention..., 1986).

RESULTS

For various reasons, imported specialised cattle breeds of Maine-Anjou, Chianina, and Santa Gertrudis are not widely distributed in Ukraine. Therewith, their features left a deep mark on the breeding process when breeding local Ukrainian, Simmental, and Southern meat breeds.

A common feature of the examined breeds was the successful acclimatisation to the sharply continental climate of the Steppe zone of Ukraine and adaptation to feeding conditions. The feed was high and amounted to 97-98%, as a result of which they showed fairly high growth energy, which is characteristic of specialised Franco-Italian and American meat breeds of livestock.

Analysis of data on the age dynamics of live weight (Table 1) showed that at birth, in accordance with their biological characteristics, bulls of the examined breeds had different live masses. The highest live weight was identified in newborn calves of the Chianina breed, in which it averaged 58.0 kg, in Maine-Anjou it was 47.7 kg, and in this indicator was lower for the Chianina breed by 17.8%. The lowest live birth weight was identified in the Santa Gertrudis breed, which did not exceed an average of 30.5 kg, which was 36.1% less than in Maine-Anjou ($p < 0.01$), and 47.4% less than in Chianina ($P < 0.001$).

Table 1. Age dynamics of live weight of bulls of different breeds, kg, $M \pm m$

Age of animals, months	Breed		
	Maine-Anjou	Chianina	Santa Gertrudis
At birth	47.7 $\pm$ 4.14	58.0 $\pm$ 5.11	30.5 $\pm$ 3.11
12	398.2 $\pm$ 7.24	369.4 $\pm$ 9.22	308.4 $\pm$ 6.28
18	579.5 $\pm$ 8.17	553.8 $\pm$ 11.31	424.3 $\pm$ 7.36
24	723.2 $\pm$ 12.84	676.6 $\pm$ 14.25	548.8 $\pm$ 15.21
30	811.0 $\pm$ 17.98	764.7 $\pm$ 13.41	627.5 $\pm$ 9.42

Source: compiled by the authors

At 12 months, the live weight of Maine-Anjou bulls compared to newborns increased 8.4 times and amounted to 398.2 kg, while in Chianina peers it increased 6.4 times and averaged 369.4 kg, which was 7.2% less than in Maine-Anjou bulls ($P<0.05$). In animals of the Santa Gertrudis breed in the period from birth to 12 months of age, the live weight increased 10.1 times and amounted to 308.4 kg, which was less than in comparison with bulls of the Maine-Anjou and Chianina breeds, respectively, by 22.6% ($P<0.001$) and 16.5% ($P<0.001$).

By the age of one and a half years, the live weight of Maine-Anjou increased 1.5 times or 31.3% ($P<0.001$) compared to 12 months of age and amounted to 579.5 kg. Therewith, the live weight of Chianina bulls also increased 1.5 times to 553.8 kg, but they were inferior to their peers in Maine-Anjou by only 4.6%. The growth energy during this period in Santa Gertrudis animals was substantially lower, since the live weight was 424.3 kg and they were inferior to their peers of the Maine-Anjou and Chianina breeds, respectively, by 26.8% ($P<0.001$) and 23.4% ($P<0.001$).

At the age of two years, the live weight of Maine-Anjou bulls reached 723.2 kg, which is 19.9% more than at the age of 18 months ($P<0.001$). By the age of two years, Chianina bulls increased their live weight by 18.2% ($P<0.001$). In animals of the Santa Gertrudis breed, it increased by 22.7% ($P<0.001$) but amounted to only 548.8 kg. The highest live weight during this period was identified in Maine-Anjou bulls, which exceeded the indicator of their Chianina peers by 6.4% ($P<0.05$), and Santa Gertrudis animals – by 24.1% ($P<0.001$). Santa Gertrudis's peers had the lowest living mass, with Chianina animals exceeding them by 18.9% ($P<0.001$).

In the final 6 months of growth, the live weight of livestock of all the examined breeds increased by 11.2-11.4% ($P<0.001$). At the age of 30 months, the live weight of Maine-Anjou reached the level of 811.0 kg, while in Chianinas it was 764.7 kg, and in Santa Gertrudis – 627.5 kg. During this period, they outnumbered the indicators of Chianina and Santa Gertrudis bulls by 5.7% ($P<0.05$) and 22.6% ($P<0.001$), respectively.

The different live weight of bulls of all the examined breeds according to the periods of growth and grazing was a consequence of the different intensity of their growing indicators. Up to one year of age, the growth energy of Santa Gertrudis was 761 g per day, while the average daily weight gain of the Chianina breed was 853 g, which was an increase of 11.2%. Therewith, the highest growth rate during this period was observed in the Maine-Anjou breed, which had an average daily live weight gain of 960 g per day, which was 11.3 and 26.1% more than the peers of the Chianina and Santa Gertrudis breed, respectively.

In the period from the age of 12 months to the age of 18 months, the highest energy was characteristic of Chianina bulls, when their average daily weight gain was 1013 g and increased by 11.8% compared to the previous period. In young animals of the Maine-Anjou breed, the average daily weight gains slightly decreased and amounted to 906 g. Therewith, the growth of bulls of the Santa Gertrudis breed decreased by 20.0% and averaged 636 g.

For the growth period from the age of 18 to 24 months, the highest average daily live weight gains were observed in Maine-Anjou bulls – 789 g, while in the Chianina breed – 674 g, and in Santa Gertrudis – 684 g. In the final period of growth up to 30 months of age, the average daily weight gains in all animals substantially decreased and in the context of the breeds under study amounted to 482 g, 484 g, and 432 g, respectively. Increases in the live weight of three meat breeds of imported selection for growing periods have a wave-like character, in which they grow by the age of one year, at the age of 18 months they acquire their maximum value, after which they substantially decrease and at the age of 30 months they make up almost half of the average daily increases compared with the age of 18 months.

Thus, in terms of grazing qualities, Maine-Anjou and Chianina bulls are characterised by higher growth energy and at the end of fattening have a higher living mass compared to Santa Gertrudis animals. Considering breed differences in growth energy, experimental bulls were characterised by different indicators for the age of reaching the control fattening weight of 300 kg (Table 2).

Table 2. Age of bulls of different breeds when reaching the control live weight, days, $M\pm m$

Live weight of animals, kg	Breed		
	Maine-Anjou	Chianina	Santa Gertrudis
300	269.0 $\pm$ 6.32	291.2 $\pm$ 4.75	359.0 $\pm$ 4.44
400	368.4 $\pm$ 7.11	383.4 $\pm$ 8.11	441.21 $\pm$ 2.89
500	469.6 $\pm$ 9.25	474.6 $\pm$ 4.21	602.22 $\pm$ 1.78
>600	577.8 $\pm$ 12.12	581.7 $\pm$ 3.75	766.31 $\pm$ 3.37

Source: compiled by the authors

It took 269 days for the Maine-Anjou bulls to reach a live weight of 300 kg, while the Chianinas needed

291 days, which was 8.2% ($P<0.01$) longer than in Maine-Anjou. It took 359 days for Santa Gertrudis

animals to reach such a live weight, which was 33.5% more ($P<0.001$) and 23.4% more ($P<0.001$) compared to Maine-Anjou and Chianina bulls. In 368 days of cultivation, Maine-Anjou bulls reached a live weight of 400 kg. Animals of the Chianina breed needed 3.9% more time to achieve this indicator of live weight and animals of the Santa Gertrudis breed needed 19.8% ($P<0.001$).

The live weight of Maine-Anjou bulls at the level of 500 kg was reached in 469 days, while for young animals of the Chianina, breed only 5 more days were necessary, while for the Santa Gertrudis breed – 33 days or 28.3% ($p<0.001$) more compared to the Maine-Anjou breed, 27.0% ($P<0.001$) with the Chianina bulls. In 577.8 days, Maine-Anjou bulls and in 581.7 days, Chianinas achieved a live weight of 600 kg, while in Santa

Gertrudis animals this indicator was achieved in 766.3 days, which was 32.8 ($P<0.001$) and 31.8% ($P<0.001$), or 185-189 days more, respectively.

Thus, the different intensities of growth and development of meat breeds ultimately determine the economy of production, because the shorter the period of reaching the slaughter mass, the more efficient the production. Changes in the weight indicators of the live weight of bulls of the breeds under study naturally led to changes in the body structure and exterior. Linear assessment of the exterior, which was performed in experimental bulls at 12, 18, and 24 months of age, showed that both the height at the withers and the oblique length of the body were preferable on the side of animals of the Maine-Anjou breed (Table 3).

Table 3. Linear indicators of bulls development by growing periods, cm, $M\pm m$

Age of animals, months.	Breed		
	Maine-Anjou	Chianina	Santa Gertrudis
Height at the Withers			
12	123.0 $\pm$ 2.11	116.5 $\pm$ 2.14	112.3 $\pm$ 1.24
18	137.4 $\pm$ 1.17	124.0 $\pm$ 7.08	115.4 $\pm$ 1.31
24	139.6 $\pm$ 4.25	135.9 $\pm$ 6.31	134.9 $\pm$ 2.77
Oblique torso length			
12	132.4 $\pm$ 3.75	128.9 $\pm$ 4.33	126.1 $\pm$ 2.77
18	141.5 $\pm$ 2.22	137.6 $\pm$ 4.45	131.4 $\pm$ 1.23
24	187.7 $\pm$ 4.77	174.8 $\pm$ 3.54	149.3 $\pm$ 3.56

Source: compiled by the authors

Notably, there is a substantial lag in height measurements of young animals of the Santa Gertrudis breed at the age of 12 and 18 months, compared with their peers by 3.6-9.8% and 7.5-19.1%, respectively. However, by the age of 2 years, the height at the withers in animals of the Santa Gertrudis breed reached 134.9 cm, which corresponded to the same indicator of Maine-Anjou bulls at the age of 18 months and Chianinas at the age of 24 months. That is, by the age of two years, the height measurements in animals of the examined breeds were almost equal.

Analysis of data on oblique body length showed that according to this indicator, the experimental animals were more strikingly different from each other. In Maine-Anjou bulls, the oblique body length increased

from 132 cm to 187 cm, or by 42.2% ($P<0.01$), in Chianina – by 35.6% ($p<0.01$), and in Santa Gertrudis animals – from 126 to 149 cm, or by 18.4% ($P<0.001$). In the same age periods, a control slaughter of experimental bulls was conducted.

Table 4 shows the indicators that were examined after the slaughter of animals. When slaughtering experimental animals at the age of 18 months, the mass of paired carcasses of Maine-Anjou and Chianina bulls was quite high and amounted to 324.2 and 311.3 kg, respectively. Therewith, the mass of the paired carcass of Santa Gertrudis bulls was only 233.3 kg, which was less than the mass of the paired carcass of Maine-Anjou and Chianina bulls, respectively, by 1.39 ($P<0.001$) and 1.33 times ($P<0.001$).

Table 4. Slaughter indicators of bulls of different ages, $M\pm m$, ($n=3$)

Age of animals, months	Weight, kg				Slaughter yield, %	Coefficient of meat
	paired carcass	internal fat	offal	leather		
18	Maine-Anjou					
	324.2 $\pm$ 9.18	15.9 $\pm$ 1.02	31.3 $\pm$ 2.11	57.3 $\pm$ 9.05	68.9 $\pm$ 2.03	5.7
24	405.0 $\pm$ 12.11	16.2 $\pm$ 2.09	33.8 $\pm$ 4.23	72.11 $\pm$ 4.11	65.3 $\pm$ 1.11	5.6
30	473.6 $\pm$ 15.05	18.9 $\pm$ 4.22	38.9 $\pm$ 4.45	81.14 $\pm$ 9.08	63.0 $\pm$ 2.17	5.4

Table 4, Continued

Age of animals, months	Weight, kg				Slaughter yield, %	Coefficient of meat	
	paired carcass	internal fat	offal	leather			
18	Chianina						
	311.3±5.09	14.2±1.31	30.6±2.02	52.21±1.14	62.4±1.21	5.5	
	24	390.5±13.14	15.8±3.42	31.9±3.11	68.1±5.22	61.6±1.38	5.4
	30	454.9±14.08	17.9±5.33	36.5±4.15	74.3±12.02	61.7±2.14	5.4
18	Santa Gertrudis						
	233.3±1.77	13.6±3.35	25.0±0.48	42.4±1.08	62.7±1.26	5.6	
	24	304.4±1.34	16.4±2.24	30.7±0.27	42.7±4.18	64.2±2.14	5.4
	30	381.9±1.19	18.9±1.99	35.9±0.84	67.0±3.22	59.8±1.29	5.5

Source: compiled by the authors

The mass of the paired carcass of Santa Gertrudis bulls slaughtered at the age of 24 months remained the smallest since it averaged 304.4 kg. The mass of the paired carcass of Maine-Anjou and Chianina bulls was 405.0 and 390.5 kg, respectively, which is 1.33 ($P<0.001$) and 1.28 ($P<0.001$) times higher than that of the Santa Gertrudis breed, respectively. At the age of 30 months, the mass of the paired carcass of slaughtered Maine-Anjou and Chianina animals was 473.6 and 454.9 kg, respectively, which was 24.0% ($P<0.001$) and 19.1% ($P<0.001$) more than the same indicator of the Santa Gertrudis breed, respectively.

The amount of offal increased with the age of slaughter of bulls and reached its maximum at the age of 30 months. Therewith, if this production in the Santa Gertrudis breed at the age of 18 and 24 months was inferior to its peers in the Maine-Anjou and Kyan breeds, then at the age of 30 months it levelled off and averaged 35.9 kg. With the age of slaughter of animals, the weight of the skin also increases, which at the age of 30 months in Maine-Anjou bulls averaged 81.1 kg, and in Chianinas – 74.3 kg. During this slaughter period, the skin weight of Santa Gertrudis bulls was less and amounted to only 67.0 kg.

In terms of slaughter yield, the advantage was for Maine-Anjou bulls, especially for animals that were

slaughtered at the age of 18 months – 68%. In general, all experimental bulls had a slaughter yield of more than 60%, the highest was at the age of 18 months, after which it gradually decreased, and its lowest value was at slaughter at 30 months. Despite the fact that the mass of the paired carcass for three periods of the slaughter of experimental bulls was different, the indicator of the meat coefficient was very close and ranged between 5.4-5.7 conventional units.

Thus, according to the indicators of slaughter qualities, animals of the Maine-Anjou breed have the best values, and peers of the Chianina breed are characterised by indicators close to them. Santa Gertrudis bulls have relatively lower slaughter qualities, although they are not inferior in meat content to their peers of other breeds.

A complete deboning of one half-carcass was conducted to determine the chemical composition of the entire carcass, and to examine the quality of the meat, the longest back muscle was used, which was previously separated from surface fat and connective tissue membranes. Assessment of the quality of meat of experimental bulls slaughtered in different age periods, according to a complex of physico-chemical and organoleptic indicators, is given in Table 5.

Table 5. Quality of meat of bulls of different breeds, $M\pm m$

Age of animals, months	Longest back muscle				Chemical composition of the average sample, %			
	pH, units	loss in boiling, %	tenderness, g/cm ²	moisture capacity, %	water	fat	protein	fat: protein ratio
<i>Maine-Anjou</i>								
18	6.4 ±0.34	44.2 ±1.21	0.59 ±0.003	1.82 ±0.541	57.1 ±1.79	15.2 ±1.94	16.1 ±0.14	0.9
24	6.3 ±0.12	40.4 ±0.99	0.69 ±0.004	2.61 ±0.557	54.4 ±2.01	18.1 ±1.54	17.0 ±0.18	1.1
30	6.5 ±0.32	37.7 ±1.17	0.71 ±0.001	3.04 ±0.614	51.3 ±1.77	21.4 ±2.11	22.4 ±0.22	0.9
<i>Chianina</i>								
18	6.2 ±0.44	45.3 ±2.11	0.49 ±0.002	1.91 ±0.701	54.2 ±2.11	23.2 ±1.15	14.3 ±0.17	1.6

Table 5, Continued

Age of animals, months	Longest back muscle				Chemical composition of the average sample, %			
	pH, units	loss in boiling, %	tenderness, g/cm ²	moisture capacity, %	water	fat	protein	fat: protein ratio
24	6.4 ±0.54	42.6 ±1.81	0.70 ±0.007	2.72 ±0.201	52.1 ±1.28	25.4 ±2.14	14.7 ±0.25	1.7
30	6.6 ±0.74	38.0 ±1.14	0.71 ±0.005	3.17 ±0.199	50.3 ±2.14	26.5 ±1.18	17.6 ±0.19	1.5
<i>Santa Gertrudis</i>								
18	6.4 ±0.15	45.5 ±1.18	0.48 ±0.004	1.73 ±0.215	51.73 ±1.51	18.4 ±1.77	14.0 ±0.28	1.3
24	6.5 ±0.22	39.8 ±1.19	0.70 ±0.19	2.55 ±0.261	52.53 ±2.14	20.9 ±1.16	15.5 ±0.29	1.3
30	6.4 ±0.37	38.1 ±1.27	0.71 ±0.214	3.11 ±0.114	53.11 ±1.15	21.4 ±2.14	14.3 ±0.41	1.5

Source: compiled by the authors

Analysis of the obtained data showed that the acidity of meat of all experimental groups of animals was at the same level, did not go beyond the norm and the PH was 6.2-6.4 conventional units. Boiling loss indicators were in the range of 38-45% and with increasing age, this indicator decreased. This is due to an increase in the moisture capacity of animal meat, which increased with age. Notably, the meat of

Maine-Anjou bulls is the leanest in comparison with other breeds and the ratio of fat to protein in different age periods is 0.9-1.1. The highest fat content is inherent in animals of the Chianina breed, where this ratio is 1.5-1.7, and in Santa Gertrudis – 1.3-1.5. Breed age factors based on the growth energy of the examined meat genotypes also affected the conversion of feed to meat productivity of animals (Table 6) (Prudnikov et al. 2018).

Table 6. Feed energy consumption per 1 kg of live weight gain of bulls, MJ, M±m

Indicator	Breed		
	Maine-Anjou	Chianina	Santa Gertrudis
Age of animals, months	Per 1 kg of live weight		
120-15	69±1.82	84±2.41	108±2.44
15-18	78±0.96	99±2.68	110±2.49
18-24	121±4.23	139±3.01	150±2.54
24-30	138±5.02	141±3.04	154±2.61
Live weight of animals, kg	At the control live weight		
<300	71±1.39	89±2.06	84±1.96
301-400	80±1.47	97±3.04	100±2.04
401-500	118±2.12	117±4.01	123±3.01
501-600	134±3.01	133±4.68	138±4.04
>600	140±4.03	141±4.83	144±4.37
An increase per 1000 MJ, kg	9.2±2.03	8.6±1.94	8.1±1.73

Source: compiled by the authors

When assessing the energy consumption of feed, it was identified that the lowest feed consumption was inherent in the Maine-Anjou breed. This figure was 3.2% less than that of Chianina animals, and 10.3% less than that of Santa Gertrudis. As for the increase per 1000 MJ, the highest increase was also observed in animals of the Maine-Anjou breed – 9.2 kg, which is 6.9% higher compared to Chianinas, and 13.5% higher than in the Santa Gertrudis breed (Table 6).

DISCUSSION

The most important task for the meat cattle industry in Ukraine is to increase the number of livestock and improve the quality of the resulting products. No less relevant and debatable at the present time is the question of the potential of internal tribal resources in solving this problem. The practice has shown that it is advisable to create a breeding base in meat cattle breeding using the world's best gene pool by purchasing

outstanding animals, especially bulls and their sperm products (Hladii *et al.*, 2022).

Although in Ukraine, imported specialised meat breeds of cattle of Maine-Anjou, Chianina, and Santa Gertrudis breeds are not quite common, they were used in the breeding of local Ukrainian, Simmental, and Southern meat breeds.

Any breed of cattle differs in economically useful characteristics and is determined in comparison with other breeds and genotypes, and manifests itself in the development of meat productivity in different ways, depending on the accepted cultivation technology (Kozyr, 2018; Cortese *et al.*, 2019; Lee *et al.*, 2020). In addition, the degree of realisation of the genetic potential of productivity depends on the ability of animals to adapt to new ecological and climatic conditions. (Pankieiev, 2019). For further effective involvement of these breeds in the breeding process, studies on the subject of their meat productivity and product quality in the conditions of Ukraine are relevant.

Ukrainian and foreign researchers note that when considering the issue of acclimatisation, it is advisable to examine the full range of factors to which animals transferred to a new living environment should adapt. These factors will determine the viability and affect the productivity of animals over several generations. T.N. Rowan *et al.* (2021) proved that the most important indicators of successful adaptation of imported livestock from abroad are the preservation of their high productivity, the implementation of normal reproductive function, digestibility, and efficiency of feed use. Therewith, in new ecological and feed conditions, a living organism either degenerates or adapts, undergoing certain changes in the exterior, interior, and economically useful features.

The conducted analyses of growth and development indicators and productive qualities of imported genotypes based on the results of cultivation and fattening showed that they are quite successful in adapting to new conditions. The food consumption was high and amounted to 97-98%, as a result of which the animals showed fairly high growth energy, which is characteristic of specialised Franco-Italian and American meat breeds of livestock. According to the studies (Michael *et al.*, 2019; Olson, *et al.*, 2021) the food intake, high intensity of growth and development of the body also have a positive effect on the reproductive qualities of animals, which indicates the adaptive potential of the breed.

Meat productivity can be assessed both during the life of the animal and after slaughter. The lifetime definition of meat qualities is quite relative since live weight and appearance cannot give a complete description of the quality of meat. The most complete and objective meat qualities of livestock are reflected by the control slaughter. The quality characteristics of beef carcass and meat are influenced by many factors of

different origins (Maresca *et al.*, 2019; Nantongo *et al.*, 2021; Wang *et al.*, 2021). C. Berri *et al.* (2018) argue that breed, sex, slaughter age, diet, and feeding regimen can affect muscle characteristics, which in turn affects meat quality. In young animals, the process of formation of muscle fibres occurs, the intensity of which is higher the younger they are. Therewith, with intensive feeding, there is not only an increase in meat but also fat distributed between muscle fibres, forming the so-called marbled beef. In adult animals, little new muscle fibres are formed. An increase in meat yield occurs through the thickening of muscle fibres. Therefore, when grazing adult livestock, excess feed turns into adipose tissue, which is located mainly under the skin and on internal organs. It is necessary to adhere to an intensive animal feeding regimen to quickly conduct fattening. This will allow reducing labour and money costs per unit of production (Prudnikov *et al.*, 2018).

The dynamics of live weight gains of experimental animals over the growing periods had a wave character. The most intensive growth was observed in young animals up to one year of age, and the maximum value of live weight was acquired by bulls at the age of 18 months. Animals of the Maine-Anjou and Chianina breeds were characterised by higher growth energy and, when removed from grazing, while Santa Gertrudis prevailed in terms of the live weight. The shorter the period of reaching slaughter mass, the more efficient the production is, so different intensities of growth and development of animals ultimately determine the economy of production. This indicator was best in Maine-Anjou bulls, who reached a live weight of 400 kg at the age of 368 days.

Lifetime assessment of the meat productivity of animals and determination of its level is conducted mainly by the intensity of growth and live weight. Therewith, the most complete characteristic of meat productivity can be determined only after slaughtering animals. In all experimental bulls, the slaughter yield was more than 60%, and the highest at the age of 18 months, after which it gradually decreased and its lowest value was when slaughtering animals at 30 months. Slaughter indicators of experimental animals showed an advantage in the slaughter yield of Maine-Anjou bulls. Similar data were obtained in the study by Upperman (2021), where, after slaughter, an assessment of the meat productivity of bulls of different breeds showed the greatest carcass mass in bulls of the Maine-Anjou breed.

Carcasses consist of muscle, fat, bone, and connective tissues. The ratio of these tissues in carcasses is of great importance when conducting a qualitative assessment of carcasses. The demand for beef from consumers of both the population and the meat processing industry dictates high requirements for its commodity and quality indicators. In meat cattle breeding, special importance is attached to the taste characteristics of beef – its juiciness, tenderness – marbleness.

Among the genes that control qualitative traits, calpain (CAPN1), somatotropin (GH), and leptin (LEP) were identified as the most promising (Widyobroto *et al.*, 2020; Ramalingam *et al.*, 2021).

Somatotropin (GH) is produced by the anterior pituitary gland and is one of the most important regulators of somatic growth in animals. It was identified that the gene that controls the synthesis of somatotropin regulates the growth of the animal, and also plays a key role in metabolic processes (carbohydrate, fat) (Widyobroto *et al.*, 2020). Leptin (LEP), a hormone produced by adipose tissue cells, plays an important role in metabolism, especially in the accumulation of fat in the body. In cattle breeding, the leptin gene polymorphism is an important genetic factor affecting the slaughter yield and quality of meat (Ellie-Oury *et al.*, 2019). Meat should have a high nutritional value and be highly technological.

It is important to examine the slaughter parameters and morphological composition of carcasses since they are affected by the breed affiliation of the animal. It is known that the standard for determining the quality of meat in animals is the long back muscle since it consists of almost one muscle tissue. The chemical composition of meat depends on the type of animal, age, sex, fatness, level of feeding, and other factors (Anthony, 2016). Different growth rates of bone, muscle, connective, and adipose tissues change their ratio in the carcass depending on the breed.

Today, the efforts of researchers and practitioners around the world are aimed at meeting the global needs of the food industry for vital nutrients, among which protein is the main one. Therefore, appropriate requirements are put forward for animal husbandry, creating more pressure on it than ever before. For these reasons, a better understanding of the underlying mechanisms of muscle protein metabolism is essential for animal health and productivity.

Over the past two decades, advances in genomics have allowed the breeding process to be more informed and thus targeted. Recent technological findings have allowed the strengthening if not replacing of the genomic age with the age of proteomics and metabolomics (Gagaoua & Zhu, 2022). These technologies allow asking even more complex questions, directing researchers from genotype monitoring to phenotype. A deeper examination of the phenotypic mechanisms that regulate muscle mass, in turn, will provide new insights into how best to address the challenges of animal growth and development and improve the overall health of livestock to predict and manage meat quality.

Knowledge of the mechanisms of metabolism and pathways of protein synthesis opens up the prospect of regulating this process within the biological capabilities of the body. Protein is an important component of muscle tissue, and the consumer value of beef is primarily determined by the ratio of fat and protein that

accumulate during the life of the animal (Kozyr *et al.*, 2021). In muscle tissue, protein accounts for about 20% and 70-77% is water. Studies showed that the meat of Maine-Anjou bulls is the leanest compared to other breeds, and the ratio of fat to protein in different age periods is 0.9-1.1. A higher fat content was observed in the meat of animals of the Chianina and Santa Gertrudis breeds. A higher level of fat in the longest back muscle has a positive effect on the taste of meat and may indicate higher fatness and a tendency of this breed to acquire marbling during fattening, thereby providing the possibility of obtaining high-quality beef from young animals of these breeds.

Thus, the results of the study on the assessment of meat productivity of imported bulls are the basis for determining the effectiveness of their further breeding in the conditions of the Steppe zone of Ukraine and use in the breeding process.

CONCLUSIONS

Studies of productive and slaughter indicators of imported meat breeds of various ecological and genetic origins have determined the periods of their effective cultivation in the climatic conditions of the steppe zone of Ukraine and determined the most optimal slaughter time for obtaining high-quality competitive beef. Successful acclimatisation to extreme conditions of the steppe zone of Ukraine and rapid adaptation to feeding conditions are proved, which is confirmed by the high feed consumption (97-98%) and growth rate.

The wave-like nature of live weight gains of experimental bulls for the growing periods was identified, in which young animals of the Maine-Anjou breed with an average daily live weight gain reached 960 g per day by the age of one year are characterised by higher growth energy. In the period from 12 to 18 months of age, Chianina breed bulls had the highest intensity, whose average daily weight gain was 1013 g. During the period of cultivation from 18 to 24 months, the highest average daily weight gains were characteristic of the Maine-Anjou breed – 789 g, while the Chianina bulls had 674 g, and Santa Gertrudis – 684 g. At the end of the grazing period at the age of 30 months, the intensity of live weight gain in all animals, relative to the indicators of 18 months of age, substantially decreased and in the context of the examined breeds was 482 g, 484 g, and 432 g, respectively.

It was identified that in terms of grazing qualities, the Maine-Anjou and Chianina bulls are characterised by higher growth energy and have a higher living mass compared to animals of the Santa Gertrudis breed at the end of the grazing period. The advantage in growth energy and conversion of feed of animals of the Maine-Anjou breed contributed to their achievement of a greater live weight before other peers in key periods of growth and due to the massiveness and habit of the body, they were characterised by a greater mass of carcass, internal

fat, offal, and higher slaughter yield. Beef of all the examined breeds meets the demand for physical, chemical, and organoleptic qualities, has a pronounced marbling, which is due to the ratio of fat to protein.

Considering the quality indicators of beef as the final product for the consumer, growing Maine-Anjou bulls up to 12 months of age is suggested since during this period they reach a live weight of 400 kg and produce lean beef. It is advisable to raise young animals of the Chianina breed up to 18 months of age and greater

weight conditions. Further research may be aimed at determining the productive and slaughter indicators in the offspring of imported meat breeds obtained from animals grown in the Steppe zone of Ukraine.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Енергія росту та якість яловичини бугайців порід Мен-Анжу, Кіанська і Санта-Гертруда вирощених в Україні

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Анотація. З метою нарощування поголів'я м'ясної худоби в Україні вже створено зональні генотипи з використанням імпорتنих порід, проте досліджень пов'язаних з особливостями вирощування та відгодівлі імпорتنих генотипів в умовах степової зони України проведено недостатньо, що є актуальним. Мета досліджень – вивчення продуктивних і забійних показників бугайців імпорتنих м'ясних порід різного еколого-генетичного походження в кліматичних умовах степової зони України. Під час досліджень були використані зоотехнічні методи, морфометричні, біометричні та статистичні. Наведено результати дослідження м'ясної продуктивності бугайців імпорتنих м'ясних порід Мен-Анжу, Кіанської і Санта-Гертруда у віковому аспекті в умовах степу Придніпров'я України. Встановлено, що за забою піддослідних тварин у віці 18 місяців маса парної туші Мен-Анжу та Кіанських була достатньо високою і становила відповідно – 324,2 і 311,3 кг, а бугайців породи Санта-Гертруда – 233,3 кг, що менше ніж у молодняку Мен-Анжу і Кіанських, відповідно в 1,39 і 1,33 рази. Доведено, що з метою більш ефективного використання поголів'я і отримання високоякісної яловичини для поліпшення постачання населення м'ясом, доцільно їх вирощувати до 18-24-місячного віку. За енергією росту, віком досягнення живої маси у ключові періоди вирощування, конверсією корму домінують тварини породи Мен-Анжу. Вони також за рахунок яскраво вираженої масивності і габітусу тіла мають більшу масу туші, кількість внутрішнього жиру, субпродуктів, в результаті чого і вищий забійний вихід. На підставі проведених досліджень доведена можливість ефективного вирощування бугайців породи Мен-Анжу до 12-місячного віку, оскільки за цей період вони досягають живої маси 400 кг і відзначаються продукуванням пісної яловичини, а молодняк Кіанської породи - до 18-місячного віку та більш вагових кондицій

Ключові слова: м'ясна худоба; імпорتنі генотипи; молодняк, жива маса; забійні показники; яловичина



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Slaughter and meat quality of broiler turkeys using different light programmes during growing

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Abstract. The issue of selecting light programmes in poultry houses is of great importance in growing broiler turkeys, as neglecting it results in the deterioration of the movement of the bird. Such a factor leads to deterioration of general health and destabilises the proper functioning of body systems. The purpose of the research was to identify the effect of different lighting methods on the slaughter and meat qualities of broiler turkeys. The following methods were used in the research: histological, anatomical, morphometric, light-optical, statistical. The research was conducted in 2022 on two groups of Big-6 cross broiler turkeys in the poultry houses of the control group and two experimental production sites No. 7 poultry enterprises of Chernivtsi Oblast. The regulation of the light programs of each poultry house was implemented using fluorescent lamps



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of the PSP1V2-36 type, which provide warm white colour (colour temperature 2700 K) lighting. The research results established that the most developed muscle tissue was found in turkeys grown by the method using high intensity lighting. In addition, another experimental group demonstrated results higher than the control group. In addition, the quality of the meat of different groups had specific minor differences: in the pectoral muscles of the experimental groups, a slight increase in the content of dry matter (by 0.4-0.6%), protein (by 0.3-0.4%) and a decrease in fat content (by 0.3-0.4%). The caloric content has actually not changed. The experimental groups had an advantage in the chemical composition and energy value of the meat. The results of the conducted research can be used to improve the system of growing broiler turkeys, to explore in more detail the reaction of the bird to various conditions and the impact of these conditions on the body. It will allow obtaining high-quality products faster and reduce the cost of production

Keywords: breeding; light regime; fattening young birds; protein; poultry houses

INTRODUCTION

Performance of the genetic properties of the efficiency of broiler turkeys is not complete without the organisation of proper conditions for growing them, considering the light regime control. The intensity, duration, and spectrum of light affect the shift in performance indicators and the physiological state of the bird in a positive or adverse areas. The research problem is to find the most balanced lighting regime, as feed consumption was reduced and problems with legs with too low lighting. And with the too-intense light, the development of cannibalism got problems with the psyche and worse uniformity of the group. Thus, it is extremely important to find exactly what is necessary to meet the expectations of everyone engaged in breeding broiler turkeys.

E.D. Fidan *et al.* (2017) point to the possibility of using daylight for the purpose of breeding and ensuring the vital activity of turkeys of each of the production links. Sunlight has a positive effect on the vitality of birds, their optimal development and growth. On the other hand, the rapid development of technologies in turkey breeding is based on using artificial lighting devices for poultry houses, which allow controlling the length of lighting time and the level of brightness in the poultry house without being subject to natural conditions and seasonal changes. It is important to understand that the selection of lighting systems has a significant impact.

In their research, S. Barbut and E.M. Leishman (2022) indicated that blue light has a calming effect on turkeys compared to white, red, or green light. In an experiment where turkeys were given the variability of choosing a place of life between poultry houses lit by monochromatic light of different colours, preference was given to poultry houses with blue and green light. In turn, R. Frank *et al.* (2020) noted that the highest growth rate of turkeys grown for meat production was observed when using green lighting devices. In addition, the green colour contributed to a decrease in the relative cost of feed and a decrease in the level of stress of the bird. J. Linhoss *et al.* (2020) and M. Aksit *et al.* (2017) found that before sixteen weeks of age, turkey poults performed better under blue light bulbs, but for

the next 6 months they grew faster when either white or red lightbulbs were used. According to F.N.K. Soliman and K. El-Sabrou, (2020), T. Prylipko *et al.* (2020) light characterised by long waves affect the reproduction indicators of adult birds, i.e., the yellow-orange-red range has a positive effect. High-pressure sodium lamps have this lighting range.

Examining the quality of lighting, K. Weng *et al.* (2022) determined that the value of light level and wavelength for all species of birds has three important variables: the light spectrum, its intensity, and the duration of the light period. Light intensity and duration are better explored and may slightly alter the biological responses and behaviour of the bird. Combinations of waves of different wavelengths of electromagnetic radiation emitted by the lighting system in a specific order can change the spectrum of light. S. Parteca *et al.* (2020) demonstrated that differences in the light regime and spectrum affect the life of birds. An example of the consequences for broiler turkeys that were in the area of artificial light sources is the lack of ultraviolet light. Such a situation can have an adverse effect on poultry grown in closed premises, namely the inability to detect visual signals, plucking of feathers, behavioural deviations.

In their study, M.M. Abo Ghanima *et al.* (2021) explored that if the purpose of keeping turkey chicks is to obtain meat products, then it should be kept the light on throughout the day on the first day of life, and then the amount of lighting time can be reduced to 15-19 hours or less. However, notably, the result of using dark periods lasting 8 hours or more during the day can affect a partial decrease in the level of feed consumption, and the progress of growth of live weight. The accompanying problem is the problem of long periods of no movement of birds during such periods, which leads to a deterioration of the condition of the legs and plumage. J. Linhoss *et al.* (2023) found that a combination of three different factors that affect the space in the poultry house (radiation intensity, lighting duration and light spectrum) form the lighting programme. Each of the light emitting devices must meet the requirements for the synthesis of vitamin D, which saturates the

bones with minerals and, accordingly, guarantees their uniformity and growth.

A review of literature sources indicates the ambiguity of the topic of the quality of the influence of lighting systems on the growth and quality of products of broiler turkeys. Therefore, the purpose of the following research was to provide specifics in this matter.

MATERIALS AND METHODS

The experiment was performed on the growth of two groups of broiler turkeys of the Big-6 cross, which was

conducted in the poultry houses of the control group, experimental group No. 1 and research experimental No. 2 of the industrial site No. 8 of the poultry enterprise of Chernivtsi Oblast. Choosing the method of control over the lighting program for the period of growing broiler turkeys for the purpose of obtaining meat products, it was decided to use PSP1V2-36 type fluorescent lamps, which provide warm white colour (colour temperature 2700 K) lighting. The computer programme fully provided control over both the duration of illumination and its intensity (Tables 1-3).

Table 1. The lighting program approved by the Poultry Institute of the National Academy of Sciences for growing broiler turkeys (control group)

Broiler age, days	1-3	4-21	21-56	56-112 (females)	56-161 (males)
Daylight hours, h	24	17	14	16	16
Light intensity, lux	50-100	30	15	5	5

Table 2. Lighting programme adopted by Hybrid Turkeys Ltd (experimental group No. 1) for growing broiler turkeys

Broiler age, days	1	2	3-5	6-9	9-105	105-126
Light intensity, lux	100	100	100	80-100	60-100	60-100
Daylight hours, h	24	23	20	18	16	16-18
Switching on and off time	-	2:00-3:00	2:00-22:00	3:00-21:00	5:00-20:00	4:00-20:00
Switching on the light for night feeding, h	-	-	-	-	1	1-2

Table 3. Lighting programme adopted by British United Turkeys Ltd and Nicholas Turkeys Ltd (experimental group No. 2) for growing broiler turkeys

Broiler age, days	1	2-6	7+	Last week before slaughter
Light intensity, lux	>50	<50	<50	<50
Daylight hours, h	24	14-18	14-16	24
Dark hours, h	-	6-8	8-10	-
Switching on the light for night feeding, h	-	1-2	1-2	-

Source: compiled by the authors

In the course of experimental studies, a certain list of indicators was considered: preservation of birds – every day, with the recording of the reasons for leaving the flock; the live weight of turkeys – by measuring the weight of each bird in the first and last days of growing; expenditure of resources per individual bird based on the task: in research of scientific and economic field and productive verification of theoretical programmes using the group method, during the growing period, in experiments of physiological field using the method of individual examination every day. Derived values were used to analyse the progress of the growth of young birds, namely: relative, average daily and absolute growth.

With the purpose of examining the influence of different lighting programmes during growing on the

characteristics of meat and slaughter quality indicators of broiler turkeys, the chemical composition of meat, and the biological and energy value of muscles, 6 heads (3 males and 3 females) of turkeys were selected separately from all groups after the end of scientific and economic experiments No. 1, No. 4 and No. 5, and their control slaughter was performed according to the generally accepted methodology. Upon completion of the control slaughter, general deboning and anatomical processing of the raw material was implemented. Meat qualities of poultry were evaluated according to DSTU 3143-2013 (2014). Anatomical parameters of the carcass of broiler turkeys were calculated using the formulas of B.K. Hindze. Averaged samples of chest and leg muscles were selected for the purpose of chemical

analysis during anatomical processing and deboning of carcasses.

All experimental studies were conducted according to modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of ISO/IES 17025:2005 (2006). Birds were kept and all manipulations were performed according to Law of Ukraine No. 249 "On the Procedure for Conducting Experiments on Animals by Scientific Institutions" (2012), European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (1986).

RESULTS

The Big-6 turkey breed is in high demand among other categories of this poultry. It has high meat prematurity and a significant level of reproductive factors. This cross can be defined as heavyweight. The composition of this breed is effective from an economic viewpoint, in particular heavy crosses and lines. An average of 21 to 25 kg from a male bred from this line or cross can be got, while the females can give 11 kg of live weight. Evaluating the meat qualities of Big-6 turkeys obtained from medium crosses and lines, it was determined that

they are not marked by particularly large values, but are sufficient in comparison with other breeds. Each individual is characterised by white, in fact with no inclusions, feathers, and the only thing is the presence of an insignificant black tuft in the area of the sternum. Massive breasts and an extremely fast growth rate can be distinguished among the anatomical standards and features of this breed of turkeys. On average, the weight of the sternum occupies almost a third of the total weight of the carcass. The most understandable explanation for the intensity of growth of Big-6 turkeys is the following data: at the age of three months, turkeys can weigh up to 7.5 kg, and already at the age of 5 months, females can weigh up to 13 kg. A feature of this breed of turkeys can be called the final stop of growth upon reaching the age of 85-100 days, at which time they are slaughtered.

Based on the research results, notably, growing conditions, namely different light regimes, influenced the development of muscle tissue. Thus, in the experimental groups, this indicator amounted to 8077 g in the first experimental group and 7948.6 g in the second experimental group, which is 11.2 and 14.3% higher, respectively, than in the control group (Table 4).

Table 4. Meat qualities of broiler turkey carcasses

Indicators	Groups		
	Control (The Institute of Poultry of the National Academy of Sciences of Ukraine)	Experimental (Hybrid Turkeys Ltd)	Experimental (Nicholas Turkeys Ltd and British United Turkeys Ltd)
Pre-slaughter weight, g (%)	21286±18.71 (100)	24183.5±49.67 (100)	23798.3±31.89 (100)
Weight of semi-gutted carcass, g (%)	17411.9 (81.8)	19886.3±53.54 (81)	19347.7±33.82 (81.3)
Edible parts of the carcass, g (%)	12367.2±4.42 (58.1)	14218.9±4.9 (58.8)	13945.8±32.38 (58.6)
of which: edible viscera, g (%)	989.3±5.34 (8)	1192.78±7.45 (8.4)	1143.5±8.13 (8.2)
internal fat, g (%)	319.3±3.74 (1.5)	266±5.49 (1.1)	285.6±9.03 (1.2)
total muscles, g (%)	7066.9±21.73 (33.2)	8077.2±22.69 (33.4)	7948.6±12.42 (33.4)
incl. pectoral, g (%)	2171.2±16.54 (10.2)	2587.6±10.96 (10.7)	2498.8±10.61 (10.5)
leg muscles, g (%)	4895.8±11.1 (23)	5489.7±12.27 (22.7)	5449.8±4.6 (22.9)
skin with subcutaneous fat, g (%)	2831±17.09 (13.3)	3264.7±9.93 (13.5)	3236.6±20.83 (13.6)
inedible parts, g (%)	8918.8±38.36 (41.9)	9963.6±39.42 (41.2)	9852.5±19.52 (41.4)

Source: compiled by the authors

It was the most developed (8077.2 g) in the group where the recommended light regime was from a foreign breeding company (Hybrid Turkeys Ltd). In the second experimental group (the light regime of Nicholas Turkeys Ltd and British United Turkeys Ltd), this indicator was slightly lower (by 1.6%) than in the first experimental group, but by 11.2% more than in the control group (the light regime recommended by the Institute of Poultry of the National Academy of Sciences). Turkeys of the first and second experimental groups differed

favourably from their peers of the control group in terms of the weight of edible offal (liver, lungs, muscle stomach, heart): 1143.5-1192.78 against 989.3 g in the control group. A similar trend was observed in the mass of the most valuable parts of the carcass, in particular, pectoral muscles 2498.8-2587.6 g in the experimental groups, which is 327 and 416 g more than in the control group, and legs 5489.7-5449.8 against 4895.8 g in the control group. In addition, the difference between the groups was observed in terms of the mass of the total

number of inedible parts of the carcass. Compared to the control group, it was 0.7% in the first experimental group, and 0.5% in the second.

As a result of the study of the obtained data, certain differences in quality indicators of meat in groups of turkeys were outlined, which may have been caused by using different lighting modes during their cultivation. Despite the fact that the differences were not confirmed, a slightly better result was obtained when considering the meat quality indicators of the broiler turkeys of the groups grown according to the methods of commercial companies. Thus, the pectoral muscles of young animals of the experimental groups were characterised by an increase in the amount of protein by 0.3-0.4%, dry matter by 0.4-0.6%, and a decrease in the amount of fat by 0.3-0.4%. The caloric content of this muscle group in turkey chicks of the experimental groups actually did not differ from the control group (119.3-119.9 and 120.0 kcal/100 g, respectively). Differences between the experimental groups and the control in the energy value and chemical composition of thigh muscles were significantly expressed in favour of the experimental groups of broiler turkeys. Thus, the indicators of dry matter content differed by 0.4-0.9%; fat – by 0.1-0.4%; ash – by 0.2-0.3% protein – by 0.3-0.6%, and the caloric

component – by 2.0-3.1%. According to the index of relative biological value, femoral muscles of turkeys of experimental groups were characterised by an increase of 2.1-3.4%, and breast muscles – by 2.6-4.1%. Notably, the fluctuations in the quality composition of turkey muscles when using different lighting conditions were not constant, except for the biological value ($p < 0.001$).

Determining the rate of live weight dynamics of broiler turkeys demonstrated that different lighting systems had significantly different effects on the progress of weight gain of young birds. Starting from the 2-4th day of life, the lighting period was reduced to 17 hours in the control group, to 20 hours in the experimental group No. 1 and to 18 hours in experimental group No. 2. The lag in the growth rate of broiler turkeys of the control group immediately became noticeable. Already at the age of 6 weeks, it was possible to observe a significant advantage in terms of live weight of turkeys of the experimental groups with increased daylight hours. The weight of individuals grown according to the recommendations of the Institute of Poultry of the National Academy of Sciences was noticeably behind the individuals grown according to the methods of Hybrid Turkeys Ltd, British United Turkeys Ltd and Nicholas Turkeys Ltd by 73 and 138 g, respectively (Table 5).

Table 5. Effect of different lighting methods on the dynamics of live weight of broiler turkeys

Age of broiler turkeys, weeks		1	3	6	12	16	20	23
Control	$\bar{X} \pm S_x, g$	150±2.87	750±5.13	2750±8.26	9884±13.48	15354±15.35	19765±16.81	21286±18.71
	$C_v, \%$	2.3	6.9	5.1	10.2	11.4	9.8	12.3
Experimental group No. 1	$\bar{X} \pm S_x, g$	151±2.87	763±6.42	2823±9.11	11202±14.63	15975±19.14	20698±32.86	24183.5 ±49.67
	$C_v, \%$	3.4	7.1	5.3	11	12.6	12.1	11.9
Experimental group No. 2	$\bar{X} \pm S_x, g$	148±2.87	762±5.93	2888±9.88	10903±14.02	15786±17.98	20589±29.86	23798.3±31.89
	$C_v, \%$	3.5	7.4	5.7	10.3	9.8	13.2	14

Source: compiled by the authors

Approaching the age of 12 weeks, the differences between different groups in terms of live weight became even greater. When the age of 12 weeks is reached, the light day for turkeys of experimental group No. 1 was the highest among the subjects. During the sixteenth week of the experiment, broiler turkeys of the first experimental group were characterised by the appearance of compensatory growth. However, the average daily and absolute increases in live weight of turkey chicks were not much higher than that of birds of the control group and experimental group No. 2. In the course of the experiment, it was found that the most significant cases of compensatory growth were observed in the turkeys of the second experimental group. 8-10 hours of dark period was used for them during the age of 2-20 weeks. At the age of 16 weeks, an obvious advantage in terms of live weight was on the side of turkeys of

experimental group No. 1. Their live weight was measured to have higher values ($p \geq 0.999$) by 625 g and 193 g compared to control group and experimental group No. in 2. During the sixteenth week, turkey chicks of experimental group No. 2 presented cases of compensatory growth due to an increase in the length of the light period.

Notably, the smallest manifestation of compensatory growth was characterised by turkeys of the control group, in which the limitation of the period of the light factor was the smallest. The highest limit of progressive weight gain in broiler turkeys of the control and experimental groups No. 2 continued for two weeks, while it was the largest and lasted three and a half weeks for the turkey chicks of experimental group No. 1. In addition to the absolute value of live weight, the characteristics of broiler turkeys have a major impact on the performance of the birds produced, and flock uniformity plays

a significant role. Using different lighting methods for broiler turkeys affected the quantitative characteristics of flock homogeneity. Before reaching the age of six weeks in each of the groups, the homogeneity of the herd by live weight was characterised by high indicators (each indicator of homogeneity was above 80%). At 9 weeks, the homogeneity of the herd of each of the

groups decreased, but did not fall below the average level. The experimental group of broiler turkeys No. 1 and the control group lagged behind by 2.6%. Birds of experimental group No. 2, which were placed in conditions of constant light a week before slaughter, were characterised by the worst indicators of homogeneity in live weight (Table 6).

