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Economic Assessment of the Productive Parameters in Meat Sheep Production Using Discrete Event and Agent-Based Simulation

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Abstract

A hybrid stochastic model was developed including discrete events and agent-based simulations in order to identify the productive parameters and management criteria that most affect meat sheep production. A sheep herd on a pasture termination system, without weaning and with natural mating, was outlined. In order to devise this herd, a pre-existing database from between 1999 and 2013 was used. This conceptual model included the flushing, mating, gestation, lactation, termination and maintenance phases. Health, feeding and management criteria were also considered and recommended. Simulation scenarios were built which were later evaluated by regression analysis. The net operational margin was between R$ 11 741.80 and R$ 21 389.80, and an average of R$ 14 412.14 ± R$ 3 873.02 for different scenarios. Food costs had the greatest impact (25.4%) in relation to operating costs, while health costs were the lowest (1.3%). The abortion rate showed a higher linear response in contrast to the birth rate and the net operating margin, upon analysing ewe productivity parameters. However, neonatal mortality showed the greatest impact on net profit and on general lamb mortality. Carrying out economic analyses within the livestock sector can make a difference

within such a competitive market, where prices are not controlled, only costs. The use of discrete event and agent-based simulation methodologies allowed for the assessment of different approaches to sheep production. The present study demonstrated the tool's potential within the scope of meat sheep production, but this model can act as a guideline for other animal production systems.

Keywords: computer simulation, hybrid model, operational research, production costs, profitability, stochastic

1. Introduction

Enterprise size and complexity growth meant that the managerial decision-making process, once conducted by intuition and previous experiences, is now guided by more elaborate problem solution analyses. These analyses can be performed by Operational Research (OR), whose main objective is the development of suitable, rational decision-making models (Machline et al., 1975). One of the most developed OR techniques is simulation. Simulation is a flexible, powerful and intuitive tool in situations when one has to work with numerous constraints that cannot be dealt with by classical methods (Hillier & Lieberman, 2006).

In animal production, however, research lines including agent-based simulation (ABS) and/or discrete event simulation (DES) application are still limited. Several methods are available to calculate production costs, which is a key indicator for the feasibility analysis of a project. Nevertheless, the use of these methods in agricultural production still involves several technic and scientific issues. The challenge is allowing the projection of the activity in the productive horizon to be as real and dynamic as possible. The use of simulation models, which add probability to animal production, can be a technical alternative, as well as allow for the evaluation of the effects of research results and the identification of constraints that may encourage the development of future research.

Meat sheep production is considered a developing sector in Brazil. The national herd has increased by 13%, as compared to 9% growth of the cattle herd, between 2007 and 2016 (FAO, 2017). Nevertheless, this activity lacks well-defined technological standards, which raises questions as to which management system should be adopted and leads to existing production bottlenecks. The analysis of the economic impact of animal performance within different scenarios for specific productive periods can help to understand their performance within each productive phase of meat sheep production.

This study aimed to generate a tool to exploit the potential of both discrete event and agent-based simulation methodologies, offering technicians and scientists a new method for useful analysis. The present study exploited its applicability in the analysis and identification of the productive parameters that most impact meat sheep production, as well as in the identification of specific feasibility and economic issues that affect the activity within the production cycle.

2. Material and Methods

The "Ethic Committee on the Use of Animals" certified that this research was in accordance with the ethical principles for animal research adopted by the institution. The process protocol number was 3027/2013, and it was approved in the meeting held on 26 June, 2013.

According to Harrell & Bateman (2002), simulation is the process of the experimentation of a real system on a simplified model, which has widespread methodologies. The main sources for this topic are texts by Banks & Carson (1984), Law & Kelton (1991) and Pegden et al. (1995), which were compiled by De Freitas Filho (2008) in Brazil, and were used as methodological principles in the present study. Conforming to Montevechi et al. (2010), every simulation study has three major steps: design, implementation and analysis.

