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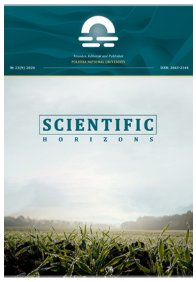

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Economic model of development of the feed crop-growing industry in the Republic of Kazakhstan

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Abstract. The livestock industry has experienced rapid growth, and the demand for livestock products is projected to continue increasing quickly due to population growth, improved living standards, and urbanisation. This article aims to assess the feasibility of utilising the created model for growing animal feed for meat-producing livestock during the standard planning phase of economic development. The authors categorise wheat as a reference culture. The study utilised analysis, statistical methods, economic

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modelling, and mathematical modelling. The authors assess the potential of utilising the created model to cultivate feed for livestock intended for meat production during the standard planning phase of economic development. The model predicts cost-effective feed. The authors' economic model enables the growth of the feed base, reduces the reliance on imported feed, and facilitates the expansion of meat breeds, which is the unique aspect of the study. The study emphasises the importance of strategically distributing, specialising, and concentrating beef cattle breeding in particular natural and economic contexts. It also highlights the significance of integrating large-scale production with medium and small agricultural enterprises in the meat industry. The study's practical significance lies in utilising specific structures and controlling the share of imports in feed production, along with restricting feed supply and ready-made food additives to guarantee food security

Keywords: forage crop cultivation; food supply; growth; food security; economic model

INTRODUCTION

Crop production constitutes 40% of the total agricultural output in the global economic management practice, with nearly one billion individuals employed in this sector worldwide (Mataeva *et al*., 2018). Agriculture's crop growing sector is highly dynamic. An advanced agricultural sector will lay the foundation for establishing new food and light industries and ensuring the nation's food security (Bauer *et al*., 2018; Soegoto *et al*., 2022; Bhat *et al*., 2022).

Natural pasture areas in the country allow for the production of organic products, which command a higher price and are sought after in global markets. This benefit is mainly a result of the minimal use of mineral fertilisers, pesticides, and herbicides on Kazakh territories (Robinson et al., 2021). The current pasture land is only being utilised at 25-30% capacity, with available water resources to irrigate an extra 2 million hectares for stable feed production in crop rotation. Livestock development in Kazakhstan is significantly influenced by the availability of labour resources, as 45% of the population resides in rural regions.

Agriculture occupies a significantly important place in our modern society, exerting a profound influence on all of us (Misiuk & Zakhodym, 2023). It is an industry undergoing unprecedented changes. Farmers are increasingly assuming complex and vital roles in striking a balance between the need for increased productivity, environmental protection, and societal value (Shahini *et al*., 2023). As agricultural challenges become increasingly extensive and intricate, it becomes even more crucial to work together to find the right equilibrium for achieving success – for farmers, for agriculture, and for future generations (Voronetska & Yurchuk, 2023). Moreover, agriculture plays a pivotal role in Kazakhstan's context as well. Farmers in Kazakhstan are navigating a landscape of considerable transformations and are essential in ensuring a harmonious coexistence between productivity enhancement, environmental conservation, and societal benefits. Addressing the expanding agricultural complexities in Kazakhstan calls for collective efforts and cooperation to achieve a sustainable and prosperous agricultural sector that caters to the well-being of future generations (Semenyutina & Svintsov, 2019).

To increase the production of competitive, export-oriented agricultural products and increase the country's food security, agro-industrial production requires the maximum use of the adaptive capabilities of innovative processes, technology modernisation, the harmonious use of the natural, industrial and scientific-technical potential of the territory (Chen *et al*., 2020). In this regard, the assessment of potential resources in crop growing as factors for increasing the efficiency of the forage production industry is relevant (Moss & Havilah, 2022).

The research aims to determine the feasibility and benefits of implementing the developed model in feed crop-growing, considering cost-effective feed prediction and specialization in forage crop cultivation. The study's objectivies are to collect data, evaluate trends, and examine the factors influencing the growth of the industry, assess government policies, identify challenges and opportunities of cattle breeding in Kazakhstan.

LITERATURE REVIEW

Kazakhstan is a significant crop producer, with wheat being its largest crop. It is the sixth largest wheat producer in the world, and wheat accounts for 80% of its grain production (Baitelenova *et al*., 2021). In addition to wheat, Kazakhstan also produces barley, cotton, sunflower seeds, rice, sugar beets, flax, and minor crops such as potatoes, watermelons, and melons. The country has developed strategies to increase crop production, with a focus on boosting yields rather than expanding the area under cultivation (Yessenova *et al*., 2023). The agricultural sector in Kazakhstan plays an essential role in the country's economic, social, and environmental development, with over a third of the population's livelihoods depending directly or indirectly on the extensive agricultural activities (Abuova *et al*., 2020). The country's agricultural potential remains substantial, with significant untapped opportunities for further development.

The Sustainable Crop Production Program for Results (World Bank, 2021) is a comprehensive initiative aimed at fostering the advancement of environmentally sustainable and economically viable crop cultivation in the Republic of Kazakhstan. This program is specifically tailored to achieve several key objectives, including the promotion of export diversification in the agricultural sector, the facilitation of small and medium enterprise expansion in rural regions, the enhancement of crop productivity through innovative agricultural practices, and the provision of improved agricultural advisory and support services to farmers (Ministry of Agriculture, 2022).