Table 6. Homogeneity indicators by live weight of broiler individuals when using different light regimes, %

Age of broilers, weeks		1	3	6	9	16	23
Light regime No. 1	Control group	85.1	94.9	81.2	77.8	76.5	75
Light regime No. 2	Experimental group No. 1	82.4	95.5	84.7	76.9	76.1	77.6
Light regime No. 3	Experimental group No. 2	81.8	93.8	83.9	76.5	75.9	70.5

Source: compiled by the authors

The calculation of the general indicator of the efficiency of growing broiler turkeys gave information that the greatest zootechnical efficiency of poultry keeping is provided by using lighting techniques with the highest intensity and a long time of limiting the light factor (experimental group No. 1). In addition, experimental group No. 1 was the best in the broiler index, by 13.6 and 8.1 points with respect to the control group and experimental group No. 2 of young meat. An indicator that describes the meat qualities of broilers, which is the preservation of young meat, is of great importance. It affects the work of factors that control the production of meat and meat products. In addition, the control group, which was grown according to the recommendations of the Institute of Poultry of the National Academy of Sciences for growing broiler turkeys, is characterised by the highest preservation rate (98.11%), which is characterised by the lowest intensity index among all groups, and a long dark period. Individuals that were grown according to the recommendation of the Hybrid Turkeys Ltd commercial company, i.e., using very high light intensity and a long light period, can be characterised by the lowest preservation index.

Using lighting techniques with a dark period of 10 hours from the 21st to the 56th day of keeping for broiler turkeys of the control group has a positive effect on the survival factor of broilers by 0.62% and 0.71%, respectively, compared to experimental groups No.1 and No. 2. Therewith, an increase in feed costs for broiler live weight gain was observed. The greatest zootechnical effect was obtained using the lighting method recommended by British United Turkeys Ltd and Nicholas Turkeys Ltd for growing broiler turkeys. The obtained data allowed understanding of the variable possibilities in growing broiler turkeys, demonstrate the ambiguity of each of the lighting methods and explain the nature of the effect of different periods of light and darkness on the bird's body.

DISCUSSION

According to the results of the study, it is indicated that the different lengths and intensities of daylight have different effects on the growth and development of the bird. Therewith, several contradictions were noticed in the above research. For a better understanding and to increase the certainty of this issue, it is worth getting acquainted with the opinions and conclusions of other authors.

V.S. Morita *et al.* (2020) determined that young birds need a higher level of illumination during the initial period of keeping (not less than 20 lux), compared to later growth, to provide the chicks with the opportunity to find feed and water without hindrance, and to familiarise themselves with the location. Over time, they get used to the placement of water bowls and feeders, thus, they are able to be oriented at a lower level of light. Accordingly, it is reduced to the level of 5-10 lux. Lower lighting during this period forms a calm behaviour of the bird, and reduces cases of cannibalism. By the way, a too low level of illumination (<5 lux) often becomes the cause of diseases of the organs of vision, the cause of which is the degeneration of the retina, and the probable development of glaucoma, myopathy, damage to the lens and blindness. It has an adverse effect on the plumage in the chest area due to the fact that the birds almost constantly sit on litter or a different type of floor. The accompanying significant decrease in the mobility of the bird and the related problems of dermatitis of the hind limbs, the formation of the reproductive system, and breast slime have an adverse impact on the development of the bird. In the study of broiler turkeys in the Chernivtsi Oblast, methods with low light intensity were not used, thus, it is only possible to confirm the advantages of a high level of light.

Therewith, the above research refutes the research done by U. Pandey (2019). In it, COBB 500 cross broilers were kept for the first 9 days under the conditions of a lighting system of 15, 25, 45 and 75 lux using the

programmes 23L:1D (0-9 days) and 20L:4D (10-55 days), which recommends reducing the level of illumination to 2-3 lux from the tenth day. The results presented that the chickens that were kept until the ninth day using 75 lux became a deviation from the general rule. They had the lowest mass indicators at the age of 9 days, the lowest yield of pectoral muscles and meat at the age of 55 weeks. Using additional methods, which included the use of 35 lux until the ninth day, did not demonstrate a destructive effect on the health and growth of the birds.

M.A. Arowolo *et al.* (2018) found that periods of night rest and daytime activity in turkeys are controlled by a part of the brain called the pineal gland. It happens by the method of isolating an enzyme that is responsible for the conversion of serotonin into melatonin. An increase in its amount in the blood causes a decrease in the body temperature of the birds and their falling asleep. Studies have demonstrated that the pineal gland is sensitive to light, but this reflectivity correlates with the time of day. It is believed that the length of the day is measured by an endogenous rhythm that contains a pair of half-cycles: "dark-sensitive" and "light-sensitive". Activation by light takes place only in those cases when the length of the light period during the day affects the "dark-sensitive" component of the half-cycles. According to recent data, the light-sensitive phase in turkeys begins 11 hours after the first light is turned on ("dawn") and lasts about 5 hours, although this period can be interrupted by short periods of darkness. In addition, this study is confirmed in an experiment on broiler turkeys of the Big-6 cross.

In turn, M.M. Romanovych *et al.* (2019), S.A. Lynch *et al.* (2018) explored that the duration of light and dark periods is one of the main variables influencing the development and reproductive phases of birds. As the length of daylight increases, the hormones responsible for this give impetus to puberty, and the initiation of egg-laying in turkeys. When the length of the light part of the day decreases, these hormones slow down puberty and stop the egg-laying period. Wild birds regulate these processes through seasonal changes, and domestic birds do this through humans, according to scientifically based light regimes. High illumination (over 40 lux), on the contrary, increases mobility, and therefore reduces the increase in live weight and increases feed consumption, but has a positive effect on the basic development of the physiological component of the organism. It is of great importance for birds that have entered the reproductive phase and young birds.

In their research, C.M. Poholsky *et al.* (2023) derived the following opinion: when growing turkeys in outdoor yards, the light intensity indicators can vary from a couple of hundred to several thousand lux. As mentioned above, sunlight increases vigour and improves the physiological condition of the bird. However, increased motor activity under such conditions leads to

a certain decrease in live weight gain and increased feed consumption, and under conditions of improper feeding, and high density, it will affect the growth of cannibalism. In addition, these problems arise when using significant parameters of lighting intensity through artificial light sources. In such cases, it is recommended to reduce the lighting parameters to 6-2 lux. However, 1 lux is the minimum level of illumination at which turkeys can clearly distinguish individual objects. This observation was mentioned in the above research.

The effect of LED lighting on laying hens and broiler turkeys is well explored. For example, in studies conducted in Great Britain by H.M. Hiscock *et al.* (2022) and in USA by K. El-Sabrout *et al.* (2022), it was established that using LED lamps in laying hens contributed to a decrease in cannibalism and an increase in egg production; when growing young chickens, it increased survival by 0.5%, live weight by 4-8%, reduced specific feed consumption, increased poultry weight, and in all cases it reduced electricity consumption for lighting by 3-12 times.

I.C. De Jong and H. Gunnink (2019), O. Kilincceker and A.M. Karahan (2020) proved that using fluorescent and compact fluorescent lamps allows reducing the specific electricity consumption for lighting poultry houses by 3-5 times, depending on the type of lamp, and using lamps with blue or green light contributes to the increase in live weight and the survival of turkeys. With all types of lamps, it is helpful to use special lighting regulators that allow turning them on in the "dawn-to-sunset" mode. It reduces stress in the bird, reduces electricity costs for lighting and increases the life of the equipment. This study is partially confirmed by using the abovementioned fluorescent lamps of the PSP1B2-36 type, which reduced electricity consumption compared to the state before the experiment. Therewith, M.A. Erasmus (2018) mentioned that another way to reduce electricity costs for lighting is to use natural light. It can be done by installing window openings, while the area of the openings should be at least 1/10 of the floor area.

In the final study, A.B. Kotlyarova *et al.* (2019) mentioned the following opinions: the adverse aspects of using a low level of illumination in premises where birds are kept are a decrease in the mobility of birds. It adversely affects the development of their internal organs, and physiological indicators in general and stimulates the development of eye diseases. In addition, as birds spend a large part of their time perched on the floor, their feathers on the lower part of the body deteriorate. Therefore, a low level of illumination when raising poultry is recommended only in exceptional cases, for example, provided that the level of cannibalism has begun to progress in the group. Various studies have only confirmed that birds grown with optimal length of dark periods are less likely to have sudden death syndrome, limb disease and additional characteristic diseases, compared to birds deliberately grown with

lights that do not turn off. Moreover, there is a significant improvement in broiler fattening parameters such as feed conversion, average daily live weight gain and meat quality. However, too long periods of darkness (8 hours or more) during the day lead to a decrease in feed consumption and live weight gain, and prolonged sitting on litter leads to problems with legs and feathers, and sludge and hematomas. The guidelines used in the research above avoided the adverse effects of low light and long periods of darkness, but an increase in cannibalism and a decrease in group homogeneity were observed.

CONCLUSIONS

The research was conducted on individuals of broiler turkeys of the Big-6 breed in poultry enterprises of the Chernivtsi Oblast in 2022. The results of the study demonstrated that the most developed muscle tissue (8077.2 g) was in experimental group No. 1, which was grown using the method of lighting with the highest intensity, rather long daylight hours and night feeding at the end of the growing period. It was the leader in growth dynamics and slaughter weight, but the indicators of homogeneity in terms of live weight of individual birds were the lowest. In experimental group No. 2, which was grown under conditions of high intensity (however less than in experimental group No. 2), average duration of light day and night feeding from the first week of life, the value of the index of muscle tissue development was slightly lower (by 1.6%) than in the

first experimental group, but by 11.2% more than in the control group. All other characteristics were average between the other groups participating in the study. A slight increase in the content of dry matter (by 0.4-0.6%), protein (by 0.3-0.4%) and a decrease in fat content (by 0.3-0.4%) was observed in the pectoral muscles of young animals of the experimental groups. The caloric content of this muscle group in turkey chicks of the experimental groups was almost at the level of the control bird (119.3-119.9 and 120.0 kcal/100 g, respectively). The control group, which was grown at a relatively low intensity, with an average length of light day and no night feeding, demonstrated the lowest mass values and the worst growth dynamics. Therewith, this group dominated in the indicators of preservation and homogeneity.

Prospects for further research may include an area of movement in exploring the influence of different wavelengths of light on the slaughter and meat qualities of broiler turkeys, under conditions of the same lighting systems and schedules. In addition, the question of researching different lighting systems specifically for turkeys remains open, as research with this bird is rarely conducted.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Забійні та м'ясні якості індичат-бройлерів за різних світлових програм під час вирощування

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Анотація. Питання підбору світлових програм у пташниках має велике значення при вирощуванні індиків-бройлерів, адже нехтування ним призводить до погіршення рухового режиму птиці. Такий фактор призводить до погіршення загального стану здоров'я та дестабілізує належне функціонування систем організму. Метою досліджень було з'ясувати вплив різних способів освітлення на забійні та м'ясні якості індичат-бройлерів. У дослідженнях використовували такі методи: гістологічні, анатомічні, морфометричні, світлооптичні, статистичні. Дослідження проводили у 2022 році на двох групах індичат-бройлерів кросу Біг-6 у пташниках контрольної групи та двох дослідних виробничих майданчиках №7 птахопідприємств Чернівецької області. Регулювання світлових програм кожного пташника здійснювали за допомогою люмінесцентних ламп типу ПСП1В2-36, які забезпечують освітлення теплого білого кольору (колірна температура 2700 К). За результатами досліджень встановлено, що найбільш розвинена м'язова тканина була у індичат, вирощених за методом з використанням високоінтенсивного освітлення. Інша експериментальна група також показала результати вищі, ніж контрольна. Якість м'яса різних груп також мала певні незначні відмінності: у грудних м'язах дослідних груп спостерігалось незначне збільшення вмісту сухої речовини (на 0,4-0,6 %), білка (на 0,3-0,4 %) та зменшення вмісту жиру (на 0,3-0,4 %). Калорійність практично не змінилася. Дослідні групи також мали перевагу за хімічним складом та енергетичною цінністю м'яса. Результати проведених досліджень можуть бути використані для удосконалення системи вирощування індичат-бройлерів, більш детального вивчення реакції птиці на різні умови утримання та впливу цих умов на організм. Це дасть можливість швидше отримувати високоякісну продукцію та знизити собівартість виробництва

Ключові слова: розведення; світловий режим; відгодівельний молодняк; білок; пташники



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Rationale for the prevention of mastitis in cows during the dry period and after calving

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Abstract. Testing cows for mastitis before starting and treating all milch cows with a long-acting antimicrobial agent is an important component of the preventive preparation of animals for the dry period. In addition, determining the sensitivity of pathogens isolated on the farm and rotating antimicrobials increases the effectiveness of therapy and reduces the risk of resistant strains of microorganisms. The purpose of this study was to determine the preventive and therapeutic effects of preparations based on povidone-iodine and cefquinome sulfate for cows with mastitis. The following methods were used in the study: calculation of the total number of somatic cells by flow cytometry; California test; sensitivity to antimicrobial agents by agar disks; clinical and physiological method; statistical method. During the examination of cows for mastitis, it was identified that in the



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control group the number of somatic cells averaged 450 thousand/cm³, the total number of microorganisms was 130 thousand. In cows of the experimental group, productivity was 23.6%, the number of somatic cells was 600 thousand/cm³, microorganisms – 550 thousand CFU/cm³. It was identified that the isolated microflora showed high sensitivity to the preparation based on povidone-iodine and cefquinome sulfate. Therefore, udder conservation for cows of the experimental group with signs of mastitis was conducted with a product based on povidone-iodine, which affected the increase in lactation and improvement of milk quality after calving. The criteria for milk in the experimental group at the end of the experiment corresponded to the grade extra – 30%, top – 60%, and first – 10%. As a result of the therapy, lactation improved in cows, and the quality of milk corresponded to the first grade. At the end of the study, the quality of milk in cows of the control group corresponded to the extra Grade – 10%, top – 40%, and first – 50%. The practical value of the study lies in the prevention of mastitis on the farm, improving the quality of the resulting products, reducing the cost of veterinary care and culling animals

Keywords: mammary gland inflammation; milk production; teat channels; pathogens of mastitis; somatic cells

INTRODUCTION

Mastitis is one of the most common diseases that occur in dairy cows and affects the productivity and health of animals. Symptoms of clinical mastitis in cows include changes in the physico-chemical and microbial composition of milk and pathological changes in the glandular epithelium. An artificial model of epithelial cells was developed to conduct analysis *in vitro* to examine the changes that occur in the mammary gland (Saed & Ibrahim, 2020; Xu *et al.*, 2021).

Mastitis is often caused by microorganisms such as *Escherichia coli*, *Staphylococcus aureus*, *Streptococcus dysgalactiae*, and *Streptococcus agalactiae* (Shkromada *et al.*, 2019). Therefore, for its treatment, veterinarians use antimicrobial agents, which include synthetic preparations that kill or slow down the growth of microorganisms. However, due to limitations in the use of antimicrobials and the emergence of resistance in microorganisms, researchers are developing new alternative methods for treating mastitis.

In addition, food mycotoxicoses caused by the presence of microscopic fungi *Aspergillus flavus* and *Aspergillus parasiticus* in the feed can contribute to udder inflammation. Animals experience acute and chronic poisoning. Researchers (Wang *et al.*, 2020) developed a method for detecting the toxin in feed. A limitation of the study is that the detection method was developed only in relation to aflatoxin. Therefore, it remains necessary to control the quality of feed for pregnant and lactating cows.

Researchers Xu *et al.* (2021) in the *in vitro* experiment determined the effect of the *T. Officinale* extract on *Staphylococcus aureus*. As a result, it was proved that the growth of *S. aureus* was suppressed after the application of phenolic extract *T. Officinale*. Researchers Zhu *et al.* (2022) also identified that the antimicrobial peptide MPX exhibits bactericidal activity against *S. aureus*. However, studies have not been replicated in production environments for the treatment of cows with bacterial mastitis caused by *Staphylococcus aureus*.

A probiotic-based method was also proposed to treat subclinical mastitis (Shkromada *et al.*, 2022). The

authors determined that *B. megaterium* NCH 55 showed the ability to inhibit the growth of microorganisms. The limitation of the study lies in the individual sensitivity of each animal to a probiotic, the effect of which is difficult to trace due to the multi-vector effect on the body.

Treatment of clinical bacterial mastitis is a complex task, due to the speed of development of the process and the risk of infection of a substantial part of the livestock. Wang *et al.* (2019) proposed to use a specific antimicrobial peptide JH-3 for the destruction of *Salmonella enterica*. The results showed that treatment with a peptide at a dose of 40 mg/kg of JH-3 had the most pronounced therapeutic effect. In addition, all physiological and clinical parameters in mice were close to normal. The experiment was conducted under laboratory conditions with a test strain *Salmonella enterica* serotype CVCC541. There is no data on the effectiveness of the antimicrobial peptide JH-3 in production conditions against field strains of *Salmonella*.

Researchers Fotina *et al.* (2018) identified that depending on the degree of mammary gland inflammation, the species composition of somatic cells can vary. Thus, the number of macrophages and eosinophils in milk increases from 1.5 to 4 times, respectively. It is proved that the number of somatic cells in the evening milk yield is 30% higher than in the morning milk yield. The results obtained by the researchers are limited only to goat's milk, so it is not known whether there is a certain pattern in cow's milk.

Mastitis has a predominantly bacterial aetiology, so treatment is often based on the use of antibiotics (Kober *et al.*, 2022). However, due to the increase in antimicrobial resistance every year, the effectiveness of treatment decreases. A new antimicrobial agent based on triazole was developed as an alternative to antibiotics (Karpun *et al.*, 2021). However, the spectrum of action of the sensitivity of this tool was tested only on *Salmonella pullorum*, *Salmonella typhimurium*, *Salmonella enteritidis*, *Escherichia coli* O2.

Blanchet *et al.* (2021) concluded that it is necessary to change the old methods of treating mastitis based

on antibiotics and test new therapeutic agents. However, researchers faced the problem of using live probiotic cultures for the treatment of mastitis.

Prevention of mastitis in the herd is very important, especially when preparing cows for the dry period. When developing a set of necessary measures for the control and prevention of mammary gland inflammation on the farm, a multi-vector approach is necessary. It should be considered that it is impossible to completely get rid of the disease in a dairy herd, but the risks of spreading mastitis pathogens among livestock can be reduced. Researchers Zigo *et al.* (2021) considered the possible causes of mammary gland inflammation in cows, but specific methods of prevention and treatment of the disease were not proposed.

Studies, conducted by Muturi (2020), showed that udder inflammation in cows affects milk production and culling of sick cows. However, the author did not suggest measures to prevent subclinical mastitis on farms.

After calving, cows have the most difficult first three weeks, when postpartum stress can lead to inflammation of the udder. For the treatment of mastitis in lactating cows, there is a fairly limited amount of preparations, due to the risk of absorption into milk. I. Holko *et al.* (2019) investigated isolated pathogens of mastitis: coagulase-negative staphylococci, *Escherichia coli*, *Staphylococcus aureus*, *Streptococcus uberis*, and *Streptococcus agalactiae* and identified a high overall resistance to aminoglycosides (streptomycin, neomycin) in dairy farms in Slovakia, but studies did not propose an alternative solution to this problem.

The purpose of the study was to establish the effect of preparations based on povidone-iodine and cefquinome sulfate on the body of cows in the treatment of mastitis. The objectives of the study were: determination of mastitis patients in a herd of cows; examination of antimicrobial activity of preparations based on povidone-iodine and cefquinome sulfate; identification of the therapeutic effect of the products based on povidone-iodine and cefquinome sulfate for cows with mastitis.

MATERIALS AND METHODS

The study was conducted on the dairy farm of the North-Eastern region of Ukraine "Agrofirma Lan" on Holstein cows in the period of February-August 2022 in accordance with directive 2010/63/EU (Hartung, 2010), which was approved by the conclusion of the Commission on ethics and bioethics of the Faculty of Veterinary Medicine of Sumy National Agrarian University dated 11.04.2022.

Examination of cows for subclinical mastitis. Milk tests for mastitis were performed two weeks before the dry period and after calving for 4 weeks to dry off the cows. Milk samples were obtained in sterile vessels. Determination was performed using the California test (Bhutto *et al.*, 2012), SCC (somatic cell count), and

QMAFAnM (Quantity of mesophilic aerobic and facultative anaerobic microorganisms) in each cow. The total number of somatic cells was calculated by flow cytometry using the SomaCount Flow Cytometer device. QMAFAnM in cow's milk was determined by the bacterial method. Endo agar elective media were used for the *Salmonella* and *Escherichia* microorganisms identification; yolk-salt agar (Chistovich) – *Staphylococcus aureus*; Saburo agar – mould fungi and yeast. PCR (polymerase chain reaction) was also used to determine *Mycoplasma spp.* in milk. The number of colony-forming units was determined in CFU/cm³ according to DSTU 7357:2013 "Milk and milk products. Methods of microbiological monitoring".

Determination of microflora sensitivity to antimicrobial agents. Isolated microorganisms from milk were examined for antimicrobial sensitivity by agar discs in Petri dishes. Antibiotics of various groups and agents based on povidone-iodine and cefquinome sulfate were used in the study (Garkavenko *et al.*, 2021).

Investigation of the therapeutic effect of the use of preparations based on povidone-iodine and cefquinome sulfate. The experimental group consisted of 10 heads. Cows in the dry period (6 weeks before calving) after the last milking were intracisternally injected once into each quarter of the udder at a dose of 10 g of povidone-iodine-based agent. Therewith, cows of the control group (10 animals) had their udder preserved with a jelly-like substance without the use of an antimicrobial agent. After calving, SCC in milk, QMAFAnM, and milk productivity were determined in control and experimental animals. Animals with elevated SCC and QMAFAnM values and reduced milk production were treated with cefquinome sulfate-based agents to treat udder inflammation. The results were recorded for 4 weeks. When conducting experiments, DSTU 3662:2018 "Raw cow milk" was adhered to.

Statistical analysis. The Microsoft Excel 2010 programme and Fisher-Student statistical analysis were used, considering statistical errors and data probabilities of more than 95% to analyse the results obtained ($p < 0.05$).

All experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). The keep of animals and all manipulations were conducted in accordance with the provisions of the procedure for conducting experiments and experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (European convention..., 1986).

RESULTS AND DISCUSSION

Results of the examination of cows for subclinical mastitis. Cows were prepared for the dry period after a thorough examination for mastitis since it is necessary to dry

off the animals with a healthy udder. Therefore, at the beginning of the experiment, all the cows that were

preparing for such a procedure were examined. SCC and QMAFAnM were determined in their milk (Fig. 1).

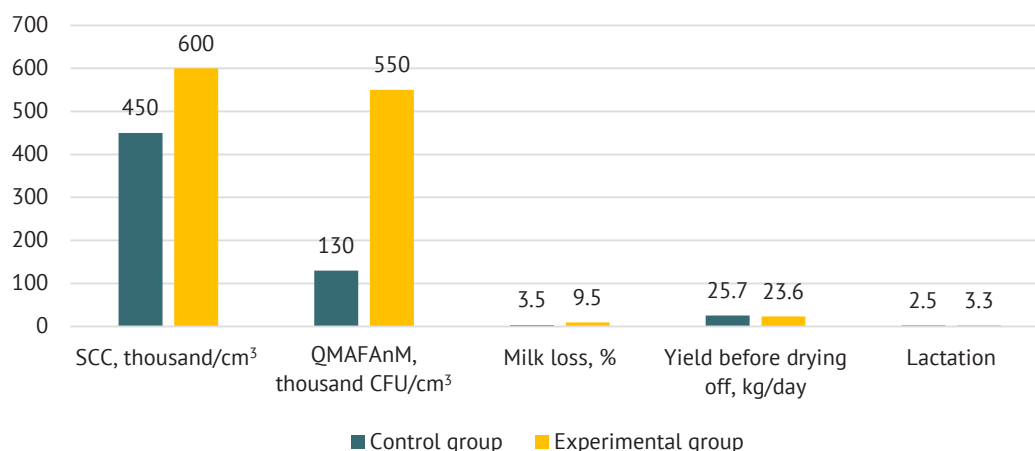


Figure 1. Results of the examination of cows for mastitis before starting drying off (on average)

Source: compiled by the authors

In the control group, the average number of somatic cells was 450 thousand/cm³, QMAFAnM – 130 thousand CFU/cm³, the estimated loss of milk at such indicators is 3.5%, milk yield – 25.7 kg/day. The main share of the control group consisted of cows of the second lactation. The experimental group included animals mainly of the third lactation with milk productivity of 23.6 kg/day before drying off. On average, in the experimental group, SCC was 600 thousand/cm³,

QMAFAnM – 550 thousand CFU/cm³. A control group of ten cows was formed, the milk of which showed a low content of somatic cells and microorganisms. For healthy cows, udder conservation was conducted with a jelly-like sealant without the antimicrobial agent, to prevent microorganisms from entering the milking canal during the period of drying off. During the examination of cows for mastitis, isolated pathogenic microorganisms were monitored (Fig. 2).

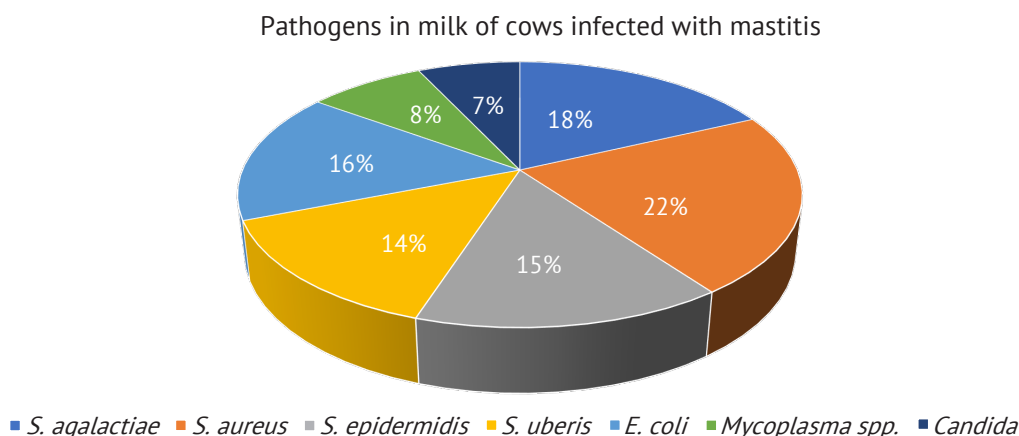


Figure 2. Monitoring of mastitis pathogens in cows before the period of drying off

Source: compiled by the authors

The conducted studies established the predominant number of isolated pathogens of *S. aureus* (22%), *S. agalactiae* (18%), *E. coli* (16%), *S. epidermidis* (15%), and *S. uberis* (14%).

Thus, a change in the structure of the udder, such as a deformity, can be used as a sign of inflammation. Therefore, animals with deformed udders and teats were not used in the experiment, due to possible

individual health problems that may affect the overall result of the experiment.

Results of the study of antimicrobial activity of products based on povidone-iodine and cefquinome sulfate. In cows of the experimental group, where SCC and QMAFAnM had high indicators, udder sealing was performed with a preparation to which the isolated microflora showed sensitivity (Fig. 3).

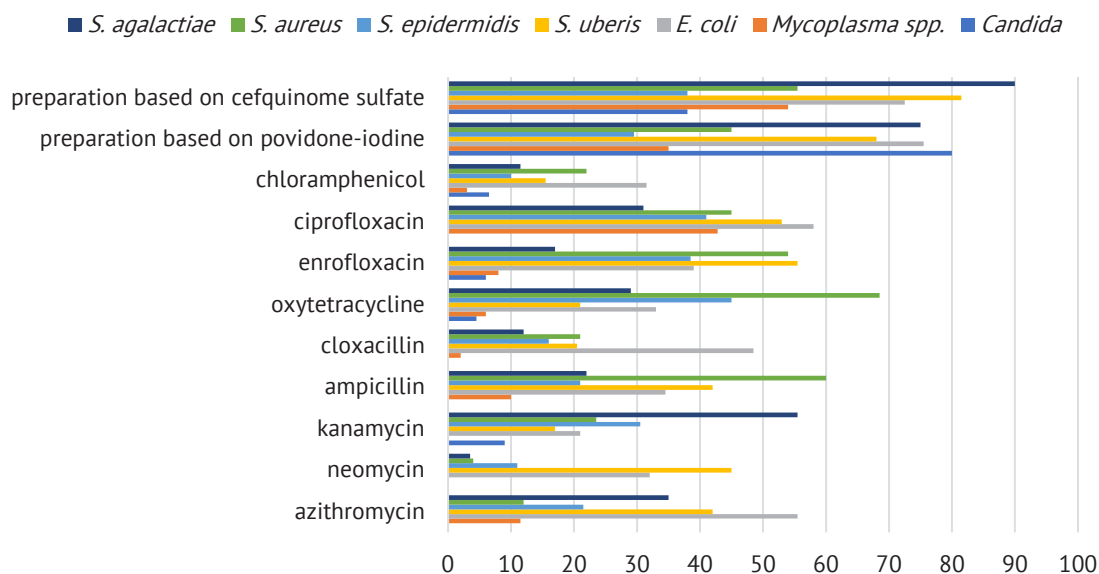


Figure 3. Sensitivity of mastitis pathogen isolates to antimicrobial agents (%)

Source: compiled by the authors

According to the results of the conducted studies, it was identified that the isolated microflora showed high sensitivity to a preparation based on povidone-iodine and cefquinome sulfate (Garch *et al.*, 2020). The most resistant were the bacteria of *Mycoplasma spp.* genus and yeast fungi of the *Candida* genus. Udder hygiene is very important and affects the risk of developing subclinical mastitis caused by staphylococci and streptococci, which are identified in large numbers on the udder skin (Paliy *et al.*, 2021). Therefore, in animals of the experimental group that had an

increased content of SCC and QMAFAnM, udder conservation was conducted with a povidone-iodine-based agent to prevent the development of intramammary infection.

Results of determining the therapeutic effect of preparations based on povidone-iodine and cefquinome sulfate for use in cows with mastitis. After udder conservation, the control and experimental groups were monitored for the entire pregnancy period of cows. After calving, cows were re-examined for mastitis and their productivity was monitored (Table 1).

Table 1. Cow productivity indicators

No.	Productivity before drying off		Post-calving productivity			
	kg/day		kg/day			
	identification number of the animal		I week	II week	III week	grade
Control group						
1	4520	25	27	30	30	extra
	QMAFAnM, thousand CFU/cm ³	195	287	134	100	
	SCC, thousand/cm ³	360	489	430	387	
2	8023	24	18	24	28	first
	QMAFAnM, thousand CFU/cm ³	196	1020	800	480	
	SCC, thousand/cm ³	254	986	550	395	
3	3645	26	20	25	29	first
	QMAFAnM, thousand CFU/cm ³	120	1123	870	500	
	SCC, thousand/cm ³	347	1045	956	460	
4	0123	28	22	25	30	top
	QMAFAnM, thousand CFU/cm ³	145	350	300	215	
	SCC, thousand/cm ³	420	480	420	400	
5	6231	31	25	31	35	top
	QMAFAnM, thousand CFU/cm ³	150	450	300	280	
	SCC, thousand/cm ³	419	467	412	400	

Table 1, Continued

No.	Productivity before drying off		Post-calving productivity			
	kg/day		kg/day			
	identification number of the animal		I week	II week	III week	grade
6	6045	25	26	29	32	first
	QMAFAnM, thousand CFU/cm ³	245	480	430	378	
	SCC, thousand/cm ³	456	440	423	356	
7	7630	24	26	28	31	top
	QMAFAnM, thousand CFU/cm ³	234	369	350	240	
	SCC, thousand/cm ³	350	420	345	304	
8	7656	25	25	25	27	first
	QMAFAnM, thousand CFU/cm ³	206	506	480	403	
	SCC, thousand/cm ³	436	490	380	354	
9	7659	22	20	25	30	top
	QMAFAnM, thousand CFU/cm ³	156	320	300	300	
	SCC, thousand/cm ³	340	400	456	380	
10	0355	24	28	32	34	first
	QMAFAnM, thousand CFU/cm ³	120	320	300	360	
	SCC, thousand/cm ³	350	456	400	490	
Experimental group						
11	0348	28	29	30	30	extra
	QMAFAnM, thousand CFU/cm ³	500	316	300	100	
	SCC, thousand/cm ³	610	400	368	350	
12	0944	24	27	29	31	top
	QMAFAnM, thousand CFU/cm ³	523	290	312	300	
	SCC, thousand/cm ³	515	450	380	345	
13	0956	26	29	29	30	first
	QMAFAnM, thousand CFU/cm ³	515	438	400	325	
	SCC, thousand/cm ³	645	450	433	400	
14	6269	27	29	29	32	extra
	QMAFAnM, thousand CFU/cm ³	527	345	307	100	
	SCC, thousand/cm ³	644	419	400	370	
15	6735	25	26	27	29	top
	QMAFAnM, thousand CFU/cm ³	513	250	245	234	
	SCC, thousand/cm ³	512	456	380	382	
16	6957	24	29	30	30	extra
	QMAFAnM, thousand CFU/cm ³	556	300	218	98	
	SCC, thousand/cm ³	550	420	400	385	
17	7645	25	29	30	32	top
	QMAFAnM, thousand CFU/cm ³	540	420	360	250	
	SCC, thousand/cm ³	660	500	430	400	
18	7823	24	26	29	30	top
	QMAFAnM, thousand CFU/cm ³	557	320	300	250	
	SCC, thousand/cm ³	680	450	435	390	
19	0368	23	25	26	29	top
	QMAFAnM, thousand CFU/cm ³	690	357	360	280	
	SCC, thousand/cm ³	700	510	480	445	
20	0657	25	27	29	30	top
	QMAFAnM, thousand CFU/cm ³	670	420	320	240	
	SCC, thousand/cm ³	720	538	470	398	

Source: compiled by the authors

Animals that were preparing for the dry period were selected in the control group, and their indicators (somatic cells and the number of microorganisms in milk) were within the normal range, that is, they corresponded to the grade not lower than the first. Before launching, each cow was injected with sealant into all four udder lobes. For healthy cows in the control group, a jelly-like sealant without an antimicrobial agent was used. Animals of the experimental groups were treated with a preservative based on povidone-iodine to treat existing subclinical mastitis and prevent the occurrence of a new infection during the dry period. In addition, animals the milk values of which did not correspond to the grade and tended to worsen were given a separate course of treatment.

As the results in the table show, in cows of the control group before the dry period, SCC and QMAFAnM were within the normal range and corresponded to a grade not lower than the highest. Milk yield for this period was low in cows of the control and experimental groups, which corresponds to productivity before drying off. Therefore, pre-drying off performance was not considered. Cows that were selected in the experimental group had high SCC and QMAFAnM before starting, which is a sign of the development of subclinical mastitis.

After calving, cows in the control group of ten heads – two had high SCC and QMAFAnM, which is 20%. A study by Tomanić *et al.* (2023) shows that when antimicrobial preservatives are no longer used, udder health worsens. In cows of the control group, a conventional sealant without an antimicrobial agent was used to preserve the udder. During the period of drying off, an intramammary infection developed in the udder and after calving, which is a stress factor, the cows showed signs of mastitis (Ndahetuye *et al.*, 2022).

The milk yield of Cow No. 8023 decreased by 25% compared to the pre-drying off period. In the first week, QMAFAnM increased by 420.3%, SCC – 288.2%, which indicates inflammation of the udder. In cow No. 3645, in the first week after calving, productivity worsened by 23.0%, QMAFAnM indicators increased by 835.8%, SCC – 201.1%, compared to the dry period. Cows No. 8023 and No. 3645 were treated with cefquinome sulfate, 8 g of which was injected intracisternally into the affected quarter of the udder from a syringe tube every twelve hours three times. Previously, studies have shown that the isolated microflora was sensitive to the cefquinome sulfate-based agent.

After the treatment in the second week, the productivity of cow No. 8023 increased by 33.0%, QMAFAnM indicators decreased by 22.0%, and SCC – 44.2% compared to the first week. Animal No. 3645 also had improved performance indicators by 25% after treatment, QMAFAnM – 22.5%, SCC – 9.3% compared to the period before treatment.

In the third week, the productivity of cow No. 8023 increased by 16.6%, QMAFAnM decreased by 40.0%, SCC – 28.2%, compared to the second week after

calving. In cow No. 3645, milk yield increased by 16.0% during the third week, QMAFAnM – 42.5%, SCC – 51.9%, compared to the second week.

In cow No. 4520, lactation increased in the first week after calving by 8.0%, in the second and third – 20.0%. Therewith, the indicators of QMAFAnM and SCC changed during the study period, but in the third week, the quality of milk corresponded to the extra grade.

After the calving of cow No. 0123, productivity changed during the study period. In the first week, lactation decreased by 21.4%, in the second – 10.7%, and increased in the third week – by 7.1%, compared to the period of drying off. The quality of milk corresponded to the top grade.

Cow No. 6231 after calving was 19.4% less productive in the first week, and in the second – the indicators corresponded to the initial values before the drying off. At the end of the experiment, lactation increased by 12.9%, and the quality of milk corresponded to the top grade. After calving, animal No. 6045 showed an increase in lactation by 4.0%, in the second week – 16.0%, and in the third – 28.0%. Therewith, the milk criteria corresponded to the first grade.

In cow No. 7630, milk production increased by 8.3% in the first week, 16.6% in the second, and 29.2% in the third, compared to the period before drying off. The quality of the milk corresponded to the top grade. Cow No. 7656 after calving had productivity in the first and second weeks similar to the drying off period. In the third week, lactation increased by 8.0%, and the quality of milk was of the first grade.

In the first week after calving, the productivity of cow No. 7659 decreased by 9.0%, in the second week it increased by 13.6%, and in the third week – 36.4%. The milk quality corresponded to the top grade. In cow No. 0355, lactation after calving increased in the first week by 16.6%, in the second – 33.3%, and in the third – 41.6%, and corresponded to the first grade. In general, for the entire period of the study, the quality of milk in cows of the control group corresponded to the extra grade – 10%, top – 40%, and first – 50%. Accordingly, the farm suffered funds loss due to the deterioration of product quality.

After calving in all cows of the experimental group, the levels of SCC and QMAFAnM were within the normal range and did not tend to increase. Prior to the drying off, cows in this group showed signs of subclinical mastitis (Bari *et al.*, 2022) and therefore udder conservation was conducted using a povidone-iodine-based preparation. During the dry period, udder treatment was conducted and milk quality and productivity indicators returned to normal (Keefe, 2012). Thus, the productivity of cow No. 0348 increased by 3.5% in the first week after calving and 7.1% in the second and third weeks. The quality of the milk corresponded to the extra grade.

After calving, the lactation of cow No. 0944 increased by 12.5% in the first week, 20.8% in the second, and 29.1% in the third, compared to the pre-drying off

period. The quality of the product corresponded to the top grade. In cow No. 0956, productivity in the first and second weeks increased by 11.5%, and in the third – 15.3%, the milk quality indicators corresponded to the first grade. In the first and second weeks after calving, the lactation of cow No. 6269 increased by 7.4%, and in the third week – 18.5%. The quality of the milk corresponded to the extra grade.

In cow No. 6735, lactation increased by 4.0% in the first week, in the second – 8.0%, and in the third – 16.0%, compared to the period before drying off. According to the criteria, the milk corresponded to the top grade. The first week after calving was favourable for cow No. 6957, productivity increased by 20.8%, and in the second and third – by 25.0%. The quality of the milk was the extra grade. For animal No. 7645, the first week began with an increase in milk yield by 16.0%, the second – 20.0%, the third – 28.0%. The milk grade met the top criteria.

Cow No. 7823 after calving had productivity higher by 8.3%, in the second week – 20.8%, in the third – 25.0%, compared to the period of drying off. The quality of the product corresponded to the top grade. In the first week, cow No. 0368 had an increase in lactation by 8.6%, in the second – 13.0%, in the third – 26.0%. Therewith, the quality of the milk corresponded to the top grade. In cow No. 0657, milk productivity after calving increased by 8.0% in the first week, 16.0% in the second, and 20.0% in the third. The resulting product corresponded to the top grade. At the end of the experiment, the overall productivity of the cows of the experimental group was high and corresponded to the quality of the extra grade – 30%, top – 60%, and first – 10%.

Studies showed that the number of somatic cells averaged 450-600 thousand/cm³, and the number of mesophilic microorganisms and facultative anaerobic microorganisms was 130–550 thousand CFU/cm³, productivity ranged between 23.6–25.7 kg/day. The results obtained indicate the beginning of the development of subclinical mastitis. Researchers Müller *et al.* (2023) established that there is a need to treat cows during the dry period, but not all microorganisms show the same sensitivity to the antibiotic.

Microorganisms were isolated from the cows' milk: *S. aureus* (22 %), *S. agalactiae* (18 %), *E. coli* (16 %), *S. epidermidis* (15%), and *S. uberis* (14%), which are the main causative agents of mastitis in the animal husbandry. According to (Hasan *et al.*, 2022), about 137 species of microorganisms can cause mammary gland inflammation in cattle. The main cause of subclinical mastitis in cattle and other animal species is considered to be bacteria.

Damage to the udder and teats contributes to the penetration of microorganisms into the teat channels and can cause subclinical mastitis (Sharun *et al.*, 2021). Paliy *et al.* (2021), identified that careful mechanical washing of the udder before milking with special brushes cleans and stimulates the teats, which allows

for reducing microbial contamination and preventing infection of the teats.

Many factors contribute to the high prevalence of mastitis in dairy cows on farms. These components include the method of keeping (tethered or loose), hygiene of the room and feed, floor quality, quality of milking equipment, udder sanitation, etc. (Neculai-Valeanu & Ariton, 2022). A particularly important period for dairy cows is the period of three weeks before and after calving (Zhao *et al.*, 2020). During this period, health problems may occur. Creating conditions for the timely adaptation of animals to a new physiological state requires an appropriate balanced diet and compliance with sanitary conditions of keep (Cheng *et al.*, 2020).

Z. Kovačević *et al.* (2022) determined that, despite calving, selective treatment of cows with mastitis before drying off allows for reducing the overall use of antibiotics in the dairy herd. Due to changes in the technology of keeping animals, it became necessary to control the occurrence of mastitis, which is caused by conditionally pathogenic microorganisms from the environment (Ruegg, 2017).

Studies showed that the prevention of mastitis in cows during the dry period is based on the timely culling of sick animals and their treatment before drying off. It is also necessary to use a sealant with antimicrobial properties to preserve the udder. In addition, after calving, it is necessary to continue to monitor the manifestations of subclinical mastitis and rotate antimicrobial agents in a timely manner, to which the isolated microflora shows the greatest sensitivity.

CONCLUSIONS

In healthy animals of the control group, the number of somatic cells was 450 thousand/cm³, the number of mesophilic aerobic and facultative anaerobic microorganisms was 130 thousand CFU/cm³, and productivity – 25.7 kg/day. Animals of the experimental group with signs of mastitis had a somatic cell count of 600 thousand/cm³, the number of mesophilic aerobic and facultative anaerobic microorganisms – 550 thousand CFU/cm³, and productivity – 23.6 kg/day.

Microflora isolated from the milk of sick cows (*S. aureus* (22%), *S. agalactiae* (18%), *E. coli* (16%), *S. epidermidis* (15%), and *S. uberis* (14%)), showed high sensitivity to products based on povidone-iodine and cefquinome sulfate, except for bacteria of the *Mycoplasma spp.* genus and yeast fungi of the *Candida* genus.

It was identified that 20% of cows that underwent udder conservation without the use of antimicrobial agents had high indicators of SCC and QMAFAnM. Therefore, sick cows were treated with a cefquinome sulfate-based agent in each affected quarter of the udder, 8 g from a syringe tube every twelve hours three times. During the week, the productivity and quality of milk were restored to the first grade. In animals of the control group, at the end of the study, milk quality

corresponded to the following grades: extra – 10%, top – 40%, first – 50%.

Cows of the experimental group, for which the udder was preserved using a preparation based on povidone-iodine, after calving had a healthy udder and milk quality that corresponded to the extra grade – 30%, top – 60%, first – 10%. During the entire study period after calving, no treatment was applied to the animals, and no signs of subclinical mastitis were recorded. The

prospect of further research is to determine the possible dependence of the occurrence of mastitis on the lactation period in cows.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Обґрунтування профілактики маститу корів в сухостійний період та після отелення

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Анотація. Дослідження корів на мастит перед запуском та обробкою всіх дійок протимікробним засобом тривалої дії є важливим компонентом профілактичної підготовки тварин до сухостійного періоду. Крім того, визначення чутливості ізолюваних в господарстві патогенів та проведення ротації антимікробних засобів збільшує ефективність терапії та зменшує ризик виникнення резистентних штамів мікроорганізмів. Метою цього дослідження було визначення профілактичного та терапевтичного ефекту засобів на основі повідон-йоду та цефквіну сульфату для корів, хворих на мастит. У роботі були використані наступні методи: підрахунок загальної кількості соматичних клітин методом проточної цитометрії; каліфорнійський тест; чутливість до протимікробних засобів методом дисків на агарі; клінічний та фізіологічний метод; статистичний метод. Під час дослідження корів на мастит було встановлено, що у контрольній групі кількість соматичних клітин в середньому склала 450 тис/см³, загальна кількість мікроорганізмів – 130 тис. У корів дослідної групи продуктивність становила 23,6 %, кількість соматичних клітин – 600 тис/см³, мікроорганізмів – 550 тис. КУО/см³. Встановлено, що виділена мікрофлора проявляла високу чутливість до засобу на основі повідон-йоду та цефквіну сульфату. Тому консервацію вимені коровам дослідної групи з ознаками маститу проводили засобом на основі повідон-йоду, що вплинуло на збільшення лактації та покращення якості молока після отелення. Критерії молока в дослідній групі по завершенню експерименту відповідали ґатунку «екстра» – 30 %, «вищий» – 60 %, «перший» – 10 %. В результаті проведеної терапії у корів покращилася лактація, і якість молока відповідала ґатунку «перший». По завершенню дослідження у корів контрольної групи якість молока відповідала ґатунку «екстра» – 10 %, «вищий» – 40 %, «перший» – 50 %. Практична цінність дослідження полягає у профілактиці маститу у господарстві, поліпшенні якості отриманої продукції, зменшенні витрат на ветеринарне обслуговування та вибраккування тварин

Ключові слова: запалення молочної залози; молочна продуктивність; дійкові канали; збудники маститу; соматичні клітини



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Pathogenesis and pathomorphology of distraction trauma in the framework of pre-trial investigations of cruelty to animals

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Abstract. The importance of identification and differential diagnosis of spinal injuries, in the case of polytrauma, the ability to distinguish the pathogenesis of various injuries are important and relevant both during clinical and during pathological examination of the animal's body. The purpose of research is to provide veterinary practitioners and lawyers with strategies for identifying the cause (mechanism) of spinal cord injury and to assist triers of fact (decision-makers) in arriving at plausible and reasoned veterinary forensic conclusions. The research was performed using pathological and anatomical dissection and histological studies. It was established that damage to the cervical spinal cord due to traumatic bending of the neck was accompanied by partial or complete rupture of the intervertebral disc and destruction of the ligaments of the vertebrae.



