Optimizing feed balance of dairy cows: The case of a farm in the Sofia region

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Abstract

The aim of the study is to optimize the feed balance of dairy cows. For this purpose, an optimization model based on linear programming is applied. In order to establish the most balanced nutrition of the cows on the farm, the production structure is optimized. A case from a farm operating in the Sofia region is presented. The optimization model has been successfully adapted to the management of an agricultural enterprise, with the criteria for optimal gross margin and profit. The solution of the task optimizes the feed balance of the dairy cows and optimizes the production structure of the farm.

Key words: optimizing, production structure, feed balance, dairy cows

Introduction

The feed balance of cows is often the subject of debate among the scientific community and practitioners. Research on the diet and feed balance of cows is available (Oba and Allen, 2003; Todorov et al., 2007; Stoop et al., 2009; Weisbjergn, 2014; Daniel et al., 2016; Sarov and Kostenarov, 2019; Ignatova et al., 2020; Krastev and Grigorova, 2020; Price et al., 2021).

According to Todorov (2010, pp. 252-253) when presenting norms for feeding cows, it is specified that they are not accurate because ”... they do not take into account the needs for all functions”. It is emphasized ”... that only the needs for life support and milk productivity are taken into account and can be used to roughly balance rations for a group of animals, especially when feeding at will with basic roughage or whole milk mixture”. Todorov (2010, pp. 253) presents norms for feeding cows depending on the multiple indicators (for the maintenance of life; for 1 kg of milk; for pregnancy; for growth in cows per 1 lactation; for 1 km movement in cows with 550 kg live weight, etc.).

An important and responsible task is to compile the ration of ruminants, in this case dairy cows (although, to be precise, there are also dry cows in a herd, id est, it is necessary to make a separate ration for this one as well group of animals). When drawing up a ration for free-range cows, the following shall be specified: feeding norms; the participation of roughage; concentrated feed; minerals and vitamins (Todorov, 2010).

The aim of the study is to propose a model for optimizing the feed balance of cows. For this purpose, an optimization model based on linear programming is applied. A case from a farm operating in the Sofia region is presented. In order to establish the most balanced nutrition of the cows on the farm, it will be necessary to determine the production structure. This means: the area of crops; a number of animals; other activities.

Materials and Methods

When determining the feed balance of dairy cows, it is necessary to take into account the following indicators: live weight; daily milk yield; growth; protein and fat content of milk; days after calving; grazing distance; road slope, etc. (Todorov, N., ed., 2010, pp. 253-254). Most often the lactation period is maximum during the second half of the first and second lactation months.

In determining the optimal ration of dairy cows on the farm in the current optimization model are taken into account the requirements for ration of animals by tracking mainly the balance of feed units or Net Energy Lactation (NEL) and no other important components (Dry matter (DR); Crude protein (CR); Protein digestible in the gut (MS); Abdominal protein balance (BPT); Calcium (C); Phosphorus (P); Salt (NaCl); Vitamins A and D) when eating.

The development of technical and economic standards is an important stage in the collection of information. For the various agricultural crops, livestock and other activities are used data from developed standards according to the methodology of experts from the Ministry of Agriculture, Food and Forestry, Agricultural Academy, Institute of Agricultural Economics, Institute of Animal Sciences – Kostinbrod. Gathering information is a difficult and time-consuming process. Information from experts and specialists (agronomists and zoo engineers) in the respective field, scientists and publications on the topic are used to obtain it (Todorov, 2010; Todorov et al., 2007). Information on zonal norms and production costs is available in collections and manuals.

On the farm, crops are commodity when final production is obtained, i.e., products for sale. These are: wheat, barley, sunflower, cow's milk.

Non-commodity activities are those from which intermediate production is obtained. On the farm such are:

• fodder crops that are necessary for animal nutrition – wheat, barley, sunflower, corn for silage;

• animals for the reproduction process.

