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OPTIMIZATION OF FEED PROCUREMENT TECHNOLOGY TO MINIMIZE THE COST OF MILK FOR FARMS OF DIFFERENT PRODUCTION CAPACITIES

The object of research is the processes of harvesting, storage and feeding of stalk fodder in the feed supply system of Ukrainian dairy farms of various sizes and their impact on the economic indicators of milk production.

The research solves the problem of choosing the optimal and economically feasible method of fodder procurement for certain production conditions. A nonlinear model has been developed for choosing the method of procurement for silage-hay feed rations of dairy farms of various production capacities (from 100 to 1200 heads) has been developed.

The relevance of research is due to the need to create a scientifically based tool for optimizing the technology of fodder procurement, aimed at increasing the efficiency of fodder production, preserving the nutritional value of products and ensuring the competitiveness of dairy cattle breeding.

A model has been developed for optimizing production based on nonlinear programming, which takes into account technological, biochemical and economic losses of nutrients. The optimization criterion was chosen as the cost of 1 kg of milk, provided that the physiological needs of animals in dry matter, protein, and metabolizable energy are met. The theoretical model was built on the basis of nutrient balance ratios, production function of productivity, cost function and optimization of the production structure taking into account resource, technological and market constraints. The implementation was carried out using iterative methods. The results indicate an economically feasible production volume within 944–1150 cows for the productivity level, where the minimum specific costs are achieved. It is proven that a reduction in dry matter losses by 5% provides a reduction in the cost of milk by 3–6% depending on the size of the farm. Three-dimensional response surfaces were constructed, which can serve as a tool for planning dairy farms.

Keywords: roughage, diet, nutrients, dairy farm, model, optimization, cost price.

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1. Introduction

Successful and productive development of livestock farming directly depends on providing animals with complete and high-quality feed throughout the year and at all stages of their physiological cycle. A rational cattle feeding system must guarantee a stable supply of nutrients in the required quantity and ratio, which determines the planned level of productivity, reproduction, and overall economic efficiency of the industry. At the same time, modern practice of feed production is characterized by a significant variety of technologies for harvesting plant raw materials – from traditional ensiling and haying to intensive preservation methods using biological and chemical preservatives [1]. Technological requirements for the production of conserved feeds and ensuring their stability during long-term storage have been studied in detail [2]. In particular, the parameters of heat and mass transfer and factors for prolonging the shelf life of feed raw materials were substantiated [3]. Within this set of technological solutions, the problem of choosing the most optimal and economically feasible methods of feed procurement for specific production conditions is relevant.

In the structure of cattle feeding, concentrated, coarse, juicy and green feeds are used. Their assortment and feed value depend on the type

of forage crop, its vegetation phase, agricultural cultivation techniques, harvesting method, preservation technology and storage conditions [4]. Scientific researches prove that the quality of prepared feeds is formed under the influence a complex of interrelated factors. The key factors are the chemical composition of the initial plant mass, the degree of crop ripeness, technological parameters of grinding or compaction, fermentation mode, as well as the duration and storage conditions. Violation of optimal modes at any of the stages of the technological process leads to losses of dry matter and a decrease in the nutritional value of feeds [5].

Dry matter, which indicates the nutritional value of feed, consists of organic and mineral parts (ash). The organic component, in turn, is represented by nitrogen-containing components (proteins, amides) and nitrogen-free substances (crude fat, crude fiber, nitrogen-free extractives). Losses of dry matter during harvesting and storage actually mean a decrease in the proportion of each of the listed components. This directly affects the energy and protein content of diets [6].

Given the reference values of the chemical composition of feeds allowing transforming dry matter losses into losses of nutrients – protein, fat, fiber and nitrogen-free extractives [7]. Thus, technological errors in the canning process have not only a physical but also an economic dimension, as they reduce the yield of nutrients per unit of resources spent.

Despite a significant body of empirical research, the issue of a comprehensive economic and mathematical justification for the choice of canned feed production technology on the example of cattle farms remains underdeveloped in the scientific literature. Existing approaches are mostly based on a comparative analysis of individual indicators such as yield, cost and percentage of losses [8]. While modern management conditions require a systemic toolkit capable of integrating production, technological and economic parameters into a single optimization model [9].

In this regard, the scientific problem of developing a mathematical model of canned feed procurement. Such a model should formalize the process of minimizing losses of dry matter and nutritional components, assessing the impact of technological factors on the final quality of feed and determining the economically optimal procurement technology taking into account resource and technical constraints. The model must consider the nonlinear nature of the relationships between feed quality, loss levels, production volume and costs. It should also allow predicting results under different production scenarios [10].