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It was found that the hyperemia of the vessels of the meninges of the brain is the result of blood circulation disorders in the occipital artery and the caudal artery of the meninges, and mechanical damage to the integrity of the intervertebral discs or the destruction of the ligaments of the neck vertebrae led to various disorders of the innervation of various organs and systems of the body and ended the death of animals. It was proved that the distraction injury of the cervical spine led to the swelling of the medulla of the brain, haemorrhages of the caudal-ventral part of the brain substance. It was found that irritation of nervus vagus led to hyperemia of vessels of large (aorta and trunk of pulmonary artery) caliber, cranial mesenteric artery) caudal mesenteric artery and, accordingly, hyperemia of thoracic and abdominal organs. Application of research results will help in differentiation of various types of mechanical injuries of the spine (including differentiation from other pathological conditions of the body), determination of the area of the applied force vector

Keywords: traumatic bending of the neck; distraction injury; cervical vertebrae; spinal cord; swelling; bleeding

INTRODUCTION

The problem of cruelty to animals becomes more urgent every year and is raised both by specialists in law enforcement agencies and doctors of veterinary medicine and by society in general. Without a forensic veterinary examination, a full and comprehensive investigation of offences related to animal cruelty is not possible (Bright *et al.*, 2018; Longobardi & Badenes-Ribera, 2019; Parry & Stoll, 2020). In recent years, there has been a growing awareness of the field of veterinary forensics, involving veterinary professionals in a wide range of investigations, from the assessment of possible injuries to domestic animals to wildlife crimes involving the capture, transport and killing of protected animals and endangered species. In addition, there is increasing recognition of the potential for forensic pathologists to contribute to the field in collaboration with veterinary specialists. One of the tasks of forensic-veterinary research is to establish the method of committing a crime; determination of the instrument (facilities) of committing the crime. All this becomes possible via applying knowledge in the field of veterinary medicine using special research methods (Kazantsev & Yatsenko, 2021).

Studies conducted by Spanish scientists (Rebollada-Merino *et al.*, 2020) indicate that in large cities, the most common cause of death of dogs related to violence is injuries by blunt objects, which accounts for 43.64% of mechanical injuries in general; sharp objects – 1.82%; injuries by firearms – 18.18%, bites by other animals – 1.82%, respectively. In cats, the most common cause of death is blunt force trauma – 21.95%, gunshot wounds – 7.32% and bites – 4.88%.

However, during violence, animals not infrequently receive spinal injuries of varying severity and nature. In many cases, the mechanism of injury (flexing, extensor, flexor-circular and compression) conditions the animal's chance of recovery in the future. The most common cause of damage to the spine is the mechanism of compression along the axis of the spine (for example, falling from a great height, hitting the front part of the head against a hard object at a high speed of the animal, etc.) (Parilovsky & Yatsenko, 2021).

Züger *et al.* (2018) noted, that the most common cause of damage to the cervical spine is mechanical action of a traumatic nature. Vertebral injuries include fractures, dislocations, and subluxations. Vertebral dislocation occurs when the vertebral body is displaced from its normal cranial/caudal synovial joint with adjacent vertebrae. Vertebral subluxation occurs when there is partial displacement of a vertebra from its normal cranial/caudal synovial junction with adjacent vertebrae (Saengthong *et al.*, 2022).

Schmidli *et al.* (2019) declared that isolated vertebral dislocations (without bone fracture) occur in any part of the spine. Therewith, there is a displacement in the intervertebral joints. Dislocations of the cervical vertebrae occur more often with indirect and less often with straight injuries of the spine. In addition, mild forms of subluxations, which are called functional vertebral blocks, can be observed at any level. Vertebral dislocations, as a rule, are accompanied by a violation of the static and dynamic function of the spine. In the event of a fracture of the transverse processes of the lumbar and cervical vertebrae, there are symptoms of the inability to shift the position of the limb and sharp pain in the lumbar region during extension of the pelvic limb bent at the hip joint (Yayla *et al.*, 2023). Parilovsky & Yatsenko (2021) indicated, that damage to the cervical spine can manifest as fractures of the dorsal or ventral arch of the first cervical vertebra, fracture dislocations and fractures of the bodies or arches of the second to seventh cervical vertebrae, fracture of the dentate process of the second cervical vertebra. Not in all cases, trauma to the cervical spine leads to a violation of the integrity and function of the spinal cord. Dislocations and subluxations of the cervical vertebrae can pose a threat to the animal's life. If the injury results in a vertebral fracture, this in turn can cause damage to the spinal cord.

The most dangerous neurological component of damage to the cervical spinal cord is acute respiratory failure, which manifests itself when the C3-C4 vertebrae and C1-C2 vertebrae are damaged (Hansen *et al.*, 2019). In the early stages, after damage at the level of C3-C5, aspiration of gastric masses and a state of shock

can be observed, which will be the cause of death. Neurological symptoms that occur, therewith, can be a manifestation of disorders of the spinal cord or spinal nerves. At the molecular level, immediately after the injury, there is a violation of the ion balance due to the stoppage of membrane ATPase pumps. Violation of membrane integrity leads to the release of glutamate with the subsequent development of excitotoxicity. These processes occur in parallel with the growing damage to the brain tissue due to the increase in active forms of oxygen (Blando *et al.*, 2022).

The purpose of research is to provide veterinary practitioners and lawyers with strategies for identifying the cause (mechanism) of spinal cord injury and to assist triers of fact (decision-makers) in arriving at plausible and reasoned veterinary forensic conclusions.

MATERIALS AND METHODS

Pathomorphological studies were conducted as part of pre-trial investigations on the grounds of a criminal offence provided for in Article 299 of the Criminal Code of Ukraine (2022) based on the educational and scientific laboratory of the Faculty of Veterinary Medicine of Odesa State Agrarian University. The purpose of the research was to determine the causes of death and the nature of injuries of 10 animals (domestic cats) aged 3-5 months that died violently as a result of mechanical damage to the spine in the cervical region. The injuries were caused as a result of the cruel treatment of people towards these animals. Cadavers were dissected by the method of complete evisceration in the generally accepted sequence (Yatsenko & Kazantsev, 2021). A comprehensive patho-anatomical study of the organs and systems of the animal body at the macroscopic level was performed. The production of histological preparations was conducted according to the generally accepted scheme with staining with hematoxylin and eosin and subsequent encapsulation in polystyrene (Horalskyi *et al.*, 2015). A histological examination of the brain and lungs was conducted, pathological changes at the microscopic level were established.

All experimental studies were conducted according to modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they correspond to the requirements of DSTU ISO/IEC 17025:2005 (2006). The animals were kept, and all manipulations were performed according to the provisions of the Procedure for conducting experiments and experiments on animals by scientific institutions (Law of Ukraine No. 249, 2012), the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (European convention..., 1986).

RESULTS AND DISCUSSION

Autopsies were conducted and analysed the results of pathomorphological studies of several cases of mass

killing of small animals (cats), the death of which was associated with a primary complex injury of the spine and spinal cord. It was established that pathological anatomical changes had their characteristics depending on the area of the vector of mechanical destructive action directed at the cervical spine, namely:

- 1) damage to the integrity of the axial skeleton in the neck area (dislocations and fractures with complete or partial rupture of the capsular-ligamentous apparatus) due to traumatic bending of the neck (3 animals);
- 2) distraction closed mechanical injury of the cervical spinal cord (mechanical injury using opposite pulling forces with stretching of the spinal cord) (7 animals).

All spine injuries were closed and were characterized by the preservation of the integrity of the skin and subcutaneous tissue at the level of the injury. No traces of bites and other mechanical damage (fire, puncture and cut wounds) were found on the body of the animals.

Cervical spinal cord injury due to traumatic neck bending in kittens was accompanied by various combinations of partial or complete rupture of the intervertebral disc and destruction of the vertebral ligaments. Considering the fact that the cervical plexus of nerves is developed by the anterior branches of C1-C4 spinal nerves and is located under m. *Sternocleidomastoidea*, and sensitive, motor and mixed nerves depart from the plexus, which innervate the skin of the lower lateral surface of the head, the lateral and frontal areas of the neck, the auricle, the skin of the back of the head, the diaphragm, the pleura, the peritoneum, the pericardium and, accordingly, mechanical damage to the integrity of the intervertebral discs or the destruction of the ligaments of the vertebrae of the neck led to various disturbances of the innervation of various organs and systems of the body and ended in the death of the animals. All examined cases of damage to the cervical spine were classified as closed unstable injuries. The death of the animals occurred during the period of acute injury (the first period of injury) with the development of primary and secondary signs that were manifested in hemodynamic and lymph circulation disorders, primary traumatic necrosis at the site of application of the traumatic force.

According to a number of authors, the most severe and life-threatening for animals is a complete rupture of the intervertebral disc in combination with the rupture of the ligamentous complex, stretching and compression of the spinal cord, which make up 35-48% of the total number of injuries of the cervical spine, and injuries of the atlanto-occipital sites that range from complete atlanto-occipital or atlanto-axial dislocation to undisplaced occipital condyle fractures (Beauséjour *et al.*, 2022).

Below are the results of the postmortem examination of the corpses of 7 kittens aged 3-5 months due to mechanical trauma, which resulted in dislocations and fractures with partial rupture of the capsular-ligamentous apparatus of the cervical vertebrae, ruptures

between the vertebral discs of the atlanto-occipital and atlanto-axial joints.

The mechanism of dislocation and subluxation of the cervical vertebrae in animals consists in the fact that due to excessive tilting of the head, the left and right caudal articular processes of the cervical vertebra are displaced ventrally behind the facet of the articular surfaces of the left and right cranial articular processes of the cervical vertebra located immediately behind it. Therewith, the capsules of the intervertebral joints (right and left) are torn, and the articular surfaces come in one behind the other, resulting in a bilateral bending (flexor) dislocation. Flexion dislocation of the cervical vertebrae is manifested by the following signs: the head is tilted forward so that the symphysis of the lower jaw hangs almost to the chest; the spiny process of the dislocated vertebra is located more cranially and is palpable with difficulty, and the soft tissues in this area are inflamed; the spinous process of the vertebra located caudal to the dislocated vertebra is clearly contoured under the skin. In cases where a traumatic dislocation is accompanied by a fracture of the articular

end of the bone, then such a condition is diagnosed as fracture (Parilovsky, Yatsenko, 2021).

During the lifetime of all studied animals, there was a violent excessive bending of the body (in the ventral direction and to the side in relation to the axial skeleton) in the cervical spine, which led to damage to the ligamentous apparatus of the atlanto-occipital and atlanto-axial joints, the spinal canal between 1 and 2, 2 and 3, 3 and 4 cervical vertebrae. Excessive (violent) bending of the body in the neck area led to cervical damage to the ligamentous apparatus and joints of the cervical vertebrae, spinal canal, and rupture of the spinal cord membranes. cervical vertebrae. After the skin resection, it was established that the muscles of the neck, in the area of increased mobility of the cervical vertebrae, have a more saturated red color, compared to the general color of the muscles of other areas of the neck. There was hyperemia and haemorrhages in the muscles of the skin around the mechanical injury. In most animals, pronounced blood filling of the lingual veins and sublingual venous arch was established (Fig. 1).



Figure 1. Marked blood filling of lingual veins and sublingual venous arch (B)

In one animal, excessive bending of the head led to a fracture of the tooth-like process of the second cervical vertebra (epistrophe). Another animal had separation of the body of the second cervical vertebra from its arch (animal no. 1-2). Sharp tilts of the head to the side led to stretching and rupture of intervertebral ligaments, ruptures of intervertebral arteries and fracture of the transverse processes of the vertebrae. There was a violation of the integrity of the ligamentous apparatus of the joints of the axial and 3rd cervical vertebrae, stretching and rupture of the spine and spinal canal in the axial plane at the level of the 2 and 3 cervical vertebrae, the membranes of the spinal cord (animal No. 3); violation of the integrity of the ligamentous apparatus of the joints of the axial and 3rd cervical vertebrae, damage to the

membranes of the spinal cord (animal No. 4). In animal No. 5, the injury was accompanied by a violation of the integrity of the ligamentous apparatus of the joint of the 3rd cervical vertebra, damage to the membranes of the spinal cord; joints 2 and 3 of the cervical vertebrae in animal No. 6. Violent excessive bending of the body in the cervical part of the spine to the right in relation to the axial skeleton led to cervical damage to the ligamentous apparatus of the joints of the 4 and 5 cervical vertebrae, the spinal canal, rupture of the membranes of the spinal cord 1-5 cervical (animal No. 7). Vertebral and other vertebral openings (intervertebral and wing, transverse, lateral) of 1-5 cervical vertebrae contain blood. The surface of the pits (articular, wing) is red (Fig. 2). Spinal cord around the area of damage, uneven light red color.

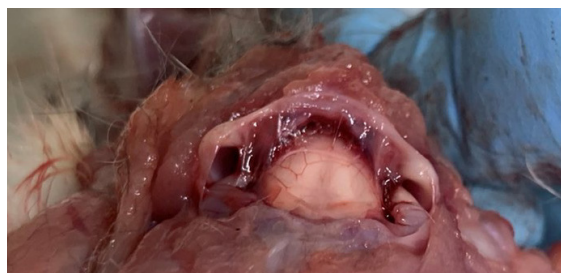


Figure 2. The vertebral and intervertebral openings of the cervical vertebrae contain blood. Blood vessels of the spinal cord with signs of hyperemia

After resection of the skin, it was established that the bluish color of the brain can be traced through the bones of the skull. In most animals, the brain membrane has a diffuse to focal dark red color, the brain substance has an

uneven light to dark pink color, which is more intense in the ventral part. In many animals, the brain membrane in the medulla oblongata has a saturated, uneven red color, and the blood vessels are above the average blood level (Fig. 3).



Figure 3. General view of the skull (top view) after skin resection (A). Hyperemia of the brain (more pronounced in the rhomboid brain)

Considering the fact that the vertebral artery anastomoses with the occipital artery, accordingly, hyperemia of vessels of the meninges of the brain is a consequence of impaired blood circulation in the occipital artery and caudal artery of the meninges. According to the above, as a result of the injury, there was a violation of hemodynamics of the brain. Spinal cord injury, in all cases, led to a violation of the blood-brain barrier, and to bleeding and swelling, which in turn disrupted blood circulation and led to ischemia due to damage to blood vessels and increased pressure inside the dura mater.

Bleeding in the lumen of the vertebral openings in the zone of mechanical damage, moderate hyperemia and haemorrhages in the muscles around the mechanical injury of the axial skeleton indicate the fact that the injuries were inflicted during the life of the animals. There was a violation of hemodynamics, which was manifested by hyperemia of the cervical spinal cord and brain.

Compression squeezing of the chest during fixation of the animals during the infliction of injuries led to a fracture of 3 to 5 ribs on both the right and left side of the body, in one animal there was a violation of the integrity of the right lung by a fragment of a rib. In most animals, along the ribs on the medial side, there are striped haemorrhages, located parallel to the ribs, bruises of a rounded shape (formed by the pressure of human fingers), located

on the right and left sides of the body, clearly visible from the lateral surface (superficial muscles).

The physiological role of the vagus nerve is very large, the zone of its innervation covers the head, neck, thoracic and abdominal cavities, and therefore regulates the activity of the heart. *Irritation (damage)* vagus nerve and (or) depression of the respiratory center due to mechanical injury of the cervical spinal cord and compression pressure on the chest led to pathological changes in the lungs. In all animals, the lungs acquired an uneven color, on the side of the pleura and in the thickness of the organ, there were areas from light to dark red with a purple tint. On the section, the tissue is dry and somewhat sunken in relation to the general surface. The lumen of the alveoli is empty. Areas protruding above the general surface, pink in color, contain air, when pressed on them - crepitate. Focal foci of lung atelectasis can be attributed to the so-called "reflex atelectasis". Alveolar emphysema is a manifestation of compensatory and adaptive processes to reduce the functional capabilities of the lungs and indicates the vital capacity of the body for some time after the spinal cord injury.

There is a direct causal relationship between mechanical damage to the cervical vertebrae and the death of kittens, the injuries were assessed as fatal. Distractive closed mechanical injury of the cervical spinal

cord (mechanical injury with the use of opposite pulling forces with stretching of the spinal cord). Distraction is a strong stretching of the parenchyma of the spinal cord in the axial plane. All cases of damage to the cervical spine explored by the author were classified as closed unstable injuries. According to Beauséjour *et al.* (2022) both discs and facet joints are damaged in neck sprains. A common disc injury is a “rim lesion” or transverse tear near the front edge of the vertebra. It is caused by distraction and shear when suddenly stretched. Both the back of the disc and the facets are compressed, causing disc bruising or herniation, facet hemarthroses, bruising around the C2 nerve, or articular process fractures (Beauséjour *et al.*, 2022).

Immediately after the injury, the animals developed spinal shock, and as a result – a critical drop in arterial blood pressure, a decrease in heart rate, and a decrease in body temperature. Bradycardia, resulting from an increase in the parasympathetic tone of the vagus nerve, with a simultaneous decrease in the sympathetic tone

(which is provided by the last cervical and first thoracic segments of the spinal cord) led to an increase in arterial hypotension, and, accordingly, a deterioration in the level of blood supply to the heart muscle. As a result of the above-mentioned processes, there was a decrease in the force of heart contractions and a decrease in stroke volume with further progression of arterial hypotension.

In the animals, foci of hyperemia of the mucous membrane of the palate (clearly defined rectangular area of dark red color) and the ventral part of the tongue – spotted (Fig. 4) were found. The mucous membrane of the gums and the buccal part of the oral cavity (more pronounced in animal No. 2) has an uneven to diffuse dark red color, the integrity of the mucous membrane of the oral cavity is not disturbed. The soft tissues around the oral cavity are unevenly colored and contain haemorrhages (more pronounced in animal No. 2). The conjunctiva had a dull red color; the skin of the lateral edge of the ears is light red.



Figure 4. Hyperemia of the mucous membrane of the palate; spotted hyperemia of the ventral part of the tongue

Focal hyperemia and spotty haemorrhages of soft tissues were registered in the neck area, there are symmetrically located areas of red color in the form of a strip of 0.1 cm similar in shape to a crescent (haemorrhages in the places of fixation of animals with fingers). Damage to tissue integrity was not detected. Large (aorta and pulmonary artery trunk) and medium-caliber vessels (vessels of the middle cranial mesenteric artery,

pancreatoduodenal anastomosis, caudal mesenteric artery (rectum) were above the average blood volume (Fig. 5). The above-mentioned violation of blood circulation is not characteristic of the death of animals due to mechanical trauma by a blunt object to the occipital region of the head and mechanical trauma resulting in dislocations and fractures with partial rupture of the capsular-ligamentous apparatus of the cervical vertebrae.



Figure 5. Spotted haemorrhages in the muscles and subcutaneous base of the cranial part of the neck, blood filling of the vessels of the cranial part of the neck (jugular veins, common carotid artery)

Spinal cord injury results in interference with the autonomic nervous system, which ultimately affects various systems, including respiratory, cardiovascular, genitourinary, gastrointestinal, and sexual function (Corcos *et al.*, 2020). In all animals, the injury of the cervical spine was accompanied by a respiratory syndrome, the essence of which is the exclusion of the intercostal muscles from the act of breathing, which ultimately leads to critical hypoxemia, further hypoxia of organs and tissues. In addition, the detected violation of the function of external breathing in the case of spinal cord injury can be caused by neurogenic pulmonary edema. This condition is caused by significant sympathetic hyperactivity, which leads to the stimulation of some parts of the hypothalamus or is caused by an increase in intracranial pressure (Mattucci *et al.*, 2021; Pascoal *et al.*, 2022).

The wall of the trachea and esophagus is within normal limits: its integrity is not disturbed, the mucous membrane is light to dark pink in color, moderately moistened. In the work of the respiratory system, and in the work of the cardiovascular system, there is an activation of the tone of the parasympathetic system against the background of a decrease in the tone of the sympathetic system. The expansion of the cavity of the right ventricle of the heart was registered, the blood was semi-liquid, dark red in color. In animal No. 3, the membrane of the wall of the right ventricle (epimyocardium) has a diffuse dark red color. Lungs in all animals have an uneven red-pink color, on the cut surface

there is a small amount of straw-like transparent liquid (transudate).

The spleen has a uniform dark red color, is elastic, the edges are pointed, the parenchyma is moderately moistened. The pancreas is unevenly red in color. Focal hyperemia of the serous membrane of the intestine was registered. Hyperemia of the thoracic and abdominal organs is a consequence of irritation of the vagus nerve.

The meninges of the brain are of an uneven red color, the vessels are filled with blood. Brain substance of uneven color (milky, pink, red of different saturation in different animals) due to blood filling of medium and small caliber vessels, white matter of uneven color with areas of milky and red color, changes are more pronounced in the caudal-ventral way, there are small haemorrhages.

There were no signs of blunt trauma, vertebral fracture, disc extrusion, or injection puncture in the surrounding soft tissues. The vertebral foramina of the cervical vertebrae and the surface of the articular fossae contain blood. Changes in the spinal cord were accompanied by haemorrhages as a result of rupture of blood vessels. The spinal cord in the cervical and thoracic regions is of an uneven milky-red color. Hyperemia of the vessels of the meninges of the brain is a consequence of impaired blood circulation in the occipital artery and caudal artery of the meninges. Bleeding into the lumen of the vertebral openings in the zone of mechanical damage indicates the fact that the injuries were inflicted during the life of the animals (Fig. 6).

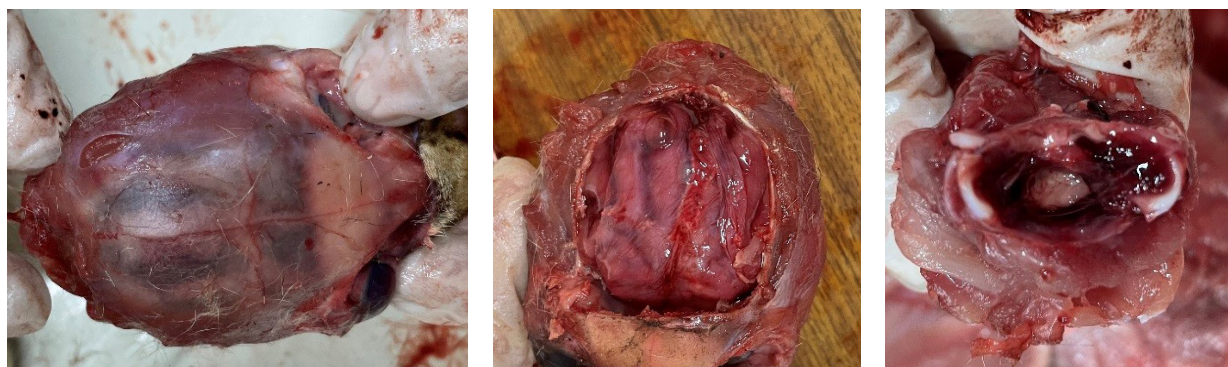


Figure 6. General view of the skull (top view) after skin resection (A); hyperemia of the dura mater (top view) (B); the vertebral openings of the cervical vertebrae and the surface of the articular fossae contain blood (C)

According to the results of histological studies of the spinal cord taken from animals that died as a result of traumatic bending of the neck, pronounced blood filling of the lingual veins and sublingual venous arch was established; for distraction injuries of the cervical vertebrae and spinal cord – bleeding into the lumen of the spinal canal, haemorrhages in the tissues of the spinal cord. The lesion was accompanied by damage to the integrity of the vessel wall, swelling of the spinal cord with the development of extracellular and intracellular edema. The above-mentioned changes led to a

compression syndrome of the tissue of the spinal cord and brain (the caudal part of the trunk), the spinal canal. Focal ischemia of the spinal cord, formation of microthrombi, and microeffusions were recorded. haemorrhages are surrounded by edema with necrosis of neurocytes, edema and destruction of axons, endothelial cells of capillary walls are registered. The swelling of the axons indicates that at least 30 minutes passed from the injury to the death of the animals. The absence of neutrophils on histological preparations indicates the fact that the life expectancy of animals after trau-

matisation was less than 6 hours. In most animals, the swelling of the spinal cord spread to the brain stem and led to the disruption of the vital functions of the body and to the death of the animals. The death of the animals occurred during the period of acute injury (the first period of injury) with the development of primary and secondary signs that were manifested in hemodynamic and lymph circulation disorders, primary traumatic necrosis at the site of application of the traumatic force.

According to the results of studies (Beauséjour *et al.*, 2022) of spinal cord injuries after flexion-distraction injuries of the cervical spine, white matter compression is determined as the main post-traumatic mechanism. The results of this research confirm the fact of the development of compression syndrome of the tissue of the spinal cord and brain (the caudal part of the trunk) in the case of cervical spine injuries. In most animals, the swelling of the spinal cord spread to the brain stem, which led to a violation of the vital functions of the body and to death. The established signs of hemodynamic disturbances (haemorrhages, edema, microthrombi and ischemia of brain tissues), dystrophic changes and necrosis of neurocytes coincide with the features of the manifestation of secondary damage due to mechanical trauma of the cervical spine, which were described in scientific works Corcos *et al.* (2020), Blando *et al.* (2022), Thomas *et al.* (2022).

Thus, according to Corcos *et al.* (2020), during the first 3 hours after the injury, degeneration of the white matter of the spinal cord occurs, damage to the myelin of axons, which leads to spinal shock. Scientists have indicated that the primary injury in spinal cord injury is the initial mechanical trauma that can compromise the physiology of the spinal cord by disrupting neural transmission. Secondary damage is caused by vascular and biochemical effects. Secondary damage mechanisms are manifested in the form of vascular and biochemical disturbances that lead to an imbalance of the physiology of the microenvironment and are accompanied by hypoxia, hypoperfusion, inflammation, edema, microhaemorrhages and thrombosis (Blando *et al.*, 2022; Thomas *et al.*, 2022).

In the available scientific literature, the author was unable to find data on hemodynamic disturbances (hyperemia, haemorrhages) of the brain, blood filling of lingual veins and sublingual venous arch, blood filling of vessels of the cranial neck (jugular veins, common carotid artery), no data on chest hyperemia and abdominal cavity for flexion-distraction injuries of the cervical spine in animals of any species.

In scientific sources there is information about respiratory complications as the main cause of morbidity and mortality after spinal cord injury; about the dependence of the degree of respiratory dysfunction on the neurological level of damage, however, these data are given from the practice of humane medicine and refer to the period of stabilisation of the patient in the

conditions of a medical institution (Pascoal *et al.*, 2022; Gee *et al.*, 2022). Pathological changes in the lungs of animals established during the pathomorphological examination and described in this work as “reflex atelectasis” and pulmonary edema, the corresponding profile was not found in scientific works.

Therefore, according to the results of the pathomorphological studies, the primary injury of the cervical spine and brain stem was established as the cause of the death of the animals as a result of human cruelty to them. The results of the conducted studies demonstrate that even as an isolated injury, an injury to the cervical spine can cause death, due to such complications as: paralysis of the respiratory muscles, neurogenic shock, spinal shock.

CONCLUSIONS

One of the objective signs of cruelty to animals (method of committing a crime) established under Art. 299 of the Criminal Code of Ukraine was examined, namely: infliction of mechanical injuries with violation of the integrity of the axial skeleton in the neck area as a result of traumatic bending of the neck and distracting mechanical injury to the cervical spinal cord, which caused pain, suffering and led to their death.

All examined cases of mechanical damage to the cervical spine were classified as closed unstable injuries. Moderate hyperemia and haemorrhages in the muscles, bleeding in the lumen of the vertebral openings in the area of mechanical damage, indicate that the injuries were inflicted during the life of the animals. Hyperemia of the vessels of the meninges of the brain is a consequence of impaired blood circulation in the occipital artery and caudal artery of the meninges. In the case of a traumatic neck bend, pronounced blood filling of the lingual veins and sublingual venous arch was established, in the case of a distraction injury – blood filling of the vessels of the cranial neck area (jugular veins, common carotid artery).

As a result of a mechanical injury due to a traumatic bending of the neck, the integrity of the axial skeleton in the neck area was damaged (dislocations and fractures with complete or partial rupture of the capsular-ligamentous apparatus), hyperemia and haemorrhages occurred in the tissue of the spinal cord, bleeding in the lumen of the vertebral openings in the area mechanical damage. The development of “reflex atelectasis” is a consequence of suppression of the respiratory centre or damage (irritation) of the vagus nerve due to injuries, compressive pressure on the chest; alveolar emphysema is a manifestation of compensatory and adaptive processes.

Distraction injury of the cervical spine led to swelling of the brain's medullary substance, haemorrhages of the caudal-ventral part of the brain's substance. The pathological process was accompanied by a respiratory syndrome with the development of hypoxia and

neurogenic pulmonary edema with subsequent asphyxia of the animals. Hyperemia of the thoracic and abdominal organs is a consequence of nervus vagus irritation and, accordingly, hyperemia of large vessels (aorta and trunk of the pulmonary artery), cranial mesenteric artery (pancreatoduodenal anastomosis), caudal mesenteric artery (rectum). Massive haemorrhage in the tissues of the spinal cord led to compression syndrome. Prospects for further research: analysis of pathomorphological changes in the body of domestic animals (dogs, cats) due to mechanical trauma of the lumbar and sacral spine.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Патогенез та патоморфологія дистракційної травми в рамках досудового розслідування жорстокого поводження з тваринами

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Анотація. Важливість ідентифікації та диференціальної діагностики ушкоджень хребта, у разі політравми, вміння розрізняти патогенез різних ушкоджень є важливими та актуальними як під час клінічного, так і під час патологоанатомічного дослідження організму тварини. Мета дослідження – надати практикуючим ветеринарним лікарям та юристам стратегії ідентифікації причини (механізму) пошкодження спинного мозку та допомогти судовим експертам (особам, які приймають рішення) у формулюванні правдоподібних та обґрунтованих висновків ветеринарно-медичної експертизи. Дослідження проводили з використанням патолого-анатомічного розтину та гістологічних досліджень. Встановлено, що пошкодження шийного відділу спинного мозку внаслідок травматичного згинання шиї супроводжувалося частковим або повним розривом міжхребцевого диска та руйнуванням зв'язок хребців. Встановлено, що гіперемія судин мозкових оболонок головного мозку є наслідком порушення кровообігу в потиличній артерії та каудальній артерії мозкових оболонок, а механічне пошкодження цілісності міжхребцевих дисків або руйнування зв'язок шийних хребців призводило до різних порушень іннервації різних органів і систем організму та закінчувалося загибеллю тварин. Доведено, що дистракційна травма шийного відділу хребта призводила до набряку головного мозку, крововиливів у каудально-вентральну частину речовини мозку. Встановлено, що подразнення блукаючого нерва призводило до гіперемії судин великого (аорта і стовбур легеневої артерії) калібру, каудальної брижової артерії і, відповідно, гіперемії органів грудної та черевної порожнини. Застосування результатів дослідження допоможе в диференціації різних видів механічних пошкоджень хребта (в тому числі диференціації з іншими патологічними станами організму), визначенні зони дії вектора прикладеної сили

Ключові слова: травматичне згинання шиї; дистракційна травма; шийні хребці; спинний мозок; набряк; кровотеча



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Parameters of apple tree crowns depending on the crown shape and pruning time

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Abstract. The apple tree is a leading fruit crop in Ukraine in terms of production volumes and planting areas and is a valuable food product with a high content of vitamins. In new modern plantings, fruit producers prefer intensive cultivation technologies that ensure the maximum amount of high-quality fruit yield per unit area. The main criterion for solving this problem is the design of plantings: a narrow-row scheme for planting trees and a low-volume crown shape. The purpose of the study was to establish the influence of the pruning period of different types of crown formations on the growth and productivity of apple trees of two varieties: Fuji and Honey Crisp. The study was conducted in the conditions of the central Forest-Steppe of Ukraine (Uman National University of Horticulture). The scheme of planting was 4x1 m, M.9 rootstock, chernozem sod-podzolic soil, drip irrigation. Field, statistical, and computational-analytical methods



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were used in the course of the study. It was identified that the growth pattern of the examined varieties differed substantially, and crown volume, projection area, and development of the feeding area prevailed in Honey Crisp trees. However, in terms of productivity, the plantings of the Fuji variety substantially exceeded the values of the Honey Crisp variety. Forming a ballerina crown with the removal of overgrown wood in a 25 cm zone on the central trunk above the lower tier of semi-cellular branches provided an increase in the growth activity of the examined trees by 3-5%. A substantial decrease in the values of crown parameters was provided by the formation of the French axis crown – there was a decrease in the crown diameter by 44%, the crown volume – by 67%, and the crown projection area and the development of the feeding area – by 69%. Performing additional summer pruning of trees also helped to reduce growth activity by 6-11%. However, the specific productivity of plantings doubled in plantings with the formation of the French axis and by 45-50% with the introduction of double pruning of trees. It is recommended that agricultural producers investigate the terms of pruning low-volume crown forms, considering varietal characteristics, to create compacted apple stands and increase the intensification of production

Keywords: apple tree; crown shape; pruning time; crown volume; summer pruning

INTRODUCTION

The apple tree is the leading fruit crop in Ukraine, which ranks third in terms of fruit production in the world, second only to citrus fruits and bananas. It is necessary to substantially increase the productivity of fruit plantations to meet the needs of the population for horticultural products. The introduction of new cultivation technologies, which will be based on the creation of efficient, intensive plant designs and plant care systems, can substantially increase the productivity of plantings and improve the quality of the grown crop. Ultimately, the intensification of gardening involves obtaining higher yields of high-quality fruits per unit area. This can be achieved by creating gardens with a smaller planting pattern and compacting the plantings. Therefore, the development of methods for the formation and subsequent care of new, small-sized crown forms, which, due to the features of their architectonics, would provide maximum interception of solar radiation, forming fruitwood and better-coloured fruits determines the relevance of these studies.

Modern intensive plantings are characterised by the rapid development of the feeding area and an increase to the physiological optimum of the leaf surface – 35-40 thousand m²/ha or more and the early beginning of industrial fruiting. Light is important for all physiological processes in the plant. With 100% sunlight according to Laužikė *et al.* (2020), only 40% falls on plants, and 15% (out of 40%) are limited by the garden design and leaf area

The relatively low level of light use (the proportion of total photosynthetic active radiation by plant structural parts) in the intensive apple growing system remains the main limiting factor for improving garden productivity. In their studies, Tustin *et al.* (2022) and Musacchi (2018) established a close correlation between the formation and the level of illumination of all parts of the crown. According to Lordan *et al.* (2018), planting pattern, crown shape, and tree height are the main determining factors for the maximum light level of trees. These factors often set an upper limit on the

productivity of plantings along with physiological ones: pomological variety, rootstock, and soil fertility. However, according to observations by Johansen *et al.* (2018), due to low or high temperatures, intense lighting, or water scarcity, photoinhibition leaf damage may occur.

Crown formation of fruit trees aims to create a specific crown architecture to improve the interception and use of light to increase yield and optimise fruit quality. Therefore, according to Raig *et al.* (2019), choosing a molding system is crucial for improving the profitability of the garden. The correct crown shape and rational pruning of the aboveground part of apple trees can achieve the uniform formation of generative buds and fruiting throughout the entire crown volume (Strnad *et al.*, 2020; Wang *et al.*, 2023).

Adjusting the parameters of the aboveground part of the crown, Siefen *et al.* (2023), were able to provide 35-40% higher illumination of its central part, improving air circulation, thus stabilising fruiting and improving the commercial quality of the crop. Pruning apple trees is a very labour-intensive agricultural measure in the apple production process (Fransen, 2016; Marini, 2020). When choosing the best pruning method, a number of factors are considered, the main ones being, according to He & Schupp (2018) and Goke *et al.* (2020), are the degree of intensity of the garden and the time of conducting, variety-rootstock combination, planting density, age, crown shape, height and dimensions of crowns.

The production of the same type of high-quality fruit is the key to successful gardening because it is the quality of fruits that is crucial for price formation, creates demand, and has the greatest impact on the potential profit of the farm. However, according to Zhang *et al.* (2016) and D'abrosca *et al.* (2017), fruit quality can be very heterogeneous within a single tree, depending on the shape of the crown and the placement of their structural elements in the space, mainly due to different lighting levels.

Attempts to control tree size by various methods, such as dwarfing rootstocks, spur varieties, tree pruning

methods, and growth inhibitors, remain the focus of scientific attention. In particular, Zahid *et al.* (2020) identified that one of the most effective ways to control tree growth and the formation of evenly eliminated crowns is to introduce summer pruning. On the recommendation of Ruiz-Sánchez *et al.* (2022) and Conesa *et al.* (2019), it consists of removing unproductive shoots and is performed mainly for controlling tree growth, reducing the need for winter pruning.

The purpose of the study was to identify the influence of the pruning period for various types of crown formation on the productivity of apple trees in an irrigated apple orchard in the conditions of the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The examination of methods of care for small-sized forms of the crown of apple trees, in particular, pruning dates, started in the spring of 2019 at the Uman National University of Horticulture. An experimental apple orchard, found in the spring of 2015 had varieties of Fuji and Honey Crisp grafted on the M.9 T337 rootstock. Experimental trees are planted in the garden according to the 4x1 m scheme, the soil is sod-podzolic chernozem. In the row spacing, the soil was kept behind a sod-humus system and herbicidal steam in the trunk strip, drip irrigation. Trees were pruned in two periods: in winter and twice per season: in winter and in summer after the June shedding of the ovary (second decade of June) forming slender spindle, ballerina (with the removal of overgrown wood in 25 cm zone on the central trunk above the lower tier of semi-cellular branches), and the French axis crown shapes.

Crown parameters were assessed at the end of the growing season according to the methods of

Kondratenko P.V., Bagel M.O., 1999. The crown diameter was defined as the distance between the extreme points of its width.

The area of the crown projection was calculated by the formula:

$$S=0.196*(D_1+D_2)^2$$

where S – area of the crown projection, m^2 ; 0.196 – constant conversion coefficient; $D_{1,2}$ – crown width in two perpendicular directions, m ;

The crown volume was determined by the following formula:

$$V=0.523*D^2*h$$

where V – crown volume, m^3 ; 0.523 – constant conversion coefficient; D – crown width, m ; h – crown height from the bole to the top of the crown, m .

The degree of development of the feeding area was determined as the ratio of the crown projection area to the feeding area provided for by the planting scheme.

Specific productivity was defined as the ratio of tree fruit load to crown volume or crown projection area.

RESULTS AND DISCUSSION

During the experiment, a substantial dependence of the crown diameter value on both the shape of the crown and the term of its pruning was established. In general, according to the experiment, the value of the crown diameter in the plantings of the Honey Crisp variety was dominated by the corresponding indicator of the Fuji variety (Table 1) with its minimum value for twice pruning the crown of the French axis (0.62 m), which is twice lower than the value of the control option – 1.24 m ($LSD_{05}=0.18$).

Table 1. Parameters of the apple tree crown depending on the shape of the crown and the time of pruning (2019-2022)

Pomological variety	Crown shape	Pruning period	Crown diameter, m	Crown volume, m ³	Crown projection area, m ²	Development of the nutritional area, %
Fuji	Slender spindle	In winter (control)	1.24	1.71	1.22	30.6
		In winter and summer	1.12	1.32	0.99	24.8
	French axis	In winter	0.70	0.56	0.38	9.6
		In winter and summer	0.62	0.45	0.31	7.8
	Ballerina	In winter	1.20	1.60	1.15	28.7
		In winter and summer	1.21	1.52	1.17	29.2
Honey Crisp	Slender spindle	In winter	1.31	1.95	1.34	33.5
		In winter and summer	1.27	1.86	1.29	32.1
	French axis	In winter	0.75	0.69	0.46	11.4
		In winter and summer	0.66	0.52	0.35	8.8
	Ballerina	In winter	1.34	2.02	1.42	35.6
		In winter and summer	1.30	1.89	1.34	33.4
LSD ₀₅			0.18	0.48	0.33	8.4

Source: compiled by the author

The results of the variance analysis indicate a 10% predominance of crown dimensions in Honey Crisp trees (Fig. 1a) and a 45% decrease in the indicator values as a result of crown formation. There was no substantial difference in the diameter of the crowns as a result of their formation according to the type of slender spindle and ballerina. The reduction in the indicator values was facilitated by the introduction of pruning of trees twice in winter and summer by 6%.

The greatest influence on the crown diameter value was caused by the crown shape factor by 78.6% (Fig. 2a). The greatest direct correlation of the crown diameter was identified with the crown volume ($r=0.99\pm0.01$), its projection area ($r=0.99\pm0.01$),

the number of fruits ($r=0.84\pm0.08$), and the number of shoots ($r=0.66\pm0.19$).

The volume of the crown among the examined varieties prevailed in Honey Crisp plantings and was substantially inferior in the formation of the French axis (Table 1), which is explained by the absence of semi-skeletal branches in its structure. A total increase by a quarter of the indicator value in Honey Crisp trees (Fig. 1b) retained the dependence, in the plantings of both varieties, on a substantial decrease in the crown volume during the formation of the French axis – 0.55 m^3 , which is $1.16\text{--}1.22 \text{ m}^3$ less than other types of formations examined ($\text{LSD}_{05}=0.12$). A decrease of 13% (0.16 m^3) in the volume of the crown is facilitated by repeated pruning of trees during the season in summer.

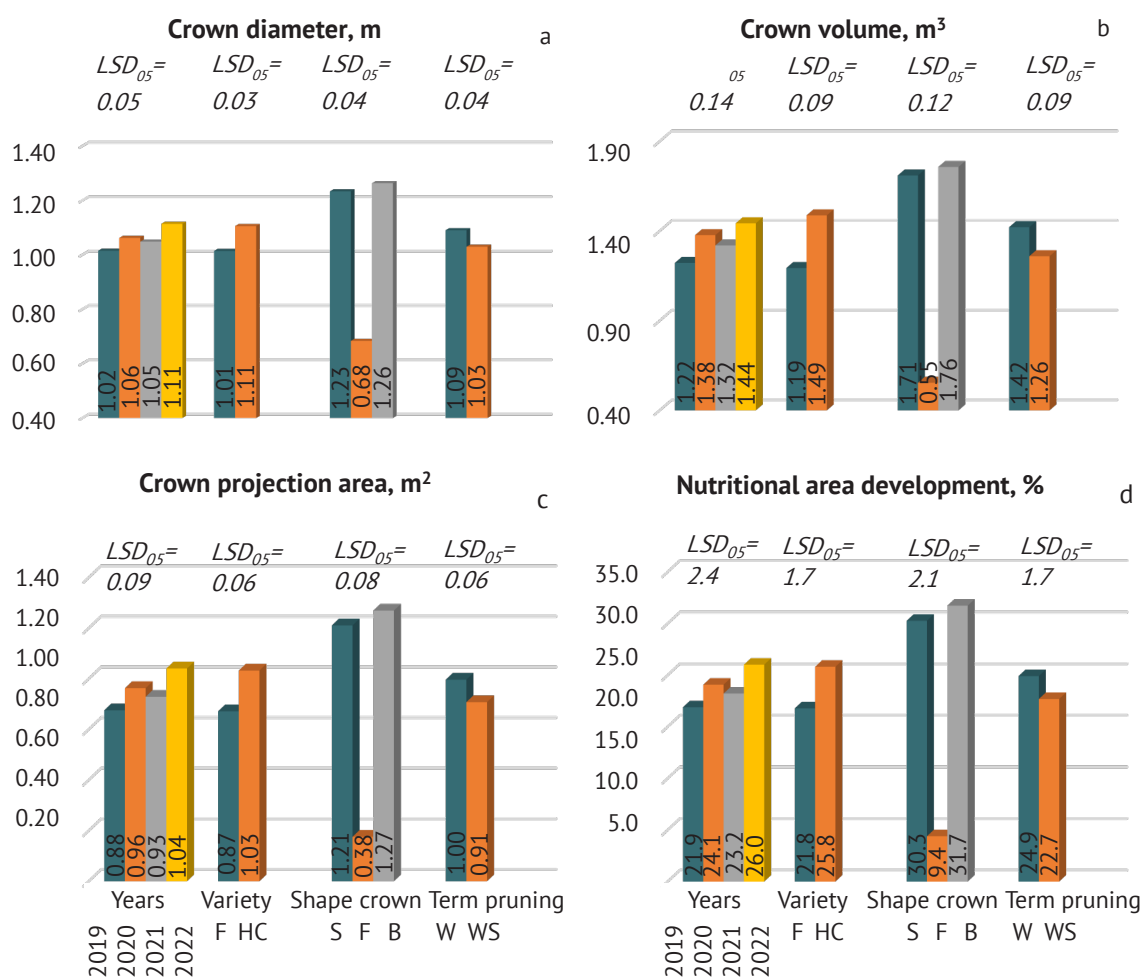


Figure 1. The average diameter (a), volume (b), area of the crown projection (c), and level of development of the feeding area (d) of apple trees for the 2019-2022 studies, depending on the shape of the crown and the pruning period (results of variance analysis)

Note: Varieties: Fuji (F), Honey Crisp (HC); crown shape: slender spindle (S), French axis (F), ballerina (B); pruning term: winter (W), winter and summer (WS)

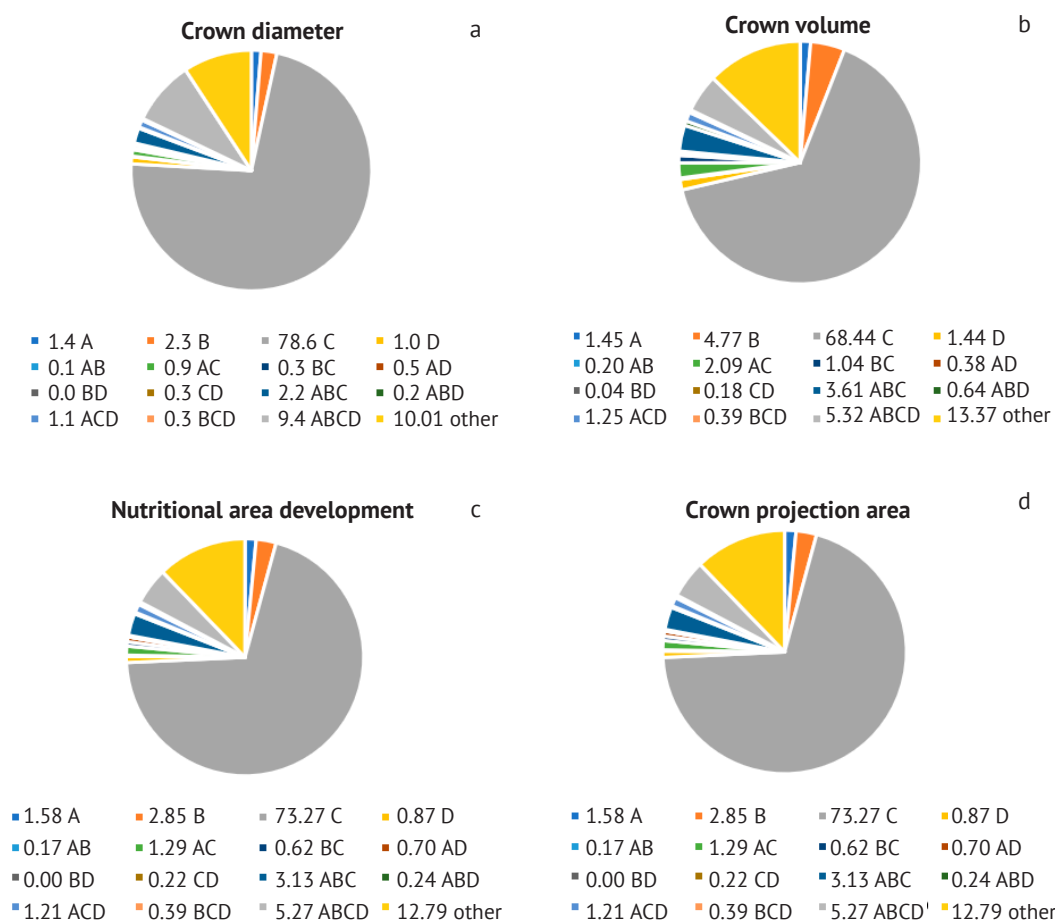


Figure 2. The strength of the influence of the examined factors on the diameter (a), volume (b), development of the feeding area (c), and the crown projection area (d).

Note: A – the year of the study; B – pomological variety; C – crown shape; D – pruning period

Source: compiled by the author

Change in crown volume (Fig. 2b) substantially depends on the shape of the crown (influence of the factor 68.4%) and the characteristics of the pomological variety (4.7%). Crown volume directly correlates with the number of fruits ($r=0.83\pm0.09$), yield ($r=0.92\pm0.04$), and inversely with the length of shoots ($r=-0.81\pm0.10$).

Fuji trees are substantially inferior to The Honey Crisp variety in terms of crown projection area (Table 1), with the maximum predominance of the indicator as a result of ballerina crown formation in winter (1.42 m^2). The formation of the crown of the French axis of Fuji trees and its subsequent pruning twice a season in winter and summer ensured that the lowest value of the indicator was obtained at the level of 0.31 m^2 ($\text{LSD}_{05}=0.33$).