P. Romanovska *et al.* (2023) conducted a study on a statistical weather-driven crop model that accurately predicts wheat yields in Kazakhstan at the oblast level up to two months before the harvest. The model can accurately predict the total wheat production for Kazakhstan with R2 values ranging from 0.86 to 0.73. The forecast model can complement existing forecasting methods to help countries in Central Asia meet their food demand. The model demonstrates high accuracy in predicting wheat yields during the growing season up to two months prior to harvest (Bissenova *et al.*, 2023). The model benefits from low computational power and minimal input, relying solely on yield and weather data. In conjunction with this study, the work of P. Romanovska *et al.* (2023) emphasises the importance of collaboration and scientific rigour, as well as the importance of addressing food security and resource efficiency in agricultural development.

In their study, S. Suieubayeva *et al.* (2022) show that the agricultural industry in Kazakhstan is facing several problems, including corruption, issues related to subsidies, and a lack of a clear mechanism for tracking problems at a lower level. The population of Kazakhstan has experienced a shortage of vegetables and fruits, which are on the market at inflated prices. The article recommends building a model for assessing the state of problems to improve the level of development of the agro-industrial complex. The article concludes that the agricultural industry needs high-quality assistance from state executive bodies and subsidies to improve its scientific and technical equipment and post-harvest processes.

These research efforts, policy initiatives, and programs collectively form a crucial framework for advancing food security, reducing corruption, and promoting the long-term sustainability of Kazakhstan's agricultural industry.

METHODOLOGY

The study was conducted from 2020 to 2023 on the territory of different regions of the Republic of Kazakhstan (Akmola region, Kostanay region, North-Kazakhstan region, Northern Kazakhstan). The study followed a systematic approach to investigate the state of the cattle breeding industry in Kazakhstan and its relationship with government interventions. The research commenced with Stage 1, where the authors identified a significant challenge: a low proportion of breeding stock in the industry. Proceeding to Stage 2, comprehensive data were collected, encompassing breeding stock proportions, production figures, input costs, and market demand. A comparative analysis was carried out, benchmarking these metrics against highly developed countries to provide context.

In Stage 3, the researchers constructed a mathematical model. Using differential equations and numerical modelling, the model captures the complex relationships between variables such as production, input costs and market demand, allowing scenario analysis to assess the potential impact of government policies. In addition, the model allows for the assessment of product quality according to international standards. Ultimately, by combining the results of mathematical modelling and product quality analysis, the model elucidates the intricacies of the impact of public policies on industry development and product quality, offering invaluable information for policy makers and stakeholders. Let $Pv(t)$ be the amount of sown feed crop in the process of growth in fields, measured in tons (Wu *et al.*, 2023). The change in this value will be calculated by the formula (1):

$$Pv(t) = Pv(t)kw - Pvr(t) + 0.05Pvrmax(t), \quad (1)$$

where kw is the coefficient of influence of weather conditions, which is in the range from 0 to 1 and shows how much of the harvest entrepreneurs can lose if weather conditions affect negatively. Ideal weather conditions: $kw = 0$. On average, a quarter of the potential harvest is possible due to adverse weather conditions during the year; $Pvr(t)$ is the amount of harvest that was actually harvested in a given year; 0.05 – coefficient showing how much feed crops were planned for one day if this process was planned for 20 days (Tsuru, 2023); $Pvrmax(t)$ is the available amount of feed culture that can be obtained if the given area is a certain number of seed.

It is equal to zero when there is no sowing, and in the days of sowing is determined according to the formula (2):

$$Pvrmax(t) = \begin{cases} 0, t \notin [244; 263] \\ Pvmax, t \in [244; 263] \end{cases}. \quad (2)$$

In this model, $Pvrmax$ will be considered a constant value and determined by the formula (3):

$$Pvrmax = SDsz\ nz\ kk\ np, \quad (3)$$

where S – the area of fields planned for feed crop, hectare; Dsz – crop rotation necessary to obtain large harvests, because when processing the culture on the same field (plot), the soil is depleted, the risk of developing diseases and pests increases. Crops are placed on the fields so that each of them returns to its previous place no earlier than 3-4 years later (Li *et al.*, 2022). The time during which cultures pass each field in a certain sequence is called crop rotation; nz – the grain dissimilarity coefficient, that is, the average coefficient showing the loss of seed due to the loss of germination ability; kk – the tillering coefficient of grain; tillering is a process in which elevated lateral shoots are formed from the buds of a tillering node, that is, cereals, and similar herbaceous plants; *np* – the sowing rate of the material, tons per hectare; the sowing rate is an important indicator that affects the harvest in the future, since the density of the standing of the plants determines how much they will receive nutrients, water, sunlight.