The object of research is the processes of harvesting, storage and feeding of stalk fodder in the feed supply system of Ukrainian dairy farms of various sizes and their impact on the economic indicators of milk production.

The aim of research is to optimize the technology of feed procurement to minimize the cost of milk production on cattle farms. This ensures the maximization of enterprise profits, taking into account the effect of scale, technological losses of feed, herd productivity, logistical costs, and resource constraints.

This aim can be achieved by solving the following objectives:

1) to analyze the current state and formalize the structure of nutrient losses in the processes of harvesting and storage of stem feeds, as well as to establish the relationship between production, technological and economic parameters of dairy farming;

2) to develop a nonlinear multifactorial mathematical model for optimizing the structure of the production process under resource, technological and market constraints;

3) to form analytically based recommendations for strategic planning development of dairy farms of various production capacities.

2. Materials and Methods

The methodological basis of research is a systematic approach to analyzing the feed procurement process as a multifactorial production and economic system, in which the quality of the final product is formed under the influence of technological, biological and logistical parameters.

The subject of research is the economic and mathematical dependence between the structure of the diet, the parameters of canning technology, animal productivity, and total production costs.

The methods of mathematical modeling, nonlinear programming, constraint analysis, gradient optimization, and numerical solution were used. The theoretical model is built on the basis of nutrient balance ratios (Fig. 1), production function of productivity, and cost function, which take into account the nonlinear nature of the dependencies [11].

Total nutrient losses during ensiling of various forage crops can be divided into two parts: field losses and losses during storage of feed in the storage facility [1, 2]. Analyzing the literature on this issue, it turned out that it is important to take into account another type of loss – these are losses during laying the silage in the storage facility [12] and losses due to poor feed digestion. The quantitative value of different types of losses during ensiling varies greatly according to different authors. This is probably due to the fact that different technologies are characterized, different silage crops are used, and data on losses in feeds of different quality categories are also given [13]. In general, the higher the quality of the silage (quality class), the lower the losses of nutrients and energy, and vice versa, the lower the quality of the silage, the greater the losses (Table 1) [5].

Table 1

Losses of energy and nutrients in dry matter of grass silage depending on the quality class of feed

Indicators	Losses, %			
	First grade	Second grade	Third grade	Unclassified feed
Dry matter	5–10	8–12	10–15	12–16
Energy	8–10	12–18	16–23	20–30

When using ensiling, there are inevitable losses and losses that can be eliminated [6]. The inevitable losses include: slow filling of the storage, insufficient compaction of plant raw materials, secondary fermentation and, as a result, burnout, aerobic decomposition of the silage after unloading (Fig. 2).

All these losses should be minimized. Separately, it is necessary to note the losses of silage due to heating and burning, which are obtained when laying a dried – up silage due to its insufficient sealing. Due to heating of the laid plant mass even by 15–20°C in the silo there are losses of energy and protein Table 2 [6].

To reduce nutrient losses due to excessive silage juice release, feed producers dry the green mass before ensiling to a moisture content of 55–75%, or bind moisture and leave it in the silage mass using plant additives: straw, dry beet pulp [7, 14].

Important for minimizing nutrient losses are the processes of active ventilation and drying of plant mass, which affect the reduction of moisture and stabilization of feed during storage [15]. The experimental results obtained confirm the need to take into account the kinetics of drying in the formation of the coefficient of technological losses λ_t .

