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Sustainable livestock grazing in Kazakhstan practices, challenges, and environmental considerations

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ABSTRACT

Livestock grazing is an integral part of Kazakhstan's agricultural sector, contributing significantly to the nation's economy and rural communities. The study explores both traditional and modern grazing practices utilized in the country. It emphasizes the importance of understanding livestock physiology, nutrition, and environmental needs to implement effective grazing management strategies. Environmental and socioeconomic impacts of livestock grazing are discussed, with a focus on pasture degradation, soil erosion, water resource utilization, and biodiversity conservation. Additionally, the paper addresses the role of livestock grazing in sustaining traditional nomadic practices and its significance for rural livelihoods. This paper delves into the practices, challenges, and impacts of livestock grazing in Kazakhstan, with a specific focus on sustainable modern management approaches. Grazing management practices, including rotational grazing, rest periods, and grazing intensity control, are examined in-depth. These practices aim to optimize pasture usage, prevent overgrazing, and promote healthier vegetation growth while ensuring animal welfare. Moreover, it analyses the existing policy and regulatory framework surrounding livestock grazing in Kazakhstan and evaluates its effectiveness in promoting sustainable practices. The current study also introduces dynamic forage rotation (DFR) as a new tool and technique which has privilege compared to the traditional management approach and improves the modern management approach. The obtained results show that the DFR has been improved averagely 55.77% and 42.52% compared to the traditional and modern management approaches, respectively.

Keywords: Dynamic forage rotation, Kazakhstan, Livestock physiology, Modern management approach, Traditional management approach.
Article type: Review Article.