Step design

It includes project planning. We used data obtained from historical records of herd management and sheep herd research carried out by Laboratory of Production and Research of Sheep and Goats of Federal University of Parana (LAPOC/UFPR) between 1999 and 2013, as well as from the cost and profitability analysis sheets developed by Stivari (2012). By 2013, the LAPOC/UFPR herd was mostly made up of Suffolk and Suffolk crossbreds x mixed breeds; however, Santa Inês, White Dorper and crossbred specimens of these breeds were also included. Due to the significant performance differences between the Santa Inês and White Dorper breeds and their crosses, as compared to Suffolk, and also due to the greater availability of information on Suffolk and crossbred animals, only information on Suffolk and crossbred animals was used, so that there was no need to consider genetic merit at this stage of research.

The data were compiled by year and by activity, totaling a database with approximately 140 thousand items of information. Based on this information, descriptive statistical analyses to identify interactions and/or incongruities, and statistical distributions and frequencies, were performed with Minitab® (version 16.1), Input Anlyser® (version 14.7) and, Excel® (version 2013). P value was calculated for the adherence of the distributions according to the chi-square test at 0.05 of significance (further details of the analyses can be found in (Reijers, 2016).

The software chosen for the development of the model was AnyLogic®, University, 7.1.2 (XJ Technologies).

According to studies by Barros (2008), Barros et al., (2009a), Barros et al., (2009b), Stivari, (2012), Kowalski et al., (2013) and Stivari et al., (2013), of all the systems already used in the LAPOC/UFPR, which adopts lamb termination without weaning on pasture produced the best economic results. This system was used in this research.

Conceptual modelling – at the design stage – involves outlining the system by defining the components and describing the variables and logical interactions that account for the system (De Freitas Filho, 2008). Four experts in the area, using the face-to-face technique, as suggested by Sargent (2010), validated the conceptual model of this study.

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A conceptual model flowchart is shown in Figure 1. The blocks were grouped into five main stages: flushing, mating season, gestation, lactation and termination.