For the various production activities are included data from standards for 1 Decare or 1 item of production:

• Commodity crops and products – average yield, material costs, labor costs, production costs, income, profit, man-days (manual and mechanized labor);

• For intermediate products – average yield, material costs, labor costs, production costs, man-days (manual and mechanized labor). When the non-stock crop is fodder and used for animal nutrition, the fodder units (CU) and the digestible protein (FP), which are obtained from one Decare of crop production or are contained in 1 tone, are determined;

• For different groups of animals – productivity (milk, meat), conditional income, material costs excluding feed costs, conditional income, labor costs, conditional profit, man-days for the year, required CE and SP, min / max limits for the ration of animals.

Argo-economic problems are among the most complex (Nikolov, 1998; Nikolov et al., 1994).

Many interdependent factors must be taken into account in solving them (Nikolov et al., 1994). Solving a certain economic problem with the help of mathematical methods means to compose an economic-mathematical task. In a broader sense, modeling is a approach to the study of complex problems, which involves replacing the object with another that is similar to the original. The Economic-Mathematical Model (EMM) is a mathematical task that reflects with satisfactory accuracy the most important, the most important connections and dependencies that characterize the economic problem.

To achieve the goal of the present study, the model applied by Sarov and Kostenarov (2019) was used, which was developed according to Nikolov et al. (1994), based on data from agricultural farm located in Sofia district.

We can construct this task in a system of linear dependences. They should reflect the conditions to be taken into account when solving the task. The objective function expresses the optimality criteria (min, max):

$$A_{11}X_1 + A_{12}X_2 + \cdots + A_{1n}X_n \leq B_1$$
$$A_{21}X_1 + A_{22}X_2 + \cdots + A_{2n}X_n \geq B_2$$

$$\underline{A_{m1}X_1 + A_{m2}X_2 + \cdots + A_{mn}X_n = B_1}$$
$$F = C_1X_1 + C_2X_2 + \cdots + C_nX_n \rightarrow \max\ (min), \quad (1)$$

Where:

- X_j – indicates the size (magnitude) of the activities or metrics;
- A_{ij} and C_j – indicates the activities that will be done;
- B_i – means the number of available resources or the number of activities (restrictions);
- The objective function F gives the optimality criteria.

Description of the farm

The necessary information was gathered with the assistance of specialists from the studied farm. The farm is a legal entity registered under the Commercial Law as a sole limited liability company (EOOD). Its activities are in a mountainous area on a territory of Sofia region, Aldomirovtsi village. For this area are common cinnamon forest soils, falling in the group of infertile lands in the Quality assessment 0–20 ball, 10 categories. Climate conditions create prerequisites for growing the following crops of wheat, rye, vineyards, fruit trees, late vegetables.

Livestock activities

The farm has the opportunity to grow up to 100 cows. At the moment there are 75 dairy cows with an average milk yield of 10 liters of milk per day or about 3600 liters per year. The breeds are the following: ”Bulgarian Rhodope cattle” and ”Iskar cattle”. Due to the commitment because of the subsidy received, the farm is obliged to grow a minimum of 20 animals of every breed. Every day the produced milk is bought from a processing plant at a price of BGN 0.70 / l. At this stage, the cows are fed with a milk yield of 4,000 liters per year. The necessary food for animal feeding is farms own production. Additionally for the ration of the animals can be bought concentrated fodder at the price of BGN 0.65 / kg. On the farm, cows are fed according to a rationally determined by the zootechnics, in agreement with the farm manager.

The required Net Energy Lactation (NEL) per year for one cow will be determined according to the technical and economic standards. According to zootechnical requirements, we assume that the relative share of fodder to get the required NEL may vary within the following limits:

1) Concentrated Feeds from 20 to 40% from the necessary NEL;
2) Silage - from 30 to 48% of NEL;
3) Hay - from 5 to 12% of NEL;
4) Green fodder - from 10 to 20% of NEL;
5) Straw – maximum 10%.