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INTRODUCTION

Kazakhstan's agriculture is as varied as its vast terrain. The country's expansive steppes and fertile valleys have fostered a diverse range of agricultural activities. Traditional nomadic herding coexists with modern crop cultivation, reflecting a harmonious blend of historical practices and contemporary techniques. By a strategic focus on sustainable practices and agricultural innovation, Kazakhstan's agricultural landscape embodies both the legacy of its past and the promise of its future (Myrzaliyev *et al.* 2023). Agriculture plays a pivotal role in Kazakhstan's economy and society. It provides livelihoods for a significant portion of the population, particularly in rural areas. The agricultural sector contributes to food security, serving as a primary source of nutrition for the nation. Additionally, agriculture serves as an essential driver of economic growth through exports of crops, livestock, and processed products. This sector's multifaceted significance underscores its vital role in ensuring both sustenance and prosperity for the people of Kazakhstan (Tleubayev *et al.* 2022). Livestock hold a central place within agriculture, contributing multifaceted value to societies worldwide, including Kazakhstan (Qin *et al.* 2022). Livestock provide a consistent source of protein-rich meat, dairy, and other products essential for human nutrition. Beyond sustenance, livestock contributes to rural economies by generating income and employment opportunities. Their role as draft animals in plowing and transportation further supports agricultural activities. Livestock also play a vital role in nutrient cycling through manure, enriching soils and enhancing crop productivity. In Kazakhstan, as in many regions, the integration of livestock into agricultural systems fosters a holistic and sustainable approach to farming (Yerassyl *et al.* 2022). The importance of physiology in livestock is unequivocal, serving as the foundational science that unravels the intricate tapestry of life processes within animals (Rashamol *et al.* 2020). Physiology not only provides insights into the physiological mechanisms that underpin the well-being of livestock but also acts as a guiding light for optimal management practices. Understanding the physiological responses to environmental changes, nutrition, stressors, and disease is pivotal in safeguarding the health and productivity of livestock. From regulating metabolic processes that drive growth and reproduction to deciphering the nuanced signals of distress or comfort, physiology empowers farmers and researchers with the knowledge needed to make informed decisions that enhance animal welfare, ensure sustainable production, and elevate the agricultural industry. The application of physiological principles in livestock management embodies a profound commitment to responsible stewardship, where science converges with compassion to nurture livestock and sustain the delicate equilibrium between animals and their environment (Neethirajan 2020). The importance of effective management practices in improving physiological conditions within livestock cannot be overstated. Management strategies play a pivotal role in creating an environment that optimally supports animal health and well-being. Through well-designed feeding regimes, controlled grazing patterns, stress reduction protocols, and proper housing conditions, management interventions directly influence the physiological responses of livestock. By minimizing stressors, providing balanced nutrition, and ensuring access to clean water and comfortable shelter, management practices help mitigate adverse physiological reactions and create conditions conducive to growth, reproduction, and overall vitality. Effective management not only enhances the physiological robustness of livestock, but also contributes to the overall sustainability of agricultural systems, forging a harmonious connection between responsible stewardship, improved animal physiology, and the well-being of both livestock and the environment (Anas *et al.* 2020). These management approaches are not mutually exclusive and can often be combined to create a holistic and effective grazing strategy. The choice of approach depends on factors such as the type of livestock, landscape, available resources, and specific goals for sustainability and productivity. It's important to consider that the application of these approaches might need to be tailored to specific regions within Kazakhstan due to variations in climate, soil types, and cultural practices. Customizing these management strategies to align with the unique characteristics of Kazakhstan's agricultural landscape is key to their successful implementation (Seidakhmetova *et al.* 2022). The traditional management approach to livestock in Kazakhstan, deeply rooted in its nomadic heritage, has historically revolved around free-range grazing and seasonal migrations (Blench 1999). While this approach has been adapted over generations to the vast and diverse landscapes of the country, it carries inherent limitations and challenges in the face of modern agricultural demands. The reliance on extensive grazing without rotational systems can lead to overgrazing, soil degradation, and the depletion of vegetation, impacting both animal nutrition and ecosystem health. Additionally, the unpredictability of weather patterns and climatic extremes further exacerbates these challenges, making it difficult to ensure consistent access to adequate forage and water sources. The traditional approach, while respecting cultural norms, needs to be adapted to integrate sustainable practices that mitigate overgrazing, enhance animal welfare, and safeguard the delicate ecological balance within Kazakhstan's diverse terrain (Weymes 2004). The modern management approach in Kazakhstan represents a strategic shift towards harmonizing traditional practices with contemporary agricultural insights (Derner *et al.* 2017). This approach acknowledges the need to address the limitations of the traditional system by integrating scientific knowledge and technological advancements. Modern management incorporates rotational grazing systems, where livestock are systematically moved between pastures, allowing vegetation to regenerate and preventing overgrazing (Franzluebbers 2007). It also emphasizes monitoring and data-driven decision-making, enabling farmers to tailor grazing patterns and livestock distribution based on real-time physiological and environmental data (Zhang *et al.* 2021). By embracing modern practices, Kazakhstan's livestock management seeks to enhance animal nutrition, minimize soil degradation, and increase overall agricultural productivity (Romagnoli *et al*. 2022). This approach bridges the gap between tradition and innovation, optimizing the benefits of both while aligning with sustainable principles to ensure a resilient and thriving agricultural future (Rodríguez-Espíndola *et al*. 2022). The modern management approach holds profound significance in shaping the physiological well-being of livestock. By integrating scientific understanding with cutting-edge technologies, this approach transcends traditional boundaries, offering a dynamic framework to optimize animal health, productivity, and sustainable agricultural practices (Matson *et al.* 2016). Through practices such as rotational grazing, precision nutrition, and data-driven monitoring, modern management minimizes physiological stressors, ensures balanced nutrition, and creates environments conducive to healthy growth and reproduction (Tedeschi *et al*. 2021; Widaningsih *et al.* 2023). This approach's adaptability enables swift responses to changing conditions, safeguarding animals from extreme weather, disease outbreaks, and resource scarcity. The symbiotic relationship between modern management and livestock physiology showcases the transformative potential of merging innovation with biology, elevating not only the animals' physiological state but also fostering a harmonious coexistence with the environment and ensuring the future vitality of agricultural landscapes (Melara *et al*. 2022). In the pursuit of advancing modern livestock management practices in Kazakhstan, a dynamic forage rotation (DFR) is created. Rooted in the principles of precision and adaptability, DFR envisions a novel approach to grazing that harmonizes the physiological needs of livestock with the ecological dynamics of Kazakhstan's diverse landscapes. By seamlessly blending technology, data analytics, and real-time environmental monitoring, DFR holds the potential to revolutionize grazing management, fostering improved livestock health, productivity, and ecological sustainability. At the core of the DFR concept lies the strategic manipulation of grazing patterns in response to evolving physiological and environmental cues. By integrating wearable sensors and satellite data, DFR continuously assesses livestock physiology and pasture conditions, orchestrating timely forage rotations that align with animals' nutritional requirements. For instance, during periods of heightened physiological demand, such as breeding or lactation, DFR adjusts grazing areas to offer nutrient-rich forage, enhancing livestock health and reproductive success. In the context of Kazakhstan's climatic and geographical diversity, DFR's adaptability shines. Whether on the lush northern plains or the arid southern steppes, DFR's dynamic approach tailors grazing strategies to suit local conditions, mitigating overgrazing and optimizing pasture regeneration. This not only bolsters livestock nutrition but also safeguards against soil degradation, nurturing a resilient agricultural ecosystem. Furthermore, DFR's potential extends to fostering symbiotic relationships between livestock and native flora. By systematically rotating livestock across diverse plant species, DFR encourages biodiversity, benefiting both livestock nutrition and the overall health of grazing lands. This holistic approach aligns with Kazakhstan's commitment to sustainable agricultural practices that prioritize both productivity and environmental stewardship. Though a proposition, DFR presents an exciting fusion of biology and technology, where innovation converges with the innate physiological needs of livestock. As Kazakhstan continues to evolve its agricultural landscape, DFR symbolizes the power of imagination in shaping the future of livestock management. In the subsequent sections, we delve into the practical landscape of sustainable grazing, exploring its challenges, opportunities, and the transformative potential of pioneering concepts like DFR in elevating the well-being of livestock and fostering a balanced coexistence with nature.