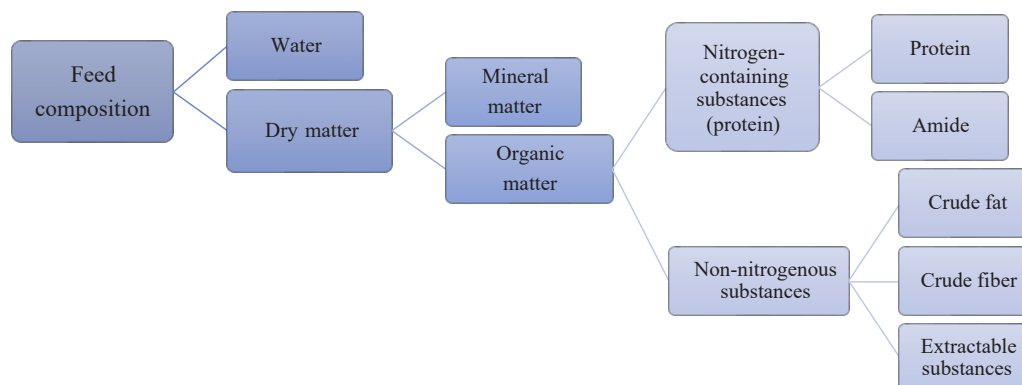


Fig. 1. Scheme of the general composition of most nutritious feeds

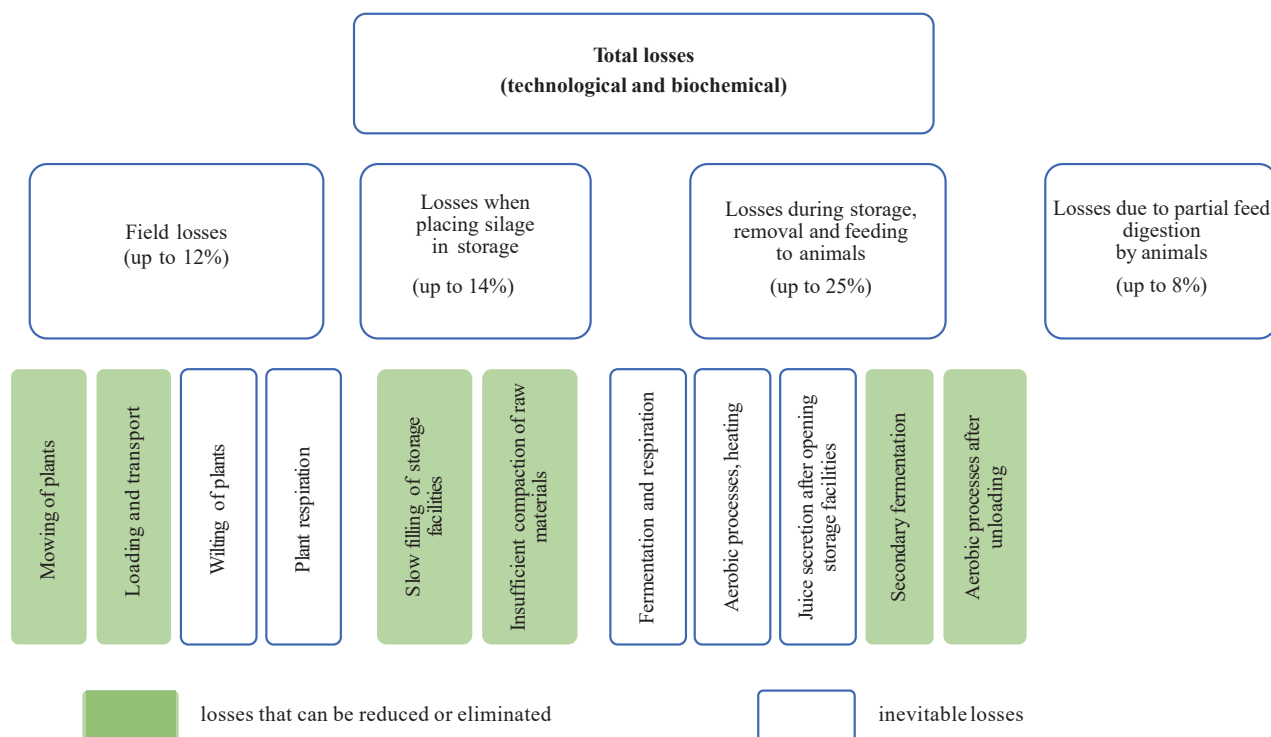


Fig. 2. Nutrient losses during the ensiling process

Dependence of energy losses and digestible protein on heating of silage mass

Table 2

Silage quality	Losses	
	energy, %	digestible protein, %
High quality, warming below 40°C, lactic acid fermentation	6–8	0–5
Average quality, slight warming to 40–50°C, undesirable fermentation	12–15	15–20
Low quality, high heating above 50°C, undesirable fermentation	20–25	25–30

When harvesting haylage, nutrient losses always occur: during harvesting; during storage; due to nutrient deficiencies.

Losses during haymaking can be divided into biochemical and mechanical. The group of mechanical losses includes losses during mowing, turning, stacking, tying grass, picking up and transporting haylage. When mowing, a high stubble height is often allowed, which leads to a shortage of plant raw materials of up to 40%. When raking dried grass, leaves, inflorescences and other parts of the plant are lost [3].

In Europe and the USA, silage of fodder crops in rolls is becoming widespread. In this case, one roll of average weight 400–500 kg is tightly covered with film, tightened like a bag, and laid on the ground. A group of rolls is covered with another film, and the edges of the film are fixed with earth or sand [14].