Additional information

According to the technological requirements, the following restrictions must be observed:

1) Autumn crops under non-irrigating conditions occupy not less than 45% and not more than 55% of the crop rotation area;
2) The sunflower does not occupy more than 17% of the crop rotation (1/6).

The farm has received subsidies under 1 Pillar of the CAP for 2017 as follows:

1) BGN 41 / dca, distributed as follows – BGN 19.50 under Single payment per area scheme, BGN 12.50 green payments, BGN 9 for disadvantaged areas;
2) 75 animals (BGN 419 / animal) Scheme 11 CAP for support for dairy cows and / or meat cows under selection control.

Results and Discussion

Doole et al. (2013) describes a nonlinear optimization model (IDEA model) of a dairy farming system. Linear dependencies (LP) in determining the feed balance of dairy cows are found in Nottea et al. (2020). The authors present a framework for multi-objective optimization with the Differential Evolution (DE) algorithm applied to dairy feeding systems. The LP model attained the lowest feed costs. Alqaisi et al. (2021) demonstrate the results of potential of using the LP method for different feed supply situations in order to improve feed efficiency in dairy production. Moraes et al. (2012) presents a developed and solved model of the least cost diet (BASEM). The limitations of the model are the needs and intake of nutrients for the animals, certain limits of feed in the diet and proportions in the diet.

This article presents a model for optimizing the feed balance of dairy cows and at the same time optimizing the production structure of the farm: maximum economic result at minimum cost.

Development of the mathematical model.

Constants on land use:

$$\sum_{j \in M_i} X_{ij} \leq B_i \qquad (2)$$

Where:

M_i – a set of indexes, denoting the area of the *j*-culture;

x_{ij} – the area *j*-th crop on the *i*-th rented land;

B_i – rented land from category *i*.

Constraints on min / max size of the areas of the autumn crops:

$$\sum_{j \in M} X_j - k \sum_{j \in N} X_i \geq 0 \qquad (3)$$

Where:

k – min / max relative share of areas of autumn crops;

M – a set of unknown variables x_j, describing the area of fused surface;

N – a set of unknown variables x_j, expressing the area of row crops.

Constraints on agro-technological requirements of sunflower to crop rotation (1/6 of the crop rotation area):

$$X_j - k \sum_{j \in N} X_j \geq 0 \qquad (4)$$

Where:

k – a coefficient representing the crop rotation area of the *j*-th culture;

N – a set of unknown variables x_j, expressing the area of crops in crop rotation.

Constraints on labor resources:

$$\sum_{j=1}^{n} A_{ij} X_j \geq, \leq B_2 \qquad (5)$$

Where:

A_{ij} – the quantity of the *i*-th resource required to carry out one unit of *j*-activity or the quantity of the i-th product obtained by the one unit of *j*-activity;

B_2 – labor resources.

Constraints for min / max number of dairy cows:

$$\sum_{i \in I} X_i \geq; \leq B_j \qquad (6)$$

Where:

I – a set of unknown variables, indicating the number of cows of the *i*-th breed;

B_j – min / max number of dairy cows.

Constraints for min number of dairy cows under selection control:

$$X_i \geq S_i \quad i \in I \qquad (7)$$

Where:

I – a set of unknown variables, indicating the number of cows of the *i*-th breed;

S_i – minimum number of cows of the *i*-th breed.

Constraints on the feed balance:

$$\sum p_{Mi} X_{Mi} - \sum d_{Mi} X_{Mi} - \sum d_{Mi} X'_{Mi} = 0 \qquad (8)$$

$$M \in M \quad i \in I$$

Where:

M is the sum of the indices of the unknowns of the different feeds in NEL;

I – a set of unknown variables, indicating the number of animals;

p_{Mi} – the need for the fodder in NEL for one animal;

d_{Mi} – NEL of a M-th fodder, produced in the farm;

x'_{Mi} – the amount of M-th fodder purchased to feed the animals.

