

Paper type: Original Research

Using modelling to enhance zootechnical and economic performance in drylands goat meat production

João Paulo de Farias Ramos^{1,*}, Wandrick Hauss de Sousa², Thiago de Sousa Melo², Rodrigo Vasconcelos de Oliveira¹, Felipe Queiroga Cartaxo³, Flávio Gomes de Oliveira², Larissa Kellen da Cunha Morais², Thais Thatiane dos Santos Souza², Danillo Marte Pereira⁴, Thamires da Cunha Leal¹

¹Federal Rural University of Rio de Janeiro, Department of Animal Production, Institute of Zootechnics. Seropédica -RJ, Brazil

²Research, Rural Extension and Land Regulation Company of Paraíba. João Pessoa-PB, Brazil

³State University of Paraíba, Center for Agricultural Sciences. Catolé do Rocha-PB, Brazil

⁴Federal University of Paraíba, Center for Agricultural Sciences. Areia-PB, Brazil

*Corresponding author,
E-mail address:
joaopaulofr@ufrj.br

Received: 19 Feb 2025,
Received in revised form: 12 Aug
2025,
Accepted: 13 Aug 2025,
Published online: 14 Aug 2025,
© The authors, 2026.

ORCID

João Paulo de Farias Ramos
0000-0001-6159-5026
Wandrick Hauss de Sousa
0000-0001-8761-0626
Thiago de Sousa Melo
0000-0003-1862-9571
Rodrigo Vasconcelos de Oliveira
0000-0002-7420-1097
Felipe Queiroga Cartaxo
0000-0002-2378-0420
Flávio Gomes de Oliveira
0000-0002-0948-7543
Larissa Kellen da Cunha Morais
0000-0002-5551-2850
Thais Thatiane dos Santos Souza
0000-0002-6887-5677
Danillo Marte Pereira
0000-0003-0567-7371
Thamires da Cunha Leal
0009-0009-0921-9213

Abstract This study aimed to develop a mathematical function for the performance of a goat production system for meat production, based on zootechnical and economic indicators. Data on the technical and economic parameters used in the models were obtained from the goat herd control file database, which covered the years 2013 to 2017. Descriptive statistics were performed using PROC UNIVARIATE, while multiple linear regression models were developed using PROC GLMSELECT. Multiple linear regression analysis showed an adjusted coefficient of determination, indicating that the variables mortality rate, calving interval, weaning rate, and reproductive efficiency explained 95 percent of the variations in total goat weight at weaning. The results indicated that total weight of offspring at birth and weaning, mortality rate, reproductive efficiency, and gross income affect the system's profitability and can be used as decision-making criteria in meat goat farming. Furthermore, feed costs and rainfall also influenced the predicted variables, highlighting the importance of integrating climatic and economic factors in herd management. The multiple linear regression equations developed in this study are a useful and accessible tool for ruminant technicians and producers, allowing simulations and analyses of different production and economic scenarios, contributing to strategic planning and the development of the meat goat production system.

Keywords: bioeconomic models; goat meat; meat production; multicollinearity; semi-arid

Introduction

Goat farming has been recognized as an activity with significant potential to drive economic and social development in the semi-arid region of Northeast Brazil. It contributes to income generation, family employment, and the creation of new businesses. Despite this potential, the sector lacks an organized production chain

capable of meeting consumer market demands in terms of both quality and consistent supply of goats for slaughter (Sousa, 2018). This issue is closely linked to the low productivity rates of herds, primarily due to the low technological level of current production systems.

Therefore, economic analysis of goat farming is crucial because it will help producers to understand and efficiently

utilize production factors (land, labor, and capital), identify problems, and improve management practices and technological efforts. This approach aims to achieve the objectives of maximizing profits or minimizing costs.

A systematic analysis of technologically advanced production systems is crucial for enhancing the sustainability, efficiency, quality, and competitiveness of goat meat production, particularly in Brazil's semiarid region.

Modelling and scenario analysis of technical and economic performance indicators for goats allows the creation of mathematical models that replicate the behavior of a goat meat production operation. This approach aids management by generating a base scenario through a set of equations that simulate real-world conditions. From this base scenario, optimal solutions can be sought, and scenario simulations can be conducted by altering events to assess their impact on the final results. Moreover, computer tools can facilitate the creation and evaluation of change strategies by observing their potential short, medium, and long-term effects on the activity.

Bioeconomic modelling is a crucial tool for calculating the marginal economic values of traits. While it is widely used to establish selection criteria and indices in other species, its application in meat goat breeding, has been limited, both in Brazil and globally. Recent studies by Jembere et al. (2019) and Amayi et al. (2021) have addressed this gap, contributing to the advancement of knowledge in this area. In this context, modelling tools can assist specialists and producers in decision-making, helping to reduce losses within the goat production system. Mathematical models provide an approach to explain phenomena that are not easily observable by producers. Therefore, understanding the various applications of modelling in goat meat farming is necessary.

This study aimed to enhance the development of a bioeconomic model that evaluates zootechnical indicators in a goat meat production system in the Brazilian semi-arid region. Additionally, it sought to model and analyze the effects of different parameters on the productivity and profitability of this system.