Simultaneously, in Stage 4, the Runge-Kutta method was employed to implement the mathematical model. This numerical technique allowed for the simulation of variable interactions over time, providing a more accurate representation of system dynamics. Stage 5 involved an analysis of agricultural product quality. Through systematic data review and comparative analysis with international standards, it was revealed that the agricultural products in Kazakhstan did not meet the required global quality standards. In Stage 6, the findings from both the mathematical modelling and product quality analysis were integrated.

RESULTS

In agriculture, taking into account the natural, climatic, economic, social and environmental conditions, different regions of the country have developed various specialisation of production, which reflects the inter-regional division of labour (Nurgazy *et al.*, 2019). The region of Northern Kazakhstan, including the Akmola, North Kazakhstan, and Kostanay regions, has grain and livestock specialisation, crop production predominates in gross agricultural output (Table 1).

Table 4*. Gross agricultural output of Kazakhstan and Northern Kazakhstan for 2020-2023, bln KZT*

Region	2020	2021	2022	2023
Akmola	189.6	227.7	258.1	745.7
Kostanay	195.2	223.9	247.8	721.4
North-Kazakhstan	270.8	294.7	363.6	851.3
Republic of Kazakhstan	1815.1	2040.8	2256.3	7741.9

Source: *compiled by the authors based on Bureau of National Statistics (2023)*

As a result of a radical economic reform in agriculture in Northern Kazakhstan, a multi-layered economy was formed based on a variety of forms of ownership and management. The transition to the formation of marketable meat on the market in private farms led to a decrease in the productive qualities of the herd, a low yield of meat in slaughter weight, and low-quality characteristics of meat (Baimukanov *et al.*, 2021). Analysis of the cattle stock in Kazakhstan and the Akmola region, presented in Table 2, shows a steady tendency to increase over the years.

Table 2*. Cattle stock in Kazakhstan and Akmola region from 2019 to 2022, thousand heads*

Indicators	2019	2020	2021	2022	2023	Increase in 2023 compared to 2019, %	Increase in 2023 compared to 2022, %
Total number of cattle, thousands of heads							
Total in Kazakhstan	6,279.2	6,496.4	6,515.6	6,813.9	8,538.05	35.99	25.31
including:							
agricultural organisations	307.5	385.3	394.6	552.3	806.6	162.2	46.0
peasant households	884.2	1,202.5	1,394.1	1,724.7	3,373.8	281.6	95.62
personal subsidiary plots	5,087.5	4,908.6	4,726.9	4,536.9	4,357.4	-14.37	-3.95
Akmola region	401	400.1	421.8	484.9	458.4	14.3	-5.47
including:							
agricultural organisations	72.7	89.1	115.5	128.2	134.3	84.67	4.76
peasant households (farms)	46.9	46.0	70.3	135.1	92.3	96.76	-31.67
personal subsidiary plots	281.4	265.0	236.0	221.6	231.7	-17.64	4.56

Source: *compiled by the authors based on Bureau of National Statistics (2023b)*

The gradual increase in livestock requires an increase in the food supply for the meet stockbreeding industry. An effective way to solve this problem is to expand the sown area for growing feed crops on the fields of agricultural entrepreneurs. Requires the formation of a complex of high-quality varieties of feed adapted to local growing conditions. In order for agricultural entrepreneurs to be interested in growing feed crops in their fields, a pricing strategy for the sale of feed in the market will be calculated, which takes into account the climatic conditions of the region and the state agrarian policy aimed at economic support for the development of meat stockbreeding through budget subsidising and financing mechanisms.

Thus, the crop rotation condition *Dsz* may be equal, for example, to the value presented in formula (4):

$$Dsz \in \{0.5; 0.33; 0.25\}. \quad (4)$$

Suppose that $Dsz = 0.5$, which means that in the first year, 50% of the available area will be sown with feed crops, and in the second year, the remaining 50%. Provided that the harvest begins on the 225th day of the year (approximately mid-August), the amount of harvest that was actually harvested in a given year is determined by the formula (5):

$$Pvr(t) = \begin{cases} 0, t \neq 225, \\ Pv(t), t = 225. \end{cases} \quad (5)$$

Denote $Ps(t)$ – the amount of feed that does not meet the International Grain and Feed Trade Association (GAFTA) standard (raw materials). Then the change equation $Ps(t)$ looks like this, as indicated in formula (6):

$$\dot{Ps}(t) = -Ps(t)\, a_1 + Pvr(t) - Ps(t)u_2(t), \quad (6)$$

where a_1 is the share of raw materials that entrepreneurs want to bring to the GAFTA standard ($a_1 \in [0; 1]$). This value may be limited by the financial and production capabilities of enterprises; $u_2(t)$ is the share of raw materials that the state wants to bring to the GAFTA standard after purchasing raw materials from entrepreneurs ($u_2 \in [0;1\text{-}a_1]$) (Bavorova et al., 2019).