On average, the experiment increases the area of the crown projection (Fig. 1b) at the level of 1.04 m^2 as of 2022 (influence of the factor – 1.6% (Fig. 2d)). Fuji trees were 18% inferior to the corresponding value of the Honey Crisp indicator. The French axis crown formation reduced the projection area by 66% (influence of the factor – 73.3%), but in trees with the ballerina crown formation, this indicator increased by 6% compared to the slender spindle option. The introduction of double pruning in

winter and summer with the removal of strong-growing unproductive shoots of the current season leads to a decrease in the area of the crown projection by 6%.

The area of the crown projection directly correlates with the crown volume ($r=0.99\pm0.01$), the number of fruits ($r=0.83\pm0.09$), and the yield ($r=0.79\pm0.11$).

The development of the nutritional area, which indicates a rationally selected tree planting scheme and the level of planting intensity, somewhat prevailed (by 4%) in the planting of the Honey Crisp variety (Fig. 1f). The average value of the indicator for both examined varieties is substantially lower as a result of crown formation – 9.4% with more than 73% influence of the factor on the change in the indicator (Fig. 2c). The formation of the crowns of the slender spindle and ballerina did not differ substantially and amounted to 30.3–31.7%. The combination of winter and summer pruning reduced the value of the indicator by 9%.

A substantial influence of various methods of crown formation and the time of their pruning was obtained on the productivity indicators of trees. The specific productivity per unit volume of the crown varied substantially with the increase in the indicator with

the introduction of a more compact, low-volume crown, which indicates an increase in the level of intensity of horticulture technology. Therewith, an increase in the specific productivity of plantings of both varieties under study was noted with the implementation of double pruning of tree crowns in winter and summer, due to an increase in the level of illumination and, as a result, an improvement in the laying of fruitwood. The maximum specific productivity per unit volume of the crown was

obtained as a result of double pruning of the French axis crown – 20.7 kg/m³ in Fuji and 17.5 kg/m³ in Honey Crisp varieties (Table 2), by 14.7 and 12 kg/m³ accordingly, exceeded the value for the winter pruning of the slender spindle crown, where the lowest value of the indicator ($LSD_{05}=7.4$) was obtained. During the formation of the ballerina crown, there was also a slight increase in the values of the indicator relative to the data of the control variant.

Table 2. Specific productivity of apple trees depending on the crown shape and pruning period (2019-2022)

Pomological variety	Crown shape	Pruning period	Specific productivity per unit crown volume, kg/m³	Specific productivity per unit of nutritional area, kg/m²
Fuji	Slender spindle	Winter (control)	6.0	8.4
		In winter and summer	9.8	13.0
	French axis	In winter	12.8	18.6
		In winter and summer	20.7	29.1
	Ballerina	In winter	9.4	13.2
		In winter and summer	11.6	15.1
Honey Crisp	Slender spindle	In winter	5.5	7.9
		In winter and summer	7.8	10.9
	French axis	In winter	10.2	15.3
		In winter and summer	17.5	25.6
	Ballerina	In winter	5.9	8.4
		In winter and summer	7.5	10.5
LSD ₀₅			7.4	10.1

Source: compiled by the author

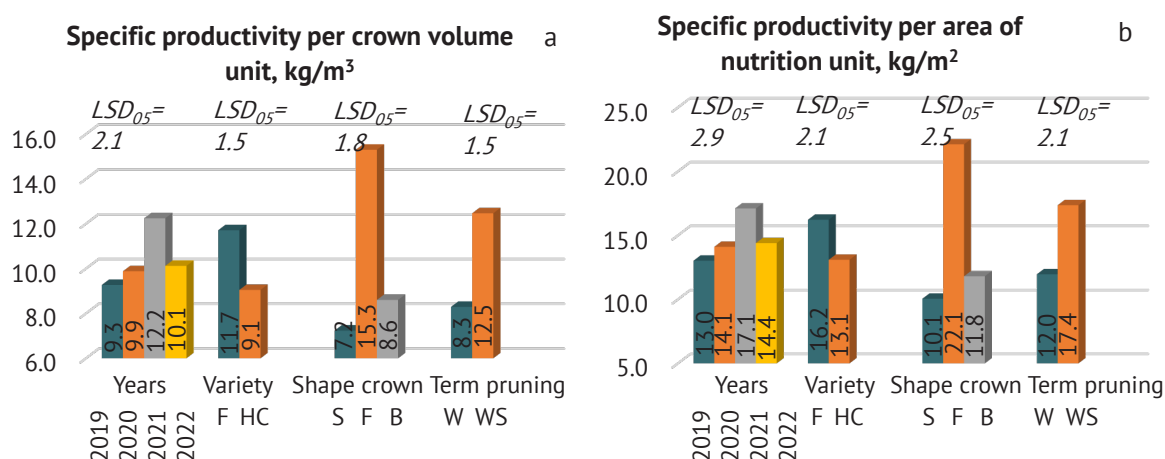


Figure 3. Averaged data on specific productivity per volume (a) and area of nutrition (b) unit of apple trees, depending on the shape of the crown and the pruning period (results of variance analysis).

Note: Varieties: Fuji (F), Honey Crisp (HC); crown shape: slender spindle (S), French axis (F), ballerina (B); pruning term: winter (W), winter and summer (WS)

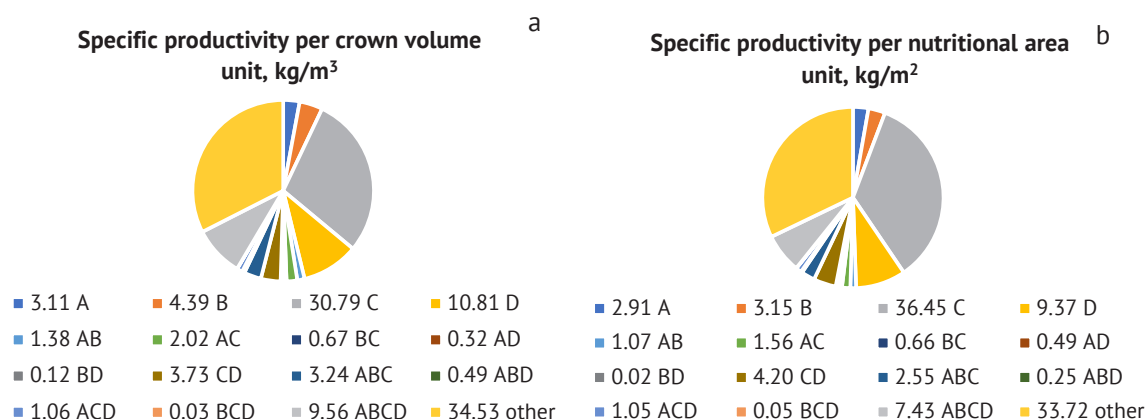


Figure 4. The strength of the influence of the examined factors on the specific productivity per unit volume of the crown (a) and the specific productivity per unit area of the feed (b)

Note: A – the year of the study; B – pomological variety; C – crown shape; D – pruning period

Source: compiled by the author

In general, during the experiment, according to the analysis of variance, the value of specific productivity per unit volume of the crown increased annually with the achievement of the maximum value in 2021 at the level of 12.2 kg/m³ (Fig. 3a). On average, the specific productivity per crown volume of the Fuji variety increased by 28.5%, or 2.6 kg/m³ exceeding the value of the Honey Crisp variety ($LSD_{05}=1.5$). However, the highest value of the indicator (15.3 kg/m³) was achieved due to the introduction of a low-volume French axis crown shape, which was more than twice the value of the slender spindle crown formation (7.2 kg/m³). In addition, the ballerina crown contributes to a 20% increase in the value of specific productivity per crown volume (8.6 kg/m³). Additional pruning of tree crowns in summer contributed to a substantial increase in specific productivity (by 50%).

An inverse strong correlation of the specific productivity per unit crown volume was obtained with the crown diameter and volume ($r=-0.86\pm0.07$). Among the examined factors, crown shape and pruning period had the greatest influence on the change in the indicator values – by 30.8% and 10.8%, respectively (Fig. 4a).

The specific productivity per crown projection area also substantially depended on the examined crown shape and pruning time. An increase in the indicator values indicates an increase in the projected yield of plantings per unit area with an optimally selected tree planting scheme due to the influence of the examined agricultural measures. A substantial increase in the values of the specific productivity indicator during the crown projection in the plantings of both examined varieties was obtained due to the formation of the French axis crown. In addition, a substantial impact on the growth of the values of the examined indicator is caused by the introduction of additional pruning of trees in the summer. Performing winter and summer pruning of trees, in particular, the crown of the French

axis, provided a maximum increase in the value of specific productivity per crown projection area to the level of 29.1 kg/m² in the Fuji variety and 25.6 kg/m² in Honey Crisp, respectively (Table 2), the difference to the control was 17.6-20.7 kg/m² ($LSD_{05}=10.1$).

Due to the relatively larger area of the crown projection in the planting of the Honey Crisp variety, the specific productivity per the area of its projection was substantially inferior to the value of the Fuji variety. The excess of the latter values is 23.6%, or 3.1 kg/m² ($LSD_{05}=2.1$) (Fig. 3b). Among the examined crown forms, the ballerina crown increased the indicator by 1.7 kg/m² relative to the values of the slender spindle. However, the most substantial increase in specific productivity per crown projection area is 12 kg/m² obtained as a result of the French axis crown formation. The implementation of additional summer pruning of trees contributed to a reduction in the size of the crown, better formation of fruitwood and, as a result, an increase in specific productivity per unit area of the crown projection by 45%, or 5.4 kg/m² ($LSD_{05}=2.1$).

A strong correlation of the specific productivity per unit area of the crown projection is obtained with the diameter and volume of the crown ($r=-0.89\pm0.06$). To the greatest extent, the change in specific productivity per unit area of the crown projection is caused by the crown shape and pruning period factors by 36.4% and 9.4%, respectively (Fig. 4b).

The introduction of modern small-sized crowns using the latest highly productive varieties will determine the design of plantings and, as a result, the level of intensification of the garden. According to Kolmanič *et al.* (2021) and Crassweller *et al.* (2020), summer pruning in apple orchards is a common practice to improve the illumination of the crown and reduce vegetative growth next year. It also leads to an increase in the intensity of leaf photosynthesis as a result of improved light levels after pruning, the area of which is reduced by 10-30%

(Mierowska *et al.*, 2022). The results of the study indicate a substantial decrease in the crown size as a result of summer pruning, which is confirmed by Mu *et al.* (2018) and Kolmanič *et al.* (2021). A similar relationship was obtained in the studies of Chaploutsky and Melnik (2019), Strnad *et al.* (2020), examining Golden Delicious and Jonagold varieties, according to which, winter pruning in combination with early summer pruning caused a 5% decrease in the crown diameter, a 10% decrease in its volume, and a 9% decrease in the projection area and the degree of development of the feeding area. Melnyk and Kravtsova (2018) observed a reduction in crown dimensions of the Gala and Jonagold Wilmut varieties, in particular, volume – by 15-17% and the crown projection area – 10-12%. By reducing the size of the crown, it is possible to create compacted plantings, which, when forming an axillary crown, will not affect the level of their illumination. Therewith, according to Lugaresi (2022), the percentage of more than 50% red-coloured fruits increases by 20.5% if summer pruning is introduced and the sugar content in the fruit increases (Vosnjak, 2021).

Thus, the constant updating of the assortment of fruit stands, especially in modern intensive gardens, requires research on agricultural techniques for tree care, the influence of pruning times, crown formation features, fruit wood formation, etc. Ultimately, varietal characteristics, the growth force of variety-splitting combination, shoot-forming ability, and type of fruiting substantially affect the formation of productivity of plantings and determine the features of their care.

CONCLUSIONS

The study of the influence of crown shape and tree pruning time showed that the examined varieties have different growth activity, which prevails in the Honey Crisp variety, which should be considered when choosing plantings. It was identified that the dimensions of the crown, in particular, the diameter and volume of the crown prevailed in trees of the Honey Crisp variety for

the formation of the ballerina crown in winter – 1.34 m and 2.02 m³ accordingly. The greatest influence on the reduction of crown dimensions is caused by the method of formation (influence of the factor – 68-78%), in particular, by forming the crown of the French axis, which is marked by the smallest values of diameter indicators in the Fuji variety – 0.62 m and the crown volume of 0.45 m³. In general, according to the experiment, the formation of the crown of the French axis helps to reduce the diameter of the crown by 44% and its volume – by 54%. An additional effect of reducing the size of the crown by 6-13% in both varieties under study was achieved due to the introduction of double pruning of trees in winter and summer. These agricultural measures provided an increase in the specific productivity of apple trees of both examined varieties. The specific productivity per crown volume during the formation of the ballerina crown increased by 19%, and more than a twofold increase was achieved by forming the French axis crown (15.3 kg/m³). In addition, the implementation of additional pruning of trees in the summer increased the specific productivity per crown volume by 50%. The same dependence was observed with the specific productivity per unit of the nutritional area. This allows for developing technologies for growing gardens with a smaller planting scheme, and therefore a larger number of trees per unit area, which will help to increase the productivity of plantings.

Considering the importance of apples as a valuable food product for fresh consumption or as a processed product, further research may be based on an extended range of crown pruning dates and determining the optimal planting scheme to ensure higher productivity of plantings.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Параметри крон дерев яблуні залежно від форми крони та строку обрізування**Андрій Миколайович Чаплоуцький**

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Анотація. Яблуня лідируюча плодова культура в Україні за обсягами виробництва та площами насаджень та є цінним харчовим продуктом з високим вмістом вітамінів. В нових сучасних насадженнях виробники фруктів надають перевагу інтенсивним технологіям вирощування, які забезпечують отримання максимальної кількості якісного урожаю плодів з одиниці площі. Основним критерієм вирішення даної задачі є конструкція насаджень: вузькорядна схема садіння дерев та малооб'ємна форма крони. Метою досліджень було встановлення впливу строку обрізування різних типів формувань крони на ріст та продуктивність дерев яблуні двох сортів: Фуджі та Хоней Крісп. Дослідження виконувались в умовах центрального лісостепу України (Уманському національному університету садівництва). Схема садіння досліджуваних дерев 4x1 м, підщепа М.9, ґрунт чорнозем дерново-опідзолений, зрошення краплинне. Під час виконання дослідження використано польові, статистичні та розрахунково-аналітичні методи. Виявлено, що характер росту досліджуваних сортів істотно різнився та за показниками діаметру, об'єму крони, площі проекції та освоєнням площі живлення переважав у дерев сорту Хоней Крісп. Проте, за показниками продуктивності, насадження сорту Фуджі суттєво перевищували значення сорту Хоней Крісп. Формування крони балерина з видаленням обростаючої деревини в 25 см зоні на центральному провіднику вище нижнього ярусу напівскелетних гілок, забезпечило підвищення ростової активності досліджуваних дерев на 3-5 %. Істотного зменшення значень параметрів крони забезпечило формування крони французька вісь, на 44 % відбулось зменшення діаметра крони, на 67 % об'єму крони, на 69 % площі проекції крони та освоєння площі живлення. Виконання додаткового літнього обрізування дерев також сприяло зменшенню активності росту на 6-11 %. Проте питома продуктивність насаджень зросла вдвічі у насадженнях з формуванням французької вісі та на 45-50 % з запровадженням двократного обрізування дерев. Рекомендовано сільгоспвиробникам досліджені строки обрізування малооб'ємних форм крони з урахуванням сортових особливостей, з метою створення ущільнених насаджень яблуні та підвищення інтенсифікації виробництва

Ключові слова: яблуня; форма крони; строк обрізування; об'єм крони; літнє обрізування



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Assessment of the genetic diversity of red fescue in the Western region of Ukraine

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Abstract. Red fescue (*Festuca rubra* L.) is a perennial plant of the cereal family (Poaceae), which is used as a fodder and lawn crop. Despite substantial research, the number of high-yielding varieties adapted to specific soil and climatic conditions is insufficient. Therefore, the examination of the genetic diversity of red fescue plants is the main stage in the creation of new varieties. The purpose of the study was to evaluate samples based on the main economic-biological characteristics and divide them into three groups of ripening for further use in breeding as a source of valuable traits. The study used general scientific (analysis, synthesis, experiment, description, observation, and comparison), field (phenological observations and accounting), and statistical methods. According to the results of the study, populations of different ecological and geographical origins created by different breeding methods were similar. The coefficients of variation in the parameters of the main features were in the



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range of 0.34–8.02% and depended on the biological and ecological characteristics of the samples. According to the duration of the growing season, the samples were divided into early-ripening (16 pcs.), medium-ripening (20 pcs.), and late-ripening (12 pcs.). When clustering by eight features, all samples were divided into three clusters. In the early-ripening group, substantial correlations were established between the duration of the growing season and 1000 grain weight, between plant height and seed yield, and between dry matter yield and leaf colour intensity. Positive associations between dry matter yield and regrowth intensity, between 1000 grain weight and leaf colour intensity were observed in the middle-ripening group. In the late-ripening group, reliable relationships were identified between plant height and tillering intensity, seed yield and 1000 grain weight, seed yield and leaf colour intensity, and dry matter yield and leaf colour intensity. The results obtained will be used in further breeding work when creating varieties of red fescue of various ripening groups with improved seed productivity, suitable for fodder and lawn use

Keywords: *Festuca rubra* L.; sample; yield; economic-biological characteristics; correlation coefficients; cluster

INTRODUCTION

Increasing the efficiency of using red fescue seeds is possible, primarily, by creating new varieties and conducting their seed production. Despite substantial research, the number of high-yielding varieties adapted to specific soil and climatic conditions is insufficient. In this regard, breeders need to create varieties with increased seed productivity, which would resist adverse environmental factors. It is important to conduct a preliminary examination and detailed assessment of samples of various ecological and geographical origins. All this indicates the relevance of the conducted study to solving the important scientific and practical issues mentioned above.

According to Braun *et al.* (2020), red fescue is a polymorphic species represented by several subspecies: *Festuca rubra* L. subsp. *rubra*, *Festuca rubra* L. subsp. *fallax* (Thuill) Num., *Festuca rubra* L. subsp. *arenaria* (Osbeck.) O. Schwarz., *Festuca rubra* L. subsp. *arctica* (Hack.) Govor. etc. Their wide geographical distribution is the result of adaptation to different environmental conditions and cultivation.

Central Europe is the centre of origin of species in the *Festuca* family. Red fescue is distributed in North America, Iceland, Minor and Central Asia, China, England, Lithuania, and Ukraine (Soreng *et al.*, 2015). According to Mytsyk (2016), it is also located in the forest, forest-steppe, and high-altitude belts of the Caucasus and the Carpathians. Its specific thickets are present in forests, on the hummocks of swamps, and in their coastal zone. In the Steppe zone, it occurs mainly as an adventitious plant, including in its driest areas. It is absent in the modern forests of the Steppe Dnieper region.

Fescue is known for its shade tolerance, resistance to drought (Reiter *et al.*, 2017), salt (Friell *et al.*, 2013), and cold (Friell & Watkins, 2021), adaptability to infertile and acidic soils (pH 4.5–6.5). *Festuca rubra* is versatile due to its ability to withstand a wide range of mowing heights and grow in insufficiently fertile soils (Benfriha *et al.*, 2021). Ospina *et al.* (2015) presented a taxonomic review of the *Festuca* genus in Chile based on morphological and anatomical data, 19 species and two varieties were also examined.

Ostapets (2020) examined leaf blade colouration in samples of various fescue species. It was identified that the colour of the leaf blade is controlled by plasma genes that are transmitted through the maternal line, and can range from saturated green to green with a slight blue tint.

Varieties and populations of fescue differ in their morphological and biological characteristics. Mefti *et al.* (2016) and Georgieva *et al.* (2019) examined the genetic structure and biological resources of wild fescue forms when breeding for decorative properties and stability in specific soil-climatic conditions. According to Šurinová *et al.* (2019), temperature and precipitation are the best indicators of the genetic kinship of red fescue populations and can be important determining factors for population differentiation.

Afkar *et al.* (2022) evaluated genetic diversity in 22 populations of three *Festuca* species (*Festuca arundinacea*, *F. rubra* and *F. ovina*) using the seed protein electrophoresis model. Studies showed that there is a high level of genetic diversity within a species, not between species. Cluster analysis was used to evaluate populations. Researchers recommend using the best samples as parent components for hybridisation. Ustariz *et al.* (2022) examined 43 populations of *Festuca* species (in Bolivia (drought and low temperatures)) to effectively preserve and reproduce genetic diversity. The study indicated a low level of genetic differentiation between populations. The authors developed EST-SSR markers that are recommended for use in assessing the genetic diversity of Bolivian fescue (Ustariz *et al.*, 2022).

Shahabzadeh *et al.* (2020) evaluated the genetic diversity and structure of 90 high-grade fescue populations and varieties using ISSR and EST-SSR markers. The samples were classified according to the area of feed and lawn use and recommended for use in variety improvement programmes in various areas of use. All these studies confirm that the formation of collections for creating the source material of red fescue involves a preliminary examination of samples by the main characteristics and their effective use in the breeding

process by yield and other economic-biological characteristics (Bastruk-Hlodan *et al.*, 2019).

The purpose of the study was to examine the selection material of *Festuca rubra* in the conditions of the Western region of Ukraine. In addition to the characteristics of lawn and fodder use, samples should be characterised by high seed productivity. The main tasks were to evaluate samples by biological and economic characteristics, divide samples into ripening groups by the duration of the growing season, and establish relationships between the main characteristics.

MATERIALS AND METHODS

The study was conducted on the experimental basis of the Precarpathian Scientific and Research Department of the Institute of Agriculture of the Carpathian region of the National Academy of Agrarian Sciences in 2016-2020. The soil of the experimental field is typical for the region, sod-medium podzolic gumbo

medium-acidic loamy formed on diluvial deposits drained using clay tube drainage.

The climate of the Western region of Ukraine is moderately warm and humid. It is characterised by a long spring, non-hot summers, a fairly long autumn, and relatively mild winters. Over the years of the study, there were substantial differences in the amount of precipitation and temperatures during the summer months from the perennial average data, which allowed assessing growth and development indicators of *Festuca rubra* in a more diverse way.

The object of the study was 48 samples of red fescue of various ecological and geographical origins, obtained by various methods of selection (mass, individual, group) and intraspecific hybridisation. The samples are provided with the numbers of the Institute of Agriculture of the Carpathian region of the National Academy of Agrarian Sciences and the numbers of the National Catalogue of Ukraine (Table 1).

Table 1. Samples of *Festuca rubra* L., institution code, national catalogue number, and total average economic-biological characteristics, clusters

Institution registration number, PFZ	National catalogue number	Sample	Duration of the growing season, days	Plant height, cm	Grain yield per plant	Dry matter, m ²	1000 grain weight	Tillering intensity	Leaf colour intensity	Regrowth after mowing	Cluster members (membership)
1	2	3	4	5	6	7	8	9	10	11	12
early ripening group											
01548	UJ 1300370	ID from No. 925	97	56.8	2.3	0.47	0.80	3	4	3	1
00806	UJ 1300177	No. 331	95	57.9	4.1	0.51	0.94	4	3	4	2
00594	UJ 1300254	129 K	97	59.3	2.1	0.61	0.90	3	4	2	2
00587	UJ 1300253	DP	96	57.2	2.8	0.39	0.79	3	4	3	1
01545	UJ 1300334	MD from No. 1135	93	58.2	3.4	0.54	1.10	3	3	2	2
01542	UJ 1300331	ID from No. 853	95	59.3	5.6	0.55	1.11	3	3	4	2
01541	UJ 1300330	MD from No. 978	92	56.1	6.1	0.42	1.10	4	4	3	3
00936	UJ 1300280	MD from No. 3	94	57.2	4.3	0.56	0.99	2	3	3	2
01776	UJ 1300337	Eid from Hoverla	97	56.4	5.7	0.63	0.78	3	2	4	1
01154	UJ 1300291	MD from Malomice/ZG	93	60.0	3.2	0.52	0.99	4	3	4	2
01134	UJ 1300288	ID with DP	95	57.2	4.1	0.38	0.77	4	3	2	1
01007	UJ 1300285	MD with Gludas	97	59.2	5.0	0.47	0.81	3	3	2	1
02034	UJ 1300392	DP	97	57.4	4.9	0.51	0.91	3	2	2	1
01547	UJ 1300371	DP	96	55.3	6.0	0.52	0.79	4	3	2	1
00742	UJ 1300184	Hoverla	97	56.0	7.0	0.39	0.97	4	4	2	3
01397	UJ 1300390	DP	93	56.4	5.3	0.45	1.10	2	4	4	2
medium-ripening group											
00804	UJ 1300175	Gludas	102	57.4	4.3	0.58	1.05	3	4	3	2
01540	UJ 1300373	GP No. 854 x No. 925	98	56.9	3.6	0.39	1.02	3	3	3	1
00935	UJ 1300279	Selection from No. 2	103	56.1	4.1	0.47	1.00	4	4	2	3
00925	UJ 1300278	Selection from DP	101	58.2	5.1	0.54	0.98	3	3	3	2

Table 1, Continued

Institution registration number, PFZ	National catalogue number	Sample	Duration of the growing season, days	Plant height, cm	Grain yield per plant	Dry matter, m ²	1000 grain weight	Tillering intensity	Leaf colour intensity	Regrowth after mowing	Cluster members (membership)
1	2	3	4	5	6	7	8	9	10	11	12
00854	UJ 1300277	DP	99	59.3	6.4	0.52	0.87	4	3	4	2
00853	UJ 1300276	DP	100	57.1	4.7	0.49	0.99	4	4	4	2
01739	UJ 1300154	Yanka	101	60.1	5.4	0.37	1.01	3	3	2	3
00805	UJ 1300176	No. 257	101	58.6	3.6	0.36	0.96	3	4	2	3
01543	UJ 1300332	MD from No. 1363	101	54.9	4.2	0.39	0.88	2	2	2	1
01214	UJ 1300300	Varius	99	54.1	4.4	0.49	0.91	3	2	3	1
01136	UJ 1300290	MD from No. 854	101	59.2	5.1	0.54	1.05	2	4	3	2
01008	UJ 1300286	RGD from No. 257	98	56.6	6.3	0.56	1.06	3	3	4	2
00940	UJ 1300284	MD from No. 8	101	55.7	4.7	0.47	0.94	3	3	3	1
00017	UJ 1300029	Malomice/ZG	103	58.4	6.1	0.39	0.96	4	3	3	3
00018	UJ 1300028	Lidzbark Warw	98	56.3	7.8	0.52	1.04	4	4	3	3
00015	UJ 1300030	Nasiezne/KS	100	57.9	4.3	0.55	1.01	5	4	4	2
00016	UJ 1300081	Exp.S-250-11	101	57.1	5.6	0.39	0.99	4	3	3	3
02045	UJ 1300393	DP	102	56.9	5.1	0.41	0.95	4	4	4	2
01279	UJ 1300388	DP	99	58.9	3.5	0.51	0.75	5	3	3	2
01304	UJ 1300389	DP	100	57.1	8.3	0.53	0.68	4	3	3	1
late-ripening group											
00937	UJ 1300281	MD from No. 4	104	55.6	2.9	0.47	0.73	3	4	4	1
00938	UJ 1300282	MD from No. 6	109	59.1	4.3	0.38	0.70	3	4	4	1
01538	UJ 1300374	ID from No. 1008	107	59.4	5.6	0.51	0.89	4	3	3	2
01155	UJ 1300292	MD from Lidzbark Warw	104	59.3	4.7	0.60	0.93	4	3	3	2
01544	UJ 1300333	MD from No. 1007	104	56.4	3.8	0.42	0.94	2	4	3	1
01363	UJ 1300314	MD from Varius	107	59.7	4.9	0.43	1.02	4	4	3	3
01156	UJ 1300293	MD from Kalnica/KS	104	59.3	6.8	0.52	1.03	4	2	4	2
01135	UJ 1300289	MD from No. 853	108	58.1	4.7	0.60	0.98	3	3	3	2
01009	UJ 1300287	ID from No. 331	104	55.4	5.4	0.55	0.99	2	3	3	1
00939	UJ 1300283	MD from No. 7	107	57.8	3.9	0.58	1.01	4	3	4	2
01157	UJ 1300294	MD from Nasiezne/KS	105	59.1	6.0	0.43	1.14	3	3	3	3
00014	UJ 1300024	Kalnica/KS	105	60.5	5.4	0.48	1.07	3	3	3	3

Notes:* Tillering Intensity: 1 – very low; 2 – low; 3 – medium; 4 – high; 5 – very high; *Leaf colour Intensity: 1 – very light; 2 – light; 3 – medium; 4 – dark; 5 – very dark; *regrowth after mowing: 1 – very low; 2 – low; 3 – medium; 4 – high; 5 – very high

Source: compiled by the authors using descriptors for red fescue (GRIN Czech Release 1.10.3)

The study used general scientific (analysis, synthesis, experiment, description, observation, and comparison), field (phenological observations and accounting), and statistical methods. The samples were examined in a collection nursery. Plot area was 2 m². 8 bushes were planted on each plot. The repetition was threefold. Phenological observations were conducted throughout the growing season in accordance with (Formation and preservation of genetic diversity of forage and lawn

grasses in Precarpathia, 2015). The journal of observations noted the features of growth and development and the appearance of plants according to the descriptors for red fescue (GRIN Czech Release 1.10.3).

The duration of the growing season between the earliest variety of red fescue and the latest was 18 days. The variety samples were divided into three groups: early-ripening (the duration of the growing season is 92-97 days), medium-ripening (98-103 days), and

late-ripening (104-109 days). 16 samples were assigned to the early-ripening group, 20 samples to the medium-ripening group, and 12 – to the late-ripening group.

Evaluation of red fescue was conducted according to the following criteria: tillering intensity, leaf colour intensity, regrowth intensity, plant height, dry matter yield, seed yield, and 1000 grain weight. The yield of green mass was calculated by repeatedly mowing four bushes on the site at the height of 13-15 cm of the herbage. Hay yield from the green mass was determined by test sheaves weighing 0.1 kg, selected after mowing and dried to a constant mass. Grains were collected by hand by threshing, cleaning, and weighing them separately from each plant.

Statistical data processing was performed using correlation and variance analysis methods using the TIBCO Statistica 13.5.0.17 software package (1984-2018 Tibco Software Inc.).

RESULTS AND DISCUSSION

The family of cereals (Poaceae Barnh.) is the most widespread on the globe, it occupies 60-90% of the total composition of natural herbal communities. About 1000 species are known from the cereal family. The *Festuca* genus is the most diverse in the Poaceae family (about 450 species worldwide). It is used for feed, turf, landscape, decorative, and bioenergetic purposes. In total, 170 species and more than 50 subspecies of the *Festuca* genus were described in the European flora. However,

only for less than 10 species, practical importance was determined and varieties were created. Three varieties are widely used: Meadow fescue (*Festuca pratensis* Huds.), tall fescue (*Festuca arundinacea* Schreb.), and red fescue (*Festuca rubra* L.).

The effectiveness of breeding work with representatives of the *Festuca* genus is determined by numerous factors, including the area and criteria of use. The value of *F. rubra* as a forage and lawn grass used in Europe requires a better understanding of the diversity of wild ecotypes of the species due to the possibility of using them in breeding programmes. Source material is the main factor. Growing and improving grass varieties requires constant updating of the source material. Ecotypes identified in natural habitats and thus best adapted to soil and climatic conditions are a natural source of genetic diversity of species. Therefore, they should serve as the main source of enrichment of the genetic base of cultivated perennial grasses.

Economic-biological characteristics play a substantial role in the introduction of agricultural plants into production. The main ones are the duration of the growing season, the intensity of tillering, leaf colour, regrowth after mowing, the height of plants, the yield of dry matter, seed yield, and the 1000 grain weight. In the early-ripening group, the lowest coefficient of variation was based on the duration of the growing season (0.46%), and the highest – on seed yield (8.02%). All the examined features were probable ($p < 0.05$) (Table 2).

Table 2. Parameters of traits of red fescue of the early-ripening group (n=16)

Traits	Minimum value, Min	Maximum value, Max	Average indicator Mean	F-Test	Standard error Std. Error. (SE)	Standard deviation SD (p=0.05)	Coefficient of variation CV (%)
Duration of the growing season, days	92.00	97.00	95.33	*	0.44	1.77	0.46
Plant height, cm	55.30	60.00	57.50	*	0.34	1.38	0.59
Grain yield, g	2.10	7.00	4.49	*	0.36	1.45	8.02
Dry matter yield, g	0.38	0.63	0.50	*	0.02	0.08	4.00
1000 grain weight, g	0.77	1.11	0.93	*	0.03	0.13	3.23
Tillering intensity	2.00	4.0	3.25	*	0.17	0.68	5.23
Colour intensity	2.00	4.0	3.25	*	0.17	0.68	5.23
Regrowth intensity	2.00	4.0	2.87	*	0.22	0.89	7.67

Source: calculated by the authors using ANOVA software

The combination of different economically valuable traits in one variety is a complex and poorly understood problem, so the examination of the correlation structure is of practical interest. Determining the correlation between plant productivity traits allows for establishing some patterns in crop formation and identifying valuable source material when a direct assessment of

the desired trait is somewhat difficult. Of all the examined correlations between the characteristics of red fescue samples, only between the duration of the growing season and the mass of 1000 seeds (-0.722); between plant height and seed yield (-0.490); between dry matter yield and leaf colour intensity (-0.501) were negative and reliable (Table 3).

Table 3. Correlation coefficients between morpho-biological characteristics of red fescue plants of the early-ripening group

Traits	Plant height, cm	Grain yield, g	Dry matter yield, g	1000 grain weight, g	Tillering intensity	Colour intensity	Regrowth intensity
Duration of the growing season, days	-0.054	-0.041	0.121	-0.722	-0.001	-0.165	-0.362
Plant height, cm	1	-0.490	0.340	0.185	-0.076	-0.140	0.130
Grain yield, g	-	1	-0.159	0.224	0.197	-0.200	0.020
Dry matter yield, g	-	-	1	0.071	-0.321	-0.501	0.228
1000 grain weight, g	-	-	-	1	-0.184	0.195	0.308
Tillering intensity	-	-	-	-	1	-0.001	-0.165
Colour intensity	-	-	-	-	-	1	-0.055
Regrowth intensity	-	-	-	-	-	-	1

Source: calculated by the authors using ANOVA software

Using these traits is recommended when creating early-ripening high-yielding varieties. The samples of the medium-ripening group differed slightly in basic indicators from the samples of the early-ripening group.

The lowest was the coefficient of variation based on the duration of the growing season (0.34%), and the highest – grain yield (5.65%). All examined features were substantial ($p < 0.05$) (Table 4).

Table 4. Parameters of traits of red fescue of the medium-ripening group ($n=20$)

Traits	Minimum value, Min	Maximum value, Max	Average indicator Mean	F-Test	Standard error Std. Error. (SE)	Standard deviation SD ($p=0.05$)	Coefficient of variation CV (%)
Duration of the growing season, days	98.00	103.00	100.40	*	0.34	1.54	0.34
Plant height, cm	54.10	60.10	57.34	*	0.32	1.52	0.56
Grain yield, g	3.50	8.30	5.13	*	0.29	1.32	5.65
Dry matter yield, g	0.36	0.58	0.47	*	0.02	0.07	4.26
1000 grain weight, g	0.68	1.06	0.96	*	0.02	0.10	2.08
Tillering intensity	2.00	5.00	3.50	*	0.18	0.83	5.14
Colour intensity	2.00	4.00	3.30	*	0.15	0.66	4.55
Regrowth intensity	2.00	4.00	3.05	*	0.15	0.69	4.92

Source: calculated by the authors using ANOVA software

Of all the correlations examined, only between dry matter yield and regrowth intensity (0.497); between

1000 grain weight and leaf colour intensity (0.431), the relationship was positive and reliable (Table 5).

Table 5. Correlation coefficients between morpho-biological characteristics of red fescue plants of the medium-ripening group

Traits	Plant height, cm	Grain yield, g	Dry matter yield, g	1000 grain weight, g	Tillering intensity	Colour intensity	Regrowth intensity
Duration of the growing season, days	0.119	-0.199	-0.299	0.097	-0.083	0.240	-0.370
Plant height, cm	1	0.055	-0.011	0.023	0.184	0.340	0.038
Grain yield, g	-	1	0.259	-0.181	0.150	-0.023	0.254
Dry matter yield, g	-	-	1	0.003	0.155	0.221	0.497
1000 grain weight, g	-	-	-	1	-0.310	0.431	0.058
Tillering intensity	-	-	-	-	1	0.290	0.417

Table 5, Continued

Traits	Plant height, cm	Grain yield, g	Dry matter yield, g	1000 grain weight, g	Tillering intensity	Colour intensity	Regrowth intensity
Colour intensity	-	-	-	-	-	1	0.198
Regrowth intensity	-	-	-	-	-	-	1

Source: calculated by the authors using ANOVA software

In the group of late-ripening plants, the lowest coefficient of variation was based on the duration of the growing season (0.50%) and the highest – tillering intensity (6.77%). All the examined features were probable ($p < 0.05$) (Table. 6).

Of all the correlations examined, only between plant height and tillering intensity (0.632) and between

grain yield and 1000 grain weight (0.622) were positive and reliable. Between grain yield and colour intensity (-0.756), between dry matter yield and colour intensity (-0.613), the relationship was negative and substantial (Table 7). Therefore, these characteristics should be considered at the next stages of breeding when creating lawn varieties.

Table 6. Parameters of traits of red fescue of the late-ripening group (n=12)

Traits	Minimum value, Min	Maximum value, Max	Average indicator, Mean	F-Test	Standard error Std. Error. (SE)	Standard deviation SD (p=0.05)	Coefficient of variation CV (%)
Duration of the growing season, days	104.00	109.00	105.67	*	0.53	1.83	0.50
Plant height, cm	55.40	60.50	58.31	*	0.48	1.68	0.82
Grain yield, g	2.90	6.80	4.87	*	0.31	1.06	6.37
Dry matter yield, g	0.38	0.60	0.50	*	0.02	0.07	4.00
1000 grain weight, g	0.70	1.14	0.95	*	0.04	0.13	4.21
Tillering intensity	2.00	4.00	3.25	*	0.22	0.75	6.77
Colour intensity	2.00	4.00	3.25	*	0.18	0.62	5.54
Regrowth intensity	3.00	4.00	3.33	*	0.14	0.49	4.20

Source: calculated by the authors using ANOVA software

Table 7. Correlation coefficients between morpho-biological characteristics of red fescue plants of the late-ripening group

Traits	Plant height, cm	Grain yield, g	Dry matter yield, g	1000 grain weight, g	Tillering intensity	Colour intensity	Regrowth intensity
Duration of the growing season, days	0.358	-0.114	-0.120	-0.255	0.264	0.240	0.135
Plant height, cm	1	0.538	-0.098	0.323	0.632	-0.299	-0.158
Grain yield, g	-	1	0.094	0.622	0.238	-0.756	-0.272
Dry matter yield, g	-	-	1	0.243	0.287	-0.613	-0.099
1000 grain weight, g	-	-	-	1	0.087	-0.564	-0.487
Tillering intensity	-	-	-	-	1	0.340	0.245
Colour intensity	-	-	-	-	-	1	0.000
Regrowth intensity	-	-	-	-	-	-	1

Source: calculated by the authors using ANOVA software

However, the examination of the main economic-biological traits by ripening groups does not provide sufficient information on samples. Ultimately, the selected numbers may be inferior in one attribute to another. Therefore, to establish the similarity of samples by individual groups of traits and the totality and degree of

genetic divergence, a cluster analysis was performed, which allowed classifying the breeding material of red fescue. Using this method, based on Euclidean distance coefficients for eight morpho-biological features, a natural relationship was established between 48 samples of different ecological-geographical origins. The

dendrogram is constructed using the Euclidean metric and the single-link method. This method combines two samples that are most similar to each other. At the next iteration, they are joined by a sample with the maximum similarity of one of them, which leads to the formation of a cluster. Euclidean distances are used as a measure

of genetic divergence to distinguish between genetically close groups of samples. The distribution of samples into clusters is shown in Figure 1, it differed from the division of samples by the duration of the growing season. The first cluster includes 16 samples, the second – 21 samples, and the third – 11 samples (Table 1, Fig. 1).

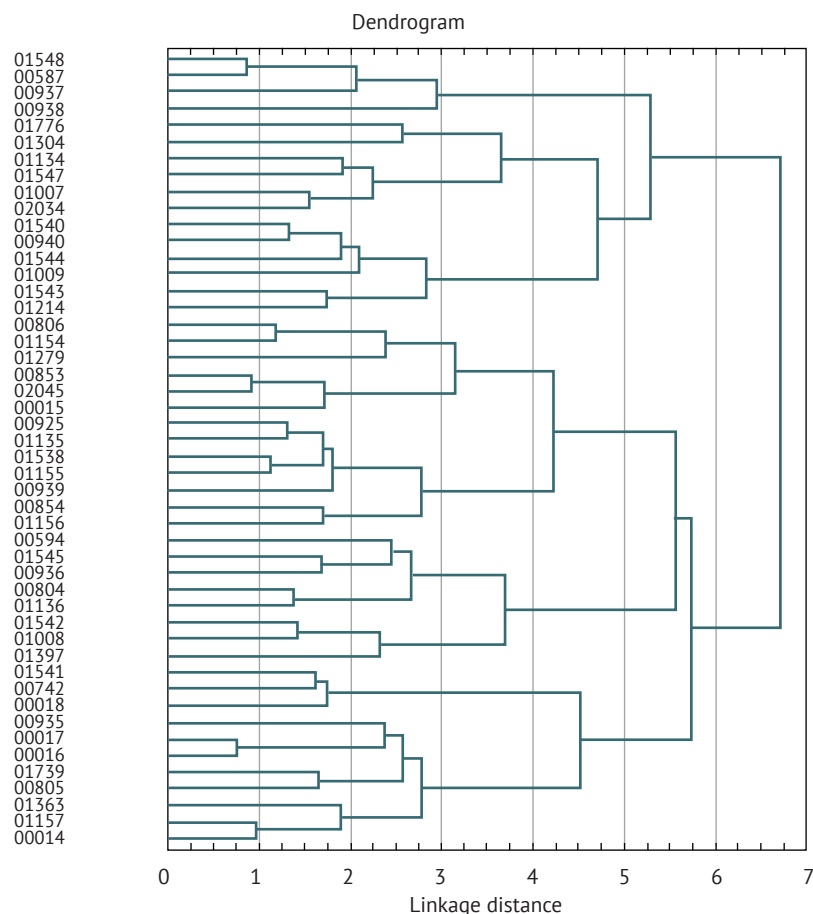


Figure 1. Clustering of red fescue samples by eight morpho-biological characteristics (horizontal – Euclidean distances, vertical – samples)

Populations of red fescue have morpho-biological plasticity and high adaptive capabilities, which opens up prospects for finding the most adapted forms to specific soil and climatic conditions. One of the important factors that determines the success of introduction and contributes to the cultivation of red fescue varieties is high grain productivity.

A number of researchers examined samples of red fescue according to various traits and identified the best of them. Angelov & Bednarska (2018) conducted a study of natural populations of species of the *Festuca* genus from Bulgaria, calculated the values of genetic identity for paired comparisons, and determined the kinship of all the examined species.

Bitarafan *et al.* (2019) investigated grain yield and lodging of red fescue samples for three years. A positive correlation was identified between the intensity of

colouration and lodging and a negative effect of lodging on grain yield. According to Braun *et al.* (2020), red fescue is characterised by substantial intraspecific variability of biological parameters.

Eleven traits in samples of red fescue were evaluated by Iwańska *et al.* (2019). Based on multivariate analysis, i.e. hierarchical cluster analysis and the component analysis principle, the authors identified and described groups of varieties and evaluated the relationships between traits. The traits that most correlate with grain productivity are identified: plant height, grain yield, plant growth rate, leaf width, and time before the start of earing. Samples of feed and lawn use are highlighted.

Stukonis *et al.* (2015) examined 38 samples of red fescue in Lithuania, which were collected in different bioclimatic regions of Ukraine and Lithuania. Samples were evaluated for 16 morpho-anatomical features. The

authors identified that the Ukrainian and Lithuanian populations differed in leaf structure. As a result of the studies, 7 promising populations were identified (6 populations from Ukraine) based on the number of grains per plant and plant height.

Similar studies of the source material of red fescue in the conditions of the Precarpathian region were conducted by Konyk (2016). Sources of valuable traits that are recommended to be used in further breeding work are highlighted. It is established that grain productivity is affected by such traits as mass of 1000 grains, number of grains in the inflorescence, and mass of grains per ear.

Bastruk-Hlodan *et al.* (2019) evaluated 37 samples of red fescue under Precarpathian conditions. Standard samples and the best samples are selected based on the following characteristics: duration of the growing season, winter hardiness, plant height, regrowth rate after mowing, yield of green mass, dry matter, and grain. These samples are recommended to be used as a starting material for creating feed varieties.

Using molecular markers and phenotypic measurements Stojanova *et al.* (2018) examined the adaptive potential of 11 populations of *Festuca rubra*. The authors proved that quantitative genetic differentiation between populations is caused by climate change.

Benfriha *et al.* (2021) evaluated the genetic diversity of fescue ecotypes from different regions of Algeria. Wild populations were compared with varieties, as a result of which, 743 markers were isolated, the variation within the population was high and amounted to 86%.

All this suggests that in the studies, the authors used a different source and its response to different growing conditions. Analysing the results obtained, it can be argued that the formation and examination of the collection of red fescue is an important stage in the breeding process. This enables the creation of a database of economic-morphological characteristics, which at the next stages of breeding should be used when creating new source material (selection, hybridisation) and new varieties of forage and lawn use. Ultimately, the requirements for them are different. Therefore, work on the selection of grass varieties for lawns, pastures, and hayfields is conducted in radically opposite directions. A good fodder variety should have rapid and intense growth and the ability to provide the maximum amount of high-quality green mass. Varieties for lawns, on the contrary, should provide: good tillering, rapid covering of the site surface, slow regrowth after mowing, juicy, beautiful greenery after mowing, have an attractive leaf mass.

CONCLUSIONS

Based on the results of the study conducted in the Precarpathian Scientific and Research Department of the Institute of Agriculture of the Carpathian region, an information database of the main economic-biological characteristics of 48 samples of red fescue and a working collection were formed. Based on the analysis of eight morpho-biological features, the samples were divided into three clusters. According to the duration of the growing season, the breeding numbers of red fescue were divided into three groups of ripening: early-ripening, medium-ripening, and late-ripening.

It was identified that the average height of plants in the early-ripening group is 57.5 cm, in the medium-ripening group – 57.34 cm, and in the late-ripening group – 58.31 cm. In terms of grain yield, samples of the medium-ripening group had the best indicators – 5.13 g per plant, samples of the early-ripening group had the lowest indicators – 4.49 g per plant. In terms of dry matter yield, samples of all ripening groups were at the same level – 0.50; 0.47; 0.50 g per plant. By 1000 grain weight, the best indicators were identified in samples of the early-ripening group – 0.93 g.

Samples with high tillering intensity were highlighted – PFZ00806, PFZ01541, PFZ01154, PFZ01134, PFZ01547, PFZ00742, PFZ00953, PFZ00854, PFZ00853, PFZ00017, PFZ00018, PFZ00016, PFZ02045, PFZ01304, PFZ01538, PFZ01155, PFZ01363, PFZ01156, PFZ00939. The intensity of leaf colour in samples of all ripening groups varied from light (2) to dark (4).

According to the rate of regrowth after mowing, samples with high indicators were identified – PFZ00806, PFZ01542, PFZ01778, PFZ01154, PFZ01397, PFZ00854, PFZ00853, PFZ01008, PFZ00015, PFZ02045, PFZ00937, PFZ00938 (for feed use) and low – PFZ00594, PFZ01545, PFZ01134, PFZ01007, PFZ02034, PFZ01547, PFZ00742, PFZ00935, PFZ01739, PFZ00805, PFZ01543 (for lawn use).

