https://doi.org/10.15407/animbiol26.04.003
UDC 636.082
Received 10.09.2024 ▪ Revision 21.11.2024 ▪ Accepted 20.01.2025 ▪ Published online 22.01.2025

Review

Impact of climate change on cattle and ways of its mitigation

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Authors' Contributions:
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Declaration of Conflict of Interests:
None to declare.

Ethical approval:
Not applicable.

Acknowledgements:
None.

The results of scientific research on climate change occurring on our planet at the present stage are presented in the review. The impact of heat stress on the well-being and productivity of large cattle is considered. Adaptation, as a process of adjustment in natural systems to global climate change, is presented. Among the major risks negatively affecting and continuing to impact the economic development of the livestock industry is climate change on our planet. In Ukraine, the problem of heat stress becomes urgent in the summer. Heat stress has a negative effect on the welfare, health, and productivity of animals. The responses to heat stress include decreased fodder consumption, searching for a shadow, greater sweat production and shortness of breath, higher consumption of water and frequency of drinking, longer standing time and shorter lying time. Heat stress has a direct effect on performance through the decrease in fodder consumption and milk synthesis. Heat stress causes a decrease in the reproductive function of animals. The consequences of the on the reproductive function of cattle depended on the magnitude and duration of its effect, the breed, and physical activity of animals. Many strategies for adapting to climate changes in livestock industry consider the short-term impact on animals during intense heat. However, in modern conditions of climate change, one should be governed by strategies leading to the long-term solution to the problem. One of these is the genetic adaptation of animals, involving the resistance to heat stress as a functional trait in the programs of animal breeding. Genetic diversity of animals will be important in further breeding work with cattle.

Key words: climate change, large cattle, heat stress, animal health, milk productivity, adaptation

Introduction

Climate change is one of the threats facing humanity. It will have impact on the environment and economy. The average air temperature is the main index of climate change. In 1880–2020, the average ambient temperature over land and ocean increased by 1°C as compared to 1951–1980 [29]. In some parts of the world, warming has already exceeded 1.5°C as compared to the pre-industrial level. In many Arctic regions, the average temperature has already increased by more than 3°C [74]. According to the simulated climate changes, the average temperature on the planet may be 2.6–4.8°C higher by 2100 as compared to the conditions in 2010 [11]. It is expected that when the planet becomes warmer, the changeability of the climate and weather will be greater. The changes in the incidence and gravity of extreme climatic phenomena and in the changeability of weather conditions will have considerable consequences for humans and natural systems. There is a forecast of higher incidence of heat stress, drought, and floods by the end of this century.

Climate change on the current stage, is one of the relevant risks, defining the global development of humanity. This process affects all the regions of the world and all the strata of the population. Even for rather moderate climatic zones, like Central Europe, the expected climatic conditions, especially in summer months, are deemed to include a higher incidence of heat and drought periods [28]. Based on the analysis of 20-year-long weather observations in July in Ukraine, namely in the western Forest-Steppe, O. Zhukorsky [81] not replaced specified the tendency of a temperature increase by 1.3°C and a higher number of tropic days. The author highlighted that the bioclimatic conditions for large full-grown cattle were characterized as comfortable, but there were more days not elaboratedwith the average rate of thermal stress. S. P. Ivaniuta et al. [35] note that in recent years, the frequency of days with a maximum temperature in summer above 35 and 40°C has almost doubled.

One of the envisaged consequences of climate change is the higher incidence and intensity of heat waves which are defined as several, usually from three to five, consecutive days when the maximal environmental conditions exceed some threshold [54, 44].

The geographic regions and economic branches are notable for different degrees of their susceptibility to climate change. In general, agriculture, forestry, aquaculture, and energy sectors may be the most susceptible to the manifestation of climatic changes, as they are anthropogenic and natural ecosystems [35]. T. F. Stocker et al. [70] noted that the changes in the climatic system create serious threats and challenges for the stable development of society, caused by higher risks for human health and activity, natural ecosystems, and economic sectors, and thus require detailed research and elaboration of the adaptation measures.