$Pp(t)$ – the amount of feed that meets the GAFTA standard (product), and can, accordingly, be implemented as a finished product, makes up a proposal on the feed crop market, the equation of change of $Pp(t)$ can be written as (7):

$$\dot{Pp}(t) = Ps(t)a_1 - min\{Qd(t); Pp(t)\} + Ps(t)u_2(t), \quad (7)$$

where $Qd(t)$ – the final consumer demand for feed crop at a given time; $Ps(t)a_1$ – the amount of feed that enterprises plan to bring to the GAFTA standard; $Ps(t)u_2(t)$ – the amount of feed that the state plans to bring to the GAFTA standard; $min\{Qd(t); Pp(t)\}$ is the amount of feed that meets current demand at a given time and thus reduces supply (Yang *et al.*, 2022).

Accordingly, the change in demand is written in the form (8):

$$\dot{Qd}(t) = a - bP(t) - min\{Qd(t); Pp(t)\}, \quad (8)$$

where $P(t)$ – the price of feed crop on the market at the current time; a – the amount of feed crops that consumer would be willing to buy at zero cost; b – the slope of the demand curve, showing how the demand for the product will change when the price changes (increases or decreases) by 1%; $a - bP(t)$ the increase in demand at a certain point in time depending on the price according to a linear law (Srinivas 2009).

The change in the price of feed that complies with the GAFTA standard is set taking into account its coefficient of elasticity Ep (Kunchamboo *et al.*, 2021). Thus, the change in the price of feed, taking into account the coefficient of elasticity, can be written by the formula (9):

$$\dot{P}(t) = -Ep(Pp(t) - Qd(d)). \quad (9)$$

Denote the money of entrepreneurs $Cp(t)$ (USD). Then the change of money of entrepreneurs $Cp(t)$ will be calculated by the formula (10):

$$\dot{Cp}(t) = -cpar(t) - Pvpr(t)(1 + toll) - Ps(t)a_1pb + r_1(t)\, min\{Qd(t); Pp(t)\}P(t)(1 - tax) + Cd(t)u_1(t) + Ps(t)u_2(t)z, \quad (10)$$

where $cpar(t)$ is the cost of fertilisers, field processing, herbicides, etc. $Pvpr(t)$ is the cost of seed that must be purchased by entrepreneurs from abroad to sow the current field area; $toll$ – state duty that must be paid for the import of seed in the country (tax for international trade); pb – the cost of processing raw materials for the product – bringing the feed to the GAFTA standard by drying and cleaning; tax – business income tax; $r_1(t)$ – the share of all sales owned by entrepreneurs at a given time; $u_1(t)$ – the share of state money used for direct investment by enterprises at a given time; $Cd(t)$ – state money; z – the price of government procurement of raw materials from private enterprises (McCain, 1995).

Assume that the cost of fertilisers, field tillage, herbicides $cpar(t)$ is zero when there is no crop in the fields during growth, as well as in winter. Define the cost of fertilisers and technical treatment according to the formula (11):

$$cpar(t) = \begin{cases} \frac{Pv(t)kpqn}{kpq}, t \in [60; 151][245; 334] \\ 0, t \notin [60; 151][245; 334] \end{cases}, \quad (11)$$

where kpq – the cost-effectiveness ratio for processing the fields, showing how much feed can be processed by a unit of money under conditions of applying a certain number of mineral fertilisers, herbicides, etc.; $kpqn$ – a depreciation coefficient showing the proportion of mineral fertilisers, herbicides, machinery for work that wears out daily, transferring its value to the potential amount of feed crop yield.

The seed purchase take place immediately before the feed crop sowing process (Cabrera-Capetillo *et al.*, 2023). Then the cost of the required seed will be determined as the product of the area of the available fields, planting rates in tons per hectare, crop rotation conditions for feed crops and seed prices per ton. This condition can be written in the form of formula (12):

$$Pvpr(t) = \begin{cases} SpzDsz, t = 244, \\ 0, t \neq 244 \end{cases}, \quad (12)$$

where pz is the price of seed per ton.

The share of all sales belonging to dependent entrepreneurs $r_1(t)$ is defined as the ratio of the share of feed crop brought by enterprises to the GAFTA standard to the amount of feed crop shares those enterprises and the state have brought to the GAFTA standard in total, as shown in formula (13):

$$r_1(t) = \frac{a_1}{a_1+u_2(t)}. \quad (13)$$

Denote the state's money as $Cd(t)$. Then the change in the state's money $Cd(t)$ will be calculated by the formula (14):

$$\dot{Cd}(t) = -Cd(t)u_1(t) - Ps(t)u_2(t)pb + Pvpr(t)toll + r_1(t)min\{Qd(t); Pp(t)\}P(t)tax + r_2(t)min\{Qd(t); Pp(t)\}P(t) - Ps(t)u_2(t)z, \quad (14)$$

where $r_2(t)$ – the share of all feed crop sales owned by the state. It is defined as the ratio of the share proved by the state to the GAFTA standard of feed culture to the sum of the shares of feed crop, as shown in formula (15):

$$r_2(t) = \frac{u_2(t)}{a_1+u_2(t)}. \quad (15)$$

Considering the above, the limitation of the system is determined:

- the sum of the shares of feed culture, which enterprises and the state in total bring to the GAFTA standard at a certain point in time, cannot exceed 1 in accordance with (16):

$$a_1 + u_2(t) \leqslant 1, \quad (16)$$

- each of the particles of feed culture, which enterprises and the state bring to the GAFTA standard at a certain point in time, cannot be less than 0 in accordance with (17):

$$a_1 u_2(t) \geqslant 0, \quad (17)$$

- the share of state money that it provides entrepreneurs with as subsidies for the development of production lies in the range from 0 to 1 in accordance with (18):

$$u_1(t) \in [0;1], \quad (18)$$

- time-dependent model parameters are integral in accordance with (19):

$$Pv(t), Pvr(t), Pvrmax(t), Ps(t), Pp(t), Qd(t), P(t), Cp(t), Cd(t), cpar(t), Pvpr(t), r_1(t), r_2(t) \geqslant 0, \quad (19)$$

- at each moment of time, demand deviates from supply no more than by a given value, as indicated in formula (20), according to the theory of equilibrium of Walras:

$$(Qd(t) - Pp(t))^2 < e. \quad (20)$$

The authors will consider modelling the income of the state and entrepreneurs as target functions, which are written in the form (21):

$$I_1 = \int_0^T (Cd(t))dt \rightarrow max, \quad (21)$$

$$I_2 = \int_0^T (Cd(t))dt \rightarrow max. \quad (22)$$

To perform the calculations of the constructed economic-mathematical model, it is necessary to have a single objective function, therefore, having completed the convolution, the objective function in the form is obtained (23):

$$I = \int_0^T (Cd(t))dt + Cp(t))dt \rightarrow max. \quad (23)$$

Taking into account the initial conditions of differential equations, there is (24):

$$Cd(0) = Cd_0;\ Cp(0) = Cp_0;\ Pv(0) = Pv_0;\ Ps(0) = Ps_0;\ Pp(0) = Pp_0;\ Qd(0) = Qd_0;\ P(0) = P_0. \quad (24)$$

Combining all the above equalities, differential equations, restrictions and initial conditions, a model of the state's influence on the development of the feed crop growing industry is obtained (25-45):

$$\dot{Pv}(t) = -Pv(t)kw - Pvr(t) + 0.05Pvrmax(t), \quad (25)$$

$$Pvrmax(t) = \begin{cases} 0, t \notin [244; 263] \\ Pvmax, t \in [244,263] \end{cases}, \quad (26)$$

$$Pvmax = SD\ sz\ nz\ kk\ np, \quad (27)$$

$$Dsz \in \{0.5; 0.33; 0.25\}, \quad (28)$$

$$Pvr(t) = \begin{cases} 0, t \neq 225, \\ Pv(t), t = 225 \end{cases}, \quad (29)$$

$$\dot{Ps}(t) = -Ps(t)a_1 + Pvr(t) - Ps(t)u_2(t), \quad (30)$$

$$\dot{Pp}(t) = Ps(t)a_1 - min\{Qd(t); Pp(t)\} + Ps(t)u_2(t), \quad (31)$$

$$\dot{Qd}(t) = a - bP(t) - min\{Qd(t); Pp(t)\}, \quad (32)$$

$$\dot{P}(t) = -Ep(Pp(t) - Qd(t)), \quad (33)$$

$$\dot{Cp}(t) = -cpar(t) - Pvr(t)(1 + toll) - Ps(t)a_1pb + r_1(t) min\{Qd(t); Pp(t)\}P(t)(1 - tax) + Cd(t)u_1(t) + Ps(t)u_2(t)z, \quad (34)$$

$$cpar(t) = \begin{cases} \frac{Pv(t)kpqn}{kpq}, t \in [60; 151][245; 334] \\ 0, t \notin [60; 151][245; 334] \end{cases}, \quad (35)$$

$$Pvpr(t) = \begin{cases} S\ pz\ Dsz\ np, t = 244, \\ 0, t \neq 244 \end{cases}, \quad (36)$$

$$r_1(t) = \frac{a_1}{a_1+u_2(t)}, \quad (37)$$

$$\dot{Cd}(t) = -Cd(t)u_1(t) - Ps(t)u_2pb + Pvpr(t)toll + r_1(t)min\{Qd(t); Pp(t)\}P(t)tax + r_2(t)min\{Qd(t); Pp(t)\}P(t) - Ps(t)u_2(t)z, \quad (38)$$

$$r_2(t) = \frac{u_2(t)}{a_1+u_2(t)}, \quad (39)$$

$$a_1 + u_2(t) \leqslant 1, \quad (40)$$

$$a_1, u_2(t) \geqslant 0, \quad (41)$$

$$u_1(t) \in [0.1], \quad (42)$$

$$(Qd(t) - Pp(t))^2 < e, \quad (43)$$

$$Pv(t), Pvr(t), Pvrmax(t), Ps(t), Pp(t), Qd(t), P(t), Cp(t), Cd(t), cpar(t), Pvpr(t), r_1(t), r_2(t) \geq 0, \quad (44)$$

$$Cd(0) = Cd_0;\ Cp(0) = Cp_0;\ Rv(0) = Pv_0;\ Ps(0) = Ps_0;\ Pp(0) = Pp_0;\ Qd(0) = Qd_0;\ P(0) = P_0. \quad (45)$$

The constructed economic and mathematical model of the state's influence on the development of the feed crop growing industry is presented in the form of a system of differential equations with initial conditions, that is, the Cauchy problem. However, it also contains a system of constraints and an objective function in the form of an integral. That is why the solution to this problem should be carried out in 2 stages:

The first stage is the solution of the Cauchy problem in numerical form without taking into account the maximisation of the objective function, provided that the state exposure parameters are $u_1, u_2(t) = 0$.