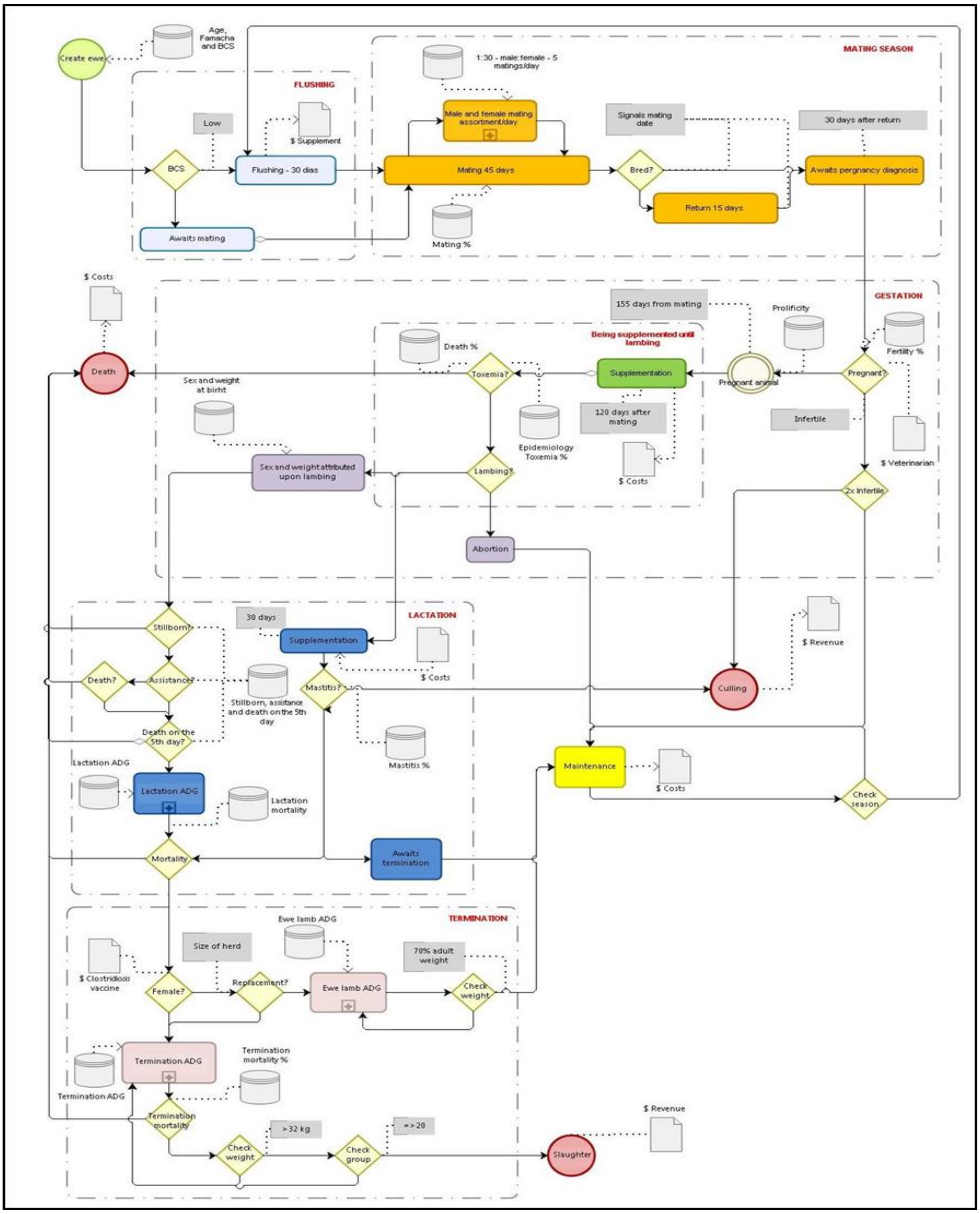

Figure 1. Conceptual model of a hybrid production system through the use of agent-based and discrete-event simulation methodologies

Continuous horizontal lines correspond to affirmative actions; continuous vertical lines correspond to negative actions; rectangles correspond to processes; diamonds correspond to decision-making; cylinders correspond to inputs; and paper sheet-shaped elements correspond to outputs. BCS: Body Condition Score

Ewes and rams were considered model agents. Fully developed ewes were given individual attributes with respect to age, body condition score (BCS), Famacha score – based on an anaemia indicator by Van Wyk & Bath (2002) – and weight. The initial physiological stage is that of maintenance; that is, in this stage, ewes have not yet started body development, gained weight or reached the reproductive phase. After the initial attributions, the model is able to identify low BCS ewes, redirecting them to flushing for 30 days, with 300 g concentrate.animal.day-1 (16% crude protein, CP; 74% total digestible nutrients, TDN, in dry matter). After flushing, all ewes are bred.

Ewes showing positive pregnancies were attributed to a gestational period and went into delay, that is, a 120-day standby mode from the beginning of the breeding season. After the delay, ewes were given supplement feed (800 g concentrate + 2.4 kg corn silage.animal.day-1) until they reached 150 days of gestation, counted individually from the date of breeding to the lambing period, maintaining the supplementation until 15 days postpartum. At this phase, the ewe may or may not have developed gestational toxemia and concomitant abortion or death. According to the statistical database findings, another Famacha score has also been attributed to pregnant mothers. Ewes showing high Famacha scores compute additional costs with vermifuge and were attributed a high Famacha score marker, which, if kept high during lactation, served as a criterion for ewe culling at the end of the year.

During lambing, the probabilities of care, ewe death, mastitis development and eventual non-lambing were attributed. For lambing ewes, the "in lactation" attribute was added, and the number of lambs born (simple – one lamb, or twin – two lambs), as well as the sex of lambs, were determined. At this stage, lambs were attributed a birth weight according to the type of lambing and sex (male or female). Then, the model assorted the possibility of stillborn lamb occurrence. Each lamb corresponded to a new temporary agent in the system, which was included in the model flowchart separately from the ewe. For each lamb born, the probability of death within the first five days of life was drawn.

