Management and Nutrition

Original

Design and Analysis of Technological Alternatives to Milk Production

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Received: September, 2022; accepted: October, 2022; Published: November, 2022.

ABSTRACT

Background: Operation research and optimization model design are essential tools for developing practical solutions to production problems. **Aim.** To design and analyze two types of milk production technologies in a tropical dairy facility. **Methods:** The study was conducted at Mina Blanca, Unit No. 41, Valle del Peru Genetic Project. Dryland conditions without fertilization were created in two simulated scenarios, which permitted *ex-ante* analysis of two types of circumstances associated with relevant agrobiological, economic, and environmental factors. The model's variables were *Cynodon nlemfuensis*, *Leucaena Leucocephala* associated with *Megathyrsus maximus*; *Saccharum officinarum*, and *Pennisetum purpureum vc Cuba CT-115*. Dry matter production per ha was considered the objective function. The model's parameters and coefficients were determined theoretically. A total of ten and nine restrictions (scenarios 1 and 2, respectively), were set up. WinQSB version 2.0 was used. **Results:** The optimum solutions and species contribution to dry matter production indicated that in the two cases, the largest portion of the area must correspond to Guinea grass in scenarios 1 and 2 (44.9 and 43.76%, respectively). **Conclusions:** Two types of technologies were designed and analyzed prospectively, in terms of milk production technologies in a tropical dairy facility. According to the restrictions, the optimum solutions to the alternative scenarios suggested that most farm areas should be planted with Guinea grass.

Key words: dairy facility, optimization, linear programming (*Source*: *AGROVOC*)

INTRODUCTION

Research done on the optimization of operations and models as fundamental tools to develop practical solutions in production particularly in agriculture, is essential, as they require technical inputs to implement strategies to maximize benefits (Arias *et al*., 2021).

Citations (APA)
Herrera Toscano, J. (2022). Design and Analysis of Technological Alternatives to Milk Production *Journal of Animal Prod.*, *34*(3). https://revistas.reduc.edu.cu/index.php/rpa/article/view/e4294

Studies of farming systems were done at different stages. One of them is the design of hypotheses for alternative technologies. In that sense, there are multiple tools that can be used in this stage, such as limited budgets, mathematical models of simulation and multicriteria programming (Benítez *et al*.,2014).

Moreover, milk and meat production from ruminants in the tropical areas undoubtedly depends on high pasture and forage yields, with about 90% of nutrients, which will also depend on the efficiency and efficacy they can be used (Gutiérrez *et al.,* 2018). Therefore, an increase in the production levels of milk and meat would require the design of efficient systems in terms of the feeding base.

Accordingly, the aim of this paper was to design and analyze two different technologies for milk production on a local dairy farm.

MATERIALS AND METHODS

Location of the farm: The research was conducted on Farm No. 41, Mina Blanca, in Valle del Peru livestock genetic project, municipality of San Jose de las Lajas, Mayabeque province, Cuba.

Model components and analysis settings: Two scenarios were simulated in dryland, with no fertilization, which led to an *ex-ante* analysis of two different settings related to important agrobiological, economic, and environmental factors (Table 1). The model's variables were determined through a survey of 60 field experts. Consequently, the following species were included: African Bermuda grass (*Cynodon nlemfuensis*); Leucaena (*Leucaena Leucocephala*) in association with Guinea grass (*Panicum maximum*); sugarcane (*Saccharum officinarum*); and CT – 115 (*Pennisetum purpureum vc Cuba CT- 115*). The target function was the production of dry matter per ha., as one of the main indicators of feeds for ruminant nutrition (López *et al*., 2018). It was modelled according to the physical parameters of the particular dairy farm in the study (73 ha. and 67 cows).

Table 1. Setting components and alternatives.

Settings	Technological alternatives
Setting No. 1	African Bermuda grass, Leucaena in association with Guinea grass, sugarcane, and CT–115.
Setting No. 2	African Bermuda grass, Leucaena in association with Guinea grass, and CT–115.