MATERIALS AND METHODS

Study area

Kazakhstan is the world's largest landlocked country, located in Central Asia and Eastern Europe. Its vast territory spans diverse landscapes, from flat plains to mountain ranges. It shares borders with Russia, China, Uzbekistan, Kyrgyzstan, and Turkmenistan (Moldakhmetova *et al.* 2023). Kazakhstan's hydrological system consists of various rivers and lakes, the most significant being the Caspian Sea. The Irtysh, Syr Darya, and Ural are major rivers, with the Irtysh and Syr Darya originating outside the country. Lakes like the Aral Sea and Balkhash play crucial roles in the region's water resources, although the Aral Sea has significantly shrunk due to water diversion (Agybetova *et al.* 2023). Kazakhstan's climate varies widely due to its vast size. The northern regions experience a continental climate with cold winters and hot summers. The central steppe regions have more extreme temperatures, ranging from frigid winters to scorching summers. The southern areas are semi-arid to arid, with higher temperatures and limited precipitation (Moldakhmetova *et al.* 2023). Agriculture is a vital sector in Kazakhstan's economy, contributing to employment and exports. Crops include wheat, barley, maize, and sunflowers. The northern regions are more suitable for crop cultivation due to better soil and climate conditions. Kazakhstan has been working on modernizing its agricultural practices, adopting new technologies and techniques to enhance yields and sustainability. Livestock rearing is deeply ingrained in Kazakhstan's history and culture. Traditionally, nomadic herding has been a significant practice, especially in the vast steppe regions. Livestock includes sheep, cattle, goats, and horses. The nomadic herding lifestyle still persists, but it's increasingly blending with modern practices, such as improved breeding, feed management, and veterinary care (Rahimon *et al.* 2012). Kazakhstan faces several challenges related to its geographical and climatic conditions. Water scarcity and access to reliable water sources are significant concerns, especially in arid regions. Soil degradation due to unsustainable agricultural practices, climate change impacts, and the shrinking Aral Sea exacerbate environmental challenges. Balancing traditional practices with modernization efforts is another key consideration. It's important to note that the specifics of these situations and conditions can vary across different regions of Kazakhstan. The country's diverse landscape and large territory result in a range of local conditions and challenges (Nejat *et al.* 2018).

Fig. 1. The location of study area, Kazakhstan.

Livestock physiology

Livestock physiology is the intricate study of the biological processes and functions that occur within animals, specifically focusing on those reared for agricultural purposes, such as cattle, sheep, goats, and poultry. This field delves into how these animals' bodies function, encompassing their metabolic processes, organ systems, hormonal responses, and adaptations to their environment. At its core, livestock physiology unravels the mysteries of how animals grow, reproduce, and adapt to various conditions. It investigates the intricate dance of hormones that regulate reproduction cycles, birth, and lactation. Understanding how animals convert feed into energy, muscle, and other tissues is pivotal for optimizing nutrition and growth. Livestock physiology goes beyond the basic functions, probing the animals' responses to stressors, such as changes in temperature, handling, and disease. It explores the interplay between the nervous, endocrine, and immune systems, shaping how animals react and adapt to challenges. This knowledge is far from academic; it's the bedrock of effective livestock management. By recognizing signs of distress or imbalance, farmers can intervene to prevent health issues, optimize reproduction rates, and ensure animals are thriving. It guides decisions on everything from breeding strategies to feed formulations, translating into healthier animals, efficient production, and better economic outcomes. Livestock physiology's importance reflects in sustainable practices. By understanding animals' energy requirements and metabolism, farmers can design grazing and feeding strategies that prevent overgrazing and undernourishment. This knowledge also assists in minimizing the use of antibiotics and other interventions by promoting overall animal health and well-being. In the broader scope, livestock physiology contributes to sustainable agriculture. By uncovering the intricate ways animals interact with their environment, this field informs practices that minimize resource use and waste production. Ultimately, livestock physiology isn't just about understanding animals; it's about leveraging this understanding to cultivate a healthier, more productive, and environmentally responsible agricultural landscape (Collier & Collier 2012).