Constants on the minimum and maximum limits of the NEL of a given type of feed:

$$X_{dit} - k \sum X_{dit} \geq 0 \qquad (9)$$

$$d \in S \quad s \in U$$

Where:

S – a set of indexes of the variables *X dit*, expressing the NEL of the d-th fodder required for animal feed;

U – a set of indexes of the variables *X dit*, expressing required NEL for one animal;

κ – minimum / maximum share of NEL of the s-th fodder.

Linking activities (the amount of one depends on the amount of other activities):

$$\sum_k A_{ik} X_k \leq \sum_k A_{ir} X_r \quad (10)$$

where:

$X_κ$ is the number of activities that depend on the amount of other activities,

X_r is the number of activities that depend on the amount of other activities,

$A_{iκ}$ and A_{ir} are coefficients, which determine the proportions between group k activities and activities form group r,

Objective function:

$$\text{Fmax (gross margin/profit)} = \sum_{j \in T}^{n} C_j X_j \quad (11)$$

Where:

C_j is (gross margin/profit) from j-th unknowns;

T is the aggregate of the indices of the unknowns from which the gross margin / profit is obtained.

The decision of one EMM is conditional. On the one hand, limiting the possible iteractions and ensuring complete biological nutrition, as well as the subjective approach in determining the minimum-maximum parameters of participation of different groups of feed in animal nutrition, on the other – subjective restrictions narrow the permissible possible solutions. The more criteria from different groups (land, crop, livestock, labor, rations) are included in the optimization, the more the model decides the balance between the created organic conditions, which is often a prerequisite for compromise solutions to the problem. The results obtained from the optimization are shown in Tables 1.

The objective function is designed to affect the area of different crops used for feed or for sale, cows and subsidies (when using optimization subsidies), the area of grazing grassland used and hay production, purchased fodder and labor costs. According to a study by Sarov and Kostenarov (2019), it was found that the rented land is 2000 decares and is used at its full capacity.

Table 1. The result of the task: optimization of the production structure and feed balance

Name	Dca	Tone	Number
Wheat feed	31		
barley feed	275		
sunflower feed	31		
corn for silage		697	
pasture meadows	514		
hay for feed, own production		674	
Purchased concentrated fodder for cows		0	
own concentrated fodder for cows		156	
green feed		835	
straw for feed, own production		0	
purchased hay for feed		11	
cows - 4 tons of milk			100
rented land	2000		
general workers, permanent workers			3
mechanics, permanent workers			3
livestock farmers, permanent workers			3
income			
variable costs			
labor costs			
fixed costs			
Gross margin			
Profit			
NEI			710000
administrative costs			
wheat, commodity	0		
barley, commodity	656		
sunflower, commodity	309		

Source: Sarov, A. & Kostenarov, K. (2019).

The solution of the optimization equation is expected to result in the area of the land to be sown with a particular crop, the optimal number of cows to grow. In determining the optimal structure of the farm, the requirements for optimal ration of animals are taken into account by tracking the balance of the NEL.

According to the results of the optimization model, in order to achieve fodder balance are needed: wheat for fodder – 31 decares, sunflower fodder is also 31 decares. The low production costs and the good market price of barley make it an optimal crop, as it is 275 decares for fodder and 656 decares for sale. The silage corn is 697 tons and a green food is 835 t. In terms of the number of animals, the solution to the task maximizes 100 dairy cows.

The economic result of the optimization model is presented in Table 2. Based on the sale of milk and included commodity crops, the Income is BGN 531.36 thousand, gross margin – BGN 288.26 thousand, and profit – BGN 190.64 thousand. Therefore, EMM optimizes the economic results of the farm (Sarov and Kostenarov, 2019).

All other parameters of the model – with regard to the structure of the areas for cultivation of different crops, grazing meadows, labor costs remain unchanged, whether or not subsidies are used.

The main conclusion from the optimization of the objective function of the gross margin is that the existence of subsidies does not affect the farmer's behavior with regard to the sown areas. His interest is to maximize the number of reared cows and maximize sown areas.