Determination of the variable coefficients, restrictions values, and the parameters of the target function: The information related to the nutritional requirements of the animals is shown in table 2. The models included pastures and forages in the dry season (210 days), the critical stage for milk production in the tropical regions. The requirements were estimated for 425 Kg cows (live weight), producing 4 Kg animal^{-1} day^{-1} (NRC, 1985), second lactation period, with additional energy consumption due to locomotion and other factors. The DM consumption per individual was estimated as 2% live weight for the African Bermuda grass, CT-115, and Guinea grass. The sugarcane and Leucaena accounted for 1 and 0.7%, respectively (Reyes *et al*., 2015).

The pasture and forage yields were estimated, considering the stabilization stage over time. The DM yields from the different species were estimated in dryland. The estimates related to the forest-grazing system comprised 70% of the area with 30% of the Leguminosae plant (Rodríguez *et al*., 2018).

Table 2. Nutritional requirement estimates of the animals.

Requirements	**Nutrients**			
	ME (Mcal)	**CP** (g)	**Ca** (g)	**P** (g)
Husbandry/animal requirements average/day	12.51	359.00	17.00	13.00
Requirements for 4 Kg of milk containing 3.5 % fat.	4.40	320.00	13.32	6.04
Grazing consumption + stress 30%	3.75			
Total requirements for a cow day^{-1}	20.66	679.00	30.32	19.04
Requirements for 67 cows in 210 days	290 686.20	9553.53 (kg)	426.60 (kg)	267.84 (kg)

Tables 3 and 4 show the values of bromatological composition and the nutritional contribution of pastures and forages, which were determined based on the nutritional value chart (García and Pedrozo, 1989). The utilization percentage of pastures was estimated in 65% and forage was 90% (Soler., *et al* 2018). Sugarcane consumption was considered according to the chemical and physiological characteristics (on average) of the species. As shown below:

Sugarcane consumption by animal per day (kg DM) = 1% LW

Sugarcane consumption by the herd in 210 days (kg DM) = (425 kg x 67 cows x 210 days) x 0.01

Sugarcane consumption by the herd in 210 days (kg DM) = (59 797.5 kg

Sugarcane consumption by the herd in 210 days (t DM) = 59.79 t

Sugarcane hectares = 59.79 t DM: 18 t DM ha^{-1}

Sugarcane hectares = 3.32 ha

Hence, the lowest number of necessary sugarcane hectares is 3.32

Table 3. Bromatological consumption assumed, and yield estimates of DM and consumable DM in both settings.

Species	**ME (Mcal kg MS^{-1})**	**CP g kg DM^{-1}**	**Ca g kg DM^{-1}**	**P g kg DM^{-1}**
Sugarcane	2.20	3.80	0.55	0.14
African Bermuda Grass	1.87	6.60	0.53	0.18
CT - 115	1.90	6.30	0.52	0.17
Leucaena and Guinea grass	1.93	10.35	1.25	0.20

The model's parameters and coefficients were theoretically determined. A total of ten and nine restrictions were set for settings 1 and 2, respectively, according to the zootechnical and farming principles of the system analyzed; the ones associated with nutrients were determined according to the nutritional requirements of the animals; the restriction related to the cost of the establishment was determined according to the average availability in the last five years in the company. The CT - 115 field was limited (Martínez, 2004). Two other restrictions linked to the environment were included, along with the potential for CH_4 and CO_2 production by animal consumption, based on their significance in terms of global warming, comprising a 30% decrease in the larger contributor.

The corresponding coefficients to the costs of establishment were estimated through every species' cost sheets, in Cuban pesos with the hard currency component (Cino, 2004).

The environmental coefficients were estimated according to the stochiometric balance (Stuart, 2010), and arithmetic proportions. The values corresponding to the organic matter fermentation and digestibility patterns of the optimization models, were theoretically determined.

The problem was solved using the primal-dual simplex method to achieve the optimum solution. The WinQSB, 2.0 software (Long Chang, 2009) was used.

RESULTS AND DISCUSSION

Table 4 shows the model's parameters and coefficients, including the nutritional contribution of every species, and other economic and environmental interest variables. In that sense, sugarcane was the species with the highest DM and energy contributed to the system by area unit. However, the nutritional and physiological constraints of sugarcane hinder its large-scale use (Guerrero *et al.,* 2018). Other grass species, such as CT – 115 and Leucaena, must contribute more with dry matter and nutrients, despite the technological restrictions (CT - 115), and nutritional (Leucaena), due to anti-nutritional factors, mainly (Castillo*., et al* 2022).