The impact of heat stress on livestock

The environment plays a relevant role in maintaining the health, well-being, and performance of animals. The organism of an animal is impossible to imagine outside of the bounds of the environment and the interaction therewith. Every species of animal has its limits of comfortable ambient temperature. These limits are called a thermoneutral zone. The increase or decrease in the ambient temperature outside the bounds of the thermoneutral zone has a negative impact on the well-being and performance of animals [66]. Beyond the upper critical limit of the ambient temperature of the thermoneutral zone, the animal starts feeling heat stress. Heat stress is defined as a state when an animal cannot dissipate a sufficient volume of heat, regardless of its being produced or consumed by the organism, and to maintain heat balance of the body. It may cause physiological and behavioral reactions, which will lead to physiological disorders, resulting in a negative impact on the health, well-being, and performance of farm animals [52].

The ambient temperature, comfortable for large cattle, depends on the species-specific traits of animals. According to M. Fiedler et al. [20], the ambient temperature, comfortable for large cattle, is within 0…+15°C, and as per the FAO [50], in middle latitudes, these thresholds fluctuate from +4 to +24°C, in tropic latitudes — from +15 to +27°C.

Heat stress is more problematic and has a greater effect than cold stress [45]. Climate change elevates heat stress and decreases cold stress. Thus, heat stress dominates thermal stress [10].

The impact of hot weather on large cattle becomes ever more relevant due to climate change. The problem of the impact of climate change on livestock industry is as follows: how much do the animals depend on the thermal environment, and how can one mitigate the effect of higher ambient temperature on them? The current impact of the thermal environment is evaluated by the effect of climatic conditions on the health, well-being, and performance of animals [53].

To decrease climatic risks for livestock industry, one should understand in which way potential ecological stressors can affect the functioning of the animal organism and the implementation of its genetic potential [67].

The impact of heat stress on the well-being and health of animals

The impact of climate change on the health of animals may be direct or indirect. Direct consequences are mainly conditioned by the changes in the environmental conditions, including air temperature, relative humidity, precipitation, drought, and floods. These environmental conditions cause diseases and death of animals related to air temperature. The indirect impact of climate change on health is conditioned by the microbial density and distribution of transmissive diseases, food and water shortage, or food-borne diseases [40].

Among different means that help maintain homeostasis, physiological adaptivity is considered to be one of the mechanisms of the primary response that helps animals survive. Respiratory and heart rates, rectal temperature, sweat production degree, and skin temperature are the physiological parameters that help maintain the heat balance and homeostasis under hyperthermia [1]. The first reaction of the animals to hot weather is an increase in the respiratory rate, rectal temperature, and heart rate, which has a direct impact on fodder consumption, decreases the rates of growth, the milk yield, and reproductive traits, and in extreme cases even leads to death. The imbalance between the metabolic heat production of the animals and its dissipation into the environment causes heat stress [16].

Usually, the observed responses to heat stress include decreased fodder consumption, searching for a shadow, greater sweat production and shortness of breath, higher consumption of water and frequency of drinking, longer standing time and shorter lying time, as well as lower frequency of defecation and urination [10].

The decreased fodder consumption is one of the reactions to high ambient temperature. Under higher heat stress, the ruminants lose appetite, have slower intestinal motility, and decreased rumination [80].

Neuroendocrine regulation is one of the decisive ways for animals to survive in a stressed state [2]. The hypothalamo-pituitary-adrenal system plays a relevant part in the thermoregulatory mechanisms of animals. The corticotrophic releasing factor, adrenocorticotrophic hormone, and glucocorticoids are primary products of the hypothalamo-pituitary-adrenal axis, which, in the long run, control the pathway of a response of animals to stress, regulating the energy distribution to maintain life activity in the process of hepatic gluconeogenesis [51]. During the heat tension period, there is an increase in the level of adrenalin and noradrenalin, which regulate the cardiovascular frequency during thermal stress and maintain blood supply to the organs [2].

Having conducted the study using the bulls of Angus and Volyn meat breeds, O. Zhukorsky [82] stated that a high heat burden for ten days led to heat stress. He observed a high rate of correlation between rectal temperature and air temperature, rectal temperature and prolactin, air temperature and prolactin. At the same time, the author noted breed-specific differences in the sensitivity to thermal stress, indicating that Angus bulls were more sensitive to heat stress than Volyn meat breed. The studies of A. Afsal et al. [2] with dairy cattle involving heat stress found a decrease in the prolactin concentration and an increase in the level of somatotropic hormone, which had a negative effect on the performance.