The samples used in the study are recommended to be used in further breeding work as parent components when creating varieties and new source material of red fescue of different ripening groups and different areas of use.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Оцінка генетичного різноманіття костриці червоної в умовах Західного регіону України

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Анотація. Костриця червона (*Festuca rubra* L.) – багаторічна рослина родини злакових (Poaceae), яка використовується як кормова та газонна культура. Незважаючи на значний обсяг досліджень, кількість високоврожайних сортів адаптованих до конкретних ґрунтово-кліматичних умов недостатня. Тому вивчення генетичного різноманіття рослин костриці червоної є основним етапом при створенні нових сортів. Метою дослідження було оцінити зразки за основними господарсько-біологічними ознаками та поділити їх на три групи стиглості для подальшого використання в селекції як джерела цінних ознак. У дослідженні використовували загальнонауковий (аналіз, синтез, дослід, опис, спостереження і порівняння) польовий (фенологічні спостереження та обліки) та статистичний методи. За результатами досліджень, популяції різного еколого-географічного походження та створені різними методами селекції були подібними. Коефіцієнти варіації за параметрами основних ознак знаходилися в межах 0,34-8,02 % і залежали від біологічно-екологічних особливостей зразків. За тривалістю вегетаційного періоду зразки було поділено на ранньостиглі (16 шт.), середньостиглі (20 шт.) та пізньостиглі (12 шт.). При кластеризації за вісьмома ознаками всі зразки було поділено на три кластери. В ранньостиглій групі між «тривалістю вегетаційного періоду» та «масою 1000 насінин», між «висотою рослини» та «врожайністю насіння», між «врожайністю сухої речовини» та «інтенсивністю забарвлення листя» встановлено достовірні кореляційні зв'язки. Позитивні зв'язки між «врожайністю сухої речовини» та «інтенсивністю відростання», між «масою 1000 насінин» та «інтенсивністю забарвлення листя» відмічали у середньостиглій групі. У пізньостиглій групі між «висотою рослини» та «інтенсивністю кущення», між «врожайністю насіння» та «масою 1000 насінин», між «врожайністю насіння» та «інтенсивністю забарвлення листя», між «врожайністю сухої речовини» та «інтенсивністю забарвлення листя» були виявлені достовірні зв'язки. Отримані результати будуть використовуватись в подальшій селекційній роботі при створенні сортів костриці червоної різних груп стиглості із покращеною насінневою продуктивністю, придатні для кормового і газонного використання

Keywords: *Festuca rubra* L.; зразок; врожайність; господарсько-біологічні ознаки; коефіцієнти кореляції; кластер



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Comparative analysis of the main economic and biological parameters of maize hybrids that determine their productivity

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Abstract. Corn kernels are characterised by the presence of all the nutrients, macro- and microelements necessary for growth and development in an easily digestible form. Considering the differentiation of soil and climatic zones of cultivation, the breeding process is designed to establish hybrids of different maturity groups. The research purposes to evaluate maize hybrids of different maturity groups for a set of economic and biological traits of productivity, high-yield stability, and further cultivation in production conditions suitable for mechanised harvesting. Methods used in the research include informational, theoretical analysis, synthesis, analogy, comparison and generalisation; research identification, and measurement. During the research, a systematic analysis was applied, considering the uniqueness of technical, productive, and economic conditions for growing hybrid corn. The research results demonstrate that to achieve successful regulation of maize hybrids productivity and improve their quality, it is necessary to select for suitability for specific soils and climatic zones, considering the biological requirements for seeds and developing effective agrotechnical means designed for processes occurring at different stages of growth and development. The seeds of corn hybrids, formed by breeding,



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were determined by a high nutrient content: In mid-early corn, the content of crude protein was 9.2-9.9%, crude fat – 4.2-4.4%, BER (nitrogen-free extractives) – 82.5-83.3%, starch – 71.4-73.7%; in the medium-late group, the content of crude protein ranged from 9.8-10.4%, crude fat from 4.1-4.6%, BER from 80.6-82.2%, and starch from 70.2-74.1%. The medium-early group of hybrids obtained the optimal height of 245-276 cm, the weight of 1000 seeds – 308-344 g, the ratio of node height to plant height – 0.445; the medium-ripening group respectively 296-351 cm, 318-382 g, 0.455

Keywords: seed quality; dry matter yield; yield; agroclimatic conditions; methods of quality determination

INTRODUCTION

Improving the agronomic characteristics of maize genotypes and management practices is essential for increasing the yields and profitability of agriculture. Successful management of corn seed productivity and quality requires careful selection of hybrids, considering soil, climatic and biological measures at different stages of growth and development.

I.V. Baskakov *et al.* (2020) characterise the optimal ratio of productivity and economic cost of cultivation, reporting that in the world about 20% of corn seeds are used for food production, 15-20% – for technological processing, 60-65% – for feed, compared to the percentage in the EU countries of 20%, 18% and 72%, respectively. V.V. Hlyva *et al.* (2022) report that the gross harvest of corn reaches 35.8 million tons, with an average yield of 7.84 t/ha.

X. Wang *et al.* (2019) prove that the development of corn biomass depends on the potential of a particular genotype and its combination with the combined effect of several factors, including hydrothermal conditions and technological methods designed to establish high-protein forms. Following Z.A. Talukder *et al.* (2022) maize hybrids resulting from crossing genetically different parental forms have the following specific properties: high yield, high disease resistance, ability to rapidly accumulate moisture, improved chemical composition, biological characteristics that affect the quality of maize grain from the influence of seed rates, seeding depth, sowing time, and crop thickening. In the work of R. Fritsche-Neto *et al.* (2021) it is reported that parental forms are established by the self-pollination of maize lines in 6-8 generations.

W.S. Rezende *et al.* (2020) state that over the past 60 years, most corn has been produced from hybrid seeds derived from inbred strains bred as a result of generations of self-pollination and artificial selection. To increase the overall grain and feed yields, the Ukrainian agro-industry supports corn production by increasing the area under cultivation and rationalising using different hybrids depending on the length of the growing season. Ukraine's soil fertility and physical and climatic conditions are suitable for growing corn, which produces high-quality food in sufficient quantities to meet domestic needs and export potential.

The optimisation of production costs and exploring market conditions for agricultural products are prioritised. R.C. Schwartz *et al.* (2022) determined that given the intensification of agricultural production, it is advisable to explore the development of model technologies

for growing crops in self-regenerating systems that are most suitable for the effective application of the laws of nature and the best use of bioclimatic resources, contributing to an increase in corn yields, preservation and improvement of soil fertility, and rational use of productive precipitation and moisture.

Ya.V. Byelov (2018) reports that in 2000, the world gross harvest of corn was 592 million tons, and using diversification of production and an increase of sown areas in 2019, the harvest reached 1148 million tons, outstripping rice and wheat. It is mainly caused by the global food crisis, which stimulated demand, thus, today corn accounts for a significant part of total grain production and is the main export crop of Ukraine.

Following O.M. Kolisnyk *et al.* (2020) corn yields can vary by up to 20% depending on the right choice of soil and climatic conditions for the hybrid in which the crop is grown. Almost 50% of the total seed yield is determined by the genotype of the hybrid, while only 30% and 20% are determined by growing conditions and climate. An appropriate supply of nutrients is essential for achieving high crop yields, as the intensity of mineral consumption depends on local soil and climatic conditions and the maturity of hybrids, etc. Corn forms a large germ mass, absorbing nutrients within a relatively short period from the intensive growth phase.

B.D. Kamenshchuk (2020) in his research, argues that due to climate differences, the requirements for hybrid composition and technology of corn cultivation are different. The climate in Ukraine is becoming less continental, and in winter it is more similar to the climate of Western Europe. It is evidenced by the fact that the center of atmospheric action that establishes Ukraine's climate has shifted by about 10° to the east. The agroclimatic conditions in the corn-growing areas are divided into three agroecological zones: Steppe, Forest-Steppe, and Polissya.

The research aims to evaluate maize hybrids of different maturity groups according to a set of economic and biological traits: productivity, suitability for mechanized harvesting, high stability, and yield for further cultivation in production conditions.

MATERIAL AND METHODS

Throughout the research, the following theoretical methods were used: information, analysis, synthesis, analogy, comparison, and generalisation; and research methods: identification – description of the main technological features of corn hybrids; measurement –

determination of morphological characteristics and constituent elements of the crop. A systematic approach was used in the study, considering the unique technical and economic conditions of the complexity of growing hybrid corn.

Following the methodology for the examination and state testing of plant varieties (Tkachyk *et al.*, 2016) biometric and morphological assessments of phenological observations were conducted to determine changes in the phases of growth and development, and periods of development of plant organs – leaves, stems, and cobs. The main area of maize hybrid breeding is designed to increase yields and product quality, resistance to diseases, pests, and adverse environmental conditions, such as drought resistance, cold resistance, and heat resistance, and establishing varieties suitable for cultivation using intensive technologies with full mechanisation of all processes. Depending on the agroecological conditions of corn hybrids of different maturity groups, different rates of plant growth and development are observed depending on the planting density. Following the systematised data of V.D. Buhayov *et al.* (2010) the main factors influencing the seed productivity of parental components represented by self-pollinated lines and simple interline hybrids with optimisation of agrotechnical measures, in particular: sowing time, plant density, and using modern drugs of biological origin, were established.

The conditions for growing productive maize hybrids are analysed: maturity, soil conditions, resistance to cold, drought tolerance, plant growth intensity and ability to suppress weeds, plant stunting, harvesting mechanisms, response to plant density, seed drying rate, and the usefulness of high-quality products, resistance to pests and diseases, male sterility, the profitability of seed production, and the periods of crop growth in terms of the emergence of seedlings, the flowering of panicles, cobs, and formation of milky, waxy, and full ripeness.

The maize hybrids were identified using morphological descriptive methods used to determine differences, uniformity and stability, field inspection, field and laboratory control of varieties: plant height, cob attachment height, node height to plant height ratio, cob length, number of rows of grains and seeds per row, total cob graininess. The weight of 1000 seeds

were determined by weighing 500 seeds from the central zone of the tuber of one genotype by two separate weights with an accuracy of 0.01 g. If the difference between the weights of the selected samples exceeded 3%, another sample was taken and weighed.

The main breeding traits of maize hybrids were evaluated by the chemical composition of nutrients and moisture content. Laboratory studies were performed under generally accepted methods for conducting research in biology by V.V. Vlizlo *et al.* (2012) for the content of total Nitrogen converted to crude protein, crude fat, crude fiber, crude ash, BER (nitrogen-free extractives), and starch.

RESULTS

As energy costs rise, corn production is increasingly focused on resource-saving technologies and the role of hybrids as an important component of growing technology. Corn is grown using resource-saving and mechanised agricultural technologies with using early maturing hybrids. The growing season is one of the main features of genotypes and an indicator of the adaptive capacity of new source material to environmental conditions, which is used to determine corn hybrids in specific agroclimatic zones.

The early maturity and cold resistance of modern corn hybrids have become significant and economically valuable features of increasing the efficiency of corn production in the development of the grain balance of Ukraine. The advantages of growing early ripening hybrids allowed growing them together with late-ripening forms to slow down competition for moisture accumulation, provide sufficient light conditions, synthesise nutrients, gain flexibility in sowing dates, program the risks of yield reduction caused by early drought, and achieve full grain maturity when sowing dates are delayed. Late-ripening hybrids have higher productivity, but the use of early-ripening and mid-early hybrids allows for diversify the risks associated with weather events throughout the growing season and ensures that agrotechnical harvesting techniques are implemented at the optimal time. Modern early hybrids, under favorable temperatures, can catch up or slow down the developmental phases during periods of heat deficit (Fig. 1).

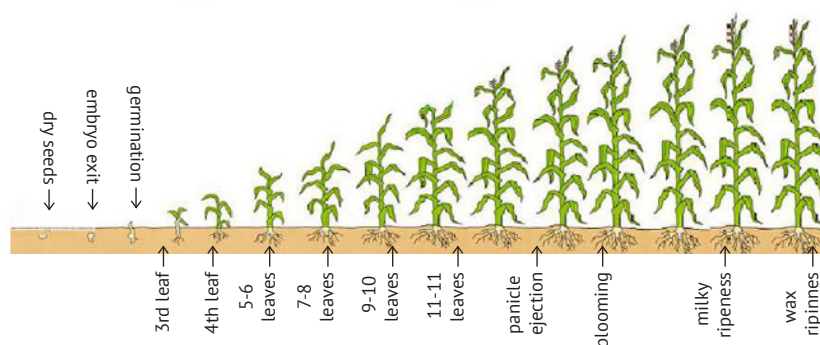


Figure 1. Phenological phases of maize growth and development

Note: based on the author data (Rudavska & Hlyva, 2018)

The length of the growing season in breeding practice is determined by such indicators as the number of leaves on the main stem, the number of veins on the leaf surface, the number of days from germination to the flowering of male and female inflorescences, the total effective temperature and moisture content of the grain. The International Food and Agricultural Organization (FAO) (2023) classifies maize hybrids by maturity

and establishes the generally accepted FAO index, which is used to assess early maturity and compare grain hybrids by biological parameters, used in agronomy and plant breeding. The global range of maize hybrids is divided by FAO numbers in a wide range of 100-999, and the established units correspond to the values of average temperatures. The FAO classification of corn hybrids is described in detail in Table 1.

Table 1. Classification of corn hybrids by FAO

Early maturity group	FAO index	A sum of active temperatures, °C	A sum of effective temperatures, °C	Vegetation period, days	Leaves count, pcs
Early ripening	100-199	2200	900-1000	90-105	12-14
Average-early ripening	200-299	2400	1100	105-115	14-16
Average ripening	300-399	2600	1150	115-120	17-18
Average-late ripening	400-499	2800	1200	120-130	19-20
Late ripening	500-599	3000	1250-1300	135-140	21-23

Note: based on the author data (Bahan et al., 2022)

Top popular corn hybrids grew by leading agricultural holdings in Ukraine: Monsanto – (DKS 4014 (FAO 310), DKS 3511 (FAO 330), DKS 3939 (FAO 320), DKS 4590 (FAO 360), DKS 4351 (FAO 350), DK 315 (FAO 310), DKS 3730 (FAO 280), DKS 4541 (FAO 380), DKS 4408 (FAO 340); NAAS of Ukraine – DB Khotyn (FAO 250), DB Galatea (FAO 250), DB Khortytsia (FAO 240), DB Ajamka (FAO 320). LG Seeds – Adeway (FAO 290), LG30315 (FAO 280), LG30273 (FAO 260); KWS SAAT SE – KWS 2370 (FAO 280), Kerberos (FAO 310); Syngenta – Phenomenon (FAO 220), NK Cobalt (FAO 330), Maize Novy (FAO 330), Twist (FAO 270), Monica 350 MV (FAO 350); Euralis EU – Method (FAO 380); Universeed – EXPI 143 (FAO 320) (2023).

The duration of the growing season and physiological phases of maize plant development is significantly influenced by a set of factors such as plant genotype, place of cultivation, the sum of effective air temperatures, precipitation, and the level of cold resistance of the genotype. Corn is a short-day plant that does not tolerate shade, which leads to a delay in plant development and therefore a decrease in grain yields, even in excessively fertile crops. With 8-9 hours of daylight, corn grows faster, but a day length of 12-14 hours delays its maturation.

The characteristic climatic conditions are determined by the appearance of the next leaves in corn; seeds germinate best at a temperature of 8-10°C, seedlings appear at 10-12°C, and growth stops at 10°C and below. During the development of generative organs, the optimum temperature is 19-23°C, and the most favorable growth level is 25-30°C. During the flowering period, corn pollen contains up to 60% moisture, at temperatures above 30-35°C and relative humidity of 30%, the cobs quickly become weak, dry out within 1-2 hours, and subsequently lose their ability to germinate, in contrast to the temperature range of 18-19°C

in cool climates. The development, filling, and ripening of corn kernels is possible at relatively low temperatures: the average daily temperature is 11-12°C, and the daytime temperature is 15°C. Seed filling and wax ripening occur faster at higher temperatures, while the interphase cycle increases significantly at temperatures below 14°C. Autumn frosts of 2-3°C damage plants and leaves. Corn can withstand spring frosts better than autumn frosts. Damaged seedlings will grow back within a week. Early varieties and hybrids can withstand low temperatures and frosts better than later ones. The total biologically active temperature required for the ripening of early-ripening varieties is 1800-2000°C, and for medium- and late-ripening varieties 2300-2600°C.

Favourable soil conditions lead to high yields in clean, ventilated areas with a deep humus layer, and soil fertility requires proper cultivation and fertilisation. The optimal reaction of the soil solution is neutral or slightly alkaline pH 5.5-7.0, while wet, acidic, heavy clay, saline and peaty soils (often lacking in copper ions) are not suitable for corn. A modern fertilisation system is impossible without diagnosing crops based on soil analysis. Higher corn yields cannot be achieved without NPK (Nitrogen, Phosphorus, Potassium) fertilisers. Increased yields per hectare and high absorption of macro- and microelements lead to a gradual decrease in their availability in the soil. A high level of consumption of the main elements is necessary to increase quantitative and qualitative productivity. For the production of 1 ton of corn grain with the appropriate amount of leaf mass, on average, 24-30 kg of Nitrogen, 10-12 kg of Phosphorus, and 25-30 kg of Potassium are injected into the soil. The development of corn grain yields at the level of 5.5-6.0 t/ha on average removes 132-180 kg of Nitrogen, 55-72 kg of Phosphorus, and 138-180 kg of Potassium from the soil.

Trace elements are essential for plant growth, but in much smaller amounts than the main nutrients such as Nitrogen, Phosphorus, Sulfur, and Potassium. Trace elements such as Ferrous, Zinc, and Manganese are important for corn nutrition. Ferrous is active in the redox reactions of plants, thus, about 75% of intracellular iron is bound in chloroplasts. The total amount of iron in the soil ranges from 200 to 100,000 mg/kg, but its solubility is negligible. Chlorophyll synthesis, cellular respiration, chemical reduction of nitrates and sulfates, and absorption of nitrogen – effectively affect the metabolism of nucleic acids, chloroplasts, and RNA (ribonucleic acid).

Considering the adaptive feature of maize hybrids, the flowering of panicles and cobs was observed on

average in early maturing plants on the 40-45th day, and mid-season plants – on the 45-55th day with a time interval between flowering and panicle blooming of 3-6 days. A medium-sized panicle is 25-30 cm long and has 12-18 branches and a high pollen production capacity. The period from flowering to ripening in many samples exceeds 50 days. By length, the main stem hybrids are divided into low 15%, medium 15%, and high 70%.

Table 2 demonstrates the levels of economic and biological traits of maize hybrids according to important factors: number of cobs per plant, multi-row seeding per cob, number of seeds per row, the total number of seeds per cob, and weight of 1000 seeds.

Table 2. The level of economic and biological traits of maize hybrids

Trait	Trait character level		
	medium	minimal	maximum
The number of days from germination to:			
flowering cob	75	44	101
full maturity	136	127	146
Crop height, cm	313	256	371
Head attachment height, cm	146	97	217
Cob length, cm	17	11	25
Seed row amount, pcs	14	6	17
Amount of seeds in a row, pcs	29	10	48
The total amount of seeds in a cob, pcs	407	60	672
Weight of 1000 seeds, grams	418	340	576

Note: based on the author data (Marchenko et al., 2021)

Yield is the main trait that best reflects the biological characteristics of hybrids and their response to growing conditions. According to the annual monitoring of Monsanto Ukraine, in 2022, the best hybrid was DKC 3705,

which at a standard moisture content of 14% yielded 12.5 t/ha, DKC 4590 – 12.36 t/ha, DKC 4014 – 12.31 t/ha. Table 3 demonstrates the agronomic characteristics of DKC corn hybrids used for intensive technologies.

Table 3. Agronomic characteristics of DKC corn hybrids

Trait	DKC 3705	DKC 4590	DKC 4014
Maturity group	medium maturity	medium maturity	medium maturity
FAO	320	360	310
Purpose	for seeds	for seeds	for seeds, silos
Seed type	toothed	toothed	toothed
Crop height	210-250	240-270	220-235
Number of rows	14-18	16-20	14-16
Amount of seeds in a row	40-46	37-42	35-42
Starch contents	73%	more than 72%	more than 72%
Weight of 1000 seeds	310-360	280-350	280-350
Yield potential	15 t/ha	15 t/ha	15 t/ha
Drought resistance	9	9	9
Resistance to lodging	8	8	9

Table 3, Continued

Trait	DKC 3705	DKC 4590	DKC 4014
Maturity group	medium maturity	medium maturity	medium maturity
Resistance to helminthiasis	9	8	9
Resistance to smut	9	9	9
Resistance to fusarium	8	8	8

Note: Based on the source data (All phases of corn development..., 2017)

The growth and development of maize hybrids reflect a complex process of interaction between genotype and environmental factors, thus, the assessment of plants in ontogeny will provide opportunities to reveal the most important dependencies in the development

of high productivity. The complex parameters of new maize hybrids, including morphological and biometric assessment of plant vegetative organs, are an important economically valuable indicator, as presented in Table 4.

Table 4. Characterisation of the examined maize hybrids by economic and biological traits

Hybrid name	flowering cob	full maturity	Crop height, cm	Head attachment height, cm	Cob length, cm	Seed row amount, pcs	Amount of seeds in a row, pcs	The total amount of seeds in a cob, pcs	Weight of 1000 seeds, grams	Moisture, %
Medium early (FAO 200-299) seeding rate, 80 thousand seed germination per 1 ha										
DB Khotyn (FAO 250)	68	113	245	88	23	38	18	223	308	19.9
Gran 310 (FAO 250)	61	117	276	95	18	28	16	250	326	19.4
Leleka (FAO 250)	65	122	271	92	22	40	17	284	344	19.9
Medium late (FAO 300-399) seeding rate, 75 thousand seed germination per 1 ha										
SI Orpheus (FAO 360)	75	136	296	99	19	45	17	239	318	20.1
Monica 350 MV (FAO 350)	68	147	300	107	18	37	18	245	355	20.6
Roziv 311 CB (FAO 310)	71	146	351	102	20	38	17	276	382	20.5

Note: Based on our research

The ratio of the height of corn hybrids by maturity groups and yield level demonstrated that for the mid-early group (FAO 200-299), in the phase of termination of linear growth, the optimal height of plants is 245-276 cm and the weight of 1000 seeds is 308-344 g, with an average ratio of node height to a plant

height of 0.445; for the medium-ripening group (FAO 300-399), the plant height is 296-351 cm, with a weight of 1000 seeds of 318-382 g, the ratio of node height to plant height is 0.455. Laboratory studies have established the content of the main nutrients in the grain of corn hybrids, which is presented in detail in Table 5.

Table 5. Chemical composition of corn hybrids under study, %

Hybrid name	raw protein	raw fat	raw fiber	raw ash	nitrogen-free extractives	starch
Medium early (FAO 200-299) seeding rate, 80 thousand seed germination per 1 ha						
DB Khotyn (FAO 250)	9.24	4.25	2.11	1.12	83.28	71.43
Gran 310 (FAO 250)	9.51	4.44	2.32	1.21	82.59	73.74
Leleka (FAO 250)	9.88	4.22	2.29	1.18	82.51	72.21
Medium late (FAO 300-399) seeding rate, 80 thousand seed germination per 1 ha						
SI Orpheus (FAO 360)	10.12	4.54	3.12	1.65	80.57	74.12
Monica 350 MV (FAO 350)	10.32	4.28	2.56	1.23	81.61	70.23
Roziv 311 CB (FAO 310)	9.76	4.12	2.73	1.16	82.23	73.12

Note: Based on our research

In medium early maize hybrids, the content of crude protein was at the level of 9.2-9.9%, crude fat – 4.2-4.4%, crude fiber – 2.1-2.4%, BER – 82.5-83.3%, starch – 71.4-73.7%. In medium-late maize hybrids, the content of crude protein was at the level of 9.8-10.4%, crude fat – 4.1-4.6%, crude fiber – 2.6-3.1%, BER – 80.6-82.2%, starch – 70.2-74.1%. Indicators of the actual content of nutrients provide reliable information about the amount but do not guarantee full digestibility in the body of animals.

DISCUSSION

The yield and quality of corn grain are the results of the interaction of genetic, environmental, and agronomic factors as one of the most productive and versatile grains in the world, which is grown for food, feed, and various technological processes. The total corn harvest in Ukraine's agro-industrial complex is increasing due to the growth of sown areas and the rational use of hybrid varieties depending on the length of the growing season. The most popular and versatile are mid-season hybrids with FAO indices of 280-390. The length of the growing season in breeding practice is determined by such indicators as the number of leaves on the main stem, the number of veins on the leaf surface, the number of days from germination to the flowering of male and female inflorescences, the total effective temperature and moisture content of the grain.

The height of the hybrids and the number of leaves on the corn stalks indicate that the activation of growth processes occurs in the early stages of growth and development. According to V. Palamarchuk and N. Telekalo (2018) it was found that early and mid-season varieties do not present significant changes in yield due to late sowing, while late varieties have a better chance of implementing their genetic potential with early sowing when the soil temperature reaches +8-10°C. Therewith, sowing in these terms leads to a decrease in grain moisture content at harvest for all biotypes. When sowing early, it is necessary to consider the degree of cold resistance of hybrids and apply appropriate technical measures to protect the seeds during preparation, with the mandatory treatment of seeds with complex preparations of fungicides, trace elements, and growth regulators. The photosynthetic potential of the leaf surface of maize hybrids is an important factor in establishing a total biological yield, characterised by the total leaf surface, growth rate, and time of active activity during the synthesis of generative organs of plants. M.R. Nunes *et al.* (2020) states that as the range of high-yielding early and medium-early maize hybrids increases, it is recommended to increase their share in total crops to 15-20% and 30-35%, respectively, and to sow 40% and 10% of the sown areas with medium and late forms, respectively. Corn hybrids with a short vegetation period shift the stages of morphogenesis to an earlier period, thus, early maturing hybrids have critical periods of

development, such as panicle ejection, flowering, pollination, grain filling, avoiding arid abnormal temperatures, passing the established deadlines in relatively better conditions.

The precise identification of the physiological and molecular biological mechanisms underlying tolerance, which is defined by the ability of plants to cope with damage-induced stress, will be useful for the control of existing maize germplasm collections. This issue will become increasingly important as agriculture becomes more mechanised. In his work A.W. Abubakar *et al.* (2019) compare the study of physiological and biochemical characteristics of maize hybrids of different maturity groups, determines the productivity of plants of a certain genotype by the ability to synthesize nutrients, form a larger assimilation surface, establish a favourable ratio between assimilation and dissimulation, and have high resistance to adverse environmental factors.

Following U. Roskopf *et al.* (2022) when sowing corn, the depth of planting depends largely on the physical and mechanical properties of the soil, moisture content, and temperature. The optimal planting depth for corn is 4-5 cm in heavy clay soils, 5-6 cm in light clay soils, 5-7 cm in black soil, and 6-8 cm in sandy loam soils. As the topsoil dries, the planting depth should be increased by 1-2 cm.

M.V. Kapustyan *et al.* (2021) states that the factors of maturity, sowing time, sowing density of maize, and favourable environmental conditions affect changes in the level of productivity and morphological and biological characteristics of plants, but the greater factor is the dependence on genotype. Since genotypes demonstrate different levels of phenotype expression under the influence of environmental conditions, significant genotype-environment interactions occur under stress conditions, thus, damage to parts that act as abiotic stress to the plant, causing significant seed losses, especially in less favourable years of maize growth, when there is a variation in seed losses between breeding races.

Breeding efforts to develop high-protein corn hybrids play an important role in improving quality. Y. Beyene *et al.* (2019) in his research, used the process of selective mutations of the *o2* and *fl2* genes, which led to the inhibition of gelatin synthesis, increase of glutelin and lysine-protein fractions, increasing the level of protein and lysine protein by 14-16% compared to conventional strains.

Photosynthetic productivity is not a constant process, it changes under the influence of many factors. Current global climate trends make it particularly important to increase the cultivation of drought and heat-tolerant maize. Climate models predict more frequent and severe extreme weather events with serious consequences for crop yields and, indirectly, for food security. The impact of climatic parameters such as water availability and temperature have been identified as important factors affecting maize productivity, for

example, rainfall in April-August has a greater impact on yield than nitrogen fertilisation. Corn is more sensitive to drought during pollination and grain filling, thus, under the influence of the continental climate, it is a significant abiotic regulator of grain yield. Reducing the impact of environmental conditions is determined by the accuracy of cob removal, with a minimum of damage to crops in unfavorable years.

Among many agrotechnical practices, fertilisation is of paramount importance, affecting the growth, development, and productivity of hybrid corn. L.P. Telychko (2020) proves that when growing corn for grain, the most important nutritional factor is not the number of nutrients supplied with fertilisers, but their ratio. Balanced nutrition helps to avoid prolongation of the second half of the growing season and to harvest at the optimal time. The maximum nitrogen consumption by corn begins during the pollen release period and continues until the milk wax ripens. Lack of nitrogen in the soil delays plant growth and reduces the intensity of photosynthesis and protein metabolism.

Technological methods studied in works A.B. Gheț et al. (2020) have different effects on the photosynthetic productivity of maize crops, thus, the introduction of nitrogen-phosphorus and full mineral complexes allows increasing crops by 27.7% and 22.9%, respectively, compared to the background of natural soil fertility. The balanced supply of plants with essential macro- and microelements occurs not only during the period of pre-sowing soil cultivation with fertilisers. Micronutrients can be absorbed much more actively by the leaf surface of corn hybrids than by the root system of plants, thus, an effective way to meet their needs is to foliar feed crops with micro fertilisers. The main advantage of organic products is increased growth energy, which leads to a rapid increase in corn biomass and improved competitiveness.

The growing season of modern corn hybrids grown in Ukraine ranges from 90 to 150 days. S.V. Filonenko (2013) cites the following parameters of the duration of the growing season and the number of leaves on the main stem of corn: early ripening – 90-100 days of vegetation and 14-15 leaves; medium early – 105-115 days and 15-16 leaves; medium ripening – 115-120 days and 17-18 leaves; medium ripening – 120-130 days and 18-19 leaves; late-ripening – 135-140 days of vegetation and 19-20 leaves. In mid-early hybrids, the second half of the growing season is shorter than the first, but both periods should be the same for hybrids grown in the mid-early and mid-late periods, and longer for hybrids grown in the mid-late period. Subject

to optimal corn sowing technology and optimal sowing dates, early hybrids ripen in late August, while mid-season hybrids ripen in the first and second half of September-October.

CONCLUSIONS

Based on the experimental studies, the expression and variability of productivity factors by the periods of ripeness of hybrids of the medium early and medium late groups were determined. It was found that the length of the growing season affects the height of plants, thus, the tallest hybrids and the height of the cob attachment belong to the medium-late group. The optimum height of medium early maize was noted at 245-276 cm, the weight of 1000 seeds 308-344 g, node height/plant height ratio 0.445 and, respectively, 296-351 cm, 318-382 g, and 0.455, which were obtained in the medium late group of hybrids.

Hybrid maize is characterised by its chemical composition of grain, high content of starch, protein, and nitrogen-free extractives, being a necessary raw material in the food industry and production of concentrated feed. In the mid-early corn group, crude protein was 9.2-9.9%, crude fat was 4.2-4.4%, crude fiber was 2.1-2.4%, BER was 82.5-83.3%, and starch was 71.4-73.7%. In the medium-late groups, crude protein ranged from 9.8-10.4%, crude fat – 4.1-4.6%, crude fiber – 2.6-3.1%, BER – 80.6-82.2%, and starch – 70.2-74.1%. The level of moisture transfer depended on the biological characteristics of maize hybrids of different maturity groups, thus, the percentage of seed moisture was 19.4% in the medium early group and 20.6% in the medium late group.

The scientific task of substantiating priority measures for the competitive production of productive hybrids under modern economic conditions was theoretically generalised and solved, the optimal parameters of plant density, sowing time, effective and rational use of biologically active preparations, levels of mineral nutrition of corn with the introduction of complex micro-fertilisers and growth stimulants were established.

In the future, to obtain high-quality and homogeneous seed material, it is recommended to explore seeding rates and resistance to pests and diseases of corn hybrids, fully unlocking the genetic potential and contributing to the economic profitability of growing the crop.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Порівняльний аналіз основних господарсько-біологічних показників гібридів кукурудзи, що визначають їх продуктивність

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Анотація. Зерно кукурудзи характеризується наявністю всіх необхідних для росту і розвитку поживних речовин, макро- і мікроелементів у легкозасвоюваній формі. Враховуючи диференціацію ґрунтово-кліматичних зон вирощування, селекційний процес спрямований на створення гібридів різних груп стиглості. Метою досліджень є оцінка гібридів кукурудзи різних груп стиглості за комплексом господарсько-біологічних ознак продуктивності, стабільності високого рівня врожайності та подальшого вирощування у виробничих умовах, придатних для механізованого збирання. Методи дослідження: інформаційний, теоретичний аналіз, синтез, аналогія, порівняння та узагальнення; наукова ідентифікація, вимірювання. Під час проведення досліджень застосовано системний аналіз, який враховує унікальність технічних, виробничих та економічних умов вирощування гібридів кукурудзи. Результати досліджень свідчать, що для успішного регулювання продуктивності гібридів кукурудзи та підвищення їх якості необхідно проводити добір на придатність до конкретних ґрунтово-кліматичних зон, враховуючи біологічні вимоги до насіння та розробляючи ефективні агротехнічні засоби, розраховані на процеси, що відбуваються на різних етапах росту і розвитку. Насіння гібридів кукурудзи, створених селекційним шляхом, визначалося високим вмістом поживних речовин: У середньоранньої кукурудзи вміст сирого протеїну становив 9,2-9,9 %, сирого жиру – 4,2-4,4 %, БЕР (безазотистих екстрактивних речовин) – 82,5-83,3 %, крохмалю – 71,4-73,7 %; у середньопізньої групи вміст сирого протеїну коливався в межах 9,8-10,4 %, сирого жиру – 4,1-4,6 %, БЕР – 80,6-82,2 %, крохмалю – 70,2-74,1 %. У середньоранній групі гібридів отримано оптимальну висоту 245-276 см, масу 1000 насінин – 308-344 г, відношення висоти вузла до висоти рослини – 0,445; у середньостиглій групі відповідно 296-351 см, 318-382 г, 0,455

Ключові слова: якість насіння; вихід сухої речовини; урожайність; агрокліматичні умови; методи визначення якості



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The effect of the application of liquid complex fertilizers and mixtures based on them on the productivity of corn in the conditions of the Western Polissia

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Abstract. The issues of optimising the phosphorous nutrition of corn are becoming increasingly relevant due to trends in the increasing cost of mineral fertilisers and meteorological risks in the post-sowing period. The purpose of the study is to determine the economic efficiency of liquid complex fertilisers applied during corn sowing as the main source of phosphorus and as an additional element in the nutrition system. A field experiment was performed, which included options for applying LCF, separate application of granular mineral fertiliser, joint use of LCF and granular fertiliser, and tank mixtures of LCF with zinc and a bacterial product based on *Pseudomonas fluorescens* to implement the set tasks. It was identified that the use of LCF in sowing contributes to a better supply of young plants with phosphorus, and, as a result, to the development of a more productive cob. Therewith, the use of LCF exclusively as a food source in doses up to 50-60 L/ha does not allow for realising the inherent potential and leads to a lack of grains from the cob compared with the option with full nutrition. The highest yield was obtained in the version using granular fertiliser and 60 litres of liquid complex fertiliser mixed with a bacterial preparation, while the yield increase relative to the version without granular fertiliser was 32% (2.8 t/ha). Separate application



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of liquid complex fertiliser under no circumstances provided a result comparable to the application of granular fertiliser, but the addition of 25 L/ha of LCF to the main application of granular fertiliser allowed obtaining a yield increase of 1.3 t/ha. The results obtained prove the high efficiency of the liquid form of starter fertiliser when applied on light granulometric soils and should be considered when planning resource-saving technology for growing corn in an area with a high degree of meteorological risks

Keywords: grain quality indicators; local application; resource-saving technologies; efficiency of phosphorous fertilisers; bacterial preparations

INTRODUCTION

Rational management of crop production in modern conditions involves not only meeting the conditions of environmental safety and soil conservation but also considering dynamically changing economic conditions. An important component of ensuring the economic efficiency of corn cultivation is the construction of a proper nutrition system, which should be based on the calculation of the removal of nutrients by the planned crop, the distribution of the total need for mineral elements for individual stages of vegetation, and consider the specific features of soil, climatic conditions, and the level of technological equipment of the manufacturer.

The need for applied studies in the area of optimising mineral nutrition is due, in particular, to increasing climate changes, which are more contrasting in the Western Polesia zone than the national average (Veremeenko *et al.*, 2021), which is a prerequisite for re-thinking agronomic risks and forming a holistic strategy for production adaptation (Baliuk *et al.*, 2018; Volkogon *et al.*, 2019; Trofymenko *et al.*, 2019).

According to previous studies (Kalenska *et al.*, 2018), reduced doses of mineral fertilisers do not ensure the formation of the maximum yield, and the use of high ones leads to a decrease in their profitability. Therewith, in years with unfavourable meteorological conditions, it is even possible to reduce the yield and worsen its biological quality due to an increase in the total salt concentration in the soil solution (Kohan *et al.*, 2019).

It is the phosphate regimen of the soil and the planning of the most efficient phosphorus nutrition that is the subject under study by leading researchers around the world (Nosko, 2017; Kratz *et al.*, 2019; Brod *et al.*, 2022). J. Zhu states that phosphorus is one of the macronutrients that limit crop productivity the most and phosphorus deficiency is common in agricultural soils around the world (Zhu & Min, 2018). Despite the long-term use of phosphorous fertilisers to increase yields, the availability of phosphorus is often low due to the high affinity of phosphate for the solid phase of the soil, which not only reduces the effectiveness of fertilisers but also leads to a number of environmental problems (Tian *et al.*, 2017; Koch *et al.*, 2018; Hospodarenko *et al.*, 2022).

Sod-podzolic soils, having a typically acidic reaction of the soil solution and sandy-loamy granulometric composition, are simultaneously exposed to the risks of washing (Li *et al.*, 2022; Raguet *et al.*, 2023) and blocking

phosphorus in an unfavourable pH environment (Barrow, 2017). Therewith, the studies by researchers from North Carolina (Gatiboni *et al.*, 2020) show that the use of starter phosphorous fertilisers on poor soils has a good economic effect. Substantially higher (in comparison with conventional mineral forms) is the efficiency of organic forms of phosphorous fertilisers (Gronberg *et al.*, 2017; Li *et al.*, 2020; Jin *et al.*, 2023), however, the volume of such raw materials in the modern realities of the economic complex of Ukraine is extremely insufficient.

Plants absorb the maximum amount of phosphorus during grain formation, but the critical period of phosphorus nutrition for grain crops begins two weeks after sowing in the 3-4-leaf phase. Lack of phosphorus during this period affects the development of the root system, worsens the formation of reproductive organs (Liu *et al.*, 2022).

The efficiency and practical feasibility of using liquid forms of mineral (in particular, phosphorous) fertilisers are justified by numerous studies (Harahap *et al.*, 2019; Drazic *et al.*, 2020).

According to M. Battisti *et al.* (2022), the use of starting phosphorous fertiliser contributes to a faster passage of phenological phases of development, substantially increasing the yield of corn and the quality of its grain.

The efficiency of applying phosphorous fertilisers for corn, as a rule, is lower than nitrogen fertilisers and substantially depends on the level of mobile phosphates in the soil. Therewith, the synergistic effect of the level of nitrogen supply on the absorption of phosphorus by corn plants (Battisti *et al.*, 2022). Similar results were obtained in studies by D.J. Quinn *et al.* (2020), according to which, the full formation of the productive corn crop is impossible either under the condition of a separate high phosphorous background or nitrogen, but only in the case of joint provision of availability levels of both.

The studies by Q. Zeng *et al.* (2022) prove that under the conditions of systematic application of phosphorous fertilisers, the activity of soil phosphorus-mobilising biota is suppressed, which increases the risk of accumulation of hard-to-reach phosphates even in poor soils. This creates prerequisites for the effective use of bacterial strains for the targeted mobilisation of blocked forms of phosphorus in the soil.

B.-G. Yu *et al.* (2022) concluded that the use of even a small amount of phosphorous fertilisers (25 kg of P_2O_5) can substantially increase the yield and quality

of corn grain, while a further increase in phosphorus nutrition does not lead to positive changes. The author noted that the use of phosphorous fertilisers increases zinc deficiency, especially in soils with its low supply. Based on this, on the sod-podzolic soils of Polesia, there is a high probability of a positive reaction of corn to its application, in particular, as part of liquid complex fertilisers during sowing.

Therewith, the comparative effectiveness of a unit of the active substance of phosphorus when it is applied in various forms (granular, liquid), in particular, on light soils with a granulometric composition, which are characterised by a low content of available nutrients, remains unexplored.

The purpose of the study consisted in the assessment of the effectiveness of the application of liquid complex fertiliser as the main source of phosphorous nutrition and an additional component in the corn nutrition system during sowing. The tasks included conducting a comparative analysis of the economic efficiency of various doses of liquid Complex Fertiliser of the 5-20-5 composition in comparison with a separate application of granular complex fertiliser and determining the combined efficiency of applying granular and liquid forms of fertilisers.

MATERIALS AND METHODS

The study programme was conducted on the territory of the Rivne region (Western Polesia of Ukraine) within the production branch of the Department of Agrochemistry, Soil Science, and Agriculture of the National University of Water and Environment Engineering during 2020-2022. Plot location: 50.998433, 26.563218. Before laying the experimental site, three soil sections and a number of digs were created to establish the

general genetic characteristics of the soil and its local differences. According to the results of the examination, it was established that the existing type of soil is sod-podzolic sandy-loamy, zonal for the Western Polesia of Ukraine. The humus content is 1.0-1.1%, the thickness of the humus-eluvial horizon is up to 20 cm. The reaction of the soil solution at the time of laying is neutral, previously liming was conducted with the full norm of limestone ameliorant (2018). The initial supply of phosphorus and potassium is low. All field observations at the site were conducted in accordance with the current standards and methods of phenological and soil observations, determination of phosphorus and potassium by the method of Kirsanov (DSTU 4405:2005, 2005).

Sunflower predecessor crop, tillage – deep loosening to a depth of 30 cm after harvesting the predecessor, working unit – Case Quadtrac 500 + Case Ecolo Tiger 730c. In the spring, the soil was re-treated with a disk unit to a depth of 6-8 cm. For sowing, the experiment used a hybrid of intensive corn type LG 30273, FAO 270. Seeding rate – 78,000 seeds/ha, wide-row sowing method, row spacing – 70 cm, Vaderstad Tempo 8 seed drill, sowing depth – 4 cm. The sowing period is when stable temperatures above 12 degrees occur at a depth of 10 cm, which corresponded to May 1-5.

As nitrogen nutrition, anhydrous ammonia was applied at a dose of 140 kg/ha of physical weight, the application period was two weeks before the planned sowing, and the application depth was 18-20 cm. Phosphorus-potassium nutrition was provided by applying granular complex fertiliser to the row. NPK Polifoska 8, produced by GrypaAzoty, with an 8-24-24 composition, was used as fertiliser. As a liquid fertiliser, the product Diaphan-Action, produced by Quantum, was used. Detailed fertiliser characteristics are shown in Table 1.

Table 1. Characteristics of fertilisers used in the experiment

Material	Diafan 5-20-5	Polifoska 8-24-24
Form	liquid	granulated
Total nitrogen, %	5 (64 g/L)	8
Ammonium nitrogen, %	5 (64 g/L)	8
Total phosphorus, %	20 (254 g/L)	24
Phosphorus is soluble in water, %	20 (254 g/L)	21
Total potassium, %	5 (64 g/L)	24
Potassium is water-soluble, %	5 (64 g/L)	24
Available sulfur, %	-	9
Density, g/cm ³	1.28	-

Source: compiled by the authors

Other sources of phosphorus and potassium were not used at the sites. The experiment includes the zinc-containing preparation Zintrac. The preparation was used in a tank mixture with liquid fertiliser, the estimated application dose is 1 L/ha. The purpose of using the preparation

is to provide a sufficient amount of available zinc in the period up to BBCH 13, to avoid potential crop losses from zinc deficiency, which is characteristic of light granulometric soils. A bacterial preparation based on a strain of live bacteria *Pseudomonas fluorenses* (Rhizophos) was

also included in the experiment, applied to test the possibility of increasing the availability of phosphorus in conditions of its deficiency due to microbiological activities. The preparation was used in a tank mixture with liquid fertiliser, the application dose is 0.2 L/ha.

Schemes for laying experimental plots are shown in Table 2. The repetition rate of vegetation records and

crop structure is fivefold, and the yield is threefold. Harvesting was conducted by direct combining with threefold yield calculation for each site. Sampling to assess the quality indicators of the crop was conducted from a batch of grain after complete threshing of the accounting area. Selection of cobs for structure assessment – before threshing in fivefold repetition from each site.

Table 2. Experiment scheme

No.	Option
1	Diafan Action 30 L/ha
2	Diafan Action 40 L/ha
3	Diafan Action 50 L/ha
4	Diafan action 60 L/ha
5	Diafan action 70 L/ha
6	Diafan Action 80 L/ha
7	Diafan action 90 L/ha
8	Polifoska 8 150 kg/ha
9	Polifoska 8 150 kg/ha + Diaphan Action 25 L/ha
10	Polifoska 8 150 kg/ha + Diafan Action 25 L/ha + Zn
11	Diafan action 60 L/ha + Zn
12	Diafan action 60 L/ha + Rhizofos
13	Polifoska 8 150 kg/ha + Diaphan Action 60 L/ha + Rhizofos

Source: compiled by the authors

Statistical processing of data obtained from the results of field and laboratory observations was conducted using generally accepted methods using Microsoft Excel, Statgraphics Centurion, and Statistica software tools.

RESULTS AND DISCUSSION

Corn hybrid LG 30273 of the French selection by Limagrain under favourable growing conditions forms a sixteen-row cob with 40-42 full-fledged grains in each row, which corresponds to a total of 640-650 grains per cob. Therewith, the beginning should be evenly pollinated,

without constrictions and shifts of rows. Therewith, in conditions of insufficient nutrition, or the manifestation of additional stresses during the development of generative organs, hybrid 30273 is able to reduce the row amount in cobs to fourteen or even twelve rows. If the impact of unfavourable conditions occurs at a later date, the plant is able to partially reduce grains, reducing their number within rows to 3032 or less, which proportionally leads to a decrease in the factual yield. In some variants of the experiment, the predicted variability of the cob structure was observed (Fig. 1).

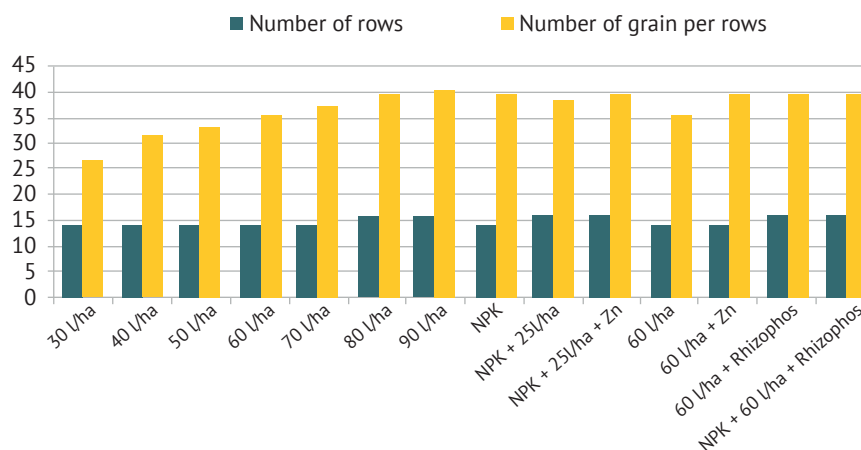


Figure 1. Structure of a corn cob depending on fertiliser

Source: compiled by the authors

Thus, the use of reduced norms of phosphorus nutrition contributed to the formation of an ear of fourteen rows of grains instead of sixteen. Analysing the options using only Diafan 5-20-5 fertiliser in doses from 30 to 90 litres, the number of grains in the row increased from 26 to 40 in proportion to the increase in the fertiliser dose. Therewith, only variants using doses of 80 and 90 litres had a cob with sixteen rows. Thus, the number of grains from one cob gradually increased from 364 to 640, that is, by 76% compared to the option using a minimum dose of fertiliser.

A separate application of complex granular fertiliser 8:24:24 with a dose of 150 kg/ha ensured the formation of a cob with fourteen rows and 39 grains in a row, which may be a consequence of the slower solubility of granular fertiliser compared to the liquid form, and, accordingly, the existing phosphorus deficiency in the root zone during the development of rows. Therewith, the additional application of a minimum amount of liquid complex fertiliser (LCF) allowed forming a cob with sixteen rows and 38-39 grains in a row. Analysing the effectiveness of introducing additional components

into the mixture to the LCF, an increase in the number of grains in a row from 35 to 39 is notable when adding a zinc-containing preparation to 60 L/ha of the LCF without using granular fertiliser. An increase in the row of the cob from fourteen to sixteen rows when introducing a bacterial preparation of phosphorus-mobilising action (Rhizofos) into the mixture, while the options with the introduction of only 60 litres of LCF and 60 litres of LCF together with the full norm of granular fertiliser did not differ from each other in terms of the structure of the cob (Fig. 1).