Materials and methods

Research site

The study was conducted at the Pendência Experimental Station in Soledade, PB, which is managed by the Paraíba State Company for Research, Rural Extension and Land Regulation (EMPAER-PB).

Data collection

The technical and economic parameter data used in the models were sourced from the goat meat herd control database, covering the period from 2013 to 2016. The study gathered zootechnical and economic indicators over four breeding seasons and four birthing cycles, totaling 48 months of data collection. The herd consisted

of 80 crossbred goats (CBG), including Boer and Savannah breed sires and their offspring (Boer × CBG and Savannah × CBG).

The breeding system was semi-intensive, covering an area of 50 hectares, which included the facilities, caatinga area (In Brazil: a large area of semi-arid country consisting of thorny shrubs and 88 stunted trees), and fields for planting prickly pear cactus and forage crops for silage production.

Model construction

The models were developed by organizing the data into electronic spreadsheets, allowing for the analysis of indicator variations. Total cost (TC/R\$) includes all variable and fixed costs, comprising the total operating cost (TOC) plus the opportunity cost (OC) of capital invested in improvements such as machinery, forage, and livestock.

The cost and revenue items adopted were as follows: gross income (GI), effective operating cost (EOC), total operating cost (TOC), and total cost of production (TC) according to Matsunaga et al. (1976).

Gross income from the herd was used as a profit indicator, with no assumptions made about the farm's financial structure. Animal sales included cull goats, goats sold for slaughter, replacement females, and surpluses from the production system, such as prickly pear cactus forage and manure. Goat sale prices were based on local trade values per kilogram of carcass, with average values calculated for each cycle from 2012 to 2016, assuming a carcass weight of 12 kg at weaning. The average gross income per production cycle was calculated using the equation $GI = Pr \times PSP$, where GI is gross income (R\$), Pr is production (R\$) in marketable live weight, manure, or forage, and PSP is product sales price (R\$). Revenue from live weight sales was estimated at US\$1.81 per kg, the average price from 2012 to 2016.

Zootechnical indicators

- Fertility (F%): Number of pregnant goats (with confirmed pregnancies)/Number of goats exposed to reproduction.
- Total goat weight at birth (TGWB/kg): refers to the total weight in kg of the goats at birth per calved goat.
- Total goat weight at weaning (TGWW/kg): refers to the total weight in kg of goats at weaning per calved goat.
- Weaning rate (WR %): The number of goats weaned multiplied by 100 and divided by the number of goats born, including stillborn goats.
- Reproductive efficiency (RE %): Number of goats weaned/Number of female goats exposed.
- Prolificacy: Number of goats born/Number of goats with kids.
- Mortality: number of goats that died during the pre-weaning phase multiplied by 100 and divided by

the total number born.

- Kidding (parturition) interval: period between two consecutive kiddings
- Cost of feeding the herd (R\$): with multi-nutritional blocks (MB), roughage feeding (RF), concentrate feeding (CF) and creep feeding (CF).
- Labor cost (LC/R\$): refers to the cost of direct labor and charges for managing the herd.

The model was constructed using linear programming after setting up the database in a spreadsheet and incorporating the variables and their values.

Statistical analysis

Statistical analyses were carried out using SAS software, SAS OnDemand for Academics (Copyright© 2023 SAS Institute Inc). Descriptive statistics were carried out using PROC UNIVARIATE. Multiple linear regression models developed using PROC GLMSELECT to predict Y1,Y2,Y3, considering X1, X2, X3 as independent variables, are given by: $\hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} + \hat{\beta}_2 X_{2i} + \dots + \hat{\beta}_p X_{pi}$, $i = 1,2,3, \dots, n$ which: \hat{Y}_i is the surface response, $\hat{\beta}_0$ estimated model intercept, $\hat{\beta}_p$ are the estimated regressors of the model, X_p are the independent variables of the model, n is the number of observations and p is the number of predictor variables.

The normality of the variables was checked using the Shapiro-Wilk normality test. The minimum protected area variable did not follow a normal distribution and was transformed using its square root. To test for multicollinearity between the variables, the Variance Inflation Factor (VIF) values were calculated, where values above 10 indicate that multicollinearity may be influencing the estimates (Freund and Littell, 2000; Chatterjee and Hadi, 2006).

Outliers were tested by regressing the studentized residual on the predicted values of a model built with all parameters included. The data was removed when the studentized residual was outside the -2 to 2 limits. The models were then generated step by step using the bidirectional elimination stepwise method, with parameters included and/or excluded one by one. The entry and permanence of the parameters in the models was determined by the P value, whereby for a parameter to be included in the model, its P value had to be less than 0.05 and for it to remain, its P value had to be less than 0.01. The comparison and quality of fit was carried out using the corrected Akaike Information Criterion (AICc) (Hurvich and Tsai, 1989), where the model with the lowest AICc value is considered the most plausible model, and the coefficient of determination (R^2), the adjusted coefficient of determination. R^2_α is given by: $R^2_\alpha = 1 - \left[\frac{(n-1)(n-R^2)}{n-p} \right]$ where: R^2 is the coefficient of determination, n is the size of the sample, and p is the number of model parameters. The corrected Akaike

criterion (AICc) is obtained by: $AICc = n \ln \left(\frac{SQR}{n} \right) + 2(p+1) + \frac{2(p+1)(p+2)}{n-(p+2)}$ where SQR is the sum of squares of the residuals. The most appropriate models were those with the lowest AICc estimate and the highest R^2 values.