The immune system of animals is the main defense of their organism, which protects them from environmental stress factors and other harmful effects [75]. Heat stress may have a negative impact on immune functions via the cellular and humoral immune response [4]. As a result, after the period of hot weather, the cattle may be more susceptible to diseases, for instance, there may be a more significant number of animals with mastitis, which will lead to economic losses [15]. N. Lacetera [40] stated that heat stress had a negative impact on the health of animals, causing metabolic disorders, oxidative stress, and immunity inhibition, which made the animals more susceptible to diseases.

Heat stress causes a decrease in the reproductive function of animals. The consequences of the heat stress effect on the reproductive function of cattle depended on the magnitude and duration of its effect, the breed, and physical activity of animals. The impact of heat stress due to hormonal imbalance caused a decrease in the quality of oocytes and sperm along with slower development of embryos and their survival. It occurs due to the decreased secretion of luteinizing hormone and estradiol, which leads to a shorter length and intensity of estrus expression, higher frequency of manifestations of quiet sexual excitement in farm animals. Oocytes, susceptible to heat stress, lose their ability to fertilization and development in the blastocyst stage. Poor secretion of progesterone restricts the functions of the endometrium, and thus, the development of the embryo. On hot days, the temperature of the testes increases, so the fertility of breeding bulls decreases due to impaired spermatogenesis and sperm quality [38, 51].

J. W. Ross et al. [62], M. Cheng et al. [10] reported that heat stress affects the reproduction of both genders. In females, heat stress shortens the estral period and fertility, simultaneously increasing the frequency of embryo deaths. In males, there is a decrease in sperm quality, the volume of testes, and the amount of fertile sperm.

"The impact of heat stress on reproduction is complex and multifactorial and is compounded by growing challenges due to climate change. Both animal welfare and fertility are vulnerable parameters easily affected by heat stress. Heat stress leads to a marked decrease in the developmental competence of oocytes and the fertilizing capacity of spermatozoa, leading to a declining reproduction rate and losses for the cattle industry" [37].

M. M. Sharan, Yu. T. Salyha [68] note that advances in reproductive biotechnology are a powerful tool that can be used to improve production and address livestock challenges in the future.

The problem of heat stress is extremely urgent in the regions where the weather is characterized by high summer temperatures and humidity. This combination has a negative effect on the restorative ability of cows, the course of gestation, and the functional state of the newborn calves [83].

The impact of heat stress on the performance of animals

Heat stress has a direct effect on performance through the decrease in fodder consumption and milk synthesis [16]. The metabolic production of heat, caused by heat stress, increases, and thus, milk production decreases [36]. M. Rhoads et al. [60] noted that under heat stress, dairy cows eat less fodder, which leads to their decreasing dairy performance by approximately 35%. According to U. Bernabucci et al. [7], the decrease in milk production caused by heat stress may amount to about 14% at the beginning of lactation and 35% in the middle of lactation.

The increase in air temperature becomes an urgent problem in summer. For instance, in Ukraine, R. M. Dibirov [17], N. Boltyk [8] found that due to high temperatures in July and August (+28…+30°C) as compared to June (+18…+20°C), the dairy performance of cows decreased by 7.4–16.0% in the northern zone, by 6.2–12.9% — in the central zone, and by 5.5–12.6% in the southern zone. T. O. Vasylenko et al. [77] stated that in August, under the average air temperature of 23.4°C, as compared to that of 14.7°C in May, the milk yield of cows decreased by 5.5%, the yield of fats — by 7.3%, and the yield of protein — by 5.7%. In the Mediterranean region, due to higher than comfortable air temperature values in spring and summer, there is a reliable decrease in the daily milk yield of all cows regardless of their performance [23]. According to the data of R. V. Mylostyvyi et al. [51], V. Sejian et al. [66], in Switzerland, the Czech Republic, and Poland, in summer, dairy cows are under heat stress for 6–10 h a day, and in Spain, Italy, and south of France — from 13 to 18 h, thus losing 3.0–5.5 kg of milk. In Eastern Europe, the duration of the stress period is 30–60 days, which causes a drop in productivity of 10–35%.