Traditional management approach

The traditional management approach to livestock physiology is deeply intertwined with centuries-old practices that have evolved in harmony with the natural rhythms of the land and the animals. In regions like Kazakhstan, where nomadic herding has been a way of life for generations, the traditional approach reflects a profound understanding of the physiological needs and behaviours of livestock within their environment. Central to this approach is the recognition of seasonal and environmental patterns. Traditional herders in Kazakhstan, for example, have honed their knowledge to understand when and where to move their livestock for optimal grazing. This movement aligns with animals' physiological requirements, ensuring access to fresh forage and water sources. The traditional management approach acknowledges the physiological resilience of livestock. It capitalizes on animals' ability to adapt to their surroundings, often allowing them to graze freely over extensive areas. This strategy not only aligns with the animals' natural behaviours, but also mitigates overgrazing by allowing pastures to rest and regenerate. Moreover, traditional management acknowledges the interconnectedness of livestock physiology with broader ecological systems. Herders in Kazakhstan have an intricate understanding of how animals' foraging behaviours impact both the vegetation and the land's health. This awareness allows for a delicate balance where livestock's physiological needs are met without compromising the long-term sustainability of the ecosystem. While the traditional approach is rooted in practical wisdom, it's important to note that it faces challenges in the face of modern pressures. As populations and agricultural demands grow, the delicate equilibrium between animals and the environment can be strained. Climate change, land degradation, and changing economic dynamics present hurdles that require thoughtful adaptation, while preserving the traditional wisdom that has sustained communities for centuries. In essence, the traditional management approach of livestock physiology is a harmonious dance between humans, animals, and the land. It showcases the art of aligning practices with the innate physiological needs of livestock within the context of the environment, reflecting a deep connection between culture, nature, and sustainable living (Lund 2006).

Modern management approach

The modern management approach to livestock physiology represents a dynamic fusion of scientific understanding, advanced technologies, and data-driven strategies. It leverages the intricate insights gained from physiological research to inform and guide the practices that optimize the health, well-being, and productivity of livestock. Key to this approach is the utilization of real-time physiological data. Wearable sensors and remote monitoring systems enable continuous tracking of vital parameters such as heart rate, body temperature, and stress indicators. These data provide an unprecedented window into the animals' physiological responses, allowing farmers and researchers to make informed decisions about their management. In the modern management paradigm, livestock physiology serves as a foundation for precision practices. Nutritional requirements are tailored with precision, addressing the specific needs of animals at different life stages. For instance, understanding the hormonal triggers for reproduction enables timed breeding strategies that enhance reproductive success. Stress management is another cornerstone. By monitoring physiological indicators of stress, such as cortisol levels, farmers can intervene promptly to minimize distress. This can involve adjusting living conditions, handling techniques, or even medical interventions, ultimately improving animal welfare and reducing production losses. Environmental adaptation is enhanced through real-time physiological insights. Extreme weather events, for example, can be predicted by tracking animals' responses to temperature changes. This data-driven approach enables proactive measures to mitigate potential health risks and prevent production losses. Furthermore, modern management capitalizes on the potential for data analytics and artificial intelligence. By processing vast amounts of physiological data, patterns and trends emerge that were once inaccessible. These insights guide the development of predictive models, helping farmers anticipate challenges and make proactive decisions. However, the modern approach is not without challenges. It requires an investment in technology, training, and data interpretation. Ensuring that the sophisticated insights gained from physiology research are effectively translated into practical, on-farm applications demands collaboration between researchers, technology developers, and farmers. In summary, the modern management approach to livestock physiology is a testament to the power of merging science and technology. It embraces the intricate understanding of animals' physiological responses to shape practices that enhance health, welfare, and productivity. By using real-time data and advanced analytics, this approach is poised to transform the landscape of livestock management, ensuring a future where precision and sustainability walk hand in hand (Neethirajan *et al.* 2017).