The use of liquid forms of complex fertilisers contributes to a better supply of young plants with phosphorus, and, as a result, to the development of a more productive cob. Therewith, the use of only LCD in doses of 50-60 L/ha in the nutrition system does not allow the further realisation of the inherent potential and leads to a lack of grains from the cob relative to the option with full nutrition using granular forms of fertilisers. A more clarifying indicator, in this case, should be considered the mass of grains obtained on average from one cob (Fig. 2).

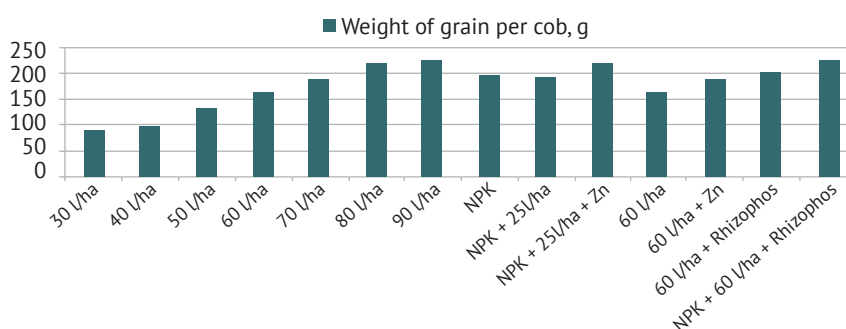


Figure 2. Average weight of grain per cob, depending on fertiliser

Source: compiled by the authors

The weight of grains from one cob varied within the variants of the experiment from 88.5 to 227.3 g. In the plot of separate application of LCF, the values of the indicator increased in proportion to the increase in the dose of application of LCF from 88.5 to 227.3 g, while increasing the dose from 30 to 40 litres per hectare had a slight positive effect, then a further increase in the dose from 40 to 80 litres contributed to an increase in the mass of grains in the cob by 36.4; 29.0; 26.6; 31.2 g for every subsequent 10 litres of fertiliser, which is certainly a substantial trend. For comparison, a separate application of exclusively granular fertiliser provided the formation of 197 g of grain from one cob, which, approximately, corresponds to the option using 70 litres of LCF. From the standpoint of nutrition, 18 kg of active phosphorus in a completely water-soluble form was added in the LCF variant, while 36 kg of P_2O_5 was added together with granular fertiliser, of which 31.5 kg was water-soluble. It is substantial that the addition of 25 litres of Diafan against the background of the introduction of granular fertiliser did not give any positive

effect, but the introduction of an additional zinc-containing product into the tank mixture contributed to an increase in the grain mass in the cob to 219 g (+14.7% relative to a similar option without zinc).

Analysing the effect of additional components in combination with LCF, the positive effect of zinc, the introduction of which provided an increase in the mass of cob grains from 161.8 to 185.7 g when using only 60 litres of Diafan can also be noted. The use of phosphorus-mobilising bacterial preparation increased the indicator from 161.8 to 201.4 g, or by 24.5%, while the implementation of the same tank mixture against the background of additional application of 150 kg of NPK 8:24:24 provided the formation of 227.2 g of grain on average per cob, which is 12.8% more compared to the option without granular NPK or 15.3% more compared to the option of applying only granular fertiliser.

In general, the weight of grain from one cob closely correlates with the structure of the cob described above, the highest, statistically identical values are obtained in variants using 90 L/ha of LCF, the introduction of 150 kg/ha

of granular complex fertiliser with the addition of 25 L of LCF and the introduction of granular fertiliser with the addition of 60 L of LCF mixed with a phosphorus-mobilising

preparation. Important indicators that characterise the realisation of potential yield are also the thousand grain weight and the grain unit, which are shown in Figure 3.

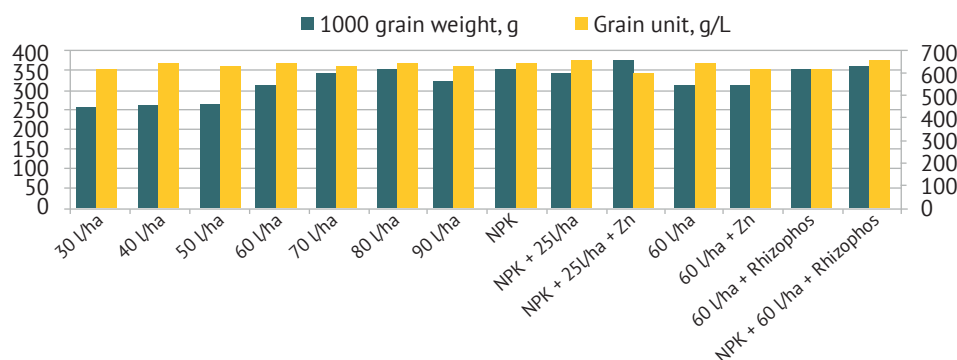


Figure 3. Quality indicators of corn grain depending on fertiliser

Source: compiled by the authors

The LG 30273 hybrid is characterised by a high thousand grain weight (more than 320 g) under normal conditions. The conditions of the growing season, in particular, during the period of grain filling, have a substantial impact on the indicator. Thus, insufficient moisture supply in the period after flowering, a sharp decrease in air temperature or its extensive amplitude during the ripening period can cause insufficient accumulation of substances in grains, and the formation of empty grains, which leads to a decrease in yield even with a sufficient number of grains per unit of sowing area.

According to the experimental variants, the thousand grain weight ranged from 259 to 379 g. An increase in the dose of LCF application from 30 to 80 litres contributed to a proportional increase in the thousand grain weight from 259 to 354 g. The option of a separate application of granular fertiliser had a result of 349 g, the addition of 25 litres per hectare of liquid fertiliser did not statistically change the value of the thousand grain weight, as in the case of the mass of grain from the cob, while the additional application of zinc contributed to an increase in the thousand grain weight to 379 g (+9.5% compared with the option without zinc). Therewith, the additional introduction of zinc against the background of only 60 litres of LCF did not affect the thousand grain weight index. The use of the phosphorus-mobilising preparation against the background of 60 litres of LCF

allowed obtaining an increase in the thousand grain weight by 43 g, or 13.9% (from 309 to 352 g), and a similar option against the background of granular fertiliser provided the thousand grain weight value – 361 g, which is only 2.5% more than in the option without the introduction of granular fertiliser.

Regarding the grain unit indicator, it is impossible to note such evident trends, however, the maximum values of the indicator (648, 654, 642 g/L) were recorded in variants using granular fertiliser. The increase in the indicator of nature in the variant using granular fertiliser + LCF + Rhizophos relative to the similar variant without the use of granular fertiliser from 614 to 648 g/L (+5.5%) is substantial. Reduced grain unit when adding a zinc-containing product is notable. Thus, the addition of zinc to the NPK + variant of 25 L LCF to the tank mixture caused a decrease in the grain unit from 654 to 612 g/L, and the additional introduction of zinc to 60 L LCF caused a decrease in the indicator from 635 to 613 g/L.

There was no direct correlation between the thousand grain weight and the nature of the grain. A normal unit at a low thousand grain weight describes the case of the formation of a small but well-filled grain, and low grain unit at a high thousand grain weight is an indicator of the development of a large grain that was not fully filled. An integral indicator that characterises the efficiency of the nutrition system is the obtained yield (Fig. 4).

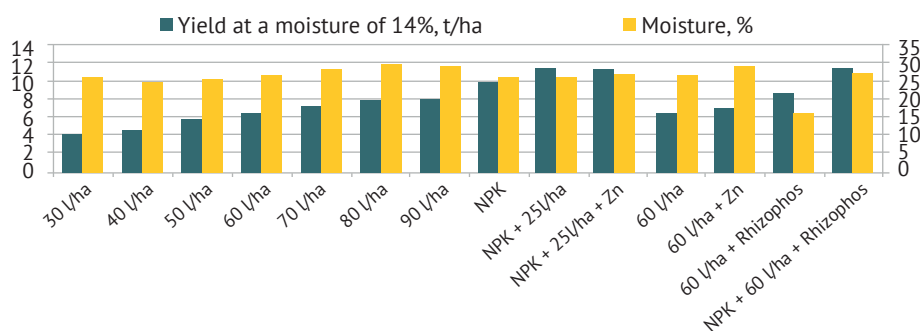


Figure 4. Yield and harvesting moisture of corn depending on fertiliser

Source: compiled by the authors

Under the condition of the same seeding structures (seeding rate, row spacing width, and row direction), the main factors of yield formation will be the analysed above number of rows of grains, the number of grains in a row, and the thousand grain weight, but the influence of additional factors that are not considered when assessing the indicators of the crop structure is also likely – the percentage of plants without a cob, the formation of individual additional cobs on the plant.

Analysing the indicators of factual yield, a substantial advantage of options with the introduction of granular complex fertiliser is noted. All cases of fertiliser application at 8:24:24 showed a result of more than 10 t/ha, while the additional application of 25 litres of LCF contributed to an increase in yield from 10.02 to 11.31 t/ha (+12.9%), and the additional introduction of zinc did not affect the result in any way. The highest yield (11.51 tonnes) was obtained using granular fertiliser and 60 litres of liquid complex fertiliser mixed with a phosphorus-mobilising preparation, while the yield increase relative to the option without granular fertiliser was 32% (2.8 t/ha).

Separate application of liquid complex fertiliser under no circumstances provided a result comparable to the application of granular fertiliser. Thus, an increase in the dose of LCF application from 30 to 90 litres per hectare increased the yield from 4.12 to 8.14 t/ha, while an additional application of every 10 litres of LCF (2.6 kg P_2O_5 in an accessible form) formed an average

of an additional 670 kg of the yield. However, even the introduction of high doses of LCF (90 L, which corresponded to 115 kg) did not bring the factual yield (8.14) closer to the level of at least net application of 150 kg of granular complex fertiliser (corresponding yield of 10.02 t/ha).

The results of using the preparation Rizofos are interesting. Its additional application to 60 litres of LCF contributed to an increase in yield from 6.53 to 8.72 t/ha (+33.5% of the indicator), and the option of joint application of LCF + Rhizophos against the background of granular fertiliser provided absolutely the best yield result. Thus, the use of the Rizofos preparation in conditions of general phosphorus deficiency has had an unambiguously positive effect on providing crops with available phosphorus, and, indirectly, on its productivity.

Comparison of NPK+25 L of LCF and NPK+60 L of LCF+Rhizophos variants shows no substantial difference in yields (11.37 and 11.51 t/ha), that is, an increase in the dose of LCF more than twice and additional introduction of the phosphorus-mobilising preparation into the tank mixture did not have a statistically positive effect on yield. This phenomenon may be associated with the release of phosphorus from the zone of the limiting factor, respectively, further increased availability of it did not lead to an increase in productivity. This can be confirmed in the results of monitoring the residual amounts of phosphorus and potassium in soil samples taken after harvesting (Fig. 5).

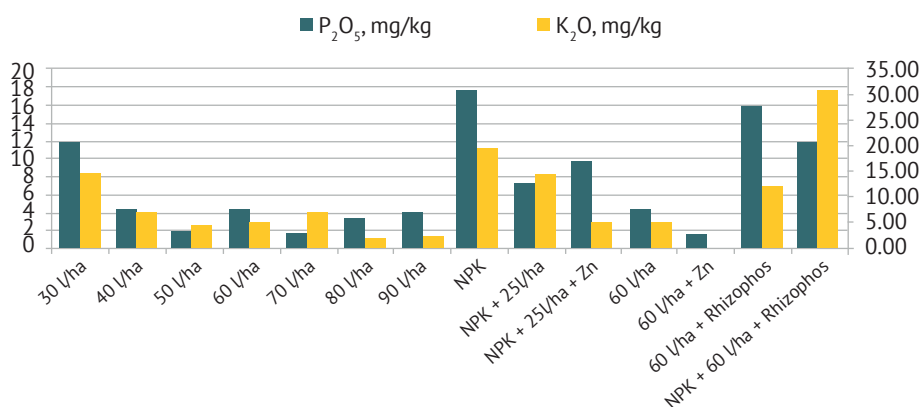


Figure 5. Residual phosphorus and potassium content in the soil after corn harvesting

Source: compiled by the authors

Analysing the residual amounts of phosphorus in the soil, its overall low content in most variants of the experiment is noted. As part of the variants with application doses from 40 to 90 litres, the residues in the soil were low and very low, statistically indistinguishable (range of changes from 1.6 to 4.5 mg/kg of the soil). The high residual content of P_2O_5 in the variant with the minimum dose of LCF (11.7 mg/kg) indicates incomplete removal of phosphorus or its untimely availability in conditions of severe deficiency (the yield was also the lowest – 4.12 t/ha). In turn, statistically substantially

higher phosphorus residues were observed in all variants where granular fertiliser was applied, so the option of separate application of Polifoska 150 was characterised by a residual amount of 17.5 mg/kg of P_2O_5 . An increase in the residual phosphorus content in the version where the preparation Rizofos was introduced is notable – 15.7 mg/kg against 4.5 mg/kg in the same version without the preparation.

An increase in corn yield was observed when using liquid complex fertiliser, which correlates with the results of M. Blandino *et al.* (2022) for 2014-2017 in

Northwest Italy. Blandino recorded an increase in yields from 7% to 15%, while the increase in this study was 12.9%. D. Quinn *et al.* (2020) in their meta-analysis show that the practical response to initial fertiliser is present in a wide window of conditions, and increases with the decrease in the overall supply of nutrients to the soil of the site, which explains the high efficiency of the application of such an agricultural practice. However, according to M. Blandino *et al.* (2022), in Italy, there was a simultaneous decrease in the harvesting moisture content of grain by 2.2% relative to the control, while the results of this study show the opposite trend. The discrepancy may be due to the variability of climatic conditions and the genetic characteristics of the corn hybrids used. M. Battisti *et al.* (2022) in their paper also prove the advantage of using a starter NP fertiliser in comparison with a granular analogue. In the conditions of Ukraine, the prospects for the introduction of liquid fertilisers are justified by Gamayunova *et al.* (2020), noting that in conditions of unstable moisture, which in modern agroclimatic conditions is characteristic of the entire territory of the country, the efficiency of the liquid form is higher, compared to solid granular analogues. Thus, in the case of sod-podzolic soils that lose moisture very quickly, the use of liquid complex fertilisers is a way to reduce agronomic risks and make more efficient use of the active substance of the fertiliser.

The effectiveness of additional use of the bacterial preparation and the associated increase in the amount of available phosphorus coincides with the data obtained by Q. Zeng *et al.* (2022) since the site that was used for the experiment during previous periods of use was in intensive crop production using full standards of phosphorous fertilisers. Phares *et al.* (2022) prove a substantial positive effect of a bacterial product based on the *Bacillus* strain when growing corn for grain, in particular, demonstrating that when the bacterium is introduced into the fertiliser system, the efficiency of assimilation of nutrients from solid granular fertilisers and, ultimately, the yield of the crop increase. Sofyan *et al.* (2023) obtained results according to which the use of bacterial preparations can increase the yield of corn by mobilising NPK from the soil while reducing the norms of fertilisers used is advisable. Since the accumulation of bound phosphates occurs even in soils of light granulometric composition and under conditions of podzolic soil formation (Tian *et al.*, 2017; Hospodarenko *et al.*, 2022), the method of improving nutrition by mobilising soil reserves by microbial cultures is extremely promising, in particular, in the Polesia zone of Ukraine.

Similarly, Yu *et al.* (2022) show the high efficiency of zinc application in corn cultivation, in particular, with intensive use of phosphorous fertilisers, which correspond to the results obtained. Zhang *et al.* (2020) also noted a positive effect of the soil use of zinc-containing preparations on the development and productivity of corn, arguing that the resulting increase in yield is achieved by

increasing the concentration of chlorophyll in the leaves and more efficient use of soil moisture. Similar results are also presented in the paper of Azam *et al.* (2022).

Thus, the convergence of the obtained agronomic reactions for the use of starting liquid fertilisers, bacterial preparation, and zinc with the results of world practices can be stated. Therewith, in the specific soil and climatic conditions of Polesia of Ukraine, which were analysed, the trends of better cob grain number, higher thousand grain weight and, as a result, corn yield were more contrasting, which is due to the properties of sod-podzolic soil (low content of nutrients, low capacity of cationic exchange, and buffering), which make it a convenient object for tracking the reaction of plants to fertiliser

CONCLUSIONS

The use of the liquid form of starting phosphorous fertiliser has a number of technological advantages (optimal uniformity of application, fast availability, reduced risks of phytotoxic effects on the crop) and shows a higher economic efficiency of the unit of the active substance relative to the granular form. The rapid action of the liquid form of fertiliser contributes to the better development of young plants and the development of cobs with a large number of grains. Thus, the use of liquid fertiliser P_2O_5 at a rate equivalent to 20 kg/ha of active substance contributed to the formation of a better cob grain number compared to the application of granular fertiliser P_2O_5 at a rate of 36 kg/ha. Therewith, the use of only a liquid form of fertiliser, even in high doses (90-100 kg/ha), is not enough to ensure full nutrition of corn during the entire growing season, so the option with the introduction of only a granular form of fertiliser had a yield advantage.

Additional application of the minimum dose of liquid fertiliser (25 L/ha) against the background of the main nutrition with granular fertiliser ensures optimal development of the crop throughout the growing season and allows obtaining an additional 1.3 t/ha (12.9%) of the yield.

The use of zinc as an additional component of the tank mixture contributes to the formation of more grains in a row and a higher mass of grain from one cob. An important component of the phosphorous nutrition strategy may also be using bacterial preparations based on strains of phosphorus-mobilising bacteria, in particular, *Pseudomonas fluoresces*, which increases the overall supply of plants with available phosphorus and gives a substantial increase in yield in conditions of phosphorus deficiency.

Further refinement and disclosure requires the issue of the effectiveness of the use of bacterial preparations to improve the phosphorus nutrition of field crops in the conditions of Western Polesia. The research on the effectiveness of liquid complex fertilisers of the composition 5-20-5 in the cultivation of sunflower is promising as well. This crop in the conditions of the specified soil-climatic zone is new, technological

approaches to its cultivation on light soils are not sufficiently justified, and substantial variability of the root system can favourably affect the effectiveness of applying starter fertilisers.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Вплив застосування рідких комплексних добрив та сумішей на їх основі на продуктивність кукурудзи в умовах Західного Полісся

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Анотація. Питання оптимізації фосфорного живлення кукурудзи стають все більш актуальними з огляду на тенденції підвищення вартості мінеральних добрив та зростаючі метеорологічні ризики в період після посіву. Метою представлених матеріалів є дослідження господарської ефективності рідких комплексних добрив, що внесені при посіві кукурудзи, в якості основного джерела фосфору та як додаткового елемента в складі системи живлення. Для реалізації поставлених задач був виконаний польовий дослід, схема якого включала варіанти окремого внесення РКД, окремого внесення гранульованого мінерального добрива, сумісного застосування РКД та гранульованого добрива, а також бакових сумішей РКД із цинком та бактеріальним продуктом на основі *Pseudomonas fluorenses*. Встановлено, що застосування РКД при посіві сприяє кращому забезпеченню молодих рослин фосфором, та, як результат, – закладці більш продуктивного качана. При цьому використання в якості джерела живлення виключно РКД у дозах до 50-60 л/га, не дає змоги реалізувати закладений потенціал та призводить до недоотримання зерен із качана відносно варіанту з повноцінним живленням. Найвищу врожайність було отримано у варіанті із застосуванням гранульованого добрива та 60 л рідкого комплексного добрива в суміші з бактеріальним препаратом, при цьому приріст врожайності відносно варіанту без гранульованого добрива становив 32 % (2,8 т/га). Окреме застосування рідкого комплексного добрива за жодних умов не забезпечило результату співставного із внесенням гранульованого добрива, однак додавання 25 л/га РКД до основного внесення гранульованого добрива дозволило отримати приріст врожаю в 1,3 т/га. Отримані результати доводять високу ефективність рідкої форми стартового добрива при його внесенні на легких за гранулометричним складом ґрунтах та мають бути враховані при плануванні ресурсоощадної технології вирощування кукурудзи в зоні із високим ступенем метеорологічних ризиків

Ключові слова: якісні показники зерна; локальне внесення; ресурсозберігаючі технології; ефективність фосфорних добрив; бактеріальні препарати



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Financial and analytical assessment of the costs of maintaining large urban park spaces in the Mediterranean on the example of Barcelona

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Abstract. The relevance of the subject is conditioned upon the fact that large park plantations have a great positive impact on the climate of Mediterranean cities, which increases the comfort of living in them. Such weather conditions as abnormal heat are increasingly manifested in Mediterranean cities due to global warming and other causes. In addition, there is air pollution in cities with solid particles and other impurities harmful to human health. The analysis of scientific literature has demonstrated that in the cities of the Mediterranean, these problems can be solved through urban park plantings and other types of landscaping. The purpose of this study is to assess the effectiveness of the costs of maintaining large urban park spaces in Barcelona. The leading method to explore this problem is the empirical method, namely, the study of urban



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landscaping programmes and budget expenditures. The research examines the sources of financing the costs of maintaining urban park spaces and considers urban programmes for the development of landscaping, and their financing. In addition, the influence of green spaces on the comfort of living in the city of Barcelona is explored. As a result of the study, it was found that landscaping in the city of Barcelona is financed for the most part from the city budget, while spending increases annually. It has been identified that the city of Barcelona receives a significant positive effect from investments in green spaces, namely, air pollution decreases, its temperature decreases, people get places for hiking, sports, and other types of activity, the psychological and physiological health of the population improves, the urban environment becomes more comfortable to live in. It is the large park plantings that allow reducing the air temperature, which improves the quality of life in the city

Keywords: landscaping; comfortable urban environment; trees; pollution; clean air

INTRODUCTION

The maintenance of large urban park spaces in Mediterranean cities, including Barcelona, can significantly increase the comfort of living of the population and contributes to improving the health of the population both psychologically and physiologically. In this regard, it is necessary to periodically make a financial and analytical assessment of the costs of maintaining park spaces in cities, considering the positive effects that large urban park spaces bring with certain investments. Investments in green spaces cannot be called commercial, their effect is mainly to improve the quality of life of the population by reducing pollution and gas contamination of atmospheric air, reducing its temperature. The economic effect here will be a reduction in healthcare costs and cooling of premises and other facilities. Nevertheless, through green spaces, social issues concerning the normal life of the urban population are being solved.

The city of Barcelona in the 21st century has big problems associated with the need to improve living conditions and public health. Particularly acute are the following issues: environmental quality; environmental pollution by hydrocarbon combustion products; urban land balance; utilities in all microdistricts; decent housing; climate change; population migration. Data from the United Nations (UN) suggests that today 54.5% of the world's population is urban, and by 2050 the share of the world's urban population may reach 70%. Therefore, cities will become the main centres for solving the problems of humanity. Park spaces and other green areas of cities are of great importance for improving the functioning of urban ecosystems and public health. For the city development effectively in terms of ecology and good life support for the population, it is necessary to properly plan and develop green urban spaces (Master Plan for Barcelona's..., 2017).

The need for urban parks is confirmed by the UN Sustainable Development Goals (Transforming our world, 2015). All UN member states agreed that environmental and social problems deeply affect society all over the world. Sustainable Development Purpose No. 11 assumes that in cities every citizen should have convenient access to open public space within a 400-metre walk from their place of residence. However,

nowadays only 21% of the world's urban population has such proximity to decent open public spaces (Rossoab *et al.*, 2021). In the Mediterranean, 60% of the population lives in cities with high rates of urbanisation. According to research by the Union of the Mediterranean, by 2030 the urban population of the region will increase by another 22.5 million people (Nature based Solutions in..., 2019). The extremely rapid growth rate of cities generates significant territorial, economic, social, and environmental imbalances. Urban settlements of the Mediterranean have common climatic features, in particular, climate changes lead to the appearance of abnormal heat.

The overlapping effects of global warming and the increase in the number of urban heat islands have a significant impact on the increase in air temperature in cities, which leads to thermal stress, entailing serious negative consequences for the physical and mental health of citizens. The study of the issue presents that green spaces have a great positive effect on the ambient temperature in cities. Large urban parks contribute to a decrease in temperature even beyond their borders, which has a good effect on the physiological and psychological state of people (Aram *et al.*, 2020). Urban parks and green spaces can establish a temperature-friendly environment and help reduce vulnerability to heat stress. One of the most significant effects of green spaces is to reduce the intake of solar radiation due to trees (Moreno-Garcia, 2019).

Urban green areas include meadows, forests, playing fields, gardens, parks, and water areas such as wetlands, corridors along riverbanks, streams, lakes, ponds, etc. A green and aquatic environment improves people's quality of life and provides a link between ecosystems and human well-being. For example, physical activity in a natural environment reduces fatigue and the impact of adverse emotions, increases life satisfaction and self-esteem, improves physical and psychological health. In addition, green spaces improve social interaction, contribute to the development of a sense of community and promote social inclusion. It has been proven that there is a positive relationship between green spaces and human health (Pinto *et al.*, 2020).

Large urban parklands and other types of urban green spaces are thus of great importance in improving the climate of Mediterranean cities and enhancing the quality of life of the population. Considering the above, a financial and analytical assessment of the costs of maintaining large urban park spaces is important, as it allows identifying the relationship between the costs of maintaining large green areas and the positive effects that society receives from them.

The purpose of the study is a financial and analytical assessment of the costs of maintaining large urban park spaces in Barcelona. To achieve this purpose, the following tasks were solved: urban landscaping programmes were explored, the costs of these programmes were analysed, and the effects received by the city from landscaping were considered.

MATERIALS AND METHODS

Theoretical methods (analysis, synthesis, concretisation, generalisation, comparison, financial and analytical assessment) and empirical (investigation of the influence of landscaping on the comfort of living in Mediterranean cities, the positive effects of landscaping; establishment of the role of large park spaces in the urban environment of Barcelona; study of urban landscaping programmes; assessment of the cost of landscaping programmes and methods of their implementation; investigation of the effect of the establishment and maintenance of large urban parks and other green areas). The research was based on the programmes of the city of Barcelona in the field of landscaping, the open budget of the city of Barcelona, materials and practical developments of the Mayor's Office of Barcelona in the field of landscaping, research by scientists and practitioners on the greening of urban areas of the Mediterranean.

The study was conducted in three stages: At the first stage, the influence of large urban park plantings on the ecology of Mediterranean cities was identified, the effects that can be obtained from landscaping were explored, and the main problems of urban climate and human habitation that can be solved through large urban park plantings and other types of landscaping were examined. The activity of the city authorities designed to solve the problems of landscaping and improving the comfort of people's living was explored. The main problem areas solved by the city authorities in the field of its landscaping were highlighted.

At the second stage, a financial and analytical assessment of the costs of maintaining large urban park spaces and other green areas of the city of Barcelona was performed. The assessment was based on data from the city's open budget and research on the effectiveness of investments in the greening of Mediterranean cities. The main problems of the urban environment that can be solved in the city through landscaping were explored. The effects of landscaping, including

large urban park plantings, were identified. Based on the materials of various studies, the main areas of work on the transformation of the urban environment to improve the comfort of living of citizens were identified. The types of effects obtained from investments in the greening of the city have been established, which consist in reducing the dustiness and gas content of atmospheric air, reducing the air temperature in areas of large urban park plantations and in the vicinity of them, improving the psychological and physiological health of the population, the expected reduction in health care costs, improving the comfort of living of citizens and their level of well-being. At the third stage, theoretical and practical conclusions were clarified, the results obtained were generalised and systematised.

RESULTS AND DISCUSSION

The city of Barcelona is currently engaged in the development and construction of new public spaces that are focused on the well-being of residents. Building an improved environment for the residents of the city of Barcelona has been reflected in a number of city programmes. In September 2015, the UN proposed 17 Sustainable Development Goals (SDGs) for the world, which Spain also shared (Transforming our world, 2015). In the city of Barcelona, according with the UN Sustainable Development Goals, the plan "Barcelona's 2030 Agenda. SDG targets and key indicators" (2020). Sustainable Development Goal number 15 is to protect, restore, and promote the sustainable use of terrestrial ecosystems, sustainable forest management, combat desertification, and halt and reverse land degradation and halt biodiversity loss. As part of this purpose, several urban programmes are being implemented, including the Master Plan for Barcelona's Trees 2017-2037 (2017), according to which work is being conducted to expand and maintain large urban park spaces and other green areas. In the city hall, there is a special service engaged in the implementation of this programme: The Directorate of Ecology, Urban Planning, and Mobility. In addition, this plan is linked to other city programmes, for example, "Climate Plan 2018-2030" (2018).

Initially, unfavourable living conditions in industrial cities led to the need to establish urban parks. Further, parks began to be used as playgrounds for sports, and finally as places established for a more centralised life of citizens (Tate, 2018). Large urban park spaces play a very important positive role in the state of the environment of the city of Barcelona. Using the example of Ciutadella Park, the largest urban park, studies were conducted that demonstrated that there is a difference between the temperatures inside the largest park in Barcelona and the surrounding urban environment for 14 days in the winter and spring of 2015, which confirmed the existence of a clean urban cool island. The maximum difference was 5.2°C on the night of December in anticyclonic weather conditions. Studies conducted in

Ciutadella Park have found that it improves the urban climate very well (Moreno-Garcia, 2019).

It was identified that green spaces in cities have the following positive effects (6 ways trees benefit all of us, 2021): absorption of greenhouse gases; improvement of the physical and psychological state of citizens; purification of the air from dust and gases; cooling of the atmosphere. The management of green spaces includes criteria and measures for the effective management of the development of green areas in the city of Barcelona. This local programme is designed to quality control and gradually increases the percentage of each species in the city (for example, to avoid the historical dominance of bananas). In addition, there are new species that can be used in urban landscaping (Management of trees, 2021).

The management of green areas ensures that any actions related to trees will improve the quality of

plantings and contribute to the conservation of biodiversity. Barcelona has more than 150 species and varieties of trees. Each of the species has a special colour, aroma, and type of foliage, which gives individuality to the streets of Barcelona and, therewith, contributes to improving the urban ecology. Choosing a variety of trees for Barcelona's green areas is a complex process that considers both the characteristics of a particular tree and the necessary environment for its successful existence since the principle of matching the necessary tree to the correct place of its growth must be observed (Superilles, 2021). The city development plan "Barcelona Superblock Plan" (2021) is designed to providing a comfortable daily life for the population, uniting the districts, and ensuring environmental safety. The plan is designed to improve the socio-economic and environmental situation in the city (Fig. 1).

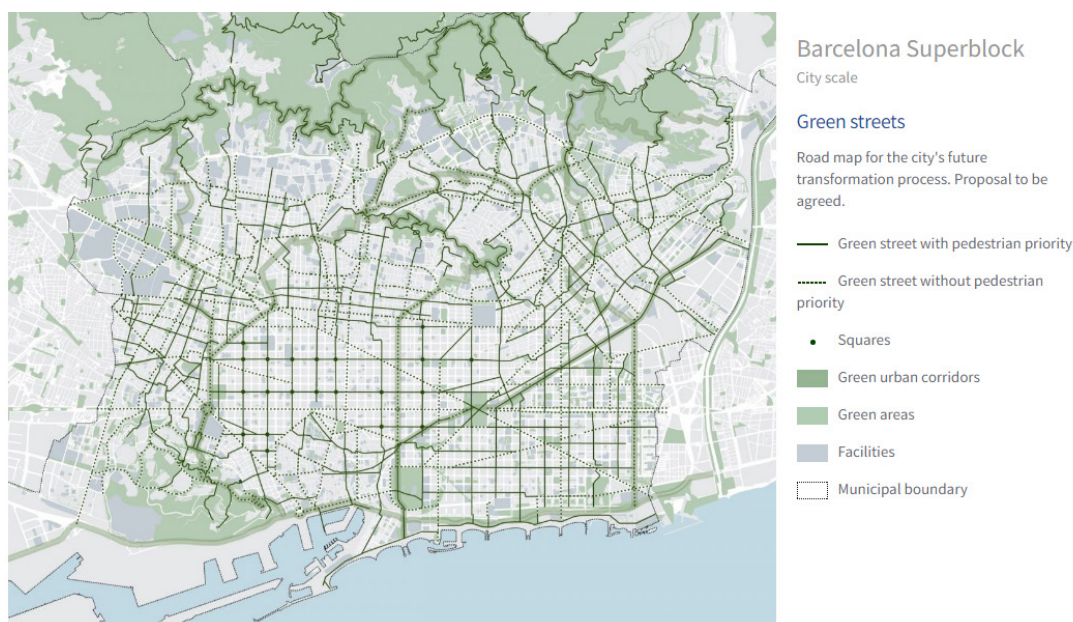


Figure 1. General scheme of Barcelona Superblock Plan

Source: Barcelona Superblock Plan (2021)

The plan model involves the establishment and implementation of various plans and projects that contribute to the improvement of urban space towards the improvement of it and comfort for the life of citizens. According to the new urban model, Barcelona should be updated and adapted to the needs of citizens and ensure environmental safety. Urban space improvement purposes (Barcelona Superblock Plan, 2021): changing public space to improve the quality of life of the population; improvement of urban neighbourhoods; growth of the city's economy; restructuring of the transport infrastructure; introduction of new public housing facilities into circulation.

The model is designed for serious transformations of public spaces in Barcelona, namely, the transformation of the area that is now used by motor transport in

urban areas, through the introduction of a more equitable structure of public space. It offers a network of green streets that extends to the whole city and gives people the opportunity to walk, as it connects green areas and gives people safety. According to the new model, green hubs with the following characteristics will be developed in the city (Barcelona Superblock Plan, 2021): limited traffic of motor vehicles; availability of a place to rest; a large number of green spaces; the possibility of hiking.

Green spaces are made to establish new squares at intersections, places convenient for people, they allow people to perform various activities, including physical. Green hubs are being established throughout the city, for example, in Eixample, 21 green centres are being established, deep in the Cerda site, with 21 new areas, establishing a total of 33.4 hectares of space for pedestrians (Fig. 2).



The historical quarters of the city designed by Ildefonso Cerda, especially the Eixample district, is a recognised image of comfortable urban planning, nevertheless, there are problems here: a large number of vehicles; high level of dust and gas pollution of atmospheric air; high noise level; lack of green spaces. All this has an extremely adverse impact on the health of the residents of the city. Using the Barcelona Superblock Plan model in the Cerda area provides a vision for the city's future, including new green streets and new urban intersection plazas. The purpose is to provide Eixample residents with squares or green streets

no more than 200 metres from their homes, and to build additional meeting and leisure areas. Green streets have the following features: a small number of vehicles; there are places for people to relax; the presence of green areas; the ability to walk. Due to the corners characteristic of the city, new city squares appear at the intersection of these green streets. These squares will occupy approximately 2000 m² of urban territory, at the moment they are used for traffic. According to the new urban model, recreation areas with green spaces and playgrounds will be built on these streets (Fig. 3).



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The transformation of the space of the Eixample district is occupied by the Barcelona City Council, which has demonstrated several priority initiatives. The City Council considers it necessary to turn certain parts of the city into green centres. Tactical initiatives have already been implemented in some of these hubs to reduce the intensity of vehicle traffic as part of measures to free up space in connection with the health emergency related to COVID-19. In the city, it is planned to establish four large squares in Eixample, each measuring approximately 2000 m². These squares will be located at the junction between two green transport hubs, occupying the space reserved so far for cars. For all this, the City Council held two open competitions to select teams of architects and engineers who will help determine the model of a quiet street of the 21st century and the squares that will be established at intersections. The purpose of the first competition is to select future developers of development projects on the four streets, who will turn them into green centres during this term of office. The second competition is dedicated to the search for developers of redevelopment projects for four squares.

In addition, other events related to the greening of the city of Barcelona are planned. The purpose of the Master Plan for Barcelona's Trees 2017-2037 (2017) is to maintain and develop well-managed, healthy and

biodiversity-rich woodlands to improve green corridors and overcome the urban heat island effect. The quantity and quality of trees, and their role as part of the green infrastructure of the city are factors of great importance for a comfortable stay in the city. This plan was developed for the municipality to be able to plan and manage urban landscaping (Nature based Solutions in..., 2019). The estimated budget for the implementation of the proposals outlined in the Master Plan for Barcelona's Trees 2017-2037 (2017) is EUR 9.6 million per year. The following aspects are considered when drawing up the budget estimates: area 1: personnel responsible for the maintenance and management of trees. This includes personnel involved in pruning and planting trees, including relevant legal and administrative resources; area 2: external contracts with contractors who provide tree care services, such as phytosanitary treatment of green spaces, removal of dead and diseased trees, stumps, etc.; changes: correspond to specific projects to improve the tree population, for example, the replacement of individual trees on iconic streets.

The estimate of the annual budget of the Master Plan for Barcelona's Trees 2017-2037 is presented in Table 1.

Table 2 demonstrates the shares of cost distribution in various strategic areas of the Master Plan for Barcelona's Trees 2017-2037.

Table 1. Estimated annual budget of the Master Plan for Barcelona's Trees 2017-2037

Area of expenses	Total amount of expenses, EUR
Area 1	4,374,869
Area 2	3,036,880
Annual investments in trees	900.000
Increase of the annual budget for the plan	1,310,000
Total	9,621,749

Source: Master Plan for Barcelona's Trees 2017-2037 (2017)

Table 2. Distribution of the Master Plan for Barcelona's Trees 2017-2037 budget by expenditure areas

Area of expenses	Share of expenses, %
1. Heritage and biodiversity	4.26
2. Knowledge	1.28
3. Communication and participation	1.1
4. Planning and connection	5.33
5. Protection and preservation	1.01
6. Tree health	12.2
7. Plant material and planting	11.48
8. Reduction and safety	36.7
9. Soil	5.86
10. Water	20.78
Total	100

Source: Master Plan for Barcelona's Trees 2017-2037 (2017)

The distribution of the budget by strategic areas presents the share of expenditures on tasks requiring solutions and additional costs. Nevertheless, in general, the budget of the Master Plan for Barcelona's Trees 2017-2037 does not imply a significant increase in costs associated with current planning and management tasks compared to previous years. The plan adds extra items of expenditure where new investments are needed. The main strategic areas of priority for investments are the management of soil and water resources. These two most important factors are the basic ones for maximising the quality and health of trees, and for society to receive environmental and social benefits brought by

green spaces. In total, 3.34% of the budget of the City of Barcelona, or almost EUR 101.4 million, is planned to be spent on the environment in Barcelona in 2021. Therewith, it is planned to spend about EUR 67.2 million on the construction and maintenance of green spaces (Open Budget, 2021). The dynamics of the expenditures of the city of Barcelona for the construction and maintenance of green spaces is presented in Figure 4.

As can be seen from Figure 4, the city of Barcelona invests quite a lot of money, about EUR 60 million annually, in its green spaces. The percentage of actual budget execution for the construction and maintenance of green spaces is presented in Figure 5.

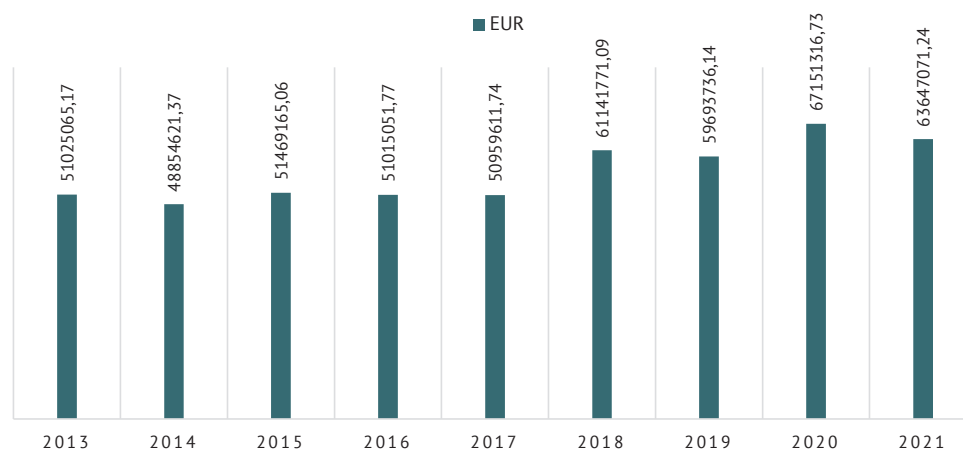


Figure 4. Dynamics of planned budget expenditures for construction and maintenance of green spaces

Source: Open Budget (2021)

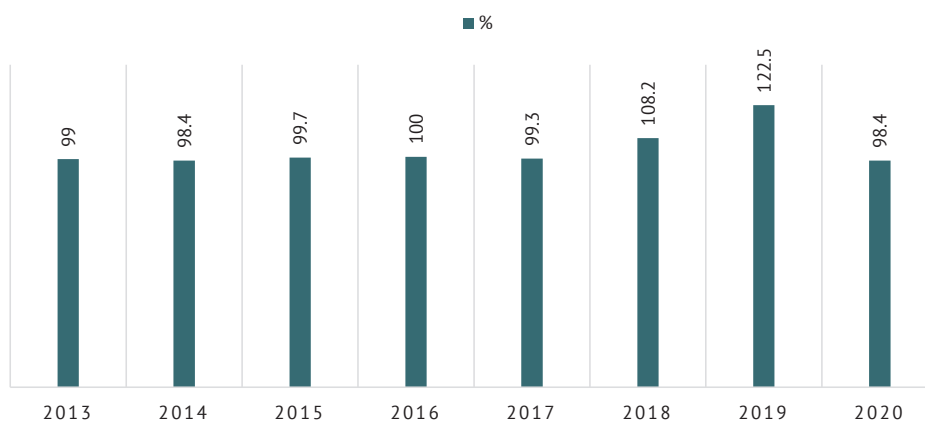


Figure 5. Percentage of actual budget execution for construction and maintenance of green spaces

Source: Open Budget (2021)

From Figure 5, it can be concluded that the planned costs for the construction and maintenance of green spaces are almost always almost completely performed (98.4-100%), and sometimes (2018, 2019) exceed the planned values. Next, the study considers the projects for financing large urban park spaces of the city of Barcelona on the example of the largest project of

the last decades – the Agrarian Park of Baix Llobregat. The beginning of the project dates back to 2004, the project is currently under implementation. The park is located in the centre of the Barcelona metropolitan area. The territory of the park (about 3500 hectares) includes rich conventional agricultural activities and contains 14 municipalities with a total population of

about 818000 people. It is protected by a special planning tool and managed by the provincial Agrarian Park of Baix Llobregat is the “lungs” of the city of Barcelona and the only one in the world that is close to the big

city. In addition, the park provides the residents of the city with high-quality food and contributes to the conservation of agricultural land. The main features of project financing are presented in Table 3.

Table 3. Financial resources of the Agrarian Park of Baix Llobregat

Type	Source
Funding sources	EU funds; city budget of Barcelona
Types of financing	targeted budget expenditures; direct financing or subsidy
Non-financial contribution of resources	provision of land; provision of goods; provision of labour; provision of other services; exchange of services
Persons making non-financial contributions	public authorities (e.g. land, utilities); citizens (for example, volunteering)

Source: Agrarian Park of Baix Llobregat (2021)

Financing of expenses for the maintenance of large urban park spaces is carried out in the city of Barcelona mainly from the city budget. Although, for example, the National Recreation and Park Association (NRPA) recommends using alternative sources of resources for the construction and maintenance of urban park spaces (Revitalising inner city parks, 2014): setting an entrance fee to the park; charging for entertainment events; partnership with government agencies; charity; raising funds from various foundations; using volunteers. Thus, in the city of Barcelona, budget funds are used for the maintenance of large urban park spaces, although, if necessary, other sources of financing can be used.

Some aspects of this problem have been explored by many researchers, while environmental and economic factors are considered in an explicit relationship. Experts believe that by 2050, most of the world's population will live in cities. The main urban environmental problems are: very dirty air; too high air temperatures. The same problems exist in the city of Barcelona. Dust, consisting of many small solid particles, is carried in the atmosphere and is an accumulation of gaseous molecules or particles that are in it. Solid particles vary in size, which is of particular importance for human health, as it determines how easily and deeply a person inhales a particle into their lungs. Both large and small particles, when inhaled, adversely affect human health. Trees provide a significant but locally concentrated reduction of solid particles. The research of the international organisation already in 2016 demonstrated that Barcelona is a city with a high efficiency of investments in tree planting. The report says that investments in green spaces in the city of Barcelona give a high positive result to improve the ecology of the city. A large number of studies demonstrate that the leaves of trees

both filter out solid particles from the atmosphere and detain many other air pollutants. The study presented that further greening of the city would help reduce the concentration of particulate matter in the atmosphere of Barcelona, and investments in landscaping are appropriate (The Nature Conservancy, 2016).

Therefore, special attention should be paid to the areas with the greatest impact of mitigation when developing green spaces. The concentration of solid particles in the air of the city of Barcelona is assessed as good, thus, safe enough for health. The study “Planting Healthy Air” (2016) quantified the ability of nature to purify and cool the air. In this study, the return on investment (ROI) was explored when investing in planting trees with a concentration of particulate matter (PM) and temperature (T) cooling. It has been identified that green spaces are an effective solution to decrease the air temperature in cities and reduce dust and gas pollution. However, the possibilities of using green spaces for this purpose vary in different cities. As mentioned above, the current environmental problem is abnormal heat. This natural disaster of high ambient temperatures kills about 12000 people worldwide every year and causes discomfort in the lives of millions. Experts estimate that by 2050, a quarter of a million people will be exposed to climate change, which will exacerbate the threat of urban heat waves. Many studies prove that the shadows from trees and their transpiration of water during photosynthesis give the following positive effects: they can help reduce air temperature; reduce electricity consumption for cooling residential premises. The maximum temperature in the city of Barcelona is 24.28°C and it is predicted to rise by 3.8°C by 2040. Green spaces will help keep the temperature in the city at a comfortable level (Planting Healthy Air, 2016).

Thus, the costs of maintaining large urban park spaces, and other green areas, give the following positive effects in the city of Barcelona: reduce air pollution; contribute to lowering the air temperature; provide an opportunity for hiking for the population and other types of activity.

All of the above increases the level of public health and improves the comfort of living in the city of Barcelona. Therefore, the city's budget expenditures for the maintenance of green areas are effective. An important economic effect also consists in reducing healthcare costs, reducing the cost of energy spent for cooling rooms, transport, etc. The social effect is to increase the welfare of the city's population.

CONCLUSIONS

The environment is the most important element of the life support system of the urban population, the guarantee of comfortable living and the health of people living in the municipality. The state of the urban atmosphere is a decisive factor in this regard. The main problems of modern cities are the presence of particulate matter and other types of pollution in the atmospheric air, and an increase in temperature in the territories of cities. Studies present that in many cases, green spaces help to improve the state of the urban atmosphere according to these indicators. In addition, it applies to the city of Barcelona.

As a result of the conducted research, it can be concluded that the costs of maintaining urban park spaces in the city of Barcelona are an important factor in

improving the standard of living of citizens. Every year, about EUR 60 million are received from the city budget for landscaping, which is a fairly large amount for a municipality. However, investments in the development of green spaces are worth it. They allow establishing a comfortable living environment for the population in the city. Ensuring decent living for people in the future is the purpose of sustainable development of the city of Barcelona, as the city supports the UN Sustainable Development Goals, and a large number of city programmes have been developed based on them.

The management of green spaces also lies in the fact that a large number of various commercial contracting organisations of the city are involved in landscaping work, which is a positive moment for the city's economy. The mayor's office engages contractors on a competitive basis. Green spaces, including large park plantings, bring a great positive effect to the city, as they contribute to the purification of the city's atmosphere from pollutants harmful to human health and a decrease in temperature. People get the opportunity to walk and perform various types of physical activity. All this allows improving the comfort of living in the city and the health of the urban population.

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CONFLICT OF INTEREST

None.