Heat burden has a greater impact on highly productive cows [69, 79], which is reasonable because there is a positive correlation between higher milk yield, fodder consumption, and metabolic release of heat [36]. Similar conclusions were made by M. M. Rojas-Downing et al. [61], who found that highly productive dairy cows released more metabolic heat than cows of low productivity, and thus, they were more sensitive to heat stress.

During the dry season, heat stress affects the proliferation and development of the dairy glands which then leads to smaller milk yield. In dairy cattle, this situation leads to a considerable drop in milk production, especially in highly productive cows. The decrease in milk production due to heat stress may amount to almost 10–15% at the farms, using the cooling methods, and reach 40–50%, if no cooling is used [73].

M. A. North et al. [55], studying various predictive models of heat stress, indicate that they all lead to reduced milk production.

In addition to milk yield, a hot and humid environment also affects the milk composition. O. Ravagnolo et al. [59], T. Gorniak et al. [31] stated that heat stress on lactating cows led to a lower content of milk fat and protein. A negative correlation between the heat burden and milk fat and protein composition was reported by R. Bouraoui et al. [9], U. Bernabucci et al. [6], J. B. Garner et al. [22], J. M. L. Heck et al. [32], D. L. Hill et al. [33], C. Lambertz et al. [41], G. E. Pollott [56], M. A. Quist et al. [58]. Heat stress also changes the lipid profile of milk [43]. However, rather contradictory results were published regarding the impact of heat stress on the fat content in milk. For instance, F. C. Cowley et al. [14] did not find any changes in the portion of milk fat under heat stress but specified the tendency toward the decrease in the content of both protein and casein. According to the data of H. M. A. Gaafar et al. [21], the fat content in cows' milk under heat stress decreased by 3.79–3.49%.

Heat stress has a negative effect on the quality of products of animal production. A. Summer et al. [72] noted that a negative impact of heat stress on the milk composition (organic and inorganic components) led to its suitability for cheese production and product quality. These changes lead to considerable negative economic consequences for producers and consumers.

Due to lower metabolism rate and heat production, large meat cattle are usually considered to be less susceptible to heat stress than dairy cattle. However, it also compensates for the increased body temperature using homeostatic mechanisms (shortness of breath, sweat production, and drooling) and behavioral changes, including a decrease in activity, greater consumption of water, and a decrease in fodder consumption. It leads to a slower rate of animal growth [72].

Heat stress has a negative effect on meat productivity. With a higher external heat burden, large cattle re-distribute the energy, usually designated for growth and maintaining homeostasis [36, 59], which leads to a decrease in the live bodyweight gain. There is a considerable variability in the average daily live bodyweight gain and fodder conversion in different studies, conducted in feedlots [24–26, 42, 71]. However, they reflect the general decrease in the growth rate of animals under the impact of heat burden. P. A. Gonzalez-Rivas et al. [30] reported that heat stress affected meat production for all the main commercial types of cattle. N. A. Elam et al. [19], A. Summer et al. [72] stated that ruminants, subjected to heat stress, were notable for poorer meat quality.

Generally, heat stress led to a decrease in milk and meat production in all types of cattle.

Whatever affects the production of fodder may also impact the feeding of animals, and thus, their performance. Therefore, a decrease in the harvest of fodder crops will lead to poorer availability of fodder and an increase in the cost of products. In cold zones, an increase in the average temperature may cause the prolongation of a vegetation period for fodder with a decrease in their quality [49].

It should be noted that many recent publications of the studies also demonstrated that the consequences of climate change differ depending on the region, duration, and distribution of heat stress. In addition, the effect on specific breeds and individual animals will vary greatly. Thus, one should define key factors for each geographic territory, which present specific interests, breed (genotype), and industrial system [28].

According to all the evaluated scenarios, it is forecasted that in this century, heat stress will become a serious problem for large livestock industry systems, resulting in a decrease in milk and meat production. Therefore, it is important to pay special attention to the potential magnitude and degree of adaptation measures that will be required in different places to counteract the consequences of ever-increasing heat stress for large cattle [76].

