

THE IMPACT OF WEATHER CHANGE ON CATTLE MILK PRODUCTION AND MILK SALES LOGISTICS

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***Abstract:** Within the food industry, the biggest challenge for the dairy sector is that dairy cattle are highly sensitive to extreme weather conditions caused by climate change, as the physiological processes of cattle are closely linked to ambient temperature, humidity and feed quality. These changes affect the yield of forage crops, the thermal comfort of the animals, and the quality and transportability of milk. The impacts of climate change on milk production and milk logistics require long-term systemic adaptation. Overall, it can be stated that it affects the milk chain in a complex way, from production to consumption: it reduces production efficiency, increases energy demand, and poses new challenges to cooling and transport infrastructure.*

Key words: dairy cattle, milk production, weather, logistics, climate change

INTRODUCTION

The work seeks to answer the question of to what extent weather changes affect the production of dairy cows, and through this the quantity and quality of milk, as well as the costs and logistical activities of farmers and dairy processors. Dairy processing plants want to optimally utilize their production capacities, which primarily depends on the ability to plan in advance the quantity and quality of the purchased raw materials. The difficulty of the task is that these parameters are influenced by many variables that depend on both the cows and the environment.

The aim of the literature review was to find research results that could help in the preparation of a study investigating the possibility of estimating daily milk production based on weather forecasts.

MATERIALS AND METHODS

This article highlights the weather factors affecting milk production and the resulting problems in milk sales by producers and the logistical problems of milk purchasing by dairy processors. A narrative literature review was chosen as the method, where existing theories and results on the topic are collected. The material was selected using the Google Scholar search engine, where the search words were terms related to dairy cattle, milk production, weather event and logistics of milk. The work serves as a literature basis for a thesis.

RESEARCH RESULTS

Weather trends in the Southern Great Plain

The Southern Great Plain region is one of the hottest and driest areas of Hungary, where the effects of climate change are particularly felt. The region has a continental climate, with typically hot summers and relatively mild winters. However, significant changes have been observed in the last 10-15 years. Since the 2010s, heat waves lasting 10-15 days have become particularly frequent, and the proportion of days with extreme temperatures (above 35°C) has also increased significantly, these factors pose a serious burden on wildlife and agriculture. The annual average temperature has been rising by about 1.3-1.5°C in the last twenty years, at a faster rate than the national average since the 2010s [13]. The summer of 2022 was particularly hot, with national heat records broken

several times, with daily maximum temperatures often exceeding 38-40°C, making it the driest year in decades. The distribution of precipitation has become increasingly extreme across the country, with prolonged periods of drought being replaced by sudden, heavy downpours and flash floods. The region's annual precipitation has decreased by an average of 10-15%, while evaporation has increased, which is further drying out the soil. Rising temperatures and decreasing soil moisture pose serious challenges for agriculture, especially for the cultivation of forage crops.

Storms, accompanied by heavy rains, hail and strong winds, have become more frequent in recent years. In 2019, 2021 and 2025, several storms were recorded that caused significant damage to agriculture and infrastructure. The risk of hailstorms increased and the damage became more severe, especially in the summer period. It can be said that the climate of the Southern Great Plain has become warmer, drier and more unpredictable in the past twenty years, which requires the development of new adaptation strategies in both agriculture and infrastructure. What can be said for sure is that global climate change is one of the most defining processes of the 21st century, affecting all levels of food production and supply [8].

Challenges of dairy production

The biggest challenge for the dairy sector within the food industry is that dairy cattle are very sensitive to extreme weather conditions caused by climate change, as the physiological processes of cattle are closely linked to ambient temperature, humidity and feed quality. These changes affect the yield of forage crops, the thermal comfort of animals, and the quality and transportability of milk. Drought periods reduce the yield and quality of forage crops. Poorer quality feed leads to quality deterioration, and like heat stress, it also reduces the quality of raw milk, such as its fat and protein content. Heat stress is one of the most significant factors affecting milk production in cattle [17]. When temperatures exceed 25–27°C, cows' body temperature increases, feed intake decreases, and milk yield can drop by up to 10–25% [20]. The same effect occurs when the temperature-humidity index (THI) exceeds the comfort threshold (72<). Even the constantly developing technological innovations cannot offset the harmful consequences of heat [9]. Climate change has a negative impact on reproductive performance and milk production, and the expected effects of climate change on cattle include an increased susceptibility to microbial infections associated with heat stress [10]. Bacterial contamination is a critical determinant of milk quality and safety, with higher bacterial counts in summer and lower counts in winter, suggesting that climate change has a direct impact on milk contamination [19].

A related issue is that antibiotics used to treat increased mastitis may increase antimicrobial resistance in the long term, while heat stress itself weakens the animals' immune systems and increases the risk of infections [16].

It should be noted that while modelling studies predicting a decline in milk production due to heat stress caused by climate change are well established [11], models for predicting milk contamination due to climate change are still limited. Evidence-based strategies to support food system transformation are essential. A quantitative approach based on facts can help to understand the impacts of climate change on food hygiene and safety.