The selected models were evaluated by residual regression on the prediction centered on their means (ST-Pierre, 2003) using PROC REG and AUTOREG. Centering the independent variable on its mean ensures orthogonality of the intercept and angular coefficient, resulting in values of 0 when the model is unbiased. The intercept was used to estimate average bias, while linear bias was assessed by the slope of the regression equation. Models were validated when the intercept and angular coefficient were not significantly different from zero ($P > 0.05$) by the t-test. The Durbin-Watson statistics tested the null hypothesis that the residuals were not autocorrelated.

Zootechnical indicators

Table 1 presents the descriptive analysis of the zootechnical indicators used in the model. These statistical analyses aimed to model the interrelationships between the zootechnical indicators, understand each variable's impact (total goat weight at weaning, fertility, and prolificacy) on others, and make the model simulations more realistic and biologically accurate. The goal was to evaluate the effect of zootechnical indicators (predicted variables) on the predictors.

Table 1. Descriptive statistics of the zootechnical indicators that were analyzed for assigning economic values to the system

Variables	Mean	Standard deviation	Minimum	Maximum
Predicted variables				
TGWW ¹ (kg)	19.895	3.330	14.990	24.900
Fertility (%)	80.356	9.868	65.00	95.23
Prolificacy (%)	1.728	0.147	1.300	1.900
Predictor variables				
TGWB ² (kg)	5.688	0.437	4.500	7.000
Mortality (%)	7.42	3.04	2.90	11.37
Weaning rate (%)	92.58	3.46	85.00	98.60
Reproductive efficiency (%)	123.56	16.28	98.50	144.50
Kidding interval (days)	265.26	26.28	230.23	320.00

¹TGWW = Total goat weight at weaning; ²TGWB = total goat weight at birth

To develop a model for assigning economic values to a goat meat farming system, we analyzed the following variables: total goat weight at weaning (kg), fertility (%), and prolificacy (%) as predicted variables; and total goat weight at birth (kg), mortality (%), weaning rate (%), reproductive efficiency (%), and kidding interval (days) as predictor variables.

Initially, the dependent variable was examined graphically using a BoxPlot, removing any outliers. Normality tests indicated that the average milk

production did not follow a normal distribution, as confirmed by the Shapiro-Wilk, Kolmogorov-Smirnov, and Anderson-Darling tests. Consequently, the data was transformed using the Box-Cox method, which then passed the normality tests. As Miot (2017) notes, the Shapiro-Wilk test assesses whether data follows a normal distribution, which in this case, it did post-transformation ($P > 0.05$).

An initial model incorporating all the aforementioned indicators was constructed to test the best hypothesis for a specific herd MLR model. To investigate multicollinearity, a Variance Inflation Factors (VIF) analysis was conducted. Hair Jr. et al (2005) suggests that multicollinearity hinders the analysis of the relative effects of independent variables and diminishes the predictive capability of the dependent variables. Thus, any variable with a VIF value greater than 10% should be excluded from the regression model. In this analysis,

only the mortality variable exceeded 10%, but it fell within the acceptable VIF tolerance range, which is 1 divided by the VIF value, needing to be greater than 0.2.

With no multicollinearity present in the data, the analysis proceeded with a partial F test to evaluate the significance of the coefficients (i.e., P-values). This test was applied to both the original and transformed average milk production data. The partial F test was repeated multiple times, each time removing a zootechnical indicator that failed to meet the assumptions, to observe how the model responded to the exclusion of the least significant variable.

These analyses facilitated the development of the model, revealing how each variable was influenced by other indicators. The P-value assessed the model's inference and the adjusted R^2 , and the final estimates of the model using the original, non-transformed variables were used to construct the equation (see Table 2).

Table 2. Estimates of the parameters, their unconditional standard errors, and the relative importance of each independent variable present in the plausible models (AICc) within the 95% confidence interval to explain the variation in total goat weight at weaning (TGWW), fertility, and prolificacy of goat meats

Total goat weight at weaning				
Coefficients	Estimative	Standard error	t	P-value
Intercept	-3.04502	11.08934	-0.27	0.7850
Mortality	-0.91530	0.20091	-4.56	<0.0001
Weaning rate	-0.40984	0.11121	-3.69	0.0007
Kidding interval	0.18199	0.01544	11.79	<0.0001
Reproductive efficiency	0.15767	0.02746	5.74	<0.0001
R^2 adjusted	0.8807			
P-value (model)	<0.0001			
AICc	66.7966*			
Fertility				
Intercept	12.33373	28.59654	0.43	0.6686
Total goat weight at birth	2.79585	1.45077	1.93	0.0613
Mortality	2.63830	0.46730	5.65	<0.0001
Weaning rate	0.74704	0.28858	2.59	0.0135
Kidding interval	-0.23189	0.03790	-6.12	<0.0001
Reproductive efficiency	0.19807	0.06450	3.07	0.0039
R^2 adjusted	0.9385			
P-value (model)	<0.0001			
AICc	138.84462			
Prolificacy				
Intercept	-4.57816	0.86755	-5.28	<0.0001
Total goat weight at birth	0.17509	0.04573	3.83	0.0005
Mortality	-0.02890	0.01366	-2.12	0.0410
Weaning rate	0.03316	0.00843	3.93	0.0003
Kidding interval	0.00417	0.00118	3.54	0.0011
Reproductive efficiency	0.01103	0.00192	5.75	<0.0001
R^2 adjusted	0.6640			
P-value (model)	<0.0001			
AICc	-169.12194			