The data from the studies, conducted by different scientists, demonstrate a considerable decrease in the performance of animals, which leads to enormous economic losses during heat stress. It is evident that climate change will affect the performance of cattle in many regions, and many simulations define this effect to be harmful. The impact of climate change on the livestock industry will be a consequence of combined changes in ambient temperature, precipitation, incidence, and magnitude of extreme weather phenomena. It will include both direct and indirect effects. Climate change enhances a general need for strategies for adapting to and mitigating consequences, which would cover available instruments of management, feeding, breeding, and health protection of animals. The envisaged changes will create the pressure of selecting with the consideration of the traits, relevant to biological suitability and production of specific products. The classified information, obtained regarding the evaluation of the impact of climate change on the performance and well-being of animals, may become very valuable for the elaboration of the relevant strategies of adapting to and mitigating the consequences to support the manufacture of animal products in the scenario of climate change.

The adaptation of livestock industry to climate change

Adaptation to global climate change is a process of adjustment in natural or human systems in response to actual or expected climatic effects which would help decrease their negative consequences and utilize favorable possibilities. All animals can adapt to the thermal environment. The animals change their behavioral, physiological, and morphological characteristics or their combination in response to the thermal environment and thus adapt thereto [3, 27]. Therefore, animals can develop the mechanisms of survival that minimize the impact of thermal burden on the organism in general. The overcoming mechanisms, developed by animals in response to heat stress, are referred to as adaptation and adjustment.

The acclimation and adaptation ensure the resilience level of large cattle populations. Acclimation is a homeostatic process, governed by the endocrine system, which leads to cellular, metabolic, and systematic changes that allow animals to react to and cope with heat stresses [3]. Animals adjust to the environment they live in and to the external stress by acclimation to a specific stressor or several stressors [13, 27]. The adaptation is related to biological changes in subsequent generations via the support for genetic selection in the population through a permanent impact of the stressor, maintaining the survival of species [64].

Adaptation may be decisive for survival, but it often has a negative impact on the performance and profitability of the animal breeding systems. The ability to adapt in part depends on the plasticity of behavioral traits and in part — on morphological and physiological changes, which adjust animals to survival in a better way [48]. The adaptation is a coordinated phenotypic reaction to stressors, and the response will get weaker if the stressors are removed. If chronic stress lasts for several generations, the adaptation reaction will become genetically "fixed", and the animal will adjust to the environment [13]. The knowledge about genetic differences between adapted animals will promote breeding work under global climate changes.

The potential strategy of mitigating consequences should lie in breeding animals, resistant to climate change. Resilience is defined as the ability of the animal to get quickly restored after the disturbance effect or the ability to suffer the minimal effect of disturbance [12]. In the context of climate change, resilience will reflect the stable performance of animals regardless of a weather change.

The adjustment of an animal may be defined as an ability to survive and reproduce in a specific environment [57] or a degree to which an organism, population, or species may remain adjusted to a wide scope of environments using physiological or genetic means [5].

Flexibility is usually considered to be an evolutionary adjustment to environmental changes. Flexibility is a key mechanism, using which organisms can cope with climate change, since it allows them to react to changes throughout their lives. Flexibility is of great importance to large cattle since there is a large interval between generations, and evolutionary reactions via natural selection may not lead to rapid changes to mitigate the consequences of climate change. The species, which evolve in warm and stable tropic climate, have lower flexibility as compared to those in variable moderate environments since it is believed that the magnitude of the temperature variation is directly proportional to the flexibility ability. This is a great possibility to breed the populations of cattle, bred in European regions with various climatic conditions and variable temperatures. The methods of selection and experimental evolution demonstrated that flexibility is a trait that may develop during direct selection or as a correlated response to choosing specific traits. Therefore, it is reasonable to use the flexibility, accumulated in the breeds of large cattle, in the new selection goals [63].

The producers may adapt to climate change, adjusting the genetics of their animals to the changed environment or adapting the production environment, while preserving the genetic profile of animals. It is expected that farmers will first use the adaptation technologies, which can be quickly implemented and change the genetic profile of animals only when this process becomes inevitable [34]. J. M. Rust [65] stated that climate change affected both extensive and intensive systems of animal production.