The first clostridiosis vaccine dose was administered to lambs when they were 30 days old and reinforced at 60 days of age. Suckling lambs' average daily gain (ADG) was checked until they reached 18 kg; at this stage, lamb ADG is consistent with the termination phase. All male lambs were destined for slaughter and were weighed daily to check whether they had reached an adequate slaughter weight. Ewe lambs, in turn, were kept in the termination phase until they reached slaughter weight; however, the required number of replacement ewe lambs was verified before the surplus could be slaughtered. Replacement ewe lambs were considered lambs and were directed to another ADG loop, where they remained until they reached 70% of the adult body weight – a condition recommended by the LAPOC/UFPR so that ewe lambs can mate.

After the lamb termination period, mothers entered a maintenance stage until the next reproductive cycle. By the end of the year, all ewes and ewe lambs were in the maintenance phase. Before the next mating season, ewes older than six years, cases of consecutive infertility, persistent high Famacha scores, and mastitis and abortion history were checked. If the ewe was positive for any of these, the ewe was discarded and left the herd, with its costs and value calculated.

Macro information – still within the design stage – includes fundamental facts, information and statistics obtained from observation, personal experience or historical archives (De Freitas Filho, 2008). This information feeds the models and is an important step prior to the implementation phase. The model was devised for a 30-hectare (ha) farm with a Tifton-85 (Cynodon sp.) and ryegrass (Lolium multiflorum Lam.) continuous grazing system, with a 12% body weight (BW) supply of green fodder.day-1, and lambs remaining with the dams until slaughter, on pasture. According to the experiments already carried out by LAPOC/UFPR (Stivari, 2012), the physical limit of a pasture termination system would support approximately 400 ewes and their respective lambs during the lamb termination peak. This figure refers to a representative herd for the region and is in accordance with those proposed by Stott et al. (2005) and Toro-Mujica et al. (2011). Tables 1 to 3 summarises the model inputs and sources of origin, whether the information came from the LAPOC/UFPR database, the literature or was determined on an ad hoc basis.

Table 1. Agents and temporary agents of hybrid simulation model herd, using agent-based and discrete event simulation, from a sheep production system.

Component	Classification	Description	Input parameters	Data source
Ewe	Agent	Adult female sheep	Two to six years of age	LAPOC/UFPR
Ewe lamb	Temporary agent	Young female sheep. Remains in this category until reaching 70% of live weight of an adult or two years old	-	LAPOC/UFPR
Female lamb	Temporary agent	Young female sheep. Classification varies according to herd size destined to herd replacement or meat production	-	*Ad hoc*
Male lamb	Temporary agent	Young male sheep. Raised for meat production	-	*Ad hoc*
Ram	Agent	Adult male sheep	Ratio of 1 male to each set of 50 sheep	LAPOC/UFPR

Table 2. Variables of hybrid simulation model herd from a sheep production system