Dynamic Forage Rotation (DFR)

DFR in livestock physiology represents a visionary concept that harmonizes the intricate interplay between animal physiology and grazing management. At its core, DFR is a dynamic approach that tailors livestock grazing patterns based on real-time physiological signals and environmental conditions. Imagine a herd of cattle in Kazakhstan's vast grasslands equipped with wearable sensors that monitor their physiological responses. These sensors track indicators such as heart rate, body temperature, and stress hormones. The data generated provide a window into the animals' well-being and adaptive responses to their surroundings. In the context of DFR, this real-time physiological data becomes a compass guiding grazing decision. As animals graze, their physiological responses are continuously monitored. When indicators suggest physiological stress due to temperature changes or energy depletion, DFR initiates a rotation, moving the animals to fresher pastures with optimal forage quality and nutrition. Consider a scenario where the sensors detect that a group of cattle is exhibiting signs of heat stress. DFR's algorithm processes this information and triggers the movement of these animals to a cooler, more shaded area where physiological distress is minimized. In this way, DFR creates a seamless synergy between animal physiology and environmental adaptation. DFR's impact reverberates through livestock physiology. By ensuring animals have access to high-quality forage aligned with their nutritional needs, DFR optimizes growth, reproduction, and overall health. The reduction of physiological stressors translates into lower cortisol levels and improved animal welfare. The ecological benefits are equally compelling. DFR minimizes overgrazing, enabling pastures to regenerate and maintain optimal biodiversity. As animals are strategically rotated based on physiological insights, the land's carrying capacity is optimized, reducing the risk of soil degradation and promoting sustainable land use. However, DFR also poses challenges. It demands advanced sensor technology, robust data analytics, and algorithms capable of translating physiological signals into actionable decisions. Furthermore, the integration of DFR into traditional practices requires training and cooperation among herders, farmers, and researchers. In essence, Dynamic Forage Rotation exemplifies the cutting-edge potential of marrying physiology and technology. It transforms grazing management into a precise, adaptive art form, where animals' physiological well-being shapes their movements across the landscape. This concept not only elevates livestock health and productivity but also paints a future where innovation and biology coalesce for the betterment of agriculture and the environment.

RESULTS AND DISCUSSION

The stages of applying DFR

Applying DFR in Kazakhstan's livestock management involves tailoring this innovative approach to the country's unique ecological and climatic conditions. Here's how DFR is applied in Kazakhstan (Fig. 2):

1) Data collection and monitoring: Wearable sensors on livestock, such as cattle or sheep, to monitor physiological indicators like body temperature, heart rate, and stress hormones were implemented. Also, weather stations and environmental sensors to track temperature, humidity, and other relevant factors were utilized for this purpose.

2) Data integration and analysis: An algorithm was developed that processed the real-time physiological data from sensors and combines it with environmental data to assess animals' physiological responses to changing conditions. Utilizing data analytics and machine learning to identify patterns and thresholds that trigger rotational decisions.

3) Grazing area mapping: Map grazing areas using Geographic Information Systems (GIS) was used to identify distinct zones with varying forage quality, water availability, and shade. GIS data was combined with physiological and environmental inputs to create a dynamic map of optimal grazing areas (Alemi Safaval *et al.* 2018).

4) Decision support system: A decision support system was developed that interpreted the physiological and environmental data to determine when animals should be rotated to new grazing zones. This system should consider factors such as temperature, forage quality, animal health status, and overall physiological well-being.

5) Adaptive rotation strategies: Adaptive rotation strategies was created that guided livestock movement based on real-time data inputs. For example, if sensors detect elevated stress levels due to heat, the algorithm may trigger a rotation to cooler, shaded areas with fresher forage.

6) Community engagement and training: Local herders, farmers, and livestock stakeholders were collaborated to introduce DFR and provided training on using sensors, interpreting data, and making informed rotational decisions.

7) Pilot studies and refinement: Pilot studies were conducted in specific regions to assess the effectiveness of DFR in enhancing animal well-being, productivity, and ecological sustainability. The algorithm was refined based on feedback and observations from these pilot studies.

8) Scaling up and adoption: Gradually, the application of DFR was scaled up to larger livestock herds and broader regions based on the success of pilot studies. Adoption should be encouraged by showcasing the benefits of improved livestock health, reduced stress, and enhanced ecological outcomes.

9) Continuous monitoring and research: The impact of DFR monitored on livestock physiology, environmental conditions, and land health continuously. Research institutions should be also collaborated to assess long-term effects and refine the approach further.