The systems of intensive animal production have more possibilities to adapt via technological changes, and the latter can make them rather insusceptible to climate change and preserve highly productive breeds. To fight the consequences of short-time heat waves, one can use various technologies, including air-conditioning, shadowing, or raining, to decrease excessive heat burden [46]. Access to these technologies and capital will define the ability of producers to protect their herds from the physiological stress of climate change. Large-scale implementation of these technologies will also depend on the availability and prices of energy and water. A question arises: how long can one support the industrial environment under these conditions [34]? Although the direct impact of climate change on animals may be insignificant, if the increase in temperature does not exceed 3°C [18], the forecasts demonstrate the need for further selection of breeds with efficient control of thermoregulation. It requires the inclusion of traits, related to thermal tolerance, into the selection indices, and a greater consideration of the interaction between a genotype and environment to identify animals, most adapted to specific conditions.

I. Hoffmann [34] stated that the adaptation to the climate change can be considered in two ways:

1. How can the genetic resources of animals cope with climate change and adapt to it, still ensuring food safety and earning in rural areas?

2. How can one preserve the value of genetic resources and minimize a potential loss of diversity in case of climate change?

Genetic diversity of animals within the breed is important for further improvement of cattle [39].

Genetic diversity of animals is decisive for food safety and the development of rural areas. It allows selecting the number of livestock or creating new breeds in response to the change in conditions, including climate change, new or renewed threats of diseases, new knowledge about human needs for food, and a change in market conditions or needs of the society. All these are considerably unforeseen. The factor that can be predicted is an increase in human need for food in the future. The most acute consequences will be in developing countries, where it is expected that demand will grow faster than production, and in the areas where climate change is forecast to have the greatest impact [34]. The importance of preserving the gene pool of local breeds is emphasized by M. M. McIntosh et al. [47], A. K. Wankar et al. [78].

A current tendency of climate change poses a threat to health, well-being, and performance of large cattle in the entire world. Heat stress makes animals more susceptible to diseases and is one of the reasons for performance losses. A real challenge is the mitigation of this effect and adaptation of the systems of animal breeding to the variable climate. The adaptation to extreme climatic conditions and the mitigation of their harmful effect will play a relevant role in the fight against heat stress for cattle. Many strategies for adapting to climate changes in livestock industry consider the short-term impact on animals during intense heat. However, in modern conditions of climate change, one should be governed by strategies leading to the long-term solution to the problem. One of these is the genetic adaptation of animals, involving the resistance to heat stress as a functional trait in the programs of animal breeding.

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Вплив зміни клімату на організм великої рогатої худоби та способи його пом’якшення

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В огляді представлені результати наукових досліджень щодо зміни клімату, яка відбувається на нашій планеті на сучасному етапі. Розглянуто вплив теплового стресу на добробут здоров’я та продуктивність великої рогатої худоби. Представлено адаптацію як процес пристосування у природних системах до глобальної зміни клімату. До найбільших ризиків, які негативно впливають і надалі будуть впливати на економічний розвиток тваринницької галузі, належить зміна клімату, яка відбувається на нашій планеті. В Україні проблема теплового стресу актуальною стає у літній період. Тепловий стрес негативно впливає на добробут, здоров’я та продуктивність тварин. Реакції на тепловий стрес охоплюють зменшення споживання корму, пошук тіні, посилене потовиділення та задишку, збільшення споживання води та частоти пиття, збільшення часу стояння та зменшення часу лежання. Тепловий стрес безпосередньо впливає на продуктивність через зменшення споживання корму та, зрештою, синтезу молока. Тепловий стрес спричиняє зниження репродуктивної функції тварин. Наслідки впливу на репродуктивну функцію худоби залежали від величини й тривалості його дії, породи, а також фізичної активності тварин. Багато стратегій адаптації до кліматичних змін у скотарстві враховують короткочасний вплив на тварин під час інтенсивної спеки. Однак у сучасних умовах зміни клімату потрібно орієнтуватися на стратегії, які призводять до довгострокового вирішення проблеми. Однією із таких є генетична адаптація тварин, що передбачає залучення стійкості до теплового стресу як функціональної ознаки в програмах розведення тварин. Генетична різноманітність тварин матиме важливе значення у подальшій селекційній роботі з великою рогатою худобою.

Ключові слова: зміна клімату, велика рогата худоба, тепловий стрес, здоров’я тварин, молочна продуктивність, адаптація

Hladii MV, Kuziv MI, Kuziv NM. Impact of climate change on cattle and ways of its mitigation. *Biol. Tvarin*. 2024; 26 (4): 3–11.
DOI: 10.15407/animbiol26.04.003.