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Фінансово-аналітична оцінка витрат на утримання великих міських паркових просторів Середземномор'я на прикладі Барселони

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Анотація. Актуальність теми обумовлена тим, що великі паркові насадження мають великий позитивний вплив на клімат середземноморських міст, що підвищує комфорт проживання в них. Такі погодні умови, як аномальна спека, все частіше проявляються в середземноморських містах через глобальне потепління та інші причини. Також спостерігається забруднення повітря в містах твердими частинками та іншими шкідливими для здоров'я людини домішками. Аналіз наукової літератури показав, що в містах Середземномор'я ці проблеми можна вирішити за допомогою міських паркових насаджень та інших видів озеленення. Метою даного дослідження є оцінка ефективності витрат на утримання великих міських паркових просторів Барселони. Провідним методом дослідження цієї проблеми є емпіричний метод, а саме вивчення міських програм озеленення та бюджетних витрат. У статті проаналізовано джерела фінансування витрат на утримання міських паркових просторів, розглянуто міські програми розвитку озеленення та їх фінансування. Також досліджено вплив зелених насаджень на комфорт проживання в місті Барселона. В результаті дослідження було виявлено, що озеленення в місті Барселона фінансується здебільшого з міського бюджету, при цьому витрати щорічно збільшуються. Виявлено, що місто Барселона отримує значний позитивний ефект від інвестицій в зелені насадження, а саме: зменшується забруднення повітря, знижується його температура, люди отримують місця для піших прогулянок, занять спортом та інших видів активності, покращується психологічне та фізіологічне здоров'я населення, міське середовище стає більш комфортним для проживання. Саме великі паркові насадження дозволяють знизити температуру повітря, що покращує якість життя в місті

Ключові слова: озеленення; комфортне міське середовище; дерева; забруднення; чисте повітря



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Factors influencing the effective use of land and resource potential in Ukrainian agricultural businesses

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Abstract. Ukrainian agrarian enterprises have significant land and resource potential, but effective use of this potential depends on many factors, the study of which is of current relevance. The purpose of the research is to develop an integrated approach to changing the process of effective use of land and resource potential and to find the main determinant of its reproduction in the post-war period of economic development of the country's agricultural sector. To achieve this purpose, mathematical tools and the income capitalisation method were applied. As a result of the study, it was established that increasing the area of land plots for growing crops that have been leased until 2025 would lead to an increase in their total size by 0.245 thousand ha in the structure of elements of reproduction and effective use of land and resource potential. Increasing



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the area of land of agricultural enterprises from the purchase (sale) of additional land plots will increase their value by 0.006 thousand ha, and enlarging the area of exchange land will increase by 0.377 thousand, which is a priority determinant in the structure of land and resource potential, and changes in emphyteusis will increase the total area of land plots by 0.347 thousand ha in the potential of enterprises. Thus, 97% of the variability of the area of agricultural land in the domestic market circulation will occur due to changes in the above-mentioned elements of the land determinant, which will provide for the effective use of the land and resource potential of agricultural enterprises until 2025 and augment the volume of production. The study of factors influencing the effective use of the land potential of Ukrainian agrarian enterprises has significant practical importance, as it allows identifying key factors that affect the success of agrarian enterprises, which can help them improve their strategy and find ways to improve productivity

Keywords: agricultural land; reproduction; economic development; monopolistic establishments; transactional circulation

INTRODUCTION

The beginning of transformational changes in the Ukrainian economy in the post-war period is associated with various models of a competitive economic system development, which puts forward one of the key conditions for the stable development of agricultural production – ensuring the highest and most efficient level of resource use. At this stage, the institutionalisation of agricultural production should be based on the rights of autonomous use of the land and resource potential of agricultural enterprises, which before the war period was ensured by regulators of land relations related to clear processes of land use, ownership and disposal of land resources. Due to the moratorium on buying and selling, the agricultural land market in Ukraine does not perform important functions – determining the real value of land plots and harmonising interests between the state and agricultural enterprises when changing the land infrastructure, stimulating alternatives for the effective use of resources in a competitive economic environment.

Underestimation of radical changes in land relations regarding the development of the agricultural land market can have unpredictable adverse socio-economic and environmental consequences for the country and its regions. This problem is actualised by the scale of reproduction of the land resource potential in those temporarily occupied regions, where the integral mechanism of the agrarian economy of Ukraine is broken, where the principles of effective development of agricultural enterprises are not ensured by a system of protection of the rights and legitimate interests of the owners of agricultural land plots, where business processes are distorted, land raiding and fraud are performed.

According to an integral approach, the land resource potential is a complex of natural and social development, which is characterised by the features of spatial and integral use of resources that are objects of economic activity, means of production, placement of productive forces in a specific territory, with certain environmental conditions that level loss of functioning of agricultural enterprises (Kaminetska, 2017). The land

and resource potential of agricultural enterprises during the production process transforms input elements (factors of production) into outputs (products), which, under the influence of the forces of nature, require time for their implementation. Accordingly, the static elements involved in the process of reproduction of the material component of the potential, as the final result of the activity of agricultural enterprises, are provided with additional value (price) of their production stocks to increase the level of efficiency in using land and resource potential (Kovalchuk & Khintsinska, 2012).

Methodologically, the connection between the input and output elements of the land and resource potential is described by the production function, which is an economic-mathematical model of analysis and forecasting of the level of its effective use. The production function, when changing the technology of agricultural production, leads to the transformation of the total value of the land and resource potential. This change is more elastic in the long-term than in the short-term and a specific combination of input elements of the land and resource potential ensures an increase in the volume of production if only two main input elements are used in the land resource potential: labour and capital. The determinant of the production function of the effective use of the land and resource potential in agricultural production is agricultural land, as a direct factor in the production of plant products and as a spatial resource that requires natural and artificial reproduction of soil fertility through the introduction of innovative technologies (Buiak & Pryshliak, 2018).

Since agricultural land depends on the quality of the soil, plant productivity, and technical and technological properties of agriculture, therefore, a specific determinant of the effective use of land and resource potential in agricultural production is the entrepreneurial ability of human capital (Kutsmus, 2017). The systematic approach allows determining the effectiveness of using the land and resource potential of agricultural enterprises due to the influence of ecological elements and to expand its production function (Schulte *et al.*, 2014).

The priority of the research is the development of an integrated approach to changing the process of effective use of the land and resource potential of agricultural enterprises in the conditions of dangerous impulses of loss of the balanced structure of its developing elements and determining the priority determinant of its reproduction through the circulation of agricultural land in the post-war period of economic development of the country's agriculture.

MATERIALS AND METHODS

To calculate the normative monetary valuation of agricultural land, the amount of absolute rental income, equivalent to 2 centners of grain from 1 ha ($A_{ri}=2h$) is used. The assessment of agricultural land is determined by the following formulas (Primdahl *et al.*, 2013; Koshel, 2015):

$$A_{al} = (D_{ri} + A_{ri}) \times T_{cap}^{D_{ri}}, \quad (1)$$

$$M_{ca} = (D_{ri} + A_{ri}) \times P_r \times T_{cap}^{D_{ri}}, \quad (2)$$

$$M_{vlag} = \sum (M_{ca} \times A_{lg}^{ag}) \div \sum A_{lg}^{ag}, \quad (3)$$

where, A_{al} – assessment of agricultural land, centner; D_{ri} – absolute rental income, centner; $T_{cap}^{D_{ri}}$ – term of capitalisation (differential rental income), years; M_{ca} – conditional

assessment of 1 ha of agricultural land of a certain group, USD; M_{vlag} – monetary value of the land plot, USD; A_{lg}^{ag} – the area of agricultural lands of a certain group.

Accordingly, requirements are set for a certain group of agricultural lands regarding the terms of their purchase and sale, with a ban on changing the intended purpose and alienating them for public needs or public necessity. Therewith, the establishment of a minimum lease term for land plots and an increase in the amount of land rent should not be a biased measure regarding using agricultural land according to the time of its operation, during which it can be cultivated to support the economically active part of agricultural enterprises and the effective use of land and resource potential (Kozlovskiy *et al.*, 2019). In the context of increasing the size of the land and resource potential of agricultural enterprises and its effective use, the circulation of agricultural land is introduced, which occurs based on a functional market formed by solvent buyers in the general land infrastructure, which regulates the socio-economic motives of the population (potential sellers of their land plots), according to the differential parameters of equally weighted land plot pricing (Fig. 1). The price determinants that influence the development of the value of agricultural land are listed in Table 1.

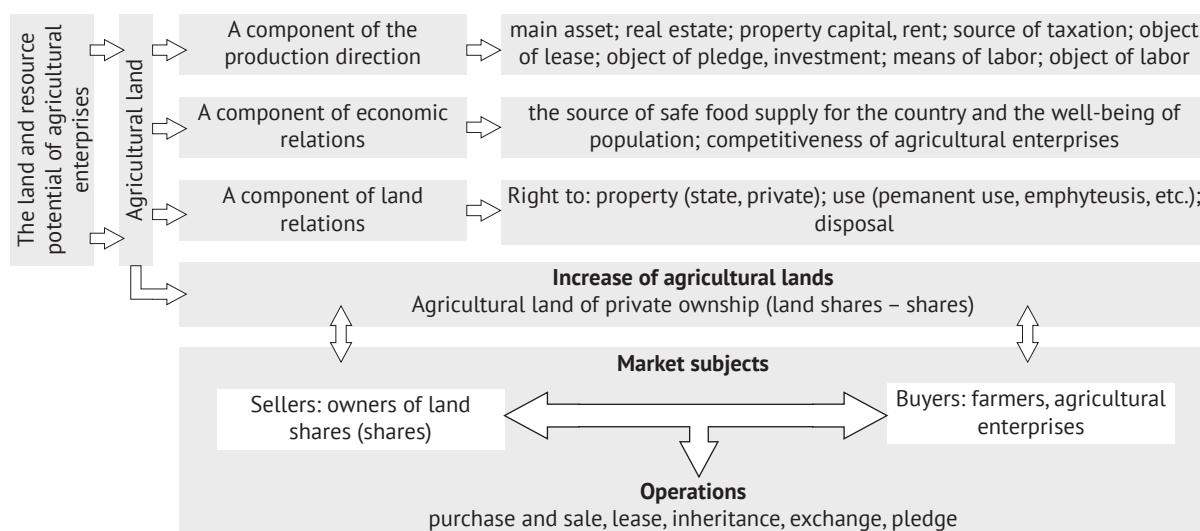


Figure 1. Targeting the effective use of the land and resource potential of agricultural enterprises

Table 1. Price determinants of influence on the development of the value of agricultural land plots

Factors	Description
Bank rate of interest	The higher the bank interest rate, the lower the price of agricultural land, and vice versa. A bank loan for the purchase of land becomes profitable at low interest rates.
Future crop yields	The higher the quality of agricultural land, the higher the yield. The price of agricultural land at the time of its purchase and sale increases, provided that the yield growth of strategic agricultural crops is forecast.
Projected prices for products that will be grown in the future	Both internal (possible price support for strategic agricultural crops by the government and legislation of the country) and external (the possibility of free purchase and sale of agricultural land by foreign legal entities, the possibility of introducing free pricing of agricultural products in the country, considering the state of world markets) factors are considered.

Table 1, Continued

Factors	Description
Projected production costs	Scientifically justified costs associated with obtaining the future harvest are used. In case of purchase and sale of agricultural land, preference is given to land plots that ensure the implementation of innovative technological operations for their cultivation.
Discount factor	This factor regulates the value of net earnings and the value of the future sale price of agricultural land depending on the bank interest rate during the entire period of agricultural land use.
Distance of land plots from communication centres	This factor in the price expression considered both material and monetary costs for the production and sale of future products, and the price of the land in case of its sale in the future. Only auctions can give the most accurate assessment of this factor.
Future value of land	Compliance with requirements for increasing the fertility of agricultural lands. After the end of the period of its exploitation, agricultural land can be sold again for its further use by other business entities.
Land quality (credit assessment of agricultural land)	When determining this indicator, the quality of agricultural land is considered, determined by agronomic properties (content and reserves of humus, nutrients, corrections for climate, hydro orphism, salinity, stony).

Source: O.V. Lebedenko (2011), U. Mander and E. Uuema (2010)

The economic valuation of the land should be defined as the discounted value of the future land rent (Kozmenko & Kuzmenko, 2014):

$$P_{ld} = \sum_{i=1}^t \frac{R_i}{(1+K)^t} \quad (4)$$

where, P_{ld} – the value of the agricultural plot of land used; R – annual rent; t – the time period considered; K – is the capitalisation ratio (income rate) at which the owner of the agricultural plot of land agrees to work to receive annual income in the amount of rent.

The cost of a land plot using the method of comparing the sale prices of similar land plots is calculated according to the following formula (Kozmenko & Kuzmenko, 2014):

$$P_{ld} = P_a + \sum_{j=1}^m \Delta P_{aj} \quad (5)$$

where, P_o – the sale price of a similar plot of land, USD;
 m – number of comparison factors; ΔP_{aj} – the difference
 (correction) in the price (+,-) of the sale of a similar land
 plot relative to the evaluated land plot, according to
 the j -th factor of comparison.

To compare the sale price of similar agricultural land, it is necessary to apply a mathematical toolkit that allows considering the coefficients adjusted according to the group characteristic and qualitative properties of the land plots:

$$n = k + 1, \quad (6)$$

where, n – the number of analog objects; k – the number of adjustment coefficients.

To perform calculations according to formula (6), it is necessary to successively compare the evaluation object with each of the selected analogues, as a result of which a system of linear equations can be obtained (Kozmenko and Kuzmenko, 2014):

[illegible]

When determining the monetary value of agricultural land, it is suggested to use the income capitalisation method, which considers the optimal lease term of agricultural land plots, the average discount rate of a long-term bank loan at the rate of the National Bank of the country, and net income (profit) from the sale of the main crops:

$$P_{la} = \frac{\sum_{i=1}^n D_s \times t}{\left(1 + \frac{Bin}{100}\right)^t} \quad (8)$$

where, P_{la} – the price of a unit of agricultural land area, USD; D_s – expected net income from strategic agricultural crops per unit area, ($i=1,2,\dots,n$); t – period (years) of land lease, USD; B_{in} – bank interest for a long-term loan.

Thus, the modern stage of finding the determinants of the effective use of land and resource potential should combine the principles of the classical method of evaluating agricultural lands, considering their purpose, market demand, resource quality, ecological condition and productive intensification. The introduction of an integrated approach to the effective use of the researched potential by all subjects of land relations of agricultural production will increase the investment attractiveness of agriculture, will allow the rational use of agricultural land, ensure the food security of the state, preserve and create new jobs in rural areas, will provide the population with unhindered access to the agricultural land destination as a resource of human capital.

RESULTS

The economic stability of Ukraine is largely ensured by agriculture, the effective development of which depends on the land and resource potential of agricultural enterprises, the basis of which are two interconnected components – internal and external. The resource determinant of potential (land, material, labour, financial resources) represents the internal potential of agricultural production entities; potential external (market) opportunities for the sale of agricultural products to consumers and receipt of income are provided by the

market determinant (Trusova *et al.*, 2021). However, the conditions of martial law in Ukraine weakened the resource and market opportunities of agricultural enterprises and reduced the scale of reproduction of their land and resource potential. Such a situation requires quick action to protect regulatory instruments in agricultural land relations and restore them to the post-war period. Regulating tools are subordinated to the sole purpose of agricultural enterprises – to reproduce, based on lease rights, the effective use of agricultural land as a powerful resource and production complex and, in the future, to be full participants in the process of pricing in the circulation of agricultural land for its intended purpose of their exploitation in the general infrastructure of the country's land fund.

The rapid damage assessment methodology from the World Bank and the Food and Agriculture Organisation of

the United Nations (FAO) allowed assessing the scale of losses of the land and resource potential of agricultural enterprises of Ukraine, which were directly affected by the active hostilities of the aggressor country. The damaged infrastructure of the land and resource potential is divided into two territories: the first, which was under occupation but was liberated (Kyiv, Sumy, Chernihiv, and Mykolaiv regions); the second – the territory that suffered from active hostilities and (or) occupied by the aggressor country (Kharkiv, Donetsk, Luhansk, Kherson and Zaporizhzhia regions). Thus, during the 9 months of 2022 of the full-scale military invasion of the aggressor country on the territory of Ukraine, the largest losses in the structure of the land and resource potential of agricultural enterprises occurred due to the destruction or partial damage of agricultural lands and failure to harvest – 2.135 million USD, (Table 2, Fig. 2).

Table 2. The scale of losses of the land and resource potential of agricultural enterprises of Ukraine due to the military invasion of the aggressor country in 2022

Category	Total losses, million USD
Agricultural lands and the unharvested harvest of grain crops	2.135
Agricultural machinery and equipment	926.1
Warehouses	272.4
Animal husbandry	136.4
Perennial plantations	89.1
Production stocks (fuel, fertilizer, plant and animal protection products)	119.6
Agricultural products in storage	613
In total	4292.3

Source: compiled by the authors

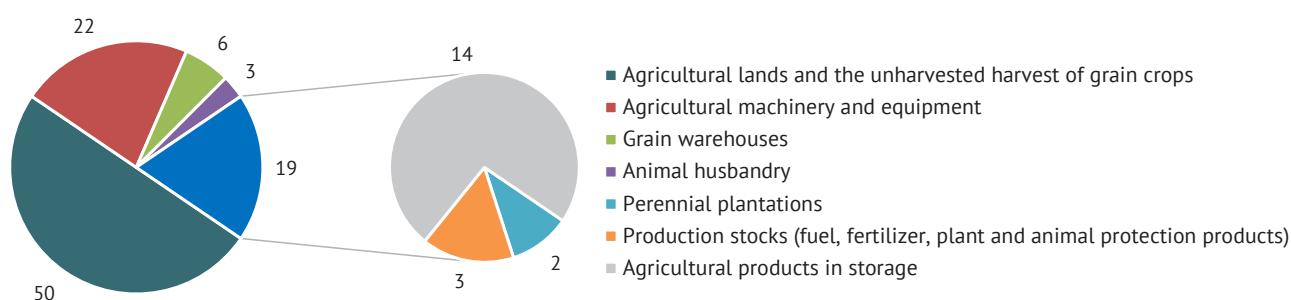


Figure 2. Losses in the structure of elements of the land and resource potential of agricultural enterprises of Ukraine due to the military invasion of the aggressor country in 2022, %

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022)

Agricultural land has suffered two significant types of damage – mine contamination and direct physical damage. Territories affected by active hostilities are contaminated with unexploded ordnance and unsuitable for agriculture. This poses a mortal threat to Ukrainian farmers and a high risk of field work. The cost of surveying these land plots in Ukraine is estimated at 436 million USD. As a result of physical damage to

the fertile soil layer (funnels from artillery shelling and missile strikes, soil damage by tank tracks or other military equipment), agricultural lands require technological restoration (reclamation and levelling of the surface) and is estimated at 39.6 million USD. The estimated cost of replacing and repairing the damaged irrigation infrastructure is 225 million USD. In addition to the direct damage to agricultural lands (occupation,

military operations, and mine damage), small and medium-sized agribusiness entities do not have full access to fields with the possibility of harvesting – approximately 2.4 million hectares of winter crops have been lost, in total worth 1.435 billion USD. Accordingly, in 2022, agricultural enterprises sowed only 75% areas of agricultural land from the total amount of agricultural land in 2021 (Agriculture during the..., 2022).

The material and technical component of the land and resource potential of agricultural enterprises (agricultural machinery and equipment) was also damaged as a result of shelling, airstrikes and hostilities. Tractors and trucks have a higher risk of damage than other types of farm equipment such as combines, planters and sprayers. In the occupied and temporarily uncontrolled territory of Ukraine, agricultural machinery of the highest price category is at risk of theft. The estimated cost of restoring damaged machinery is 926.1 million USD. The aggressor country purposefully destroys elevator capacities to weaken the Ukrainian agricultural sector. Thus, if storage facilities (barns) are relatively inexpensive to repair (average cost is 50-130 USD per ton of storage), then reconstruction of damaged modern concrete and metal silos requires restoration costs up to 250 USD per ton. The estimated volume of warehouses that were partially or completely damaged is 3.9 million tons. The total amount of losses due to damage or destruction of grain storages amounted to 272 million USD (Overview of war damage..., 2022).

The estimated value of the dead animals is more than 136 million USD. The approximate number of animals that died due to the lack of feed and veterinary services in the affected regions of Ukraine is 42

thousand sheep and goats, 92 thousand cattle, 258 thousand pigs and over 5.7 thousand poultry heads. More than 7.8 thousand hectares of perennial plantations located in the affected territories of Ukraine were partially or completely destroyed. The cost of damaged plantations is estimated at 89.1 million USD. In the occupied territories of Ukraine, the total amount of losses from damage and theft of material stocks of agricultural enterprises (physically damaged and lost fertilizers and means of protection of plants and animals; fuel lost due to looting), which ensured the production structure of their land and resource potential, is equal to 120 million USD (The impact of the war..., 2022).

In 2022, the Food and Agricultural Organisation of the United Nations provided financial assistance to restore the land and resource potential of medium and small agricultural enterprises of Ukraine in the amount of 2.4 million USD. The funds were used to restore material stocks (seeds of vegetables, potatoes and grain crops) for the 2023 harvest, and the purchase of special equipment for storage and protection of the crop; 3.605 million USD was spent on the modernisation of phytosanitary and veterinary laboratories. In general, in Ukraine in 2022, almost a quarter of the agricultural sector was lost – direct losses amount to 6.6 billion USD, indirect losses – 34.5 billion USD. It is considered in more detail the size and structural elements of the land and resource potential of agricultural enterprises of Ukraine in the pre-war and post-war periods. Thus, in 2021-2022, the number of active agricultural enterprises in Ukraine decreased from 47.34 thousand units up to 38.01 thousand units, which is only 80.3% from the level of 2021; in general, for 2017-2022, their number decreased by 11.6% (Fig. 3).

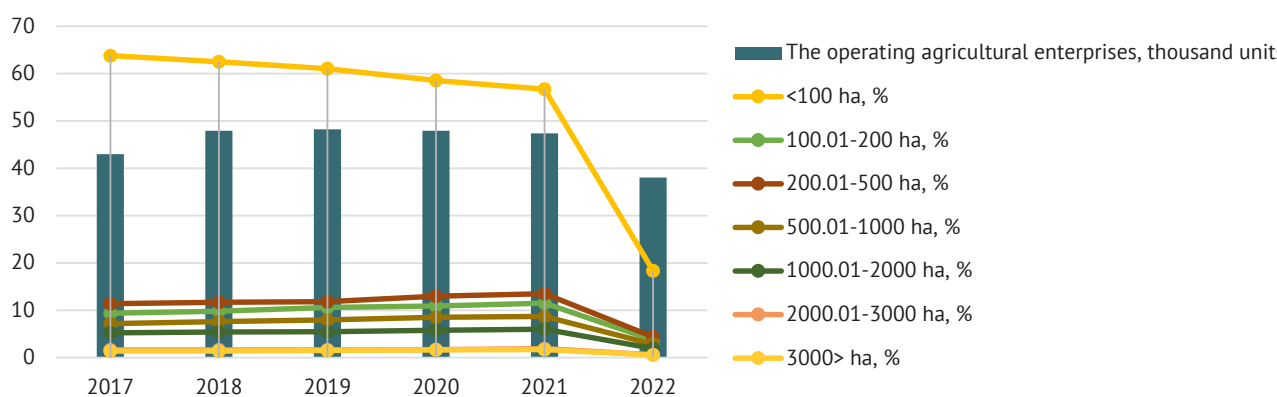


Figure 3. Structure of operating agricultural enterprises in Ukraine in 2017-2022

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)

Until the post-war period (2017-2021), the area of agricultural land in Ukraine, including the area of leased land plots that were cultivated by agricultural enterprises and developed the foundation of their land and resource potential, increased by 2.6%. However, due to the occupation of the Southern regions

of Ukraine by the aggressor country, in 2022 their share decreased in relation to the level of 2021 by 29% (Fig. 4). The yield of grain crops and sunflower is the main raw material component of the land and resource potential of agricultural enterprises of Ukraine (Fig. 5).

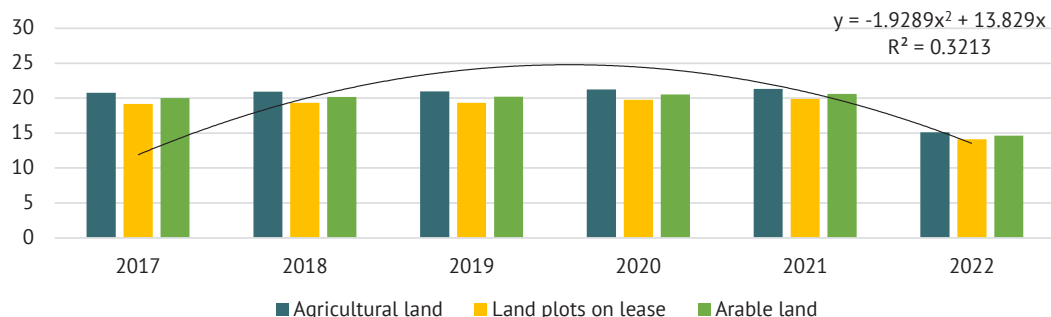


Figure 4. Area of agricultural land cultivated by agricultural enterprises of Ukraine for 2017-2022, million ha

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)

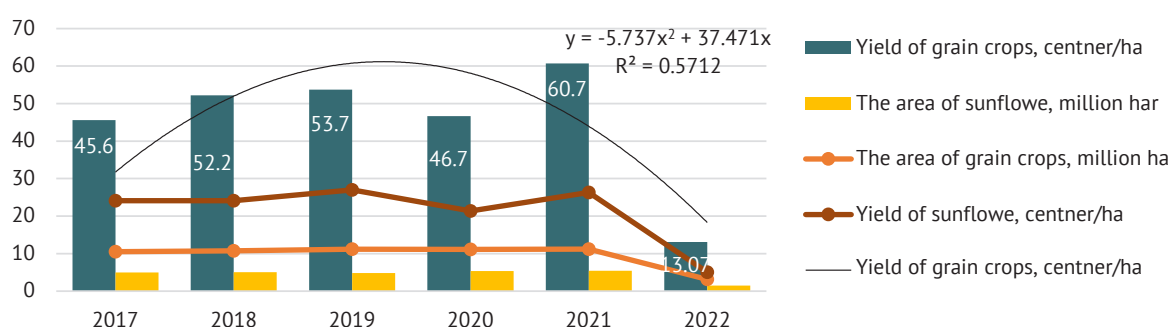


Figure 5. Correlation between harvested area and yield of priority crops of agricultural production in agricultural enterprises of Ukraine for 2017-2022

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)

In 2017-2021, the yield of grain crops increased by 33.1%, sunflower – by 9.2%, the same time, in 2022, almost 12 million hectares of arable land were lost due to military actions and the occupation of the Southern regions of Ukraine. For these reasons, agricultural enterprises did not receive 78.5% of the

harvest of grain crops and 80.8% of the harvest of sunflowers. An important component of the land and resource potential in agricultural production of agricultural enterprises is fixed assets, the level of renewal of which increased from 13.3% to 15.2% in 2017-2021 (Fig. 6).

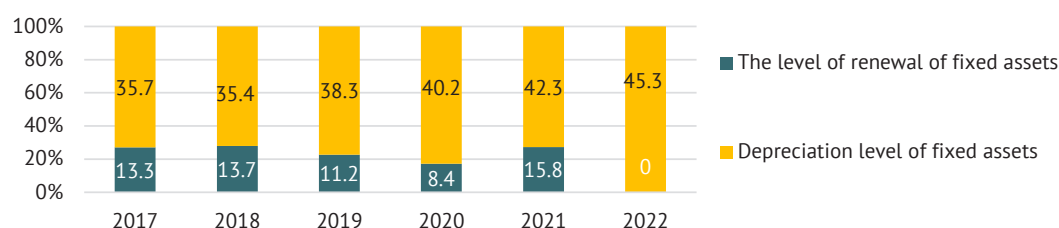


Figure 6. The level of renewal and depreciation of fixed assets in the field of agricultural production in agricultural enterprises of Ukraine for 2017-2022, %

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)

During 2017-2022, significant fluctuations in the poultry population of all species were observed in agricultural enterprises of Ukraine, which number decreased by 5.2% due to hostilities in the territory of the

Southern regions (Fig. 7). During the research period, a dynamic reduction in the number of cattle (including cows), sheep, and goats was observed at agricultural enterprises in Ukraine (Fig. 8).

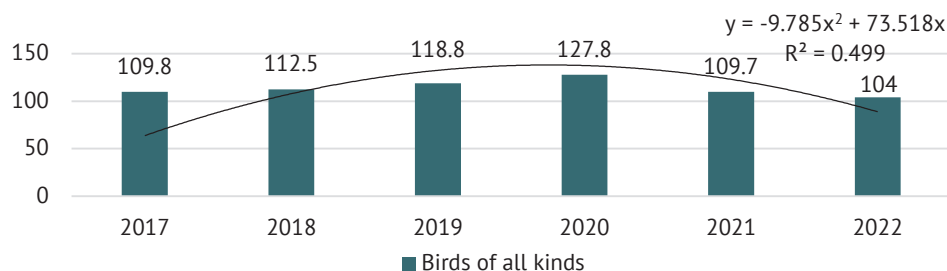


Figure 7. Poultry population of all types in agricultural enterprises of Ukraine for 2015-2021 and the third quarter of 2022, million heads

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskya (2022)

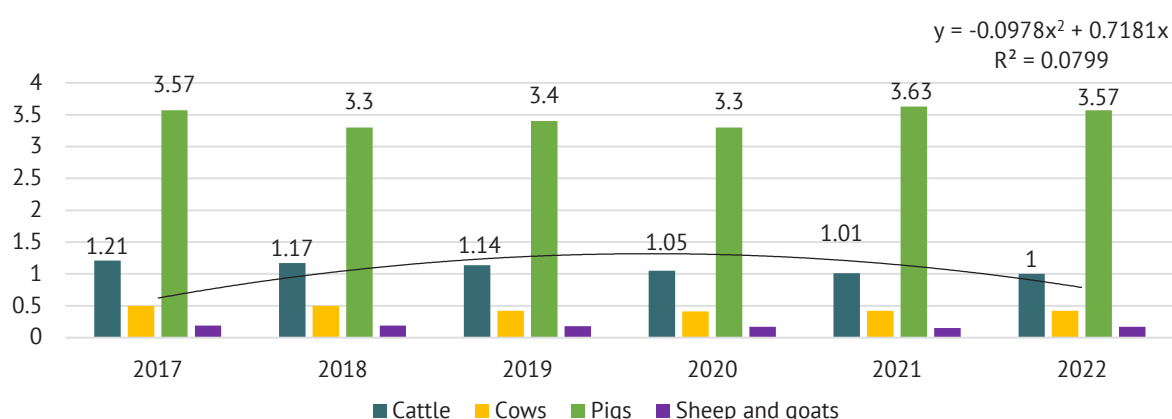


Figure 8. Livestock of all species in agricultural enterprises of Ukraine for 2017-2022, million heads

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskya (2022)

The quality of the balanced fodder ration of animals and the proper conditions of their keeping has a significant impact on livestock productivity. The volume

of feed costs per conventional head in agricultural enterprises of Ukraine for 2017-2021 increased by 9%, (Fig. 9).

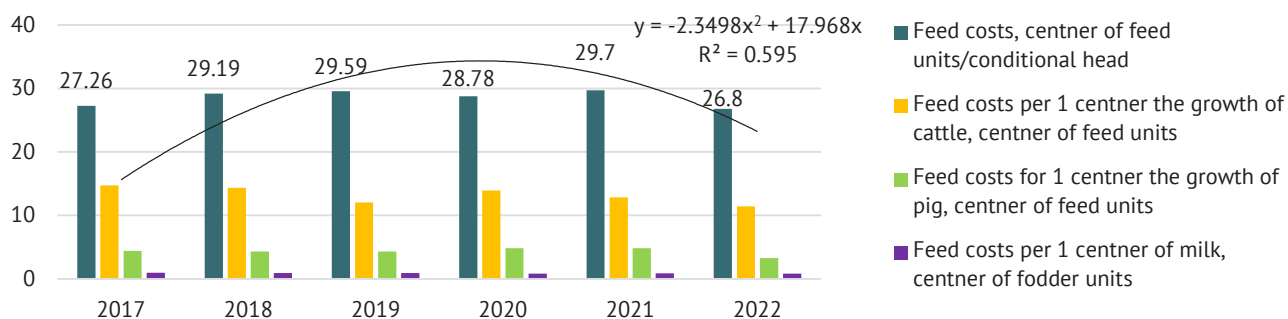


Figure 9. Feed costs for keeping animals and output of livestock products in agricultural enterprises of Ukraine for 2017-2022

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskya (2022)

Thus, during the research period, on average, from 14.74 centner to 12.84 centner of fodder units were spent on 1 centner of cattle growth in agricultural enterprises; for 1 centner of gain of pigs – from 4.41 centner to 3.29 centner of fodder units; for 1 centner of milk – from 0.97 to 0.84 centner of fodder units. The consumption of fodder for feeding animals for 2017-2021 is due, first of all, to a decrease in their number by 200 thousand heads. Meanwhile, in 2022, the volume of feed costs per 1 centner of cattle growth decreased by 11.1%, compared to the level of 2021, as a result of the death of animals

(10 thousand heads), as a result of hostilities in the territory of Ukraine, and due to the reduction of the area of agricultural land for the production of fodder base (physical damage to the fertile soil layer of land plots by the aggressor country). The adverse consequences of Russia's military aggression affected the slowdown in the increase in the productive capacity of animals in agricultural enterprises of Ukraine (Fig. 10).

The dynamics of the volume of production of certain types of animal husbandry products in agricultural enterprises of Ukraine is presented in Figure 11.

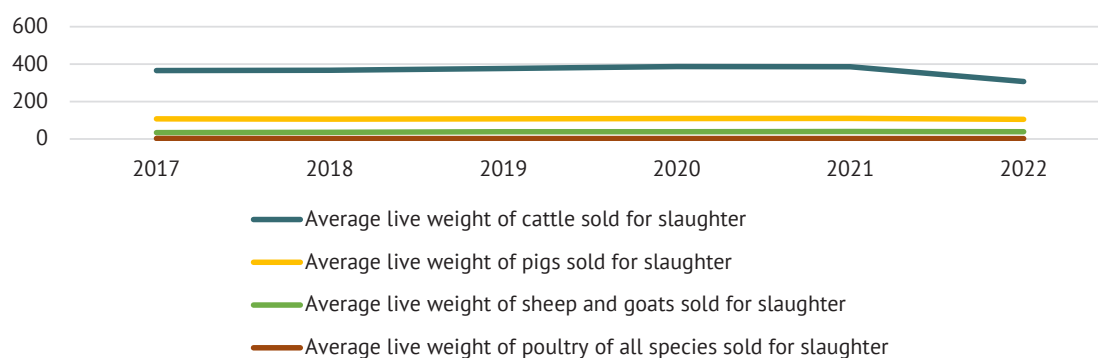


Figure 10. Productive capacity of animals in agricultural enterprises of Ukraine for 2017-2022, kg

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)

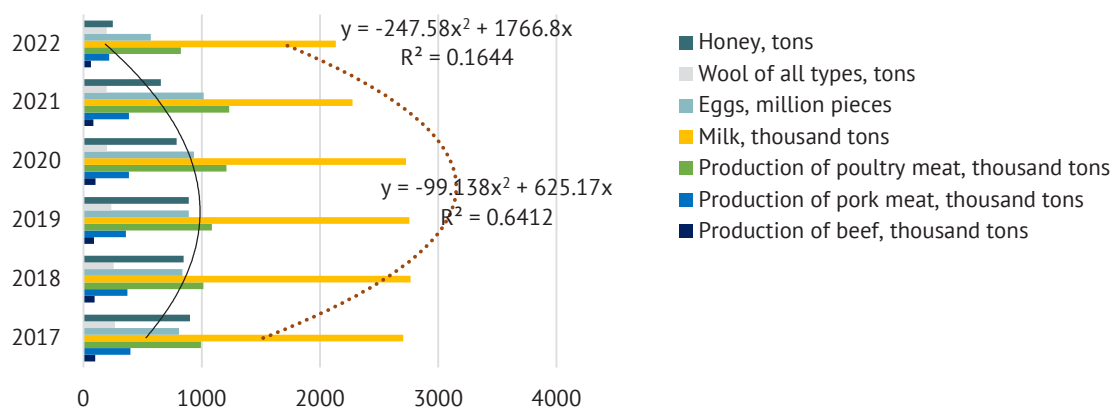


Figure 11. Production of livestock products in agricultural enterprises of Ukraine for 2015-2021 and the third quarter of 2022

Source: Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)

Thus, the volume of beef production in 2017-2022 decreased by 36.7%, pork – by 45.2%, poultry – by 17.1%, eggs – by 29.4%, milk – by 26%, honey – by 72.6%. Only during the year of the full-scale war in Ukraine, the production determinant of the land and resource potential of agricultural enterprises in the field of animal husbandry, in relation to the level of 2021, suffered large losses.

Products were not received in the following proportion: beef meat – for 25.9%, pork – for 43.5%, poultry – for 33.2%, eggs – for 44.1%, milk – for 6.3%, honey – for 62.3%. In the structure of the land and resource potential of agricultural enterprises of Ukraine, the determining lever of labor productivity of economically active human resources had a catastrophically weakened influence (Fig. 12).

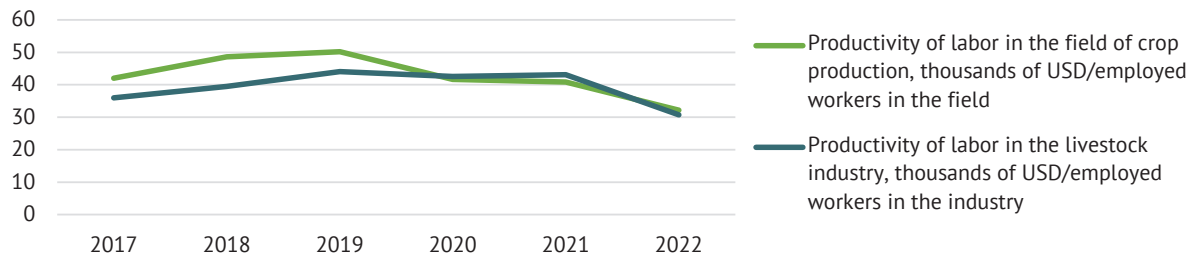


Figure 12. Labor productivity in agricultural sectors of Ukraine for 2017-2022

Source: *Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)*

Due to the military conflict, which weakened the state of economic development of the regions of the country, the number of full-time workers in agriculture, with the dynamics of their annual reduction in agricultural production, for the period 2017-2021, led to a decrease in labour productivity in the field of crop production by 23.4%, in the field of animal husbandry – to 14.5% in 2022 p. in 2022. However, with an intensive decrease in the efficiency of using economically active human resources in agriculture, in 2021 the average nominal salary of a full-time employee at Ukrainian

enterprises amounted to 634.6 USD, which is 2.7 times higher than the minimum wage (236.4 USD). Among the regions of Ukraine in 2021, full-time employees of agricultural enterprises in Mykolaiv region got – 669.6 USD and Kyiv region – 633.1 USD (the highest salary level); the least salary was valued in the Kirovohrad region – 484.8 USD. The size of the average nominal wage in the agricultural sector was 583.34 USD. In 2022, it increased from the level of 2021 by 22.2%, and compared to 2020 – by 23.1%. In general, wages in agricultural sectors for 2020-2021 increased by 48% (Fig. 13).

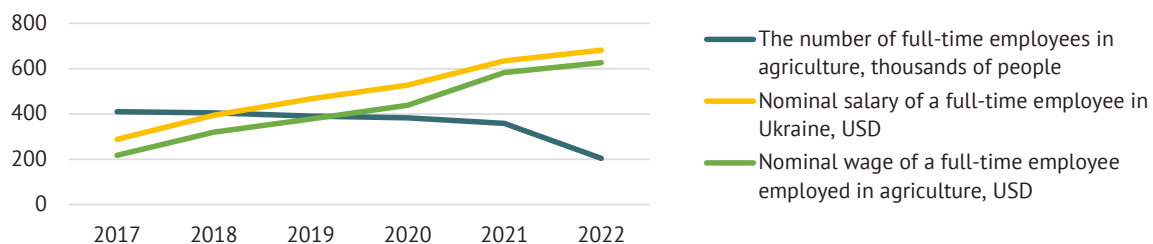


Figure 13. Dynamics of the number of full-time workers and the level of average nominal wages in the agriculture of Ukraine for 2017-2022

Source: *Agriculture during the war: Changing priorities (2022), Overview of war damage in Ukraine's agriculture (2022), The impact of the war on agriculture: The UN presented an assessment of the urgent needs of the agricultural sector and the rural population (2022), O.A. Vyshnevskaya (2022)*

Since the beginning of 2022, the average amount of payment in relation to the level of 2021 has increased by 7.4% and amounted to 681.6 USD. The recession of the economy during 2022, caused by the military aggression of the terrorist country, led to stagnation and suspension of wage growth in all spheres of agricultural activity.

Based on the downward dynamics of the development of the structural elements of the land and resource potential in the agricultural production of agricultural enterprises of Ukraine, the discrete Dirac delta function $\delta(x)$, was used, which made it possible to determine the impulse of the danger of fluctuations of its indicators, causing the probability of losing the effective use of land and resource determinants. According to the power averages, the impulse fluctuation of

the indicators, with an adverse decrease in their level, is determined as the sum of a large number of separate numerical values subject to the law of distribution of the discretionary value $M(x)$ and dispersion σ , subject to the individual random values of the following elements, as: areas of agricultural land, yields of crops, the productive capacity of animals, level of renewal and wear of fixed assets, level of feed costs per 1 centner of increase in animals and milk, and index of increase in average nominal wages of economically active human resources in agriculture. The probability of loss of efficiency in using land and resource potential in agricultural production in the presence of pulse fluctuations of its indicators and an adverse decline in their level is calculated using the following integral function (Phillips & Joao, 2017; Randolph, 2003).

$$\delta(x) = 0 \text{ for } x \neq 0$$

$$LRP_{loss}^{ef} = \int_{-\infty}^{\infty} \delta(x) \omega_i HRO_i = \sqrt{\sum_{i=1}^n (\omega_i \times HRO_i + \varepsilon_i)^2} / n_i \rightarrow \min, \quad (9)$$

where, LRP_{loss}^{ef} – the probability of the level of loss of efficiency in the use of land and resource potential of agricultural enterprises in the presence of a negative impulse of fluctuation of the n -th number of indicators during the study period; ω_i – the level of fluctuation of the i -th indicator of the effectiveness of using land and resource potential during the study period; HRO_i – change in the value of the i -th indicator, which has an impulse of dangerous fluctuations of the land and resource potential during the study period; ε_i – danger pulse error; n_i – the number of indicators in the research period.

For indicators with a variation of the impulse fluctuation from 0.1 to 0.33, the weighting factor is set at the level of 2.64 (the probability of loss of efficiency in using land and resource potential is low), from 0.34 to 0.57-3.64 (the probability of loss of efficiency in using land and resource potential is medium-acceptable), from 0.58 to 0.8-5.52 (the probability of loss of efficiency in the use of land and resource potential critical-permissible), above 0.8-8 (the probability of losing the efficiency in using land and resource potential is critical). The calculation results are presented in Figures 14 and 15.

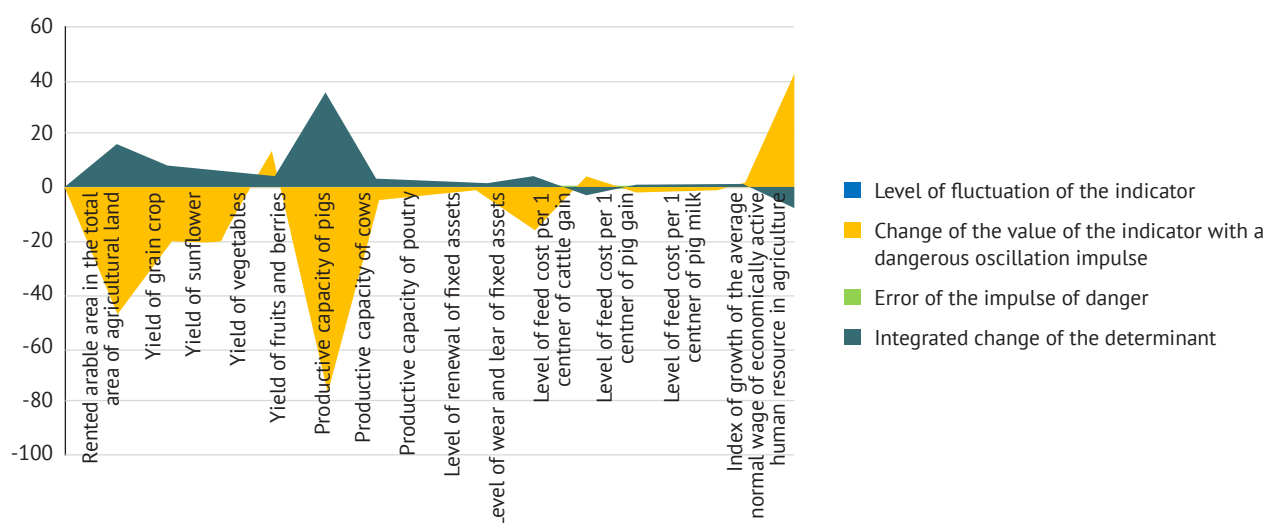


Figure 14. Impulse of adverse fluctuation of indicators causing the threat of loss of land and resource potential of agricultural enterprises of Ukraine in the period of martial law (2022)

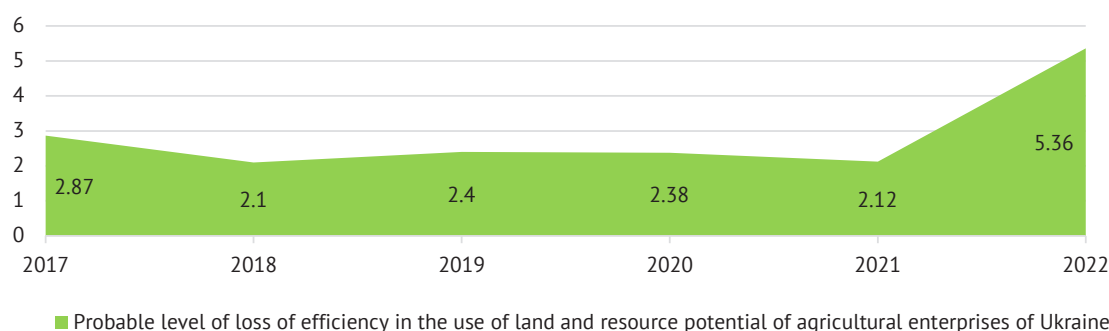


Figure 15. Probable level of loss of efficiency in the use of land and resource potential of agricultural enterprises of Ukraine for 2022

The established pulses of the danger of fluctuations in indicators of agricultural production of agricultural enterprises in the field of crop production in 2022 confirm that due to the occupation and hostilities in a significant territory of Ukraine, there was a reduction in agriculture. Leased arable land in the structure of agricultural land, in just one year of Russia's military aggression, suffered physical damage and decreased by

5.77 million hectares. It led to a decrease in the yield of grain crops by 47.7 centner/ha, sunflower – by 21.25 centner/ha, vegetables – by 18.52 centner/ha, fruits and berries – by 12.96 centner/ha. Accordingly, there is a real danger of losing the production capacity of agricultural enterprises for the effective use of land and resource potential in the field of crop production. It is evidenced by adverse changes in the integrated determinant in

the calculation indicators, a positive increase of which demonstrates the momentum of negative fluctuations of the indicator, an adverse value – the momentum of positive fluctuations. In the livestock industry of Ukraine in 2022, an even worse trend is observed than in crop production, since this industry is directly dependent on agricultural land and the technological capacities of agricultural enterprises, which suffered losses due to the occupation and hostilities in the territories of Kyiv, Sumy, Chernihiv, Mykolaiv, Kharkiv, Donetsk, Luhansk, Kherson and Zaporizhzhia regions of the country. Evidence of the adverse dynamics of the production of livestock products is the high momentum of the loss of resource and production capacities of agricultural enterprises. The integral change in the determinant of the productive capacity of cattle, cows, pigs, and poultry shows an increase in the value of indicators with a dangerous oscillation impulse, namely, by 73 kg, by 5 kg and 2 kg of average live weight and by 0.4 kg of milk yield (Fig. 14).