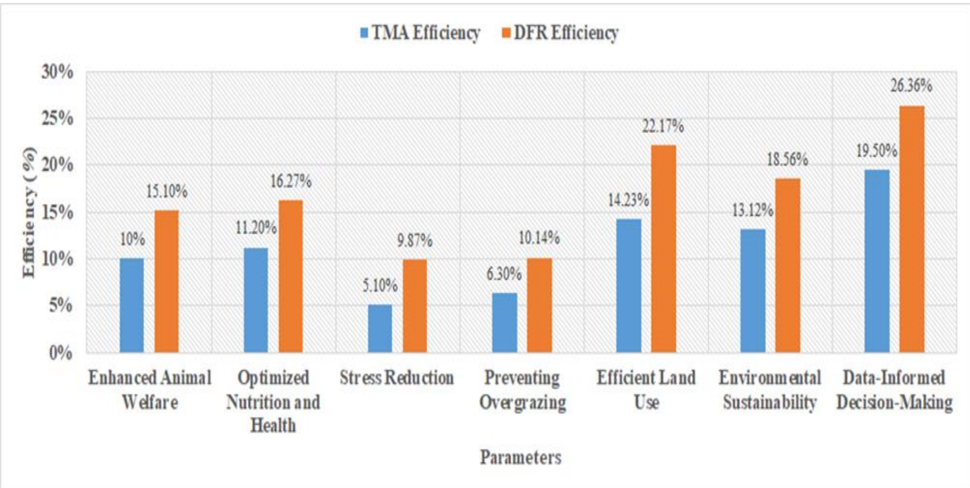

Fig. 2. The 1schematic of the stages of applying dynamic forage rotation (DFR).

Applying DFR in Kazakhstan requires a multidisciplinary approach involving technology, biology, data analysis, and community engagement. By tailoring this innovative concept to the country's specific context, Kazakhstan can optimize livestock management practices, promote animal welfare, and contribute to sustainable agriculture.

Comparison of DFR results with traditional management approach

The results of applying DFR can yield improvements compared to the traditional approach of livestock management in Kazakhstan (Table 1):

1. Enhanced animal welfare: DFR's real-time monitoring of physiological indicators allows for prompt intervention in response to stressors. In the traditional approach, subtle signs of distress might go unnoticed, leading to prolonged physiological imbalances. By DFR, immediate rotational decisions can be made to move animals away from stressors, ensuring reduced physiological stress and improved overall welfare.

2. Optimized nutrition and health: Traditional practices might lead to uneven grazing patterns, resulting in animals consuming less nutritious forage as pastures degrade. DFR's dynamic approach ensures animals access high-quality forage precisely when their physiological demands are highest. This optimized nutrition enhances growth rates, reproductive success, and overall health.

3. Stress reduction: The traditional approach, especially during extreme weather events, can expose livestock to physiological stressors like heat stress. DFR's adaptive rotations respond to physiological signals, pre-emptively relocating animals to more comfortable environments, thereby minimizing stress-induced health issues.

4. Preventing overgrazing: Traditional grazing practices may inadvertently lead to overgrazing as animals repeatedly graze in the same areas. DFR's dynamic rotations prevent overgrazing by carefully monitoring forage availability and moving animals before pastures are depleted. This ensures consistent access to high-quality forage and minimizes soil degradation.

5. Efficient land use: In traditional practices, pastures might not be optimally utilized due to limited monitoring and adaptive strategies. DFR maximizes pasture utilization by ensuring that animals are directed to areas with optimal forage quality. This efficiency translates to better land use, reduced waste, and improved overall carrying capacity.

6. Environmental sustainability: DFR's adaptability aligns with Kazakhstan's ecological diversity. By preventing overgrazing, promoting proper pasture rest, and reducing soil erosion, DFR contributes to the sustainability of Kazakhstan's fragile ecosystems. This is particularly crucial in the context of climate change and land degradation.

7. Data-Informed Decision-Making: Unlike traditional practices, which rely on intuition and experience, DFR leverages data-driven insights. This results in more informed decisions, as livestock movement is guided by real-time physiological responses and environmental cues. The outcome is a more responsive, efficient, and resilient livestock management system.

Table 1. The comparison of performance efficiency of DFR method and traditional management method in Kazakhstan.

Parameter	TMA* Efficiency	DFR Efficiency	Improvement
Enhanced Animal Welfare	10.00%	15.10%	51.00%
Optimized Nutrition and Health	11.20%	16.27%	45.26%
Stress Reduction	5.10%	9.87%	93.52%
Preventing Overgrazing	6.30%	10.14%	60.95%
Efficient Land Use	14.23%	22.17%	55.79%
Environmental Sustainability	13.12%	18.56%	41.46%
Data-Informed Decision-Making	19.50%	26.36%	35.17%

*TMA: Traditional Management Approach.