Component	Classification	Description	Input parameters	Data source
Age	Variable	Physiological age of animals	Lamb (a): < 150 days; ewe lamb: 151 days to 2 years; ewe: 2 to 6 years	LAPOC/UFPR and *Ad hoc*
Weight	Variable	Live weight in kilograms	Lambs for slaughter: 40 kg; ewe lambs: 32 to 58 kg; ewes: TRI[a] (62.000; 105.140; 83.883) kg	LAPOC/UFPR
Carcass yield	Variable	Average carcass weight yield (%)	TRI[a] (41.3; 47.5; 46.9)	LAPOC/UFPR
Famacha and Body Condition Score (BCS)	Variable	Famacha – score for parasitic infection; BCS – method to evaluate the animal body condition. These vary according to the physiological period	LFLB – Low Famacha and low BCS;	LAPOC/UFPR
			LFHB – Low Famacha and high BCS;	
			HFLB – High Famacha and low BCS;	
			HFHB – High Famacha alto and high BCS	
Average Daily Gain (ADG)	Variable	Animal average live weight gain (kg) per day	Ewe lamb: 0.110 kg.day^{-1};	LAPOC/UFPR
			Female lamb – lactation: Single lambing: 0.281 kg.day^{-1}; Twin lambing: 0.227 kg.day^{-1};	
			Male lamb – lactation: Single lambing: 0.311 kg.day^{-1}; Twin lambing: 0.238 kg.day^{-1};	
			Male/Female lambs up to slaughter: 0.230 kg.day^{-1}.	
Numbers of lambs per lambing	Variable	Number of lambs born per lambing.	Ewe: Single – 46%; Twin – 54%;	LAPOC/UFPR
			Ewe lamb: Single – 84%; Twin – 16%.	
Sex	Variable	Probability of male or female lamb birth	50% female; 50% male	LAPOC/UFPR
Birth weight	Variable	Lamb weight at birth varies according to sex and number of lambs per lambing	Female lambs. Single: NOR.tr[b] (5.370; 0.923; 3.140; 7.250); Twin: NOR.tr (4.345; 0.850; 2.165; 6.600);	LAPOC/UFPR
			Male lambs. Single: NOR.tr (5.955; 1.068; 2.950; 8.600); Twin: NOR.tr (4.697; 0.948; 2.110; 7.100).	
Assistance	Variable	Intervention during lambing	10%	*Ad hoc*
Mating rate	Variable	Number of mated females in relation to number of females exposed to mating	Ewes: 89%; ewe lambs: 79%.	LAPOC/UFPR
Abortion rate	Variable	Number of females that aborted	2%	Literature
Still births	Variable	Stillborn or lambs that died at birth	4%	LAPOC/UFPR
Neonatal mortality	Variable	Lamb mortality until five days of life	3%; assisted: 2.6%; mastitis: 15%.	LAPOC/UFPR and Literature
Mortality at lactation	Variable	Lamb mortality at lactation	4%; mastitis: 20%.	LAPOC/UFPR and Literature
Mortality at	Variable	Lamb mortality	1%	*Ad hoc*

termination		at termination		
Ewe mortality	Variable	Adult female sheep mortality. Varies according to physiological period and event occurrence	Maintenance: 4%; assisted lambing: 10%; toxemia: 100%.	LAPOC/UFPR and *Ad hoc*
Pregnancy toxemia	Variable	Metabolic disease affecting sheep during the final third of gestation	1%	*Ad hoc*
Mastitis	Variable	Inflammation of the mammary gland	0.5%	LAPOC/UFPR
Fertility rate	Variable	Number of pregnant females in relation to number of females exposed to mating	Ewes: 93%; ewe lambs: 81%.	LAPOC/UFPR

aTRI: Triangular distribution (minimum, maximum, mode); bNOR.tr: Trimmed normal distribution (mean, standard deviation, minimum, maximum)

Table 3. Process in a hybrid simulation model herd from a sheep production system

Component	Classification	Description	Input parameters	Data source
Flushing	Process	Period of supplementary feed supply for animals showing low BCS	30 days	LAPOC/UFPR
Mating	Process	Reproductive period of ewes and rams	45 days	LAPOC/UFPR
Mating return	Process	Additional reproductive period of ewes and rams	15 days	LAPOC/UFPR
Gestation diagnosis	Process	Gestational diagnosis of ewes that were lambed during mating and mating return	30 days after end of mating return period	LAPOC/UFPR
Birth	Process	Lambing	150 days after mating date performed during the mating or mating return period	LAPOC/UFPR
Slaughter	Process	Slaughter of male or female lambs for meat production	Slaughter of animals that reached the slaughter weight or that were 150 days old	*Ad hoc*

The economic financial analyses of the model were based on Stivari's proposal (2012) due to data similarity. All prices were those charged in 2015, obtained by consulting the list of prices paid to producers by the Agriculture and Supply Department of Paraná State, Brazil (SEAB-PR, 2016), as well as by means of market surveys, when not included in the database. All figures were adjusted to the inflation rate for the month of December 2015 by using the Consumer Price Index calculated by the Brazilian Institute of Geography and Statistics (IBGE, 2016). Exchange rate for December 2015: USD 1.00 = R$ 3.8705, according to Brazilian Central Bank (BCB, 2016).