Hay is a chopped stem fodder of medium humidity (40–50%), which is stored without access to oxygen. Grasses are used by cereals and legumes, which are collected in the phase of the greatest nutritional value. Hay has a number of advantages when compared to silage and hay. When harvesting hay, less time is required for drying and harvesting in general (under good weather conditions, the grass can be mowed, dried, collected and chopped in one day), due to this, field losses will be only a quarter of the losses when harvesting hay. The protein content in hay is higher than the protein content in hay. Labor costs when harvesting hay are almost half that when harvesting hay, and hay is also readily eaten by livestock [15].

If included in the composition of feed mixtures pea-oat hay, it contributes to increasing animal productivity. The group of cows that received more hay in the feed mixture digested dry matter, protein, fat, fiber and BER better. For the production of 4% milk fat content, fewer feed units (7.1–9.8%) and digestible protein (1.7–3.9%) were spent. Hay-concentrate rations are more profitable: the cost of milk decreases, and profitability increases by 27–30% [16].

Losses during hay storage can also be divided into biochemical (respiration, fermentation, heating) and technological, that is, those caused by non-compliance with technological standards during hay production: time of hay laying, low degree of forage compaction, non-compliance with the tightness of the plant raw material cover, atmospheric precipitation, groundwater and moisture entering the forage [17].

A more detailed diagram of nutrient losses during haymaking and the amount of loss is shown in Fig. 3. The identified losses can be eliminated by observing the technology of haymaking and storage.

Nutrient losses during haymaking can be extremely high. In a bad year, in some cases, the entire crop may be lost – it is not possible to dry the plants, atmospheric precipitation greatly affects the chemical composition of hay. Thus, dry matter losses are 18.3% in haystacks and 29.4% in mowing, and the losses of digestible protein are 19.8% and 38.8%, respectively [18]. According to other data, the losses of dry matter in good weather are 16.4%, in bad weather – 25.2%, and the losses of crude protein – 23.3% and 49.7%, respectively [19–21].

If hay is harvested at a humidity of more than 20%, as a result of enzymatic processes, the temperature during heating can reach 70°C. This causes losses of dry matter and a sharp decrease in digestibility. Increased humidity provokes the development of fungi, bacteria, mold, which can even cause poisoning of animals. To prevent such processes in wet hay, it is stored with the addition of preservatives: anhydrous ammonia, propionic and other acids [17].