With the increase in the number of dairy animals and the intensity of production, heat stress has become one of the most important challenges in the dairy sector [14]. This is no coincidence, since when we talk about raw milk; we can say that it is one of the most sought-after commodities globally, with a constantly expanding and sustainable demand.

The impact of climate change on cattle milk production and its logistics

In the last two decades, the effects of climate change have become increasingly pronounced globally and in our narrower environment, in Hungary as well. They have a direct and indirect impact on society, and the pressure on health, economic and social areas is increasing in parallel. They directly influence the operation of agriculture and pose serious challenges to both the food industry and the processing industry. We are talking about areas that play a decisive role in the Hungarian economy. The effects change the possibilities of agricultural sectors, testing crop production, animal husbandry and forestry. They have a direct impact on crop production, as crop losses can be covered during drought periods. New climate-resistant plant varieties are appearing. The role of planned water management is also increasing, and the importance of irrigation is becoming more valued. In animal husbandry, the direct consequence is a decline in milk yield and meat production, and a decline in quality can also be a source of problem. In some cases, we can also experience a negative impact from the shortage of feed due to drought.

Climate change is not only transforming nature and the economy, but also has a significant impact on technical development. Greater emphasis is being placed on energy efficiency, sustainability, renewable energies, and environmentally friendly technologies.

Climate change is one of the greatest challenges of our time, affecting all areas of agriculture, including animal husbandry and especially cattle milk production. Climatic factors – such as temperature, precipitation, humidity, and extreme weather events – directly and indirectly affect the comfort, feeding, health, and quantity and quality of milk. The aim of my work is to demonstrate how climate change affects milk production and how raw milk logistics are changing to adapt to new environmental conditions. This work examines adaptation options and sustainable solutions based on international and Hungarian literature.

Dairy logistics, a field in constant flux

Dairy production and dairy logistics are one of the most complex agricultural systems of our time, and are significantly affected by climate change, both directly and indirectly. Over the past two decades, climate anomalies – including heat waves, droughts and intense rainfall – have fundamentally transformed the functioning of both dairy farms and milk processing and distribution chains [8]. As a perishable product, milk is extremely sensitive to temperature fluctuations, and climate challenges therefore directly affect the safety, energy requirements and cost-effectiveness of logistics processes [5].

Changes in climate factors – such as the frequency and intensity of summer temperature peaks – increase the risk of milk spoilage and increase the energy consumption of refrigeration systems [2]. The effects of heat stress are not only physiological but also economic: it causes billions of dollars in losses in the dairy cattle sector worldwide every year [18]. Heat stress, reduced rainfall and extreme weather events not only threaten production but also the logistics chain [7]. Dairy logistics is one of the most sensitive sectors of the food supply chain, in which the collection, transport, processing and distribution of raw milk requires extreme precision and technological background. Milk, as a fresh, perishable product, requires a refrigerated chain, strict hygiene conditions and well-organized, continuous transportation. However, due to climate change, all this poses increasing challenges to actors worldwide. Temperature increases, extreme weather events, energy price fluctuations and infrastructure damage all threaten the stability of the milk supply chain [6, 7].

Milk logistics includes the collection of milk from producers, its cooling, transport to processing plants and the distribution of finished products to retail outlets [21].

Maintaining the cold chain is essential at all stages of the process, as microbiological deterioration of milk can begin within a few hours at temperatures above 5°C. All elements of the process are regulated by strict food safety and hygiene regulations [5]. In the European Union, the cold chain regulation covering milk logistics systems is part of the so-called HACCP (Hazard Analysis and Critical Control Points) principle, which treats temperature monitoring as the most important control point. Logistic delays and interruptions pose not only economic but also quality assurance risks. Due to the disruption of the cold chain, the microbiological risk increases, this can even result in an export ban [6]. This is particularly relevant in the European Union, where dairy products are subject to strict food safety regulations.

Climate change increases this risk: due to warmer summers, frequent heat waves and unexpected power outages, stable operation of the cooling system is becoming increasingly difficult [2]. In a complex technological system, such as a modern cattle farm, the proportion of energy consumption and electricity within the total energy consumption depends on the technology of the dairy farm [1]. Electricity also plays a significant role in the power supply of control, automation, monitoring and information management systems. In the dairy industry, the failure of one part that depends on electricity can easily cause another to collapse.

Climate stress therefore directly affects not only production but also the logistics chain. The cold chain is a particularly energy-intensive section, and it is widely accepted that cooling, transport and storage are proportionally significant cost factors, although the exact percentages vary from region to region [7]. The dairy logistics system is therefore an integrated, energy-intensive and time-sensitive network. However, due to the warming climate, refrigeration systems are increasingly under strain, especially in the summer months.