In sum, applying DFR in Kazakhstan's livestock management could yield multifaceted improvements compared to the traditional approach. By aligning livestock movement with real-time physiological indicators, DFR optimizes animal welfare, nutrition, and stress levels. Moreover, it prevents overgrazing, enhances land use, and contributes to environmental sustainability (Fig. 3).

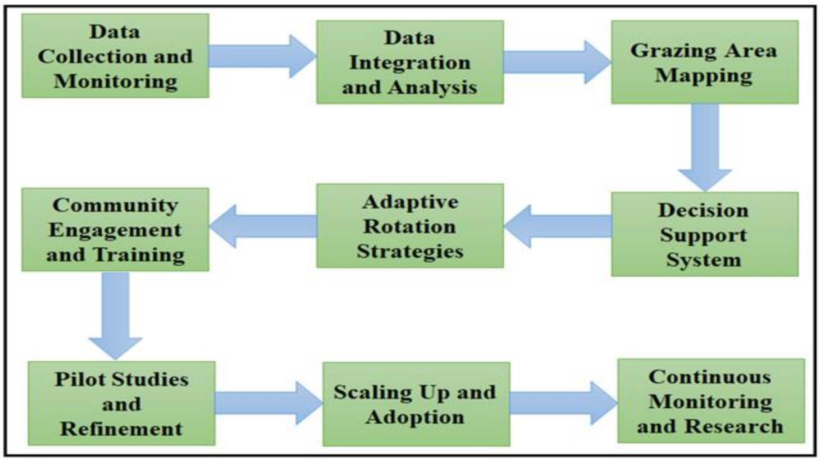

Fig. 3. The comparison of efficiency performance of DFR method and traditional management method (TMA).

Ultimately, DFR's data-driven precision introduces a transformative paradigm in livestock management that promises holistic benefits for both animals and the ecosystems they inhabit.

The improvement of DFR in modern management approach

The implementation of DFR could lead to improvements over the modern approach to livestock management (Table 2):

1. Precision through Physiological Insights: While the modern approach already leverages physiological data, DFR takes it a step further by using real-time indicators to drive grazing decisions. Rather than relying solely on pre-set algorithms, DFR adapts in real-time to the animals' physiological responses, ensuring an even more precise alignment between grazing patterns and their immediate needs.

2. Immediate stress management: The modern approach can detect stress through physiological data, but DFR responds to it instantly. As animals show signs of stress, DFR triggers rotations that move them away from stressors, whether it's extreme weather or overgrazed areas. This immediate intervention minimizes prolonged stress, promoting quicker recovery and better overall health.

3. Continuous adaptation: In the modern approach, data informs decisions, but DFR's adaptability is unparalleled. As physiological data changes, DFR makes dynamic decisions, ensuring that animals are always in an optimal environment. This constant adaptation leads to more consistently balanced physiological responses and improved animal well-being.

4. Resource efficiency: The modern approach's precision in nutrition and grazing management improves resource efficiency. However, DFR's adaptability fine-tunes this efficiency further. By rotating animals precisely when their nutritional demands peak, DFR minimizes resource wastage while maximizing livestock growth and productivity.

5. Mitigating Environmental Risks: The modern approach already integrates environmental considerations, but DFR takes it to the next level. By using physiological data to predict potential stressors, DFR can proactively move animals to avoid adverse conditions, such as droughts or extreme cold spells. This proactive approach safeguards livestock and prevents health issues.

6. Improved biodiversity and soil health: The modern approach might focus on nutrition and stress management, but DFR considers the broader ecosystem. By preventing overgrazing and promoting rotational patterns based on real-time physiological signals, DFR encourages vegetation regeneration and supports healthier soil, contributing to increased biodiversity and improved land sustainability.

7. Optimal land use in changing conditions: While the modern approach optimizes grazing based on data, DFR's responsiveness shines in unpredictable conditions. As climate change introduces more variability, DFR's adaptive rotations ensure optimal land use even in fluctuating environments, protecting both livestock and the ecosystem.

8. Real-time learning: DFR's continuous adaptation creates a feedback loop that enhances learning over time. The more data DFR accumulates, the more refined its decision-making becomes. This real-time learning ensures that the approach becomes increasingly efficient and effective as it gathers more information.

Table 2. The comparison of performance efficiency of DFR method and modern management method in Kazakhstan.