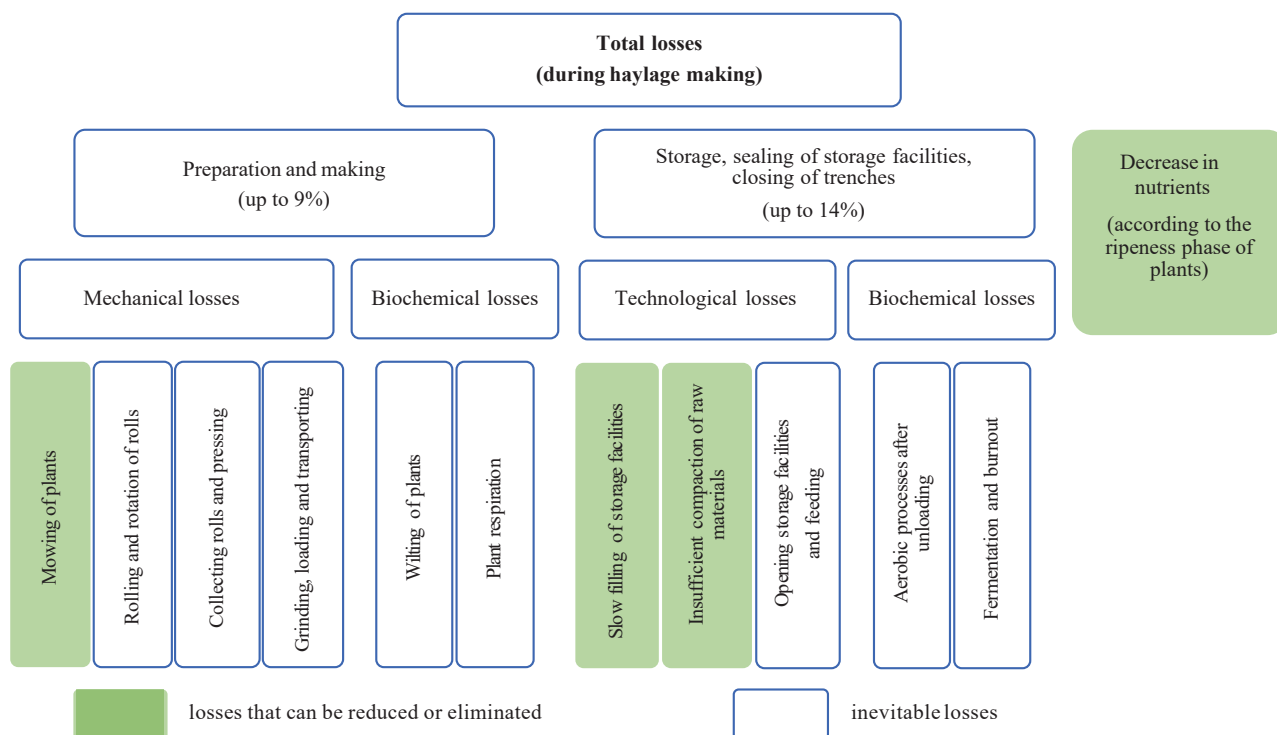


Fig. 3. Nutrient losses during haylage making

3. Results and Discussion

3.1. Analysis of the state and formalization of the structure of nutrient losses

The justification of the technological process systems for the procurement of feed for cattle is carried out on the basis of modeling the processes of procurement of stem and succulent feeds, their preparation and distribution on dairy farms for 100, 200, 400, 800 and 1200 cows [11, 20]. This methodological approach is used to justify the technological process systems for different technologies for the procurement of the main types of roughage used on dairy and fattening cattle farms – silage, haylage and hay [1, 15].

For silage harvesting, the traditional technology of harvesting in trench storages and polyethylene sleeves is simulated. For haylage harvesting, the traditional technology and technologies of harvesting in rolls wrapped in polyethylene film, as well as in polyethylene sleeves, are simulated [14]. Depending on the technology of forage harvesting, the composition of feed nutrients is determined (Table 3).

The main criterion for substantiating technological process systems is the cost of the dairy farms products. The substantiation also takes into account the indicators of specific costs for feed procurement, exchangeable energy by type of feed, which are procured using different technologies [9].

The input data of the model are: chemical composition of feed (content of dry matter, crude protein, fat, fiber, metabolizable energy),

normative needs of cows in nutrients depending on the level of productivity, technological parameters of harvesting and logistical characteristics of transportation. All values are considered as deterministic parameters with the possibility of further analysis [6].

3.2. Development of a nonlinear multifactor mathematical model for optimizing the production structure

A key element of the model is the formalization of dry matter losses of feeds during their harvesting. The effective amount of dry matter of the *i*-th feed after the completion of the technological cycle is defined as

$$DM_{efi} = DM_i \cdot (1 - \lambda_i), \tag{1}$$

where DM_{efi} – the initial dry matter content in the feed; λ_i – the total loss coefficient.

The loss coefficient is considered as a function of a set of technological parameters

$$\lambda_i = f(t_{fill}, \rho, T, W, L), \tag{2}$$

where t_{fill} – the duration of filling the storage facility; ρ – the degree of compaction of the feed mass; T – the ambient temperature; W – the mass humidity; L – the logistical transportation distance.

Table 3

Nutrient constituents of different types of feed

Technology	Traditional silage	Silage in a sleeve	Traditional haylage	Haylage roll in packaging	Traditional hay	Hay roll	Hay roll in packaging
Dry matter	0.876	0.341	0.501	0.512	0.832	0.874	0.841
Crude protein, g/kg	26	30	86	101	99	121	165
Crude fat, g/kg	9.5	11	12.3	13.6	21	22	20.2
Fiber, g/kg	85	112	105	108	214	211	214
Non-nitrogenous extractive matter, g/kg	133	164	216	218	309	337	366
Metabolizable energy, MJ/kg	–	–	4.65	4.92	6.61	7.09	7.92

This dependence is nonlinear, since the influence of each factor is interrelated and exponential or stepwise. An example is the increase in the duration of filling the storage, which increases the intensity of aerobic processes and exponentially increases the loss of organic matter. Similarly, an insufficient degree of compaction causes an increase in the oxygen diffusion coefficient, which nonlinearly affects the fermentation processes [5, 6].

Since dry matter consists of protein, fat, fiber and nitrogen-free extractives, the losses of the DM_{fji} are equivalent to the losses of the corresponding nutrient components. Thus, the effective content of metabolizable energy and crude protein are also corrected for the coefficient λ_i [7].

The following variables are used in the mathematical model of nonlinear optimization:

- x_i – the amount of i -th feed in the diet of one cow (kg/day);
 - N – the farm livestock, cows;
 - Y – the annual yield of one cow (kg).
- Annual amount using and i -th feed is

$$Q_i = N \cdot x_i \cdot 365. \quad (3)$$

Cow productivity is determined by the level of energy supply and is described by the exponential saturation function

$$Y = Y_{\max} \cdot \left(1 - e^{-k(E - E_{\min})}\right), \quad (4)$$

where Y_{\max} – the genetically determined maximum productivity; E – the actual intake of exchange energy; E_{\min} – the minimum need to maintain life; k – the digestibility coefficient.