The implementation of such a numerical solution is possible according to the 4-5 order Runge–Kutta method. To numerically solve a system of differential equations with initial conditions by the 4-5 order Runge-Kutta method, in the Matlab environment there are such built-in functions as ode23 and ode45, which differ in their accuracy of calculations. The ode23 function calculates the result up to 3 decimal places, and ode45 – a maximum of 6 decimal places.

The syntax for the ode45 function is as follows (46):

[*t*, *X*] = ode45('<*function_name*>', *t*0, *tf*, *x*0, *tol*, *trace*), (46)

where <*function_name*>' – a string variable, which is the name of the M-file in which the right-hand sides of the system of differential equations are calculated; *t*0 – the initial moment of time; *tf* – the final point in time; *x*0 – the vector of initial conditions; *tol* – calculation accuracy; *trace* – a flag that regulates the output of intermediate results and is equal to zero by default.

The 4-5-order Runge-Kutta method is one of the most common methods for solving systems of differential equations with initial conditions. Below is his abridged algorithm. Suppose that on the interval $[a, b]$ it is necessary to find a numerical solution of differential equation (47):

$$y' = f(x, y),\ y(x_0) = y_0. \quad (47)$$

Divide the segment $[a, b]$ into n equal parts with the help of points (48):

$$x_i = x_0 + i\,h (i = 0..n), \quad (48)$$

where, (49)

$$h = \frac{b-a}{n}. \quad (49)$$

In the Runge-Kutta method, successive values y_i of the desired function are determined by the formula (50):

$$y(i + 1) = y_i + \Delta y. \quad (50)$$

If to expand the function y in the form of a Taylor series, and also restrict to terms up to h^4 inclusive, then, respectively, the increase in the function Δy can be represented in the form (51):

$$\Delta y = y(x+h) - y(x) = hy'(x) = + \frac{h^2}{2} y''(x) + \frac{h^3}{6} y'''(x) + \frac{h^4}{24} y^{IV}(x). \quad (51)$$

Instead of the direct calculations that appear in the formula (51), the Runge-Kutta method determines 4 numbers by the formula (52):

$$\begin{cases} k_1 = hf(x, y), \\ k_2 = hf\left(x + \frac{h}{2}, y + \frac{h_1}{2}\right) \\ k_3 = hf\left(x + \frac{h}{2}, y + \frac{h_3}{2}\right) \\ k_4 = hf(x + h, y + k_3) \end{cases}. \quad (52)$$

If to give the numbers k_1; k_2; k_3; k_4 weights $\frac{1}{6}, \frac{1}{3}, \frac{1}{3}, \frac{1}{6}$, then the weighted average of these numbers, respectively, are accurate to the fourth power to Δy, which is determined by formula (52), as shown in formula (53):

$$\Delta y = \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4). \quad (53)$$

Using formula (53), (54) is obtained:

$$\Delta y_i = \frac{1}{6}\left(k_1^{(i)} + 2k_2^{(i)} + 2k_3^{(i)} + k_4^{(i)}\right). \quad (54)$$

Also, for each pair of values and using formulas (52) values are determined (55):

$$\begin{cases} k_1^{(i)} = hf(x_i, y_i), \\ k_2^{(i)} = hf\left(x_i + \frac{h}{2}, y_i + \frac{k_1^{(i)}}{2}\right) \\ k_3^{(i)} = hf\left(x_i + \frac{h}{2}, y_i + \frac{k_2^{(i)}}{2}\right) \\ k_4^{(i)} = hf\left(x_i + h, y_i + k_3^{(i)}\right) \end{cases}. \quad (55)$$

Finally, the following approximation will be calculated by the formula (56):

$$y(i + 1) = y_i + \Delta y_i. \quad (56)$$

Having solved the Cauchy problem in numerical form using the Runge-Kutta method, the result of the model's behaviour is obtained without taking into account the maximisation of the objective function, provided that the state does not affect the model in any way. The second stage – to take into account the influence of the state with the help of two tools listed in the model, namely: providing money to enterprises for the development of production and purchasing raw materials from enterprises for its further processing and sale. It is known that the state influence parameters $u_1(t)$, $u_2(t) \in [0,1]$.

Divide the segment into 100 intervals with a step of 0.01. Thus, there are 101 limiting values for each state influence parameter. In this case, the maximum number of combinations that need to be sorted out is 10,201. It is impractical to select a larger number of iterations due to the limited capabilities of a personal computer that calculates 1 iteration in about 11 seconds, and 10201 iteration – respectively with = 11 s×10,201 iteration = 32 hours. To solve the modelling problem, it is first necessary to identify the initial conditions (Table 3) and set the values of the model parameters (Table 4).