AICc= Corrected Akaike information criterion

Economic productivity indicator

To evaluate the economic indicators proposed in this study, we calculated the costs and gross income of the system, adhering to the previously outlined procedures.

Table 3 presents the means, standard deviations, and minimum and maximum values of the economic variables used to construct the models.

The statistical procedures followed included normality tests on the zootechnical indicator database (Shapiro-Wilk, Kolmogorov-Smirnov, and Anderson-Darling

tests), followed by a VIF analysis to check for multicollinearity, and then the partial F test, which facilitated the model construction. The model's inference was evaluated using the p-value and the adjusted R^2 . The final estimates of the model, using the original variables without any transformations, were used to construct the equation (Table 4).

Results

Zootechnical indicators

The multiple linear regression (MLR) model used to predict the total goat weight at weaning (TGWW), fertility rate (FR) and prolificacy rate (PR) of goats as a function of the other zootechnical indicators is represented by Equations 1, 2 and 3.

$$y_{TGWW} = -3,04502 - 0,91530x_1 - 0,40984x_2 + 0,18199x_3 + 0,15767x_4 \quad (1)$$

where, y represents the total goat weight at weaning (kg); x_1 is the mortality (%); x_2 is the weaning rate (%); x_3 is the kidding interval (days); x_4 is the reproductive efficiency (%).

$$y_{FR} = 12,33373 + 2,79585x_1 + 2,63830x_2 + 0,74704x_3 - 0,23189x_4 + 0,19807x_5 \quad (2)$$

where, y represents the fertility rate (%); x_1 is the total goat weight at birth (kg); x_2 is the mortality (%); x_3 is the

weaning rate (%); x_4 is the kidding interval (days); x_5 is the reproductive efficiency (%).

$$y_{PR} = -4,57816 + 0,17509x_1 - 0,02890x_2 + 0,03316x_3 + 0,00417x_4 + 0,01103x_5 \quad (3)$$

where, y represents prolificacy (%); x_1 is the total goat weight at birth (kg); x_2 is the mortality (%); x_3 is the weaning rate (%); x_4 is the kidding interval (days); x_5 is the reproductive efficiency (%).

The models were subjected to the Shapiro-Wilk normality test (P=0.4299; P=0.4193; and P=0.3320) and the Durbin-Watson independence test (P=0.9990; P=0.9301; and P=0.7912), the latter assessing the presence of autocorrelation in the model's residuals. Additionally, the coefficients of determination (R^2) adjusted by the models were 88.11%, 93.85%, and 66.40% for equations 1, 2, and 3, respectively.

Table 3. Means, standard deviations, and minimum and maximum values of the economic variables used to build the models

Variables	Mean	Standard deviation	Minimum	Maximum
Predicted variables				
Gross income (R\$)	19,684.89	1,041	18,038.00	20,877.00
Predictor variables¹				
PLUV (mm)	285	13	135	532
LC (R\$)	2,438.00	916.00	1,694.00	3,992.00
CMB (R\$)	3,188.00	667.68	2,144.00	4,033.00
RFC (R\$)	2,434.00	1,454.00	103.02	3,926.00
CFC (R\$)	5,062.00	2,236.00	1,356.00	6,761.00
CCF (R\$)	1,625.00	576.60	1,000.00	2,590.00

PLUV = Pluviosity; LC = Labour costs; CMB = Cost of multi-nutritional blocks; RFC = Roughage feed costs; CFC = Concentrated feed costs; CCF = Costs of creep feeding

Table 4. Estimates of the parameters and their unconditional standard errors and the relative importance of each independent variable present in the plausible models (AICc) of the 95% confidence model to explain the variation in economic indicators

Coefficients	Gross income			
	Estimate	Standard error	T	p-value
Intercept	16,327	328.5363	49.70	<0.0001
PLUV (mm)	1.290487	0.1844	7.00	<0.0001
LC (R\$)	0.235507	0.0350	6.74	<0.0001
CMB (R\$)	1.002927	0.0800	12.54	<0.0001
RFC (R\$)	0.294769	0.0513	5.75	<0.0001
CFC (R\$)	-0.234517	0.0291	-8.05	<0.0001
CCF (R\$)	-0.184492	0.0674	-2.74	0.0095
R^2 adjusted	0.9998			
P-value (model)	<0.0001			
AICc	306.27409			