The function is continuous, differentiable, and strictly increasing at $E > E_{\min}$, but its second derivative is negative, indicating a decreasing marginal energy yield [3].

The total costs of an enterprise are defined as

$$C_{\text{sand}} = \sum_i Q_i \cdot c_i + C_{\text{perm}} + C_{\text{en}} + \alpha \cdot L^{1.2} \cdot Q, \quad (5)$$

where $\sum_i Q_i \cdot c_i$ – the feed costs; c_i – the cost of the unit of the i -th feed; C_{perm} – the permanent costs; C_{en} – the energy costs; $\alpha \cdot L^{1.2} \cdot Q$ – the logistic component with a stepwise dependence on distance reflects the increase in costs not only due to the fuel component, but also due to time costs and depreciation of equipment [10].

The functional target optimization criterion is to minimize the specific costs per unit of output

$$F = \frac{C_{\text{sand}}}{N \cdot Y}. \quad (6)$$

Since Y is a nonlinear function, x_i the problem belongs to nonlinear fine-grained rational programming. There is a system of restrictions, namely dry matter balance, energy balance, protein balance and technological restrictions:

- by dry matter balance

$$\sum_i x_i DM_{fji} \leq DM_{\max};$$

- by energy balance

$$E \geq OE_{\text{port}i};$$

- by protein balance

$$P \geq CP_{\text{port}i};$$

- yield and agricultural land resources

$$\sum_i \frac{Q_i}{Y_{\text{yield}i}} \leq S_{\text{land res}};$$

- technological limitations

$$Q \leq P_{\text{tech}i}.$$

In this form, the domain of admissible values is bounded under the condition of finite resources, which guarantees the existence of a minimum. The model of the nonlinear programming problem with inequalities is solved using the apparatus of Lagrange multipliers and the Kuhn-Tucker condition [4]

$$L = F + \sum_k \lambda_k g_k(x). \quad (7)$$

Under the condition of stationarity

$$\nabla F + \sum_k \lambda_k \nabla g_k = 0. \quad (8)$$

The solution and numerical implementation are carried out by the iterative Sequential method. Quadratic Programming (SQP), which is effective for nonlinear problems with inequalities and verification of Kuhn-Tucker conditions. The criterion for completing the iterative process is the fulfillment of the condition

$$\nabla L < 10^{-6}. \quad (9)$$

Solving the problem of choosing and optimizing the technology of feed procurement using the example of stem feed for dairy farms based on economic and mathematical modeling. Depending on the cost of the diet, specific costs, cost of exchangeable energy, scale of production and level of productivity [1, 4].

3.3. Recommendations for strategic planning and development of dairy farms

Approximation of experimental data showed that the specific costs of forage harvesting using traditional trench technology are described by a quadratic relationship

$$C_B(x) = 2.4 \cdot 10^{-5} x^2 - 0.0552x + 227.364, \quad (10)$$

which reflects the effect of production scale. A quadratic function with a positive coefficient x^2 indicates the existence of a minimum point, after which the share of transport costs in the structure of total costs begins to grow. Analytical determination of the stationary point allows to establish the optimal size of the farm with an indicator $x \approx 1150$ cows.

Similarly, the cost of milk is determined for a base productivity level of 4,500 kg/year, which is described by the equation

$$C_m(x) = 1.08 \cdot 10^{-5} x^2 - 0.0204x + 21.73, \quad (11)$$

which also has a minimum at the point $x \approx 944$ cows.

The obtained values are practically identical, which confirms the consistency of the model and the economic feasibility of a production scale of about 950–1150 cows. In this area, a balance is achieved between a decrease in fixed costs per unit of production and an increase in logistics costs [9].

Further analysis showed that for higher productivity levels (6500–8500 kg of milk per year) the cost dependence has a stepwise nature

$$C_m(x) = kx^{-n}. \quad (12)$$

This indicates a gradual decrease in cost with increasing scale of production and productivity. With a cow productivity of over 8500 kg of milk per year, the cost decreases to 0.31 USD/kg (taking into account a 30–40% increase in costs from 2022), confirming the decisive influence of productivity on economic performance [17].

Modeling of feed supply processes of a dairy farm with a silage-haylage ratio for feeding dairy cows (haylage and silage in a ratio of 16/20 kg) shows that the specific costs of a ration, the stem fodder of which is prepared according to traditional technology – stored in trenches, are 4.7–6.4 USD/t (Fig. 4). At the same time, for silage they vary from 2.7 to 4.0 USD/t, and for haylage – from 7.2 to 8.6 USD/t. It should be noted that the slow decrease in costs with an increase in feed production is associated with a change in the component of the total costs for their preparation [10].