***Table 3**. Model parameter values (data for 2023)*

The name fof the indicator	Denotion	Value
The area of fields planned for feed crop, million ha	*S*	16
Business income tax	*tax*	0.26
The cost of processing raw materials per product, KZT	*pb*	250,175
State duty for the import of seed in the country	*toll*	0.20
Seed price per ton, KZT	*pz*	2,343,500
State purchase price of raw materials from private enterprises, KZT	*z*	323,800
Weather coefficient	*kw*	0.000757
Crop rotation condition	*Dsz*	0.7
Feed dissimilarity coefficient	*nz*	1
Tillering ratio	*kk*	36.9
Material sowing rate, t/ha	*np*	0.30
The share of raw materials that entrepreneurs wish to process	*a_1*	0.027
Depreciation rate	*kpq*	0.027
Cost-effectiveness ratio for field processing	*kpqn*	0.0085
The amount of feed crops that consumer would be willing to buy at zero price, t	*a*	10,000,000
The slope of the demand curve	*b*	1,000
Price elasticity of demand	*Ep*	0.01

***Source:** compiled by the authors based on Bureau of National Statistics (2023a, 2023b)*

***Table 4**. Initial conditions of the model (data for 2023)*

The name of the initial condition	Denotion	Value
The initial amount of sown feed crop in the process of growth in the fields, million tons	*Pv*(0)	27.5
The initial amount of feed that does not meet the GAFTA standard (raw materials), million tons	*Ps*(0)	0.14
The initial amount of grain that meets the GAFTA standard (product), million tons	*Pp*(0)	0.19
The initial price of grain per 1 ton, KZT	*P*(0)	532,550
The initial amount of money of enterprises, tn KZT	*Cp*(0)	16.83
The initial amount of state money, tn KZT	*Cd*(0)	49.72
Initial consumer demand for feed crops, t	*Qd*(0)	0

***Source:** compiled by the authors based on Bureau of National Statistics (2023a, 2023b)*

It should be noted that the availability and quality of feeding resources directly impact the growth and size of the beef cattle population. Adequate and nutritious feed supports optimal growth rates, reproduction, and overall health, enabling a larger and more sustainable population of cattle.

DISCUSSION

The primary food crops cultivated in Kazakhstan are wheat (60.3%), barley (14.9%), and potatoes (16%), as reported by D. Wang *et al.* (2022). Water scarcity and soil alkalinity are the primary constraints on wheat yield, whereas soil alkalinity is the main limiting factor for barley. The current distribution of staple crops in Kazakhstan is not ideal, but the suggested distribution plan of "Northern-Wheat, Southern-Barley, and Wheat, and Western-Potatoes" is expected to increase crop productivity significantly. The complementary findings of the author's research can be supplemented by policy analysis and growth modelling, creating a more complete understanding of agricultural optimisation in Kazakhstan.

G. Lukhmanova *et al.* (2019) identify the primary paths of innovative development for ensuring the sustainability of farmers in the country and suggest recommendations for advancing innovation in the agricultural sector. The authors propose that the modernization policy for the agricultural sector should consider the industry's operational specifics, epistemological origins, and developmental drivers. The integration of the approaches of G. Lukhmanova *et al.* (2019) and the authors of this paper could create a robust strategy combining data-driven models with tailored policies for sustainable agricultural growth and innovation in Kazakhstan.

L.A. Tokhetova *et al.* (2020) highlighted the Republic of Kazakhstan's potential for cultivating eco-friendly agricultural production due to its vast agricultural land, numerous farms, and inclination towards producing environmentally sustainable goods. Since 2016, Kazakhstan experienced a decrease in organic agricultural areas by 114 thousand hectares, representing 0.1% of all farmland in the country in 2020. This reduction was linked to the coronavirus pandemic and the global economic crisis. With the authors' results these studies can provide a comprehensive understanding of sustainable agricultural practices, inform policy decisions, and address both environmental and economic aspects, leading to a holistic approach for the development of Kazakhstan's agriculture in a sustainable and economically viable manner.

A study by T. Atakulov *et al.* (2024) conducted in southern and southeastern Kazakhstan introduced innovative techniques to maximize agricultural output through double cropping systems and developing a "green conveyor" for animal feed. Researchers identified plant species suited for two annual harvests based on local climate conditions and established a system involving winter rapeseed and triticale as primary crops followed by corn as an intermediate crop for both grain and silage. This approach led to increased yields, with rapeseed producing 676 cnt./ha and triticale generating 648 cnt./ha during their respective growth phases. Additionally, corn provided extra grain and silage yields of 73.0 and 720 cnt./ha respectively. Compared to no intermediate crops, the inclusion of corn resulted in significantly higher overall feed unit yields ranging between 198.4 and 236.0 cnt./ha. The most profitable outcome occurred when sowing intermediate crops, resulting in net incomes of 143.8-160.8 thousand KZT/ha and profitability levels of 89.8-97.5%.