PLUV = Pluviosity; LC = Labour costs; CMB = Cost of multi-nutritional blocks; RFC = Roughage feed costs; CFC = Concentrated feed costs; CCF = Costs of creep feeding

Economic productivity indicator

The multiple linear regression model (MLR) used for gross income (GI), considering rainfall, labor costs, multinutritional block costs, roughage feed costs, concentrate feed costs, and creep feeding costs as functions of the other economic indicators, is represented by Equation 4.

$$y_{GI} = 16,327 + 1,290487x_1 + 0,235507x_2 + 1,002927x_3 + 0,294769x_4 - 0,234517x_5 - 0,184492x_6 \quad (4)$$

where, y represents the gross income (R\$); x_1 is the rainfall (mm); x_2 is the labour costs (R\$); x_3 is the cost of multi-nutritional blocks (R\$); x_4 is the cost of roughage feed (R\$); x_5 the cost of concentrated feed (R\$); x_6 is the cost of creep feeding (R\$).

The model was subjected to the Kolmogorov-Smirnov normality test (P = 0.1030) and the Durbin-Watson independence test (P=0.9415). Additionally, the model's adjusted coefficient of determination (R^2) was 99.98%.

Table 5. Estimates of the parameters and their unconditional standard errors and the relative importance of each independent variable present in the plausible models (AICc) of the 95% confidence model to explain the variation in economic indicators

Coefficients	Gross income			
	Estimate	Standard error	T	p-value
Intercept	16,327	328.5363	49.70	<0.0001
PLUV (mm)	1.290487	0.1844	7.00	<0.0001
LC (R\$)	0.235507	0.0350	6.74	<0.0001
CMB (R\$)	1.002927	0.0800	12.54	<0.0001
RFC (R\$)	0.294769	0.0513	5.75	<0.0001
CFC (R\$)	-0.234517	0.0291	-8.05	<0.0001
CCF (R\$)	-0.184492	0.0674	-2.74	0.0095
R ² adjusted	0.9998			
P-value (model)	<0.0001			
AICc	306.27409			

PLUV = Pluviosity; LC = Labour costs; CMB = Cost of multi-nutritional blocks; RFC = Roughage feed costs; CFC = Concentrated feed costs; CCF = Costs of creep feeding

Discussion

Evaluating goat production systems using multiple proportional linear regression models predicts reproductive performance over time, allowing for strategic adjustments in management, such as choosing the best time to cover or inseminate, and evaluating the impact of different feeding systems on fertility. This reduces reproductive losses, improves zootechnical indices, and contributes to more rational and economical reproductive planning. As well as economic viability, the use of these statistical models is fundamental to maximizing the return on investment. Efficient reproduction reduces the costs of maintaining unproductive animals, optimizes the replacement rate, and allows greater control over the production flow. In addition, selection guided by statistical data strengthens the competitiveness of the end product, be it meat or genetics, increasing the added value of the herd.

The average total weight at weaning (Table 1) observed in this study can be considered satisfactory, as it enabled the goats to achieve an average weight of approximately four times (3.5 times) their birth weight. This result is close to the weaning weight of 3.8 times the birth weight cited in the literature for goats when weaning is carried out between 56 and 63 days (Ferreira et al., 2008).

The multiple linear regression analysis showed an adjusted coefficient of determination of 0.8233, indicating that the mortality rate, kidding interval, weaning rate, and reproductive efficiency explained 95 per cent of the variations in "total goat weight at weaning" (equation 1).

The good weaning performance of the goats (F1 Boer and F1 Savannah + crossbred goat) in this study can be attributed to the heterosis derived from the Boer and Savannah sires and the consumption of solid food, which promoted the development of the rumen papillae and improved the animals' performance. All the young animals had free access to creep feeding from the age of 10 days.

Sousa et al. (2006) stated that the superiority of small ruminants is manifested by heterosis, wherein crossbred individuals perform better than their parents. Heterosis effects are generally seen in various forms, such as individual or direct performance, represented by the performance of the offspring. Although this effect is not well understood, it can influence reproductive characteristics like libido, conception rate, adaptability, and longevity of future sires.

Reproductive productivity is crucial for economic success in animal husbandry (Taylor et al., 2018). Low pregnancy rates lead to direct financial losses related to nutrition costs in goat meat production, and delays in first kidding also result in indirect financial losses.

Reproductive efficiency is vital for meat-producing farms and depends on the fertility and prolificacy of the herd. The proper development of the offspring influences the quality and quantity of the meat produced. On average, the herd's reproductive rates were 80.35 per cent fertility and 1.72 per cent prolificacy (Table 1). Prolificacy over 1.70% can be considered excellent compared to the Brazilian average for goat production systems.

In equation 2, the fertility prediction model variable was reduced by 10 per cent, resulting in new predictions for fertility (71.29 per cent) and production efficiency (111.204). The economic value demonstrates that variations in specific indicators can significantly impact production. Multiple linear regression can serve as an additional tool to assist producers in decision-making by providing quantitative information on how certain zootechnical indicators affect the productivity and profitability of goat meat herds.