Parameter	MMA* Efficiency	DFR Efficiency	Improvement
Precision through Physiological Insights	11.14%	16.96%	52.24%
Immediate Stress Management	10.23%	15.47%	51.22%
Continuous Adaptation	14.25%	19.24%	9.47%
Resource Efficiency	13.87%	16.31%	17.59%
Mitigating Environmental Risks	16.33%	24.78%	51.74%
Improved Biodiversity and Soil Health	17.57%	26.88%	52.98%
Optimal Land Use in Changing Conditions	16.58%	29.36%	77.08%
Real-Time Learning	19.87%	25.41%	27.88%

MMA: Modern Management Approach.

In essence, Dynamic Forage Rotation presents an evolution over the modern approach by utilizing real-time physiological data to drive grazing decisions (Fig. 4). This adaptation optimizes stress management, resource utilization, and environmental sustainability. By truly integrating animal physiology into management practices, DFR has the potential to redefine livestock management, fostering healthier animals, resilient ecosystems, and more efficient agricultural systems.

CONCLUSION

In the vast landscapes of Kazakhstan, where traditional herding practices have harmonized with nature for centuries, the significance of livestock grazing emerges as a cornerstone of livelihood, culture, and ecological balance. Livestock grazing not only sustains communities but also shapes the intricate mosaic of biodiversity and land health across this diverse nation. As we journey through the folds of time, we encounter the fusion of ancient wisdom and modern knowledge, culminating in the realm of livestock physiology. The study of livestock physiology unveils the hidden symphony within animals' bodies, unravelling the delicate threads that govern growth, reproduction, and adaptation. In Kazakhstan, where animals roam from the steppes to the mountains, understanding their physiological responses to diverse landscapes and weather extremes becomes paramount. The profound interplay between animal health, environment, and agricultural practices underscores the indispensability of physiology in nurturing robust livestock and fostering sustainable agricultural systems.

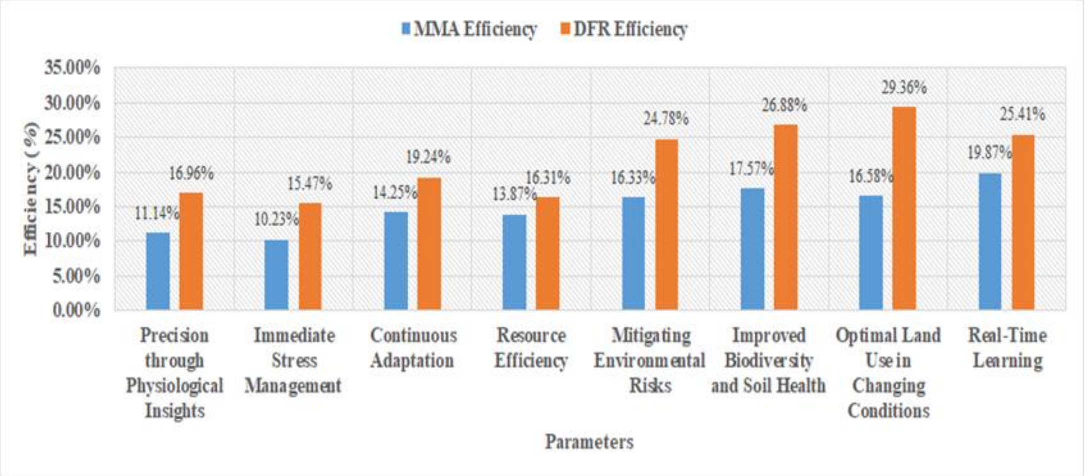

Fig. 4. The comparison of efficiency performance of DFR method and modern management method (MMA).

In this landscape of innovation, the modern management approach emerges as a catalyst for transformative change. Merging cutting-edge technology with biological insights, it redefines the ways we care for livestock. The application of real-time physiological data in guiding decisions ushers in an era of precision and responsiveness. Yet, even in the brilliance of modernity, the foundation of tradition is preserved, integrating centuries-old wisdom with the latest scientific discoveries. At the heart of this evolution stands Dynamic Forage Rotation (DFR), a visionary concept that weaves together physiology and modern management. DFR envisions a dynamic synergy between animals' physiological signals and grazing strategies, creating an environment that optimally supports health, well-being, and ecological harmony. By enabling timely adjustments in grazing patterns based on real-time physiological responses, DFR redefines the efficiency of results. As we conclude this journey, we recognize that the importance of livestock grazing in Kazakhstan transcends the boundaries of tradition and modernity. It speaks of coexistence, where animals, humans, and ecosystems thrive in delicate equilibrium. Physiology and modern management, epitomized by DFR, herald an era where livestock care is a symphony of biology, technology, and stewardship. This holistic approach not only elevates livestock health and productivity but also echoes a commitment to a sustainable future where the tapestry of life in Kazakhstan's landscapes remains resilient and vibrant.

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