G. Samenova (2022) discusses the importance of modernizing and innovating agriculture in Kazakhstan, particularly focusing on corn production as a strategic yet understudied aspect. In 2021, corn cultivation covered approximately 301 thousand hectares in Kazakhstan, split between grain corn (63%) and silage corn (37%). The Almaty region accounted for half of the total grain corn produced in the country. Over 25 different corn seed origins were offered to Kazakhstani farmers who planted over 150 diverse corn hybrid varieties. However, 60% of these seeds were imported into the country. To improve the corn industry, Kazakhstan must address challenges related to the modernization of farm machinery and agricultural techniques. Additionally, the seed system needs enhancements at every stage of the corn production chain, including the adoption of innovative solutions (Drobitko & Kachanova, 2023).

The COVID-19 pandemic has worsened global food security, which was already compromised by climate change and armed conflicts (Babayev, 2023). This has led to a high demand for methods to improve cereal production efficiency. A study by V. Uteulin and S. Zhientaev (2022) was conducted to develop a methodological approach to enhance cereal production efficiency, which relied on time series to determine trends and make projections. The research was conducted in the Kostanay region, which experienced severe weather conditions in 2019, leading to a significant decrease in cereal production. The study anticipates substantial potential for increasing cereal production in the region and proposes an action plan to enhance efficiency. This plan includes optimizing state support, creating accessible crop insurance, boosting cereal yields, improving logistic infrastructure, and implementing thorough monitoring of cereal production. The study performed an econometric analysis of cereal production trends in the Kostanay region. It identified negative trends but highlighted that the region continues to be a significant producer of cereal crops and high-quality wheat.

The mathematical model developed by the authors is built on economic theories related to cattle population growth and feed crop production, using mathematical modelling and numerical simulations. Variables were chosen based on trends, policy assessments, and factors influencing the feed crop industry. This model aids decision-makers by providing scenario analyses and policy impact assessments. Its reliability stems from its rigorous mathematical basis and real-world data alignment, though complexities in modelling real-world dynamics could be a potential weakness. The model's strength lies in its comprehensive approach and practical solutions for industry sustainability.

CONCLUSIONS

The study showed that the growth and sustainability of beef cattle in Kazakhstan is inextricably linked to the availability and quality of forage resources. Sustainable development requires an integrated, evidence-based approach that includes optimising growing practices, fertiliser use, protecting domestic producers and implementing sustainable pasture management practices. The data reveal significant growth in the gross agricultural output across regions such as Akmola, Kostanay, and North-Kazakhstan, with the Republic of Kazakhstan's output reaching an impressive 7741.9 billion KZT in 2023, a substantial increase from 2256.3 billion KZT in 2022. Similarly, the cattle stock has shown notable growth, with the total number of cattle in Kazakhstan increasing to 8538.05 thousand heads in 2023, up from 6813.9 thousand heads in 2022.

Comparing the data for 2019 and 2023, as well as for 2022 and 2023, we see a marked increase in both agricultural output and cattle numbers, indicating the positive impact of feed optimisation and government support policies. This upward trend emphasises the direct correlation between feed quality and cattle health and growth. The study recommends further optimisation of government support policies, including enterprise financing and strategic raw material procurement, to further increase forage crop production. In addition, adherence to international quality standards and the introduction of stratified crop specialisation are necessary to significantly increase beef cattle numbers in the next 5-10 years.

The prospects for further studies in the field of beef cattle population growth and sustainability in Kazakhstan are highly promising. Ongoing research should prioritize the optimization of feeding resources, including sustainable crop cultivation techniques and nutritional analysis, to ensure a consistent supply of high-quality feed. Additionally, economic modelling and policy analysis should continue to guide evidence-based decisions, particularly in terms of government support policies.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Економічна модель розвитку галузі кормовиробництва в Республіці Казахстан

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Анотація. Галузь тваринництва переживає стрімке зростання, і, за прогнозами, попит на продукцію тваринництва продовжуватиме швидко збільшуватися завдяки зростанню чисельності населення, підвищенню рівня життя та урбанізації. Метою цієї статті є оцінка доцільності використання створеної моделі вирощування кормів для м'ясного скотарства на етапі стандартного планування економічного розвитку. Автори визначають пшеницю як референтну культуру. У дослідженні використано аналіз, статистичні методи, економіко-математичне моделювання та математичне моделювання. Автори оцінюють потенціал використання створеної моделі для вирощування кормів для худоби, призначених для виробництва м'яса, під час стандартної фази планування економічного розвитку. Модель прогнозує економічно ефективні корми. Розроблена авторами економічна модель уможливлює зростання кормової бази, зменшує залежність від імпортних кормів та сприяє розширенню м'ясних порід, що є унікальним аспектом дослідження. Дослідження підкреслює важливість стратегічного розподілу, спеціалізації та концентрації м'ясного скотарства в конкретних природних та економічних умовах. Воно також підкреслює важливість інтеграції великомасштабного виробництва з середніми та малими сільськогосподарськими підприємствами в м'ясній промисловості. Практичне значення дослідження полягає у використанні специфічних структур і контролі частки імпорту у виробництві кормів, а також обмеженні пропозиції кормів і готових харчових добавок для гарантування продовольчої безпеки

Ключові слова: вирощування кормових культур; постачання продовольства; зростання; продовольча безпека; економічна модель