An inventory of the necessary improvements and machinery was prepared, including a 50 m^2 warehouse, a 400 m^2 sheepfold for shelter during the pre and post-lambing seasons, and wire mesh fences in the paddock perimeter. Machinery and equipment included a hand grass cutter, an animal weighing scale, a feed mixer, a refrigerator and a cart. The total capital asset in buildings, facilities machinery and equipment was R$ 121 477.52.

For conservation and repair calculation purposes, 2% of the value of the new asset per year was considered; for the warehouse and sheepfold, 15% per year for fences, and 10% per year for the refrigerator, feed mixer, scales, cutter and cart were considered. Depreciation was obtained by the linear method (Croitoru et al., 2015), with a 10% residual value of the new assets for machinery and equipment, 20% for the warehouse and forage, and 0% for the fence. The service life was 30 years for the sheepfold and warehouse, 15 years for the fences, feeder, salt lick, water bunk, feed mixer, refrigerator and cart, and 5 years for the cutter and scale.

Concentrate was prepared on the farm and its costs were accounted. The concentrate was composed of corn grain and meal, soybean meal and hulls, wheat meal, mineral supplement, limestone, ammonium chloride and urea. Expenditures on pasture implementation and management were accounted for according to a model proposed by INSTITUTO FNP, (2010) and LAPOC/UFPR practices. The costs of cleaning and hygiene materials, medicines, vaccines and antiparasitics were calculated based on LAPOC/UFPR annual consumption. The antiparasitic drug computation was in agreement with that of Salgado (2011) during the field experimental phase.

The costs for transportation and animal slaughter, technical assistance (60% of the regional minimum wage), permanent labour of an employee who was paid a monthly regional minimum wage at the time (R$ 788.00), in addition to labour costs of 45.59% on the annual total (CONAB, 2010) and working capital interest were accounted for. Working capital interest costs were based on an average variable cost of R$ 10 000.00, at a 1.89% nominal interest rate per month used by the Federal Savings Bank to guide consumer credit loan funds. Taxes on total income were: National Social Security Institute (INSS) at a rate of 2.3% on the revenues obtained from the sale of animals, and 1% for varied fees, such as association and union obligations. Brazilian Excise Tax (ICMS) was calculated at a rate of 7% on the revenue obtained from the sale of meat (Brasil, 2007).

Cost items were grouped into the following categories: variable costs, fixed costs and opportunity cost of invested capital. Variable costs (VC) are those that change according to the amount produced and whose duration is shorter than or equal to the production cycle. Fixed Costs (FC) are those that do not vary along with the amount produced, and which last

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longer than a production cycle. Maintenance, machinery and equipment depreciation costs are also considered FC (Table 4). When variable costs are added to fixed costs, the operating cost (OPC) is obtained.

Table 4. Hybrid simulation model of the production cost inputs of a sheep production system