Table 2. The economic result of the optimization model

Indicators	BGN/Thousand
Income	531.36
Variable costs	127.9
Labor costs	115.2
Fixed costs	46627.34
Gross margin	288.26
Profit	190. 64
Administrative costs	51

Source: Sarov, A. & Kostenarov, K. (2019).

Conclusion

The solution of the task gave the following answers:

1. Optimizing feed balance of dairy cows has been established;
2. The production structure of the farm has been optimized;
3. The optimization model has been successfully adapted to the management of an agricultural enterprise, with the criteria for optimal gross margin and profit.

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References

Alqaisi, O., & Schlecht, E. (2020). Feeding models to optimize dairy feed rations in view of feed availability, feed prices and milk production scenarios. *Sustainability*, *13*(1), 215. https://dx.doi.org/10.3390/su13010215. pp.1-15.

Daniel, J. B., Friggens, N. C., Chapoutot, P., Van Laar, H., & Sauvant, D. (2016). Milk yield and milk composition responses to change in predicted net energy and metabolizable protein: a meta-analysis. *Animal*, *10*(12), 1975-1985.

Doole, G. J., Romera, A. J., & Adler, A. A. (2013). An optimization model of a New Zealand dairy farm. *Journal of Dairy Science*, *96*(4), 2147-2160.

Ignatova, M. M., Metodieva, T. H., & Ivanova, T. V. (2020). A study on the longevity of Black-and-White cows. *Zhivotnov'dni Nauki/Bulgarian Journal of Animal Husbandry*, *57*(3), 3-9.

Krastev, K., & Grigorova, S. (2014). Influence of technological feeding régime in newborn calves on some hematological parameters ii. Summer season. *Zhivotnovadni Nauki, LI,* (4), 3-9 (Bg).

Weisbjergн, M. R. (2014). Feeding strategies for dairy cows. *Zhivotnovadni Nauki LI,* 1(2), 133-138 (Bg).

Moraes, L. E., Wilen, J. E., Robinson, P. H., & Fadel, J. G. (2012). A linear programming model to optimize diets in environmental policy scenarios. *Journal of dairy science*, *95*(3), 1267-1282.

Nikolov, N. (1998). Designing the production structure of agricultural production. Sofia: ed. Farm.

Nikolov, N., Ivanov, G., & Stefanov, L. (1994). Economic and mathematical modeling of agricultural production. *Sofia: Zemizdat*.

Notte, G., Cancela, H., Pedemonte, M., Chilibroste, P., Rossing, W., & Groot, J. C. (2020). A multi-objective optimization model for dairy feeding management. *Agricultural Systems*, *183*, 102854.

Oba, M., & Allen, M. S. (2003). Effects of corn grain conservation method on feeding behavior and productivity of lactating dairy cows at two dietary starch concentrations. *Journal of Dairy Science*, *86*(1), 174-183.

Price, T. P., Souza, V. C., Liebe, D. M., Elett, M. D., Davis, T. C., Gleason, C. B., ... & White, R. R. (2021). Short-Term Adaptation of Dairy Cattle Production Parameters to Individualized Changes in Dietary Top Dress. *Animals*, *11*(12), 3518.

Sarov, A., & Kostenarov, K. (2019). The impact of CAP subsidies on the agricultural enterprise's production structure. *Bulgarian Journal of Agricultural Science*, *25*(1), 10-17.

Stoop, W. M., Bovenhuis, H., Heck, J. M. L., & Van Arendonk, J. A. M. (2009). Effect of lactation stage and energy status on milk fat composition of Holstein-Friesian cows. *Journal of dairy science*, *92*(4), 1469-1478.

Todorov, N. (2010). Animal Nutrition Practice, ED Sofia.

Todorov, N., Кrachunov, I., Dzhuvinov, D., & Alexandrov, A. (2007). Handbook of Animal Nutrition. Mitcom Publishing House, Sofia.