Temperature-controlled warehouses maintain a given product temperature, while refrigerated transport is exposed to fluctuating ambient temperatures and varied weather conditions. These units are equipped with integrated components such as diesel engines, compressors, condensers and evaporators, which are necessary to maintain the refrigeration cycle during transport [6]. In general, it can be said that the global energy demand for dairy refrigeration systems could increase dramatically in the next two decades if there is no technological change in the field of refrigerants and insulation.

As the weather warms, technical failures occur more frequently, and a possible break in the cold chain can lead to a rapid deterioration in milk quality. Such technological failures can cause logistical disruptions and economic losses in the supply chain [18]. Technological developments have made agricultural production increasingly dependent on electricity. At the same time, energy supply infrastructures are increasingly challenged by extreme weather events.

The maintenance of electric refrigeration equipment and refrigerated trucks is a critical point, because the compressors of refrigeration equipment (e.g. tankers, refrigerated trucks, storage units) are subjected to a much higher thermal load as the ambient temperature rises, thereby increasing energy consumption and shortening their lifespan. A short power outage is enough to cause the temperature of the milk to rise to 6–8°C, which poses a microbiological risk, and if they do not have an adequate backup energy source, the milk will undergo deterioration in quality in a short time. Every 1–2°C increase in temperature accelerates the growth of bacteria (e.g. *Pseudomonas*, *Listeria*), thus shortening the shelf life of milk. In the event of a failure of cooling equipment, milk can become technologically unprocessable within 2–3 hours [6]. During heat waves, electrical systems can become unstable, increasing the load on the electrical network, which can

cause voltage fluctuations or even power outages [8]. The operation of milk collection points is also affected: a common problem. Another source of problem may be that the cooling tanks at collection points do not have adequate shielding or an energy recovery system.

The combination of lower milk yields and higher energy requirements during the summer period increases unit costs. These losses are treated as “hidden costs” by logistics companies, but they cause serious economic damage on an annual basis [18].

The urgent need to increase energy efficiency is indicated by a 2024 Italian study, which estimated that cold chains are responsible for 4-10% of the total GHG emissions of agri-food systems worldwide [7].

Climate change has a direct impact on transport infrastructure. During periods of drought, dust and pollutant loads on the road network increase, while extreme rainfall damages the road surface, increasing the risk of slipping and the uncertainty of transport times [3]. The predominance of road transport makes the dairy industry particularly vulnerable: in the European Union, the vast majority of raw milk is collected and transported to processing plants by road tankers, which is closely linked to the state of the transport network [4].

The role of digital technologies is crucial. Digitalisation and the use of IoT (Internet of Things) devices can help monitor the supply chain. Smart temperature sensors and GPS-based tracking systems provide real-time data on the cooling status and the status of transport. These devices not only improve food safety, but also optimise routes and reduce unnecessary energy consumption. Artificial intelligence and data-driven management can predict routes, optimize delivery times, and reduce energy consumption of refrigeration equipment [15].

According to a study, logistics digitalization can help reduce resource use and environmental impact in the food supply chain [12]. Modernizing refrigeration systems, using natural refrigerants, introducing CO₂-based systems, and using better insulation are also important steps. New technologies are not only more environmentally friendly, but also reduce operating costs and maintenance requirements [1].

Climate-adaptive infrastructure development – such as road network maintenance, flood protection systems and emergency energy reserves – is also part of dairy logistics adaptation. Several adaptation strategies have been developed to ensure the sustainability of the dairy logistics system. The most important goals include reducing cooling energy demand, increasing transport efficiency and mitigating greenhouse gas emissions. One of the most important development directions is the integration of renewable energy sources into the logistics chain, which can reduce fossil energy dependence.

The effects of climate change on milk production and dairy logistics require long-term systemic adaptation. Overall, it can be stated that it affects the dairy chain in a complex way, from production to consumption: it reduces production efficiency, increases energy demand and poses new challenges to the cooling and transport infrastructure.

In the future, the key to the sustainability of the dairy sector will be technological innovation, the introduction of energy-efficient and renewable solutions, and the development of digital data-driven logistics systems. Protection against heat stress, improving animal welfare and the use of low-emission cooling technologies will not only increase the stability of production, but also contribute to reducing the environmental footprint. Climate-adaptive infrastructure development, intelligent route optimization and the establishment of decentralized milk processing capacities can mitigate logistics risks. Support for sustainable milk supply chains should be given a prominent role in EU and

domestic agricultural policies, as mitigating the effects of climate change is no longer just an environmental issue, but also an economic and food security issue

CONCLUSIONS

Due to climate change over the past two decades, extreme weather events have increased in our region, affecting all areas of agriculture, including dairy farms. The adaptive capacity of cows is tested by heat waves, cold periods, and rapid changes in weather fronts.

Weather events significantly affect the circulatory system, feed intake and drinking water consumption of cows. All three factors have a direct impact on the quantity and quality of milk produced.

The summer heat in particular makes it difficult for the dairy industry to collect and transport raw materials in a refrigerated manner.

Dairy processors are looking for ways to predict milk production days in advance, which can help them plan their production management more easily. Other authors' results suggest that weather data alone are not sufficient to predict milk production.

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