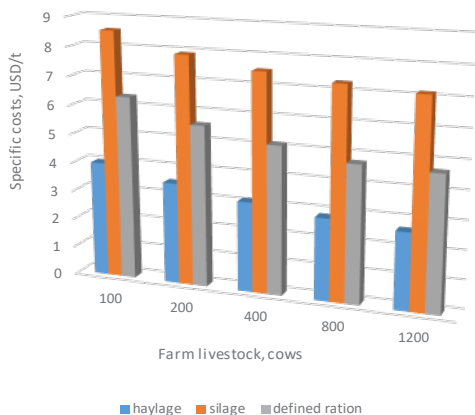


Fig. 4. Specific costs of feed procurement on farms of various sizes using traditional growing technology (4500 kg/year)

To verify the results, recalculation was performed according to the developed algorithm using different initial approximations of variables, which allows to avoid the dependence of the results on local minima. In-depth analysis is possible on the basis of the constructed three-dimensional response surfaces. Regression equations are compiled using the Statistica software package. Thus, the nonlinear programming problem with one controlled variable is formalized – the size of the $x \rightarrow [100...1200]$ head farm, taking into account the system of economic and technological constraints [4].

Analysis of the milk production cost (Fig. 5) revealed a pronounced minimum in the range of farms with a livestock of 750 to 1150 heads and high productivity indicators

$$C_m(x, y) = 1.17 \cdot 10^{-6} x^2 - 0.0027x - 4.982 \cdot 10^{-8} xy - 9.1 \cdot 10^{-5} y + 1.32 \cdot 10^{-9} y^2 + 14.104, \tag{13}$$

where x – the farm’s livestock; y – the productivity of cows on the farm; C_{cm} – the cost of milk.

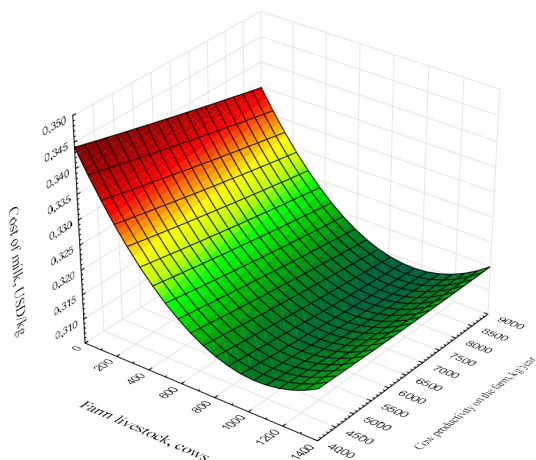


Fig. 5. Graph of the dependence of the cost of milk for different farm livestock and different animal productivity

The presented function surface in the studied productivity range has a decreasing character. This confirms the presence of a combined effect of scale and biological productivity on the cost of dairy products [9].

The impact of transportation costs on the cost of milk is represented by the surface in Fig. 6

$$C_m(x, T) = 1.41 \cdot 10^{-6} x^2 - 0.0031x - 2.86 \cdot 10^{-15} xT + 1.4T + 4T^2 + 14.07, \tag{14}$$

where T is the share of transportation costs in the cost structure.

The analysis shows that the increase in the share of transportation costs in the function leads to an increase in the cost of production. At the same time, for both small and large enterprises, the transportation and logistics costs of delivering and preparing feed increase.

The energy value of the diet is traced by the dependence of metabolic energy on nutrient losses during feed storage and farm livestock (Fig. 7) [6] illustrating that even a slight increase in nutrient losses shifts the optimum towards a larger scale of production

$$C_{OE}(x, \delta) = 7.816 \cdot 10^{-7} x^2 - 0.0016x - 1.19 \cdot 10^{-15} x\delta + 2.59\delta + 3\delta^2 + 6.615, \tag{15}$$

where δ – the storage loss coefficient.