The African Bermuda Grass was the only species that showed no restrictions, corresponding to its botanical features; however, the dry matter yields may be quite lower than the other species.

The economic analysis indicated that the establishment of the energy bank using sugarcane, as well as the forest-grazing with Leucaena associated with Guinea grass, will be the costliest by field unit.

As to the potential for CO_2 and CH_4 emissions, sugarcane consumption was the largest contributor of these greenhouse gases to the environment, thus corresponding with the previously discussed limitations of the plant, which were linked to enteric digestive and fermentation processes that take place in the animal's rumens. The expected benefits of the forest-grazing system is one of the most significant aspects of the technology, coinciding with other authors (Ruiz *et al*., 2020).

Table 4. Variable values, model's parameters and coefficients.

Parameters	Variables			
	Sugarcane	African Bermuda Grass	CT - 115	Leucaena and Guinea grass
DM production (kg ha^{-1})	18 000.00	975.00	7 200.00	6 300.00
Energy contribution (Mcal ha^{-1})	39 600.00	1 823.25	13 680.00	12 159.00
Protein contribution (kg ha^{-1})	684.00	64.35	453.60	652.05
Ca contribution (kg ha^{-1})	99.00	5.16	37.44	78.75
P contribution (kg ha^{-1})	25.20	1.75	12.24	12.60
Cost of establishment ($ ha^{-1})	6 522.42	2 303.37	2 268.50	5 672.24
Potential production of CO_2 by animal consumption (t ha^{-1})	10.5	0.19	2.84	2.83
Potential production of CH_4 by animal consumption (t ha^{-1})	5.32	0.32	1.58	1.26

The optimal solutions obtained and the species contribution to DM production (Table 5) indicated that in the two cases, most of the area should belong to the African Bermuda grass (44.9 and 43.76 % in settings 1 and 2, respectively), which could be explained, mainly by the restriction establishment cost. However, the DM contribution of the species, was the lowest of all the pastures and forages used in the simulation. Then the CT - 115 field was in both cases, using 21.6 ha (30% of the area), corresponding to the restriction stated. This was the species with the largest DM contribution in all the simulated conditions, with values that varied between 45 and 52%. Though the estimations were theoretical, they can validate the reports of Martínez and Medina (2018). Later, the model suggested that the forest-grazing system made of Leucaena and Guinea grass accounted for 20 and 26% in settings 1 and 2, respectively. This proportion coincided with the reports of Rodríguez *et al*. (2018), whose system showed high DM values.

In the case of sugarcane, the results suggested that, according to the conditions set to the systems, the top DM ha^{-1}production can be achieved if the species comprises 4.54 % of the area, which is favorable to the forage balance during the rainy season.

Table 5. Optimal solution and total DM contribution by species.

Decision variable	Optimal solution (ha)	Total contribution (kg of DM)
	Settting$_1$	**Settting$_1$**
Sugarcane	3.32	59 760.00
African Bermuda grass	33.73	32 884.52
CT - 115	21.90	157 680.00
Leucaena in association with Guinea grass	14.05	88 529.44
Decision variable	**Settting$_2$**	**Settting$_2$**
African Bermuda grass	32.89	32 067.62
CT - 115	21.9	157 680.00
Leucaena in association with Guinea grass	18.21	114 723.88

Consequently, the total contribution to the target function (DMha^{-1}) and the stocking rate in every context, depending on the technological settings, indicated that the largest contribution must be obtained in setting No.1, 2.84 % higher than setting No.2, which resulted from the fact that in such scenarios a portion of the field should be allocated for sugarcane. With the presumable feed amounts that could be produced in each setting, the stocking rate could be between 2.64 and 2.54 animals. Therefore, based on the estimations, the technologies demonstrated the potentialities of pastures and forages for dairy production in the dry season.

CONCLUSIONS

Two technologies were designed and evaluated for milk production on a local dairy farm. The optimal solution to the two alternative settings, depending on the restrictions set for most of the land, should be the African Bermuda grass.

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AUTHOR CONTRIBUTION STATEMENT

Research conception and design: JHT; data analysis and interpretation: JHT; redaction of the manuscript: JHT.

CONFLICT OF INTEREST STATEMENT

The author declares the existence of no conflicts of interests.