Due to the terrorist actions of the aggressor country, the area of agricultural land in the affected regions of Ukraine decreased by 6.19 million hectares. Accordingly, only in 2022, the level of feed consumption per 1 centner of increase in cattle decreased by 1.42 centner of feed units, pigs – by 1.55 centner of feed units, milk – by 0.05 centner of feed units. Therewith, the level of serviceability of fixed assets in agricultural enterprises of Ukraine has decreased by 3% due to the inability to update them during wartime (lack of budget funds under the programmes to support small and medium-sized agricultural businesses in the country planned for the beginning of 2022). Thus, in 2022, the probable level of loss of efficiency in using the land and resource potential of agricultural enterprises of Ukraine amounted to 5.36 and characterises the critical and acceptable limits for its recovery (Fig. 15).

In relation to 2021, the integral indicator has increased 2.5 times, which confirms the growing crisis in agricultural production of agricultural enterprises of Ukraine. Effective measures of an economic nature

are needed to level the threatening trends in the country's agriculture, which are capable of harmonizing the mechanism of land relations for targeted and timely restoration of the land and resource potential of economic entities. One of these mechanisms is the forecasting of scenarios for the development of the agricultural land market, to ensure the rational use, protection of land as a component of the natural environment, preservation, multiplication and reproduction of its productive power as a natural resource.

An optimistic scenario of the development of the agricultural land market provides consistent, qualified and free implementation of the right of ownership by landowners, attracting investments in the field of agriculture, increasing the level of effective use of the land and resource potential of agricultural enterprises. Implementation of such a scenario allow determining institutional restrictions, forms of interaction, and methods of harmonizing the interests of economic entities in the land market: lease conditions, restrictions on the area of purchase of agricultural land, transfer of land from one category to another and determination of cadastral value. The pessimistic scenario envisages the introduction of the free circulation of land without restrictions when active participants in transactions for the purchase of agricultural land plots are large agricultural enterprises that have more opportunities for effective use of land and resource potential. However, this can result in the development of monopoly ownership of agricultural land in the absence of legal protection of ownership rights to land plots of small and medium-sized agricultural enterprises. To determine the priority level of effective use of the land and resource potential of agricultural enterprises of Ukraine and the significance of its main determinant – agricultural land shortly, an analysis of the circulation of their structural elements (rent, purchase and sale, inheritance, exchange, emphyteusis and mortgage) was performed, according to transactional operations that were conducted before the war period (Fig. 16).

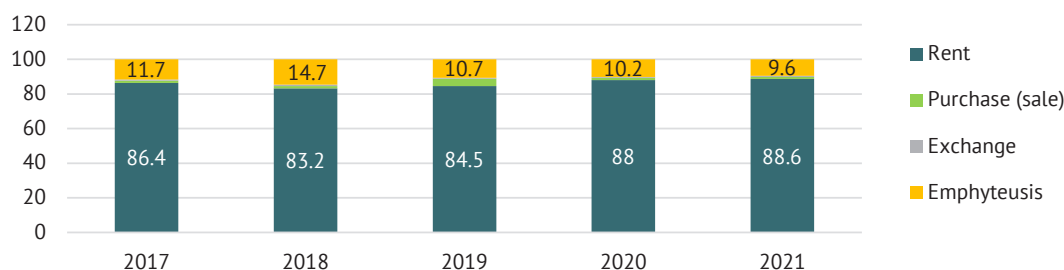


Figure 16. The structure of the transaction of elements of agricultural land in Ukraine for 2017-2021, %

Considering the extended period of martial law in Ukraine in 2023 and based on the method of exponential smoothing, the forecast values of the transaction turnover of agricultural land in Ukraine for 2024 were calculated, in particular, the area of land plots for the

production of crops, which were included in the calculation of the indicator of probable loss of the land and resource potential of agricultural enterprises due to the temporary occupation of the country's territories in 2023 (Fig. 17).

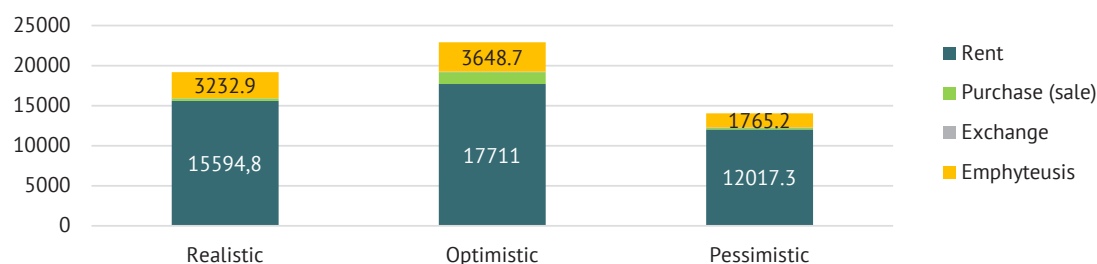


Figure 17. Forecast scenarios of the transactional circulation of agricultural land for reproduction and stabilisation of the land and resource potential of agricultural production entities of Ukraine for 2024, thousand hectares

Thus, according to the realistic scenario, a moderate increase in the number of transactions regarding the lease of land plots for the production of crops in the amount of 15594.8 thousand hectares is predicted, since the subjects of agricultural production in the domestic market will gradually exit the period of deoccupation of territories and recreate the priority determinant of the land and resource potential, with the annual growth of demand for Ukrainian products on foreign markets to the level of 2021. Such a scenario of events will gradually speed up operations to restore forward contracts for future harvests. In general, according to the scenario of realistic development, the area of land plots with which transactions will occur will increase to 19084.5 thousand hectares in 2024 (Meyers *et al.*, 2018).

According to the forecast of the optimistic scenario, in addition to the increase in transactions for the lease of land plots for the production of crops – up to 17711 thousand ha, there will be an increase in the turnover of agricultural land for emphyteusis – up to 3648.7 thousand ha and purchase (sale) agreements – up to 1466.3 thousand ha. It will be connected, first of all, with the stabilisation of the economic determinant of the land and resource potential of agricultural enterprises, secondly, with the ability to capitalise the land and material determinant for the reproduction of the livestock industry, due to the attraction of investments, thirdly, with the increase in the number of economically active human resources to revive the productivity of agricultural industries, reduce unemployment and population migration within rural areas (Levkina *et al.*, 2019).

According to the pessimistic scenario, the demand and price for agricultural land will decrease due to the inability to de-occupy the territory of Ukraine from the terrorist aggressor country, which will result in the loss of part of the elements of the circulation of land plots for purchase (sale) – up to 190.3 thousand hectares, a decrease emphyteusis transactions – up to 1765.2 thousand hectares and lease transactions – up to 12017.3 thousand hectares. In general, according to a pessimistic forecast, the total value of the priority determinant for transactional operations of building up the land and resource potential of agricultural enterprises will amount to only 14034 thousand hectares. To establish a model of reproduction of the land and

resource potential of agricultural enterprises up to the level of 2014, by introducing the determinants of the development of the internal market of agricultural land, a multiple regression model is proposed. Adequacy of the model is substantiated on the basis of Fisher's test scores. In its classic form, the multiple regression model, is depicted in the following formula (Kozmenko & Kuzmenko, 2014):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_m X_m + \varepsilon, \quad (10)$$

where, Y – dependent (resultant) variable; $X = (X_1, X_2, \dots, X_m)$ – vector of independent explanatory (factor) variables; R – parameters of the multiple regression equation to be determined; ε – random error (deviation); β_0 – free coefficient that determines the value of (Y), if all explanatory variables X_i are equal to 0.

To establish a multiple regression model, a variable value was introduced, the dependent variable, the area of land plots for the production of agricultural crops in the circulation transaction is denoted by Y ; independent variables: X_1 – area of land plots leased; X_2 – area of sold land plots; X_3 – the area of land plots for which the emphyteusis right was registered. The value of the multiple correlation coefficient (index) $R=0.99$ indicates a close relationship between the model factors and the dependent variable (Y), in particular, the coefficient of determination – $R^2=0.98$. The significance of the multiple regression model, is assessed using Fisher's F-test. Since the actual value of the criterion is greater than the critical value, $F > F_{critical}$, the multiple regression equation is recognised as statistically significant (Kozmenko & Kuzmenko, 2014). Based on the results of the calculations, the multiple regression equation was obtained:

$$Y = 0.262 + 0.245X_1 + 0.006X_2 + 0.377X_3 + 0.347X_4. \quad (11)$$

Based on the regression model, the predictive value of the circulation of the area of land plots for the production of crops in the domestic market of Ukraine was calculated, as a priority determinant of the reproduction and effective use of the land and production potential of agricultural enterprises of Ukraine until 2025 (Fig. 18).

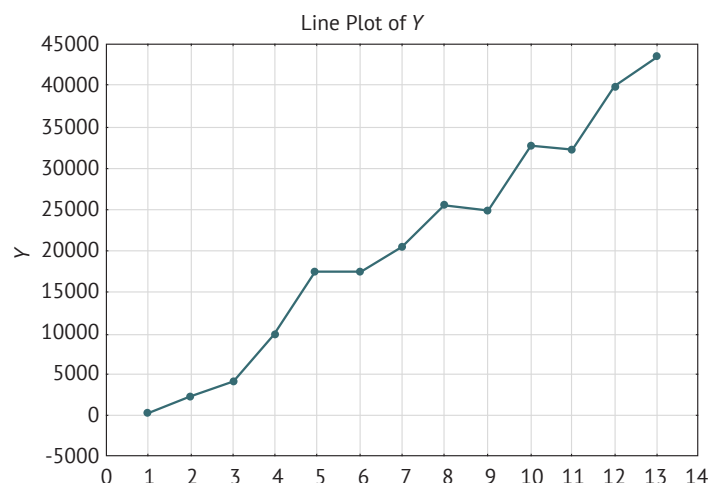


Figure 18. Estimated size of land plots for the production of agricultural crops for effective use of land resource potential of agricultural enterprises of Ukraine

Thus, the increase in the area of land plots for the production of crops, leased to agricultural enterprises until 2025 (based on 1 thousand hectares), will lead to an increase in their total size in the structure of the elements of reproduction and effective use of the land and resource potential by 0.245 thousand hectares; the increase in the land area of agricultural enterprises from the purchase (sale) of additional land plots will allow for increasing their value by 0.006 thousand ha; increasing the area of land for exchange with defined soil fertility criteria will increase by 0.377 thousand priority determinant in the structure of land resource potential; for emphyteusis changes, the total area of land plots in the potential of enterprises will increase by 0.347 thousand ha. Thus, 97% of the variability of the area of agricultural land in the circulation of the domestic market will occur due to the change of the above-mentioned elements of the land determinant, which will allow reproducing and effective using the land and resource potential of agricultural enterprises until 2025, and to increase the volume of produced products, which is demanded on the foreign market.

DISCUSSION

Land and resource potential is a complex of natural, technical, economic, and social factors that determine the opportunities for the effective use of land and other natural resources in a considering territory. Land and resource potential is the object of both commodity-money and land relations and is characterised by spatial limitations (Mander *et al.*, 2010). According to W.H. Meyers *et al.* (2018) various approaches and methods can be used to ensure the rational use of the land and resource potential of agricultural enterprises. For example, it is important to ensure the efficient use of land resources by applying rational methods of soil cultivation and modern land-use technologies, which can provide optimal land use, as confirmed by the research conducted (Meyers *et al.*, 2018).

In his research, J. Randolph notes that economic activity in rural areas is one of the key components of effective use of the land and resource potential in agricultural enterprises. An integrated approach to rural agriculture development is effective as it considers all aspects of economic, social, and ecological sustainability of agricultural production. Therefore, it is important to use modern technologies and innovations, improve employee qualifications, attract investments, and develop partnership relations with other enterprises, as reflected in the research conducted (Randolph *et al.*, 2003).

Thus, according to the results of J. Primdahl *et al.* (2013) research, the most effective strategy for rural agriculture development in rural areas is a comprehensive approach that involves using all possible resources of the territory and interaction between different industries and enterprises in rural areas. For this purpose, it is important to establish favourable conditions for the development of small and medium-sized enterprises and use various financing tools (Primdahl *et al.*, 2013).

The obtained data of the conducted research correlates with the results of R.P.O. Schulte, who believes that the development of the agricultural land market can have several scenarios designed to ensure rational use, conservation of land as a component of the environment, preservation, multiplication, and reproduction of its productive capacity as a natural resource. Several possible scenarios for the development of the agricultural land market include:

1. State-controlled land market: in this scenario, the state has full control over the land market and manages the land resources in accordance with the strategy for agricultural development and environmental purposes. The land market operates under state rules and mechanisms, ensuring efficient use of land resources and their protection:

2. Liberalised land market: in this option, the land market is completely liberalised, meaning that land plots can be bought and sold without any restrictions. In this case, the land market should develop based on efficient competition and private ownership of land.

3. Restricted land market: this option involves a land market regulated by special rules and mechanisms. For example, restrictions on selling land to foreigners or corporations, or limitations on using land for certain types of agricultural crops (Schulte *et al.*, 2014).

Ukraine is a country with a high land resource potential, which enables efficient use of agricultural land and development of other industries. However, the existing real danger associated with military aggression and a terrorist-minded state can affect the country's economy, including agriculture. Nevertheless, despite these conditions, Ukraine has significant potential in the production of agricultural products, allowing it to maintain strong positions in the international market. In particular, Ukraine is one of the largest exporters of grain crops, sunflowers, and other oilseeds.

First and foremost, the agricultural sector is an important component of the Ukrainian economy, and the government is doing everything possible to support this sector. Various support measures and programmes for agriculture have been introduced, such as subsidies, lending, and other forms of support. However, the conditions of existing danger may affect Ukraine's export opportunities, and therefore agricultural enterprises should focus on preserving and developing the domestic market, which will be more resilient to external changes (Kozmenko *et al.*, 2014).

A.O. Koshel (2015) believes that there are several factors that can affect the effective use of land and resource potential in Ukrainian agricultural enterprises. Some of these factors include:

1. Preservation of natural resources: rational use of land and other natural resources must be implemented to ensure their preservation for the future.

2. Crop rotation and organic production: adhering to rational crop rotation and using organic production methods allows for the preservation of soil fertility and ensures a sustainable production process.

3. Modernisation of equipment and technologies: using modern techniques and technologies allows for increased productivity and ensures efficient use of resources.

4. Development of human resources: it is necessary to provide training and opportunities for professional development to increase the qualifications of employees.

5. Expansion of market outlets: developing market outlets allows for increased profitability of agricultural enterprises and ensures sustainable industry growth.

6. Access to financing: lack of access to financing can limit the ability of agricultural businesses to invest in modern equipment, technologies, and infrastructure needed for effective use of land and resources.

7. Government policy: policies related to land ownership, land use, and resource management can have a significant impact on the ability of agricultural businesses to effectively use their land and resources.

8. Infrastructure: inadequate infrastructure, including roads, irrigation systems, and storage facilities, can

limit the ability of agricultural enterprises to efficiently transport and store their harvest.

9. Environmental conditions: natural disasters such as floods and droughts can have a significant impact on the ability of agricultural enterprises to effectively use their land and resources (Koshel, 2015).

R.V. Levkina *et al.* (2019) states that the functioning of the land market in Ukraine must be based on the principles of social justice and the protection of state, societal, and private interests. It means that the land market should be regulated by the state to ensure the accessibility of land for various categories of citizens, including small agricultural enterprises and individual farmers (Levkina *et al.*, 2019). Moreover, the functioning of the land market must be ensured by legality, efficiency, transparency, and openness. It means that the government should provide transparency in the processes related to the land market, including land rights registration, land assessment, and other important aspects. In addition, it is necessary to ensure the effective functioning of the land market, allowing various citizens, including foreign investors, to perform land operations without excessive obstacles (Lebedenko, 2011).

Furthermore, ensuring balanced development of both large-scale agricultural business and small-scale agricultural entrepreneurship in all areas of activity is an important aspect of the functioning of the land market. To achieve this, it is necessary to ensure equal conditions of competition, including accessibility to credit for small and medium-sized agricultural enterprises. Therefore, the effective use of land and resource potential in Ukrainian agricultural enterprises requires a combination of access to funding, government policy support, adequate infrastructure, stable market conditions, learning opportunities, and a favourable natural environment.

CONCLUSIONS

Thus, the land and resource potential has always been and will remain a special object of both commodity-money relations and land relations, which is characterised by spatial limitation, irreplaceable territory for using agricultural land in agricultural production. Even in the conditions of the existing real danger associated with military aggression and a terrorist-minded country, agricultural enterprises of Ukraine can defend the interests of farmers in the foreign market, controlling the vector of their development to the effective and rational use of land in the interests of meeting the needs of food security of the state and reproduction of land relations in rural areas. These conditions are satisfied by the national policy on land management, with clear guidelines for the reform of land ownership, established technologies for the organisation of land and real estate accounting, land cadastral assessment, land management; improvement of land resources management; preservation of land and resource potential for future generations.

Land is an exhaustible natural resource that should be used sparingly. It especially applies to agricultural land. The functioning of the land market in Ukraine should be performed based on social justice, ensuring state, public and private interests, legality, efficiency, transparency, openness, ensuring the balanced development of both large agrarian businesses and small agrarian entrepreneurship in all territories where agricultural enterprises are located. Preservation and rational use of the land and resource potential of agricultural enterprises allows optimising the necessary conditions for ecological and economic support of agricultural production under the condition

of a favourable territorial environment in rural areas to increase the productive capacity of agricultural industries. Therewith, the main generator of effective use of the potential, its economic "engine" should be economic activity in the countryside, rational use of agricultural land and multi-system functioning of the rural economy.

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CONFLICT OF INTEREST

None.

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Фактори, що впливають на ефективність використання земельно-ресурсного потенціалу в аграрному бізнесі України

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Анотація. Аграрні підприємства України мають значний земельно-ресурсний потенціал, але ефективне використання цього потенціалу залежить від багатьох факторів, дослідження яких є актуальним. Метою дослідження є розробка комплексного підходу до зміни процесу ефективного використання земельно-ресурсного потенціалу та пошук основної детермінанти його відтворення у післявоєнний період економічного розвитку аграрного сектору країни. Для досягнення поставленої мети було застосовано математичний інструментарій та метод капіталізації доходу. У результаті дослідження встановлено, що збільшення площі земельних ділянок для вирощування сільськогосподарських культур, переданих в оренду до 2025 р., призведе до збільшення їх загального розміру на 0,245 тис. га у структурі елементів відтворення та ефективного використання земельно-ресурсного потенціалу. Збільшення площі земель сільськогосподарських підприємств від купівлі (продажу) додаткових земельних ділянок збільшить їх вартість на 0,006 тис. га, а розширення площі обмінних земель – на 0,377 тис., що є пріоритетною детермінантою в структурі земельно-ресурсного потенціалу, а зміни в емпітевзисі збільшать загальну площу земельних ділянок на 0,347 тис. га в потенціалі підприємств. Таким чином, 97 % варіативності площі сільськогосподарських угідь у внутрішньому ринковому обігу відбуватиметься за рахунок зміни вищезазначених елементів земельної детермінанти, що забезпечить ефективне використання земельно-ресурсного потенціалу сільськогосподарських підприємств до 2025 р. та нарощування обсягів виробництва продукції. Дослідження факторів, що впливають на ефективне використання земельного потенціалу аграрних підприємств України, має важливе практичне значення, оскільки дозволяє виявити ключові фактори, які впливають на успішність аграрних підприємств, що може допомогти їм удосконалити свою стратегію та знайти шляхи підвищення продуктивності

Ключові слова: землі сільськогосподарського призначення; відтворення; економічний розвиток; монополістичні утворення; транзакційний обіг



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The economic effect of the measures provided for by the Kyoto Protocol by region (as of the 2020s)

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The economic effect of the measures provided for by the Kyoto Protocol by region (as of the 2020s). *Scientific Horizons*, 26(4), 136-145.

Abstract. The Kyoto Protocol has become a promising component for solving one of the most urgent and discussed problems by scientists – air pollution. Therefore, it remains important to consider what has actually been achieved over the 17 years of the treaty; what effects (environmental or economic) prevail as a result of its action. In this research, special emphasis is placed on the impact of the Kyoto Protocol on certain regions, such as Europe, Asia, America and others. Thus, the purpose of the work is to demonstrate how this agreement influenced the development of countries in certain regions, what consequences it led to and how effective it turned out to be. The following research methods were used in the work: statistical, graphic, historical, modelling and forecasting. While writing the work, it was demonstrated what advantages and disadvantages the Kyoto Protocol has as a document for protecting the external environment. In addition, the



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authors described the main environmental benefits and economic losses from this agreement. The research has demonstrated that the Kyoto Protocol does reduce CO₂ emissions in some regions and likely reduces the rate of growth in others. However, a general decline in industrial development was observed in the countries participating in the agreement. The authors conclude that it is currently impossible to say with certainty how effective this agreement will be, but its adverse political and economic consequences will be far less than the environmental benefits. In addition, regional features of the impact of the Kyoto Protocol on the development of local countries were considered. The work allows for a new perspective on the effectiveness of the Kyoto Protocol and provides new answers to questions about the usefulness of this document and the rationality of implementing its terms

Keywords: sustainable development; regional development; international relationships; external environment; air pollution

INTRODUCTION

In modern conditions of human development, the problems of protecting the external environment remain relevant. It is especially true for air pollution problems, which are considered one of the most discussed among scientists. One of the components for their solution was the Kyoto Protocol, which was signed by most countries of the world to reduce greenhouse gas emissions into the atmosphere. Therefore, it is crucial to reflect on what has been accomplished as a result of its action.

Extreme weather events in the past few decades have sparked discussion about significant future global warming caused by human economic activity (Sorokhtin, 2007). For the first time, this problem began to be discussed by scientists as early as the 19th century (Arrhenius, 1896), and it began to rise more actively in the 70s-90s of the 20th century. During the discussion among scientists, there were both adherents of the idea that it is worth fighting greenhouse gases, and those who were against it. However, in the end, over time, the Kyoto Protocol was adopted, which, in fact, delivered an ultimatum: either a general catastrophe in the future, or a reduction in industrial emissions (Vladimirov & Churakov, 2014; Scotese et al., 2021).

A large number of scientists are currently working on exploring environmental problems. In particular, notably, V.A. Vladimirov and Y.I. Churakov (2014), who in their work analysed in great detail the current and past trends in the study of climate change issues. In addition, the robot used a significant number of studies that consider empirical data on the effectiveness of the Kyoto Protocol as such. Thus, R. Najarzadeh et al. (2021) demonstrated the impact of the treaty in terms of trade and changes in competitive advantage between countries. In fact, it is a much more important indicator than it might seem since it affects both the well-being of countries and their political and economic role in the world.

The research (Dogan et al., 2022) explores the impacts of technology and Kyoto Protocol in addition to several control variables to energy transition by applying the novel econometric method of Sigmund and Ferstl. The empirical results confirm the positive and significant link between technology and energy transition. Similarly, the authors confirmed that the Kyoto Protocol has a significantly positive impact on energy transition.

The research (Kim et al., 2020) explores the environmental and economic impacts of the Kyoto Protocol on Annex I parties. The authors claim that participating as an Annex I party has a significant positive impact on CO₂ emission reductions, but an adverse impact on the gross domestic product of the participants in the long run. This research is valuable as it provides a recommendation for developing countries to focus future global climate change frameworks on balancing the impact on economic and environmental performance to ensure sustainable development.

The authors (Nguyen & Phan, 2020) analysed the effect of carbon risk on firm capital structure associated with Australia's ratification of the Kyoto Protocol. Interestingly, as a result, it was found that increased carbon risk leads to higher financial distress risk, which motivates firms to decrease financial leverage. In a study (Kanie, 2020), the authors consider the importance of country leadership in negotiations before the ratification of the Kyoto Protocol. Thus, the authors traced the relationship between the state's economic positions and the benefits of the terms it agrees to under this protocol. In addition, the study (He et al., 2022) is very useful for the chosen research subject. The author highlights future research opportunities to improve carbon accounting, which is an important clause of the Kyoto Protocol.

In addition, notably, the scientists who examined the features of the functioning of the treaty in certain regions. Thus, J. Cifuentes-Faura (2022) examined approaches in Western Europe, and R. Radovanovic (2022) demonstrated the specifics of the situation in Eastern Europe and neighbouring countries. F. Ahmed et al. (2022) demonstrated the features of the impact of the treaty on the development of Asian countries, a region characterised by a significant number of developing countries and high levels of pollution, and J. Hovi et al. (2014) attempted to demonstrate the most likely reasons why the United States of America is still not a member of the Kyoto Protocol.

Thus, the purpose of this work was to present and describe the positive and adverse effects of the Kyoto Protocol associated with its impact on the environmental, political and economic components of the development of countries.

GENERAL FEATURES OF THE PHENOMENON OF GLOBAL WARMING

Global warming (or global climate change) is a phenomenon associated with a relatively rapid increase in the temperature of the surface of the Earth and oceans. The high relevance of this phenomenon is due to the fact that it has huge adverse consequences for both wildlife and humans in general. The high rate of temperature change on the planet does not allow animals to have time to adapt to it, which can lead to a reduction in the number of species or their complete extinction. In addition, it applies to people who, due to climate change, will have to migrate from territories that have become inconvenient for living to other, more viable ones. However, it is simply impossible to transfer entire cities and states. In addition, warming will lead to an increase in the number of various kinds of natural disasters, such as floods, hurricanes, tornadoes and others, which will result in a large number of victims. In addition, the area under crops and forests will decrease; the destruction of the infrastructure of cities will begin, especially in coastal areas. Another influence is possible, more unusual, for example, a change in the configuration of the Gulf Stream, which can lead to unpredictable consequences.

Among all the scientists who participate in the discussion about the problem of global warming, four groups can be distinguished. The first is the uncompromising supporters of global warming, who believe that it is human activity that makes the greatest contribution to it; the second group are specialists who acknowledge the fact of global warming but consider the statement about its predominantly anthropogenic origin to be difficult to prove; the third – those who doubt the validity of the establishment of the very fact of global warming; the fourth one is supporters of the opinion, according to which global cooling, not warming, will occur in the coming decades (Vladimirov & Churakov, 2014; Menton *et al.*, 2020; Degroot *et al.*, 2021).

In general, the phenomenon of global climate change is confirmed by the facts. Now in the world, as the air temperature near the earth's surface is

increasing, there is a decrease in the area of sea ice near the Arctic Basin and snow cover on land, while, therewith, an increase in the average ocean level. In addition, the results of modern research indicate that the observed changes in climate with an extremely low probability (below 5%) occur without external intervention, therewith, with a high degree of probability (about 90%) it can be argued that it is the concentration of anthropogenic gases is the main cause of global warming (Vladimirov & Churakov, 2014; Pascolini-Campbell *et al.*, 2021). These data were obtained when assessing the rates and the approximate moment of the beginning of the increase in the general air temperature on Earth with an increase in industrial production by people. And although such statistics are quite convincing, they still do not give unequivocal confidence in the existence of global warming and human involvement in it. Therewith, according to other models, it makes no sense to reduce greenhouse gas emissions since the effect of this will be zero or very low, but the socio-economic consequences may appear to be adverse and very long-term.

From time to time there are assertions in scientific circles about the high role of other factors in climate change. Among these, the most frequent are increased solar activity and natural long-term trends in climate change. However, both of these theories are not proven; moreover, there is ample evidence that they are false. Another theory suggests that the current warming will be offset by subsequent cooling due to the onset of the Ice Age due to changes in the Earth's orbit. However, most likely the next cooling should be expected only in a few thousand years. Due to this, there is no way that warming can be offset by subsequent cooling in the near future (although there is still a probability that it can be expected a cooling in this millennium, it is extremely low). The rates of pollution of the Earth's atmosphere are depicted. Note that the data in the Figure 1 is displayed with an accumulation condition: thus, the actual amount of pollution produced by a region is found by finding the difference between the value of the region on the graph and the value of the previous region.

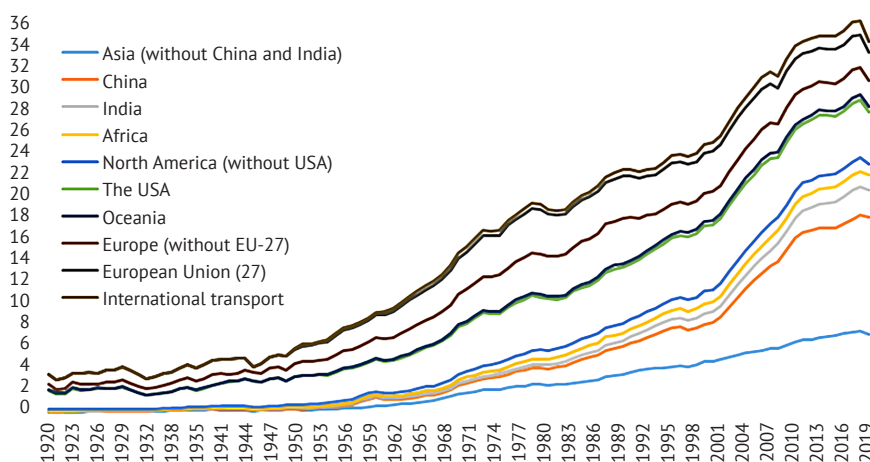


Figure 1. The amount of CO₂ emitted into the atmosphere from 1920 to 2020, billion tons

Source: compiled by the authors based on Our World in Data (2022)

Figure 1 presents that the amount of CO₂ emitted into the air is increasing from year to year. Moreover, the average growth rate of emissions over 100 years was 2.29%, while since the beginning of the 21st century it was 1.49%, and since 2005 – 1.1%, which generally indicates the effectiveness of countries' policies to reduce CO₂ emissions into the atmosphere (including the effectiveness of the Kyoto Protocol).

THE IMPACT OF THE KYOTO PROTOCOL ON THE DEVELOPMENT OF INDIVIDUAL REGIONS

It was mentioned above that the nations of Europe, its western part, more than others adhere to the principles of the Kyoto Protocol. They have made it their purpose to reduce emissions by 55% by 2030 compared to 1990, and to become the first climate-neutral continent by 2050. As can be seen from Figure 1, they really succeed: the rate of reduction of CO₂ emissions in the EU countries is the highest. Politicians in these countries seriously want to implement a circular economy model within their economies to maintain the value of products, materials and resources in the economy for as long as possible and minimise waste generation (Cifuentes-Faura, 2022; Sikora, 2021). The situation with the countries of Eastern Europe is somewhat different from the countries of its western part. Here Russia, which has huge reserves of natural gas (which is the most environmentally friendly raw material), was

able to use the rules of the Kyoto Protocol for its own purposes, putting many countries on the "gas needle"; note that this applies both to resource-poor and far too dependent on imported energy neighbouring countries (such as Georgia, Armenia and others), and to highly developed countries in Europe (Radovanovic, 2022). In general, in these countries, since the collapse of the Union of Soviet Socialist Republics, the level of CO₂ emissions has decreased, and Russia has opened access to obtaining special economic and political privileges from drawing up this protocol.

A feature of the development of the Asian region in recent years has been rapid economic growth. It has led to significant growth rates in the industrial sectors of these countries, and hence to an increase in CO₂ emissions into the atmosphere. Moreover, in most countries the situation is only getting worse, as demonstrated in the data in Figure 1. Continued expansion of industrial production in Asian countries, especially China and India, is likely to lead to subsequent serious threats to the health of the local population and the environment, since the national policies of these countries pay little attention to environmental issues, and much more to economic or geopolitical influence (Usman & Hammar, 2021; Ahmed *et al.*, 2022). This approach does not correspond to modern principles of sustainable economic development. The following data are noteworthy in terms of the impact on economic development (Fig. 2).

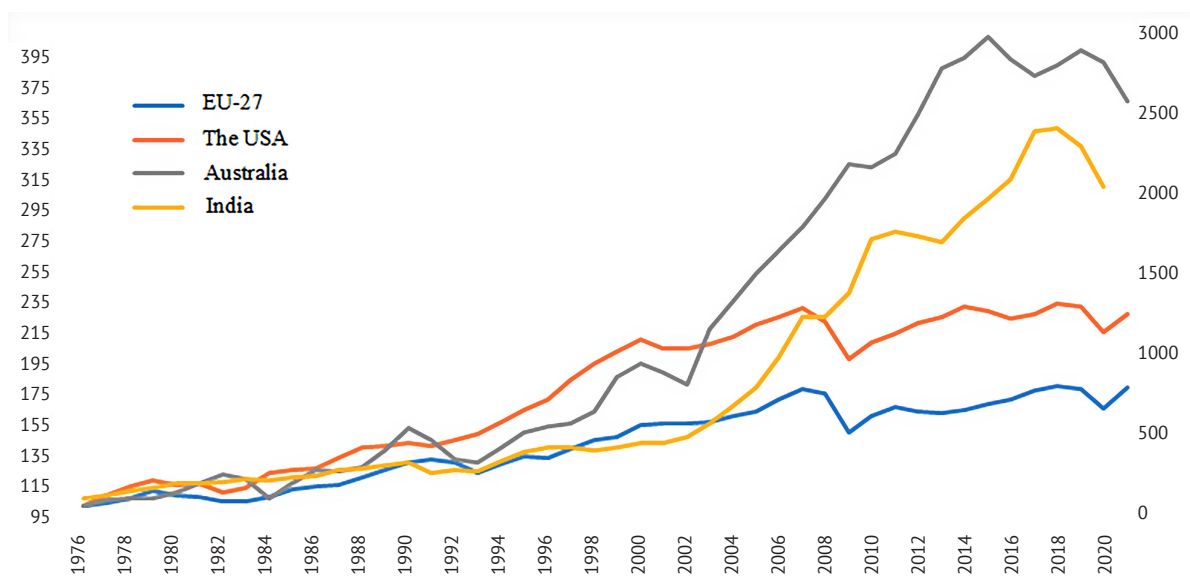


Figure 2. Dynamics of changes in the development of the industrial sector in the USA, EU-27, India and Australia in 1976-2020, indicators for 1976 are taken as 100

Source: compiled by the authors based on Organisation for Economic Co-operation and Development (2022)

Figure 2 presents the growth rates of industrial sectors in the US, EU-27, India and Australia over a period of time (left scale for US, EU-27 and Australia, right scale for India). According to the authors, data on the

dynamics of the development of industrial sectors in these countries will be able to describe quite well how the Kyoto Protocol has affected the development of economies in the regions. In the context of this study,

several time periods are important, namely: 1976-1997 and 1997-2019, 1976-2005 and 2005-2019. Data on

changes in the development of the industrial sector in these years are demonstrated in Table 1.

Table 1. Growth values of the industrial sector in certain hourly intervals, %

Period*	I	II	III	IV
Years**	1976-1997	1997-2019	1976-2005	2005-2019
EU-27	1.5378	1.0540	1.6828	0.6318
The USA	2.9033	0.9836	2.7321	0.3883
Australia	2.0964	4.0181	3.2418	3.3106
India	6.9639	7.7516	7.3600	7.9532

Notes: * – to simplify the perception of information, the gaps were numbered with Latin numerals from 1 to 4 (from I to IV); ** – the reason for using data only up to 2019 is that using data for 2020 would distort the data, since 2020 was a year of significant economic development in all countries and in all sectors, and would not reflect the impact of the Kyoto Protocol on the development of the industrial sector these countries

Source: compiled by the authors based on Organisation for Economic Co-operation and Development (2022); Macrotrends (2022)

It can be compared the values of the columns for these regions by years. From Table 1, an interesting trend can be seen: the values for the EU and the USA in the interval I are higher than in the interval II, and in the interval III are higher than in the IV. The reason for this is that these countries were among the first to implement a policy to reduce CO₂ emissions. When analysing Figure 1, it was noted that it was in the countries of Europe and the USA that a decrease in emissions of gases into the atmosphere was noticed. As evident, this affects the level of development of the industrial sector, and hence the economic well-being.

In Australia and India, growth rates are higher for period II than I, and for period IV than period III. However, differences in trends in these two countries are still inherent. Thus, compare the values for II and IV periods: for India – IV>II, and for Australia – IV<II. It may indicate that the implementation of the Kyoto Protocol still had an adverse impact on the level of industrial development in Australia (although not as significantly as in the EU or the USA). It would be important to compare trends in China, however, unfortunately, there is not a large enough list of data on the development of the industrial sector in the public domain to even draw such conclusions. However, they are likely to coincide with the trends observed in India, since the two countries are quite similar in the areas of economic and environmental policies.

An interesting situation arose with the countries of North America. Thus, the United States signed the treaty, but did not ratify it. The reason why the United States did not become a party to the Kyoto Protocol is still not completely known: several explanations can be given for this, but they all have their flaws and shortcomings (Hovi *et al.*, 2010). In turn, Canada formally withdrew from the treaty in 2012. The official reason for the withdrawal is that the protocol is not in the

interests of Canada's future development: the country has not been able to sufficiently reduce its emissions into the atmosphere, as it would have to pay fines (Canada announced its..., 2011). And although both of these countries are not parties to the protocol, nevertheless, their CO₂ emission value is declining from year to year, which seems paradoxical. It is probably due to serious rules and restrictions within the country, and the attitude of society towards the protection of nature in terms of ecology. It indicates that there are other options for reducing greenhouse gas emissions into the atmosphere, which will be less radical than the Kyoto Protocol and will cause less harm to the atmosphere.

THE MAIN ENVIRONMENTAL BENEFITS AND ECONOMIC LOSSES FROM THE KYOTO PROTOCOL

At the initial stage, only developed countries were responsible for achieving the purposes set by the protocol. However, since 2015, 196 parties have accepted the Paris Agreement (2015), a new legally binding international treaty on climate change; it proposed a purpose of reducing greenhouse gases to limit global warming and proposed a new direction for combating climate change, which "brings all countries together in a common cause to perform large-scale efforts to combat climate change". The parties to these agreements faced many difficulties. In particular, many countries (mostly developing countries) have begun to worry about the likely adverse economic consequences that the Kyoto Protocol could bring. Scientists generally believe that the global economy, in general, achieves an adverse economic effect, but it is unevenly distributed (Kim, 2020). Thus, some states receive significantly more losses than others, while others generally achieve a positive economic result. It greatly affects the desire of countries to participate in the agreement. Therefore, the prevention of such consequences plays a crucial

role in ensuring the participation of individual countries in this programme and the preservation of the international environmental regime.

In practice, developing a protocol to a significant increase in offshore processes. However, if in a classic offshore the reason for the migration of a company is most often low tax rates, then in this case the reason was the quota for gas emissions available in the country. Thus, the continued operation of the treaty over time will increase the likelihood of outsourcing of polluting production processes in regions with weaker environmental regulations; in the long run, this may lead to a change in the structure of trade based on changes in comparative advantage (Najarzadeh *et al.*, 2021). To be more precise, this will result in the fact that production will flow to poorer countries with less developed industry, which will allow them to produce more value added in exchange for worsening their environmental situation. Thus, in reality, the Kyoto Protocol only partially reduces emissions of gases into the atmosphere. In addition, this will lead to a decrease in the production of goods by highly developed states and an increase by less developed ones, which will greatly affect the processes of international trade in products of the industrial sector, since it partially offsets the advantages that industrial countries have in terms of the production of these products. It is likely that the Kyoto Protocol could be an effective method of combating pollution only in the face of restrictions on capital flows and trade, but it is impossible to achieve such a situation at the current level of economic and social development.

Admittedly, some enterprises go the other way: they try to reduce their emissions into the atmosphere through technological innovations (or, as they are called, green technologies). Indeed, if all companies in the Kyoto Protocol countries acted in this way, in the long run, countries would receive both economic benefits from the introduction of new technologies and environmental benefits due to reduced pollution levels (Lanoie *et al.*, 2011; Zhang, 2021). Support for the implementation of the protocol is strongly influenced by the concern of the local population: for example, studies have demonstrated that countries in which citizens expressed a higher level of concern demonstrated a better result in achieving the purposes of the protocol (Doyaili-Wangle, 2021). In some places, this has even led to strikes among workers: for example, in 2019, as part of the Fridays for Future movement, during the week of the climate strike, more than six million people at 6000 events in 185 countries occur against pollution (Taylor *et al.*, 2019; Fisher & Nasrin, 2021).

In fact, the question of the effectiveness of the Kyoto Protocol is more complex than it seems at first glance. The main dangers that arise from global warming have already been considered above. The Kyoto Protocol was considered one of the highest quality treaties for protecting the external environment and one of

the methods for a possible solution to these problems, since it was supposed to globally reduce greenhouse gas emissions into the atmosphere and the rate of global warming (or prevent it in principle). Based on the principle of "common but different responsibilities with corresponding capabilities", the Kyoto Protocol proposes a structure based on differentiated responsibilities for countries depending on their contribution to emissions, their history of development and economic situation (Grubb, 2004).

The problem is that at the time the protocol was written, scientists knew too little about subsequent global warming. It was assumed that the accumulation of gases and global climate change would occur gradually and at more or less equal rates throughout the entire territory of the earth's surface. However, studies conducted over the past decades present that this is far from being the case: the problem is more complex; thus, in different parts of the Earth, the climate can change in different ways. Therefore, according to the authors, this thesis about common but different responsibility is not fully justified. The reduction of gas emissions should occur evenly throughout the planet: too high levels of emissions, for example, in China and India, will cause great harm to the external environment in these countries. In addition, it is important to recall the studies cited above, which demonstrate that reducing the amount of greenhouse gases released into the atmosphere is useless in stopping or halting global warming. In other words, reducing levels of CO₂ emissions may not improve the situation with the level of pollution of the Earth's atmosphere. Therefore, there are significant doubts about how justified the protocol was and whether it is worth adhering to its principles.

Returning to the data obtained from Figure 1. Indeed, the planet, in general, is seeing a decrease in the growth rate of greenhouse gas emissions into the atmosphere. Such results may indicate the effectiveness of the Kyoto Protocol. However, this is most likely due to some other theme events. For example, with the fact that most countries have already passed the stage of industrialisation and reduce their pollution due to natural causes. In addition, it is evidenced by changes in pollution rates from some countries. It is how developed countries (mainly EU member states, and North American countries) generally reduce the amount of CO₂ emissions into the atmosphere, one of the reasons for which (although not the only one, as the effectiveness of introducing laws to protect nature, depends on the opinion of the broad masses about the importance of its protection) is the transition to post-industrial methods of building an economy. Therewith, developing countries, and especially China and India, have the highest growth rates of emissions due to ongoing industrialisation. Table 2 presents data on the growth rates of greenhouse gas emissions from some developing countries.

Table 2. Rates of environmental pollution by some developing countries in the periods from 1960 to 2020, %

Years	1960-1967	1968-1975	1976-1983	1984-1991	1992-1999	2000-2007	2007-2014	2015-2020
China	-7.57	13.24	4.72	4.56	2.96	10.64	3.97	1.61
India	5.28	4.33	5.34	7.40	5.46	4.79	6.47	1.48
Egypt	2.95	4.47	7.45	3.27	6.53	4.10	1.70	-0.53
Brazilia	5.04	10.00	0.98	3.79	4.93	1.99	3.62	-2.46
Mexico	5.22	8.31	6.07	2.12	2.31	2.78	-0.32	-5.83

Source: compiled by the authors based on *Our World in Data* (2022)

As presented in Table 2, although the emission rates of developing countries are positive (that is, physically increasing), they have generally been declining over the past 20 years. Although it is difficult to say for sure whether such a result is a consequence of the operation of the Kyoto Protocol, this at least indirectly indicates its effectiveness.

Thus, it is still difficult to say with certainty what the environmental impact of the Kyoto Protocol is, although it is more likely to have a positive impact on reducing greenhouse gas emissions. However, it is important to discuss the economic impact of this protocol. To do this, return to the data obtained in Table 1. They indicate that developed countries received an adverse effect from the implementation of the protocol, which led to a decrease in the growth rate of the industrial sector in the EU, the USA and Australia. However, interestingly, the Kyoto Protocol did not have visible adverse effects on the economic development of India, but on the contrary, it most likely became a positive factor for the development of industry. The reason for this is the tendency of companies described above to move their construction facilities to India to conduct their business. Notably, although, according to the authors, the reason for this trend is the fact of conclusion of the Kyoto Protocol, this is not necessarily the case, since a huge number of factors can influence the growth rate of the industrial complex in the country. It is indirectly confirmed by the rates of CO₂ emissions in the respective surveyed countries: a slowdown in the development of the industrial sector usually occurs together with a decrease in the level of greenhouse gas emissions into the atmosphere. In addition, the Kyoto Protocol did probably reduce the rate of industrial growth in India, but not as much as to result in a decrease. Or, based on the experience of highly developed countries, it can be assumed that the adverse effect of the Kyoto Protocol in India can still be observed over a wider distance.

The data obtained in the work are confirmed in the works of other scientists. Thus, the results of the analysis of GDP (gross domestic product) levels and CO₂ emissions in countries that are parties to the Kyoto Protocol demonstrated that their level of environmental pollution did decrease, and the GDP decreased (Kim & Tanaka, 2014). Thus, it can be agreed

that the protocol leads to both positive and adverse consequences. However, there is no consensus among scientists about which effects prevail: economic or environmental (Rhodes, 2016). Perhaps when more time passes and scientists have more data on the effects established by the protocol, it will be possible to say for sure, but not now. The protocol right now needs a lot of improvements that could level its problems (which were announced in the work). Decisions to continue the protocol or cancel it must be applied now, which is a serious problem. Therefore, this subject requires additional consideration using more accurate methods of forecasting and calculating.

CONCLUSIONS

The work examined current trends in the levels of environmental pollution by individual countries. The overall situation has been demonstrated to worsen over time, except for some regions, namely Europe and North America. In turn, in most developing countries (primarily China and India), emission levels are only increasing. There is still some disagreement among scientists about the causes of global warming, their consequences and in determining the actions that can be effective in overcoming the problem, which complicates the process of analysis.

The study has presented that the Kyoto Protocol does reduce CO₂ emissions in some regions and likely reduces the rate of growth in others. The authors presented that the Kyoto Protocol as such has a huge number of adverse aspects that are not obvious enough at first glance. Among them, notably, the general decline in the development of industry in most countries participating in the agreement, the increase in the geopolitical influence of some countries (the Kyoto Treaty even strongly affects political processes), changes in the competitive advantages of individual countries, changes in trade chains, migration of production capacities etc. The latter points are not purely adverse, as they bring benefits to individual (mainly developing) countries, however, since the relocation of enterprises to other territories is a laborious process, it still only leads to losses on a global scale.

Thus, it is impossible at this stage to say with certainty how effective this agreement is, if it is necessary in principle. The authors are inclined to believe that,

in the long term, this protocol will bring too large adverse political and economic consequences, which will be much lower compared to the benefits for the environment. It does not mean a denial of environmental problems and does not cancel their relevance, but only speaks of the demand for society to improve the terms of the contract or draw up a new one, with other principles of environmental protection. In future studies, it

is advisable to apply a comparative aspect and consider other environmental agreements for their perspective.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Економічний ефект від заходів, передбачених Кіотським протоколом, за регіонами (станом на 2020-ті роки)

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Анотація. Кіотський протокол став перспективною складовою для вирішення однієї з найбільш актуальних та обговорюваних науковцями проблем – забруднення атмосферного повітря. Тому залишається важливим розглянути, чого ж насправді вдалося досягти за 17 років дії договору, які ефекти (екологічні чи економічні) переважають в результаті його дії. У цьому дослідженні особливий акцент зроблено на впливі Кіотського протоколу на окремі регіони, такі як Європа, Азія, Америка та інші. Таким чином, мета роботи – продемонструвати, як ця угода вплинула на розвиток країн певних регіонів, до яких наслідків вона призвела і наскільки ефективною виявилася. У роботі були використані наступні методи дослідження: статистичний, графічний, історичний, моделювання та прогнозування. Під час написання роботи було продемонстровано, які переваги та недоліки має Кіотський протокол як документ щодо захисту зовнішнього середовища. Крім того, автори описали основні екологічні вигоди та економічні втрати від цієї угоди. Дослідження показало, що Кіотський протокол дійсно зменшує викиди CO₂ в деяких регіонах і, ймовірно, знижує темпи зростання в інших. Однак в країнах-учасницях угоди спостерігається загальний спад промислового розвитку. Автори роблять висновок, що наразі неможливо з упевненістю сказати, наскільки ефективною буде ця угода, але її негативні політичні та економічні наслідки будуть набагато меншими, ніж екологічні вигоди. Крім того, були розглянуті регіональні особливості впливу Кіотського протоколу на розвиток окремих країн. Робота дозволяє по-новому поглянути на ефективність Кіотського протоколу і дає нові відповіді на питання про корисність цього документа та раціональність виконання його умов

Ключові слова: сталий розвиток; регіональний розвиток; міжнародні відносини; зовнішнє середовище; забруднення повітря

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