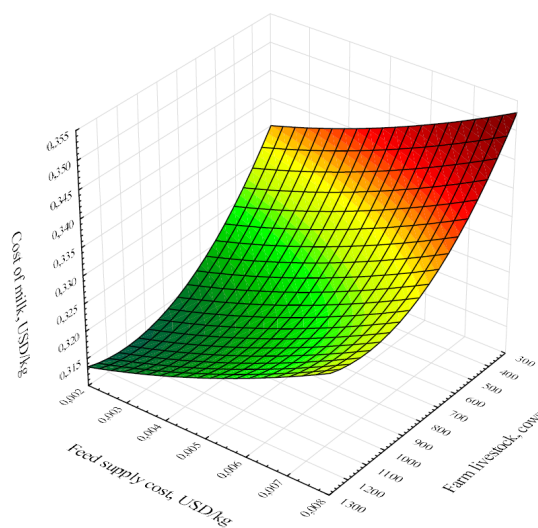


Fig. 6. Graph of the dependence of the cost of milk on the costs of transporting feed at enterprises with different animal populations

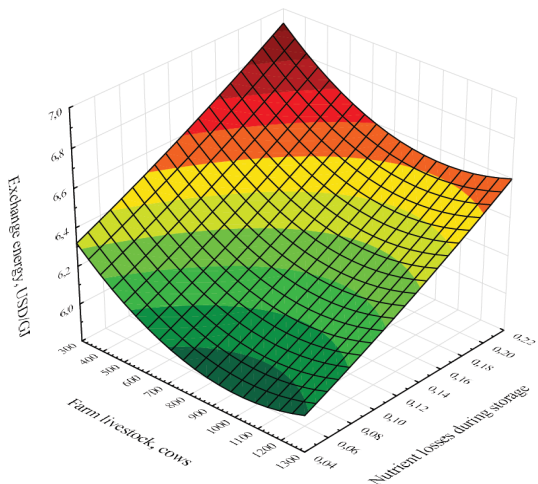


Fig. 7. Graph of the dependence of the cost of metabolizable energy on the loss of nutrients in feed during storage for farms with different numbers of animals

The model takes into account the chemical composition of feed, dry matter losses under the influence of technological and logistical factors, energy supply of animals and the scale of production, which forms the nonlinear nature of the dependences of the cost of milk [9, 11]. The optimization criterion is the minimization of unit costs per unit of production in the presence of resource, energy and technological constraints. The optimal value is the scale of production in the range of 944–1150 heads according to the results of the approximation, which showed the presence of a zone of economic minimum with the achievement of a balance between the effect of scale and the growth of logistical costs.

3.4. Discussion

Practical significance. The obtained results can be used for scientifically based selection of optimal technologies for harvesting silage, haylage and hay depending on the size of the farm. The model and three-dimensional response surfaces allow planning the optimal scale of production (944–1150 heads) and predicting the reduction of milk cost price by 3–6% when dry matter losses are reduced by 5%. The developed tool is also suitable for use in advisory services, design of new dairy complexes and justification of investment projects in the dairy industry of Ukraine.

Limitations of research. The model is based on deterministic parameters and statistical values of nutrient losses. It does not take into account random weather factors, price change of energy carriers and feed additives, as well as regional differences in soil and climatic conditions. Implementation of the results in practice requires additional adaptation of the model to specific farm conditions and verification with actual data of the enterprise.

Prospects for further research. Further research will focus on expanding the model by including additional factors, as well as integrating the model with precision farming technologies and automated feed distribution systems on large dairy farms.

4. Conclusions

1. The article examines the state of feed supply in dairy cattle breeding and analyzes nutrient losses during the procurement and storage of roughage. It has been established that the losses of dry matter and its components are nonlinear and depend on a complex of production, technological and organizational factors, in particular, the duration of filling the storage facilities, the degree of compaction, temperature, humidity, and transportation distance. It has been proven that compliance with feed procurement technologies directly affects the energy supply of animals and the economic indicators of milk production.

2. An economic and mathematical model has been developed that combines the processes of feed production, ration formation, determination of cow productivity, and calculation of the cost of dairy products. The model takes into account resource, technological, and market constraints and is implemented using nonlinear programming methods. The influence of the scale of production, variable energy output and transport component on total costs is taken into account.

3. Based on numerical modeling, an economically feasible range of cow population within 944–1150 heads has been determined, for which the minimum cost of production is achieved. The dependence of reducing dry matter losses of feed has been established provides a significant reduction significant reduction in milk production cost by 3–6%. The obtained dependences can be used for decision-making during the planning of dairy farms and optimization of production processes.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship or other, which could affect the research and its results presented in this article.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented paper.

Authors' contributions

Pavlo Luts: Conceptualization, Methodology, Investigation, Formal analysis, Software, Validation, Writing – original draft; **Ihor Babyn:** Investigation, Data curation, Resources, Writing – review and editing; **Serhii Burlaka:** Supervision, Project administration, Validation, Visualization, Writing – review and editing; **Viktor Mykytyuk:** Methodology, Formal analysis, Validation, Writing – review and editing; **Ruslan Kisilov:** Data curation, Validation, Data validation, Formal analysis, Visualization, Writing – review and editing.

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