Reproductive efficiency is one of the main factors influencing the productivity of goat herds for meat. To achieve good reproductive performance in goat farming, such as producing three kidding in two years, with a kidding interval of 8 months and a herd fertility rate above 80%, there must be perfect synchronization between genetic, nutritional, health, and environmental factors, alongside good management practices (Simplício and Azevedo, 2014; Mokhtari et al., 2010).

Therefore, it is essential to analyze animal reproductive performance, establish and evaluate reproductive parameters and indices, and recognize, set objectives, monitor, and resolve factors that compromise the reproductive and productive efficiency of the herd. This approach will improve the quality and profitability of goat farming.

The parameter estimates for prolificacy were statistically significant ($P < 0.05$). The proposed model is expressed by the equation: $\hat{y} = 5.22528 + 0.19588_{TGWB} + 0.04615_{WR} + 0.00228_{CI} + 0.00789_{RE}$. The adjusted coefficient of determination is 0.6340, indicating that 63.4% of the variation in the prolificacy rate can be explained by variations in total goat weight at birth, weaning rate, kidding interval, and reproductive efficiency.

The efficiency of an animal production system is determined by the productive and reproductive events inherent to females, as well as the weight development of their offspring (Sarmiento et al., 2010). Among the reproductive characteristics, prolificacy (number of goats born per calved female) is one of the most important for determining the efficiency of the system, as it is directly related to the economic viability of the herd (Danell, 1986). The weight of weaned goats per female generates most of the income for goat meat producers in the semi-arid region of Brazil. The number of goats born per female is a key element in the annual production of small ruminant herds.

According to Fávero et al. (2009), the lower the VIF statistic and the higher the tolerance statistic, the greater the independence of the explanatory variables, indicating no multicollinearity. Conversely, a higher VIF statistic indicates lower independence and a higher correlation between variables, suggesting strong multicollinearity.

Fávero et al. (2009) further state that a VIF statistic equal to or greater than 5, which represents a tolerance of 0.20 or less, indicates multicollinearity between the explanatory variables in the proposed model.

Table 3 shows that the predicted variables “total goat weight at weaning,” “fertility,” and “prolificacy” did not present multicollinearity issues according to these two tests.

Economic analysis considers the revenue from production activities, accounting for costs and assessing how the resources used in the production process are remunerated (Reis, 2001).

Analyzing a technologically advanced goat meat production system systematically, with a focus on increasing the sustainability of production units and aiming for greater efficiency in quantity, production stability, product quality, and cost competitiveness over time, is crucial for making sound decisions in goat meat production in the semi-arid region (Sousa, 2018).

Hoffmann et al. (1987) state that the income of an activity can be analyzed using measures of economic results, i.e., indicators of economic efficiency in the use

of production factors, to verify the business's attractiveness.

Using modelling to estimate economic indicators in goat meat production is a tool that allows simulations to aid technical decision-making.

For the economic valuation of the proposed indicators, it was necessary to calculate the costs and gross income of the system, following the previously mentioned procedures.

Based on Table 4, the t-tests for the significance of the estimated parameters (intercept and coefficients $X_1 \dots X_6$) rejected the null hypothesis, indicating that all the estimated coefficients are statistically significant at the 5% probability level.

To calculate gross income under varying economic indicators, a 50 percent reduction in concentration costs and a 100 percent increase in rainfall was simulated, generating an increase of R\$195.35 (Table 4).

The multiple linear regression analysis showed an adjusted coefficient of determination of 0.9997, indicating that the variables “rainfall, labor cost, cost of multi-nutritional blocks, cost of roughage feed, cost of concentrate feed, and cost of creep feeding” explain 95% of the variations in the “gross income” of the goat meat production system. This coefficient indicates a high degree of relationship between the predicted variable and the predictor variables.

Silveira et al. (2023) used multiple linear regression to predict a goat milk production model, which was similar to the model developed in this study. Their results, like those of Gunia et al. (2013), showed that higher herd prolificacy increases system profitability.

Given these results, this research question can be considered answered, as both the correlation coefficient (multiple R) and the coefficient of determination (R-squared) indicated a high degree of relationship between the variables “gross income” and “rainfall, labor costs, cost of multi-nutritional blocks, cost of roughage feed, cost of concentrate feed, and cost of creep feeding” in the production of goat meats in the Brazilian semi-arid region.

The model constructed in equation 4 could be a technique to improve the analysis of cost behavior and increase the objectivity and reliability of accounting information in goat meat farming.

Gross income (GI) for a given period includes the value of all goods or services produced, determined by the price of the product multiplied by the quantity sold, consumed, and/or stored. Analyzing it in isolation is inconclusive, as farms with the highest gross income are not always the best economically (Moura et al., 2010).

The economic value shows how a certain indicator can impact production financially (Gameiro, 2009), serving as a tool to help producers make informed decisions (Holanda Junior et al., 2008), especially by providing information on how certain zootechnical indicators affect productivity and profit.

Sell (2005) noted that linear regression is a useful decision-making tool in cost management, used to

estimate the values of one variable based on another, explain values, and predict future values.

Maher (2001) discussed the reliability of cost formulas obtained through regression analysis, highlighting the importance of the coefficient of determination.

Corrar et al. (2012) emphasized that the coefficient of determination, the square of the correlation coefficient, indicates the model's explanatory power based on the considered independent variables.

Another important analysis is variance analysis, a hypothesis test to establish the relationship between explanatory variables (X_i) and the explained variable. The methodology involves stating the hypotheses H_0 and H_1 : $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$, against the alternative hypothesis H_1 : there is at least one β_i such that $\beta_i \neq 0$ ($i = 1, 2, \dots, p$). A significance level, usually 5%, is adopted. If the calculated value is less than 0.05, the H_0 hypothesis is rejected, and regression is accepted.

In multiple linear regression, the t and F significance tests serve different purposes. The F-test determines if there is a significant relationship between the dependent variable and all independent variables, while the t-test assesses the validity of an independent variable's coefficient (Anderson et al., 2011).

When addressing modelling assumptions using regression analysis, Corrar et al. (2012) identified three common problems: normality of residuals, autocorrelation of residuals, and multicollinearity.

Economic value demonstrates how a certain indicator can impact production financially (Gameiro, 2009), providing quantitative information on the impact of zootechnical indicators on productivity and profit. This management approach is necessary to make production profitable and support technical improvements in response to the growing demand for animal products and the consumption of goat meat and its derivatives (Silveira et al., 2023).

This study presents methodological advances to enhance the management of goat meat production systems, allowing for more in-depth technical analyses of zootechnical indicators and profitability.

Conclusion

The conclusion is that there is a correlation, and it was possible to determine a mathematical equation for the zootechnical and economic indicators using the coefficient of determination, given that the predictor variables explained 95% of the variations in the predicted variables. The statistical tests showed that the model met expectations and allowed us to state that the model developed is valid, in accordance with the research objective. The results showed that the total weight of the young at birth and weaning, the mortality rate, reproductive efficiency, and gross income all affected the profitability of the system and can be used as criteria for decision-making in meat-goat farming. Feed costs and rainfall also influenced the predicted

variables. The multiple linear regression equations developed in this work could be useful and accessible tool for technicians and ruminant producers, as they enable simulations and analysis of different production and economic scenarios. Modeling in meat goat production systems has emerged as a promising tool to support planning, decision-making, and the improvement of production systems. However, more studies are still needed to deepen knowledge about the practical application of these models in different realities, considering regional particularities, the management systems adopted, and the complex interactions between biological, economic, and environmental factors.

Acknowledgments

All information is part of the project "Development of research to advance and consolidate the agribusiness of products and derivatives of goat and sheep farming in the Semi-arid Region," funded by FINEP (call for proposals 08/2010) and FAPESQ - Paraíba State Research Support Foundation – FAPESQ/EMPAER-PB call for proposals "n° 37/2021".

Declaration of competing interest

There are no conflicts of interest issues concerning this submission.

References

- Amayi, A.A., Okeno, T.O., Gicheha, M.G., Kahi, A.K., 2021. Breeding dairy goats for disease resistance is profitable in smallholder production systems. *Small Ruminant Research* 197:106337. <https://doi.org/10.1016/j.smallrumres.2021.106337>
- Anderson, D.R., Sweeny, D.J., Williams, T.A., 2011. *Estatística aplicada à administração e economia*. Ed. Cengage Learning, São Paulo, Brazil.
- Chatterjee, S., Hadi, A.S., 2006. *Regression Analysis by Example*. John Wiley. New York, EUA.
- Corrar, L.J., Paulo, E., Dias Filho, J.M., 2012. *Análise multivariada para os cursos de administração, ciências contábeis e economia*. Atlas, São Paulo, Brazil.
- Danell, O., 1986. Selection index for pelt lambs. Swedish University of Agriculture Science, Department Animal Breeding & Genetics Publication No. 9, Uppsala.
- Fávero, L.P.L., Belfiore, P.P., Silva, F.L., Chan, B.L., 2009. *Análise de dados: modelagem multivariada para tomada de decisões*. Elsevier, Rio de Janeiro, Brazil.
- Ferreira, M.P.B., Vilarroel, A.S.B., Barros, N.N., Façanha, D.A., 2008. A Influência da idade ao desaleitamento e da quantidade de leite sobre o desempenho de cabritas da raça Anglo-nubiana. *Revista de Medicina Veterinária* 2, 17-21.
- Freund, R.J., Littell, R.C., 2000. *SAS System for regression*. Cary, NC: SAS Institute.

- Gameiro, A.H., 2009. Análise econômica aplicada à Zootecnia: avanços e desafios. In: Santos, M.V., Albuquerque, R., Rennó, F.P., Silva, L.F.P., (Eds.). *Novos desafios da pesquisa em nutrição e produção animal*, Pirassununga, Brazil, pp. 9-32.
- Gunia, M., Mandonnet, N., Arquet, R., Alexandre, G., Gourdine, J.L., Naves, M., Angeo, V., 2013. Economic values of body weight, reproduction and parasite resistance traits for a Creole goat breeding goal. *Animal* 7, 22-33. <https://doi.org/10.1017/S1751731112001413>
- Hair, J.H. Jr., Anderson, R.E., Tatha, R.L., Black, W.C., 2005. Análise Multivariada de Dados. Bookman., Porto Alegre, Brazil.
- Hoffmann, R., Engler, J.J.C., Serrano, O., Thame, A.C.M., Neves, E.M., 1987. Administração da empresa agrícola. Livraria Pioneira, São Paulo, Brazil.
- Holanda Júnior, E.V., França, F.M.C., Lobo, R.N.B., 2006. Desempenho econômico da produção familiar de leite de cabra no Rio Grande do Norte. *Embrapa Caprinos: Comunicado Técnico* (74). <https://ainfo.cnptia.embrapa.br/digital/bitstream/CNPC/20250/1/cot74.pdf>
- Hurvich, C.M., Tsai, C.L., 1989. Regression and time series model selection in small samples. *Biometrika* 76, 297-307. <https://doi.org/10.2307/2336663>
- Jembere, T., Rischkowsky, B., Dessie, T., Kebede, K., Okeyo, A.M., Mirkena, T., Haile, A., 2019. Genetic and economic evaluation of alternative breeding scenarios for community-based productivity improvements of three indigenous goat breeds in Ethiopia. *Small Ruminant Research* 178, 46-54. <https://doi.org/10.1016/j.smallrumres.2019.07.017>
- Maher, M., 2001. Contabilidade de custos: criando valor para a administração. Atlas. São Paulo, Brasil.
- Matsunaga, M., Bemelmans, P.F., Toledo, P.D., Dulle, R.D., Okawa, H., Pedrosa, I.A., 1976. Metodologia de custo de produção utilizada pelo IEA, 123-139. *Agricultura em São Paulo* 23(1).
- Miot, H.A., 2017. Avaliação da normalidade dos dados em estudos clínicos e experimentais. *Jornal Vascular Brasileiro* 16, 88-91. <https://doi.org/10.1590/1677-5449.041117>
- Mokhtari, M.S., Rashidi, A., Esmailzadeh, A.K. 2010. Estimates of phenotypic and genetic parameters for reproductive traits in Kermani sheep. *Small Ruminant Research* 88, 27-31. <https://doi.org/10.1016/j.smallrumres.2009.11.004>
- Moura, J.F.P., Filho, E.C.P., Neto, S.G., Leite, S.V.F., Guilhermino, M.M., Menezes, M.P.C. 2010. Análise econômica da exploração de leite no Cariri Paraibano. *Acta Scientiarum. Animal Sciences* 32(2), 225-231. <https://doi.org/10.4025/actascianimsci.v32i2.7115>
- Reis, R.P., Medeiros, A.L., Monteiro, L.A., 2001. Custos de produção da atividade leiteira na região sul de Minas Gerais. *Organizações Rurais e Agroindustriais* 3, 45-52.
- Sarmiento, J.L.R., Pimenta Filho, E.C., Abreu, U.G.P., Ribeiro, M.N., Sousa, J.E.R., 2010. Prolificidade de caprinos mestiços leiteiros no semiárido nordestino. *Revista Brasileira de Zootecnia*. 39, 1471-1476. <https://doi.org/10.1590/S1516-35982010000700011>
- Sell, I., 2005. Utilização da regressão linear como ferramenta de decisão na gestão de custos. In: *Actas dos 26º Congresso Brasileiro de Custos*, Florianópolis, Brazil. <https://anaiscbc.emnuvens.com.br/anais/article/view/2224/2224>
- Silveira, N.C.S., Lopes, I.M.G., Lima, M.D., Rodrigues, G.R.D., Siqueira, M.T.S., Schultz, E.B., Silva, N.A.M., Raineri, C., 2023. Economic valuation of zootechnical indicators in a tropical dairy goat production system. *Revista Observatorio de la Economía Latinoamericana* 21, 5246-5263. <https://doi.org/10.55905/oelv21n6-108>
- Simplício, A.A., Azevedo, H.C., 2014. Manejo Reprodutivo: Foco na Taxa de Reprodução. *Acta Veterinária Brasílica* 8, 320-331. <https://doi.org/10.21708/avb.2014.8.0.3949>
- Sousa, W.H., 2018. Indicadores técnicos e econômicos de produtividade de um sistema de produção de caprinos de corte no Semiárido. João Pessoa: EMEPA-PB.
- Souza, W.H., Cézar, M.F., Cunha, M.G.G., Lobo, R.N.B., 2006. Estratégias de Cruzamentos para Produção de Caprinos e Ovinos de Corte: Uma Experiência da Emepa. In: *Encontro Nacional de Produção de Caprinos e Ovinos*, Campina Grande, PB. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/35237/1/AAC-Estrategias-de-cruzamentos.pdf>
- ST-Pierre, N.R., 2003. Reassessment of biases in predicting nitrogen flows to the duodenum by NRC 2001. *Journal of Dairy Science* 86, 344-350. [https://doi.org/10.3168/jds.S0022-0302\(03\)73612-1](https://doi.org/10.3168/jds.S0022-0302(03)73612-1)
- Taylor, J.F., Schanabel, R., Sutovsky, P., 2018. Review: Genomics of bull fertility. *Animal* 12, 172-183. <https://doi.org/10.1017/S1751731118000599>