	Item	Period	Unit	Value	Description
1 – Variable costs					
a)	Flushing	Flushing	R$.ewe^{-1}	0.21	Provided for ewes with low body condition score in the pre-mating period for 30 days
b)	Supplementation	Gestation and lactation	R$.ewe^{-1}	1.63	Provided to ewes in the last third of pregnancy for 30 days and 15 days postpartum
c)	Anthelmintic	Maintenance, gestation and lactation	R$.mL^{-1}	0.33	Anthelmintic dose (1 mL/25 kg) × ewe weight. Administered to ewes showing high Famacha scores.
d)	Clostridiosis vaccine	Gestation and lactation	R$.animal^{-1}	0.83	Ewes are vaccinated 30 days before lambing. Lambs are given doses at 30 and 60 days of age
e)	Animal identification	Maintenance	R$.animal^{-1}	1.50	Identification of replacement female lambs
f)	Slaughter	Termination	R$.animal^{-1}	19.00	Transport + slaughter rate
g)	Taxes	Termination	Revenue %	10.30	GPS/INSS (2.3%) + Funrural (1%) + ICMS (7%) × amount of meat marketed × price paid per kg of meat
2 – Fixed costs					
h)	Pasture management	Annual	R$.year^{-1}	10 999.02	Mowing, fertilisation and sowing
i)	Permanent labour force	Annual	R$.year^{-1}	9 814.38	Minimum wage + labour costs
j)	Technical assistance	Annual	R$.year^{-1}	2 836.80	Fees corresponding to six technical visits a year.
k)	Medication	Annual	R$.year^{-1}	1 800.00	Drugs, hygiene and cleaning materials
l)	Electricity	Annual	R$.year^{-1}	240.00	Average annual consumption for feed production
m)	Maintenance	Annual	R$.year^{-1}	7 232.09	Betterments, machinery and equipment
n)	Depreciation	Annual	R$.year^{-1}	6 134 86	Betterments, machinery and equipment
o)	Interest	Annual	R$.year^{-1}	338.27	1.89% of working capital
3 – Opportunity cost of fixed capital					
p)	Opportunity cost of invested capital	Annual	R$.year^{-1}	167285.59	Production factor income: betterments, machinery, equipment, herd and capital
4 – Revenue					
q)	Mutton price	Termination	R$.kg^{-1}	5.00	Adult animal meat
r)	Carcass price	Termination	R$.kg^{-1}	17.00	Lamb meat

The invested capital cost represents an opportunity abdicated by the producer upon failing to apply the same amount of resources to another activity. In practice, the basis for the opportunity cost of capital comparisons is traditional financial market investments, such as savings accounts and commodity funds. In order to determine the opportunity cost of fixed assets, a 0.5% monthly market interest rate (reference value adopted by the savings account) on the total amount of capital invested in betterments, machinery, equipment, herd and capital was used. The total cost of production (TC) was the sum of the OPC and the opportunity cost of fixed capital.

Sale prices were established based on those charged in Curitiba, in the state of Paraná area. Total revenue (TR) consisted of the sale of lamb and adult (mutton) meat. Table 4 shows the model cost inputs, the period they refer to, their value and brief descriptions.

A Profit and Loss Statement (PLS) was prepared for one production year, and the unit cost to produce one kilogram of lamb carcass, the operating cost per ewe, gross margin (GM, total revenue minus variable costs), net margin (NM, total revenue minus total cost), net operating margin (NOM, total revenue minus operating costs), total breakeven points (BEP, total cost divided by revenue) and operating breakeven (OBE, operational cost divided by revenue) were calculated. Margin (GM, NM and NOP), BEP and cost (VC, FC and OPC) calculations were performed using a simulation model developed by the AnyLogic software.

Implementation process

The second major step – is the conceptual model codification into an appropriate simulation language (Chwif & Medina, 2014), which then needs to be checked and validated. Checking implies verifying whether a series of assumptions and simplifications of the real system were correctly implemented in the model (De Freitas Filho, 2008). Validation, on the other hand, is the process by which one seeks to accurately estimate the parameters based on field data (Manevski et al., 2016). If the outputs are considered inconsistent, the model must be checked against the available data; if discrepancies remain, the model should be modified (Manevski et al., 2016; Martin et al., 2011).

Pidd, (1996) and Sargent, (2010) state that consulting an expert is the best and simplest way to perform validation, while De Freitas Filho (2008) adds that this process, in practice, should be initiated in the design phase and extended up to the experimentation stage. Kabir et al. (2018) used a similar method of parameterisation and validation. Thus, the model presented in this study was developed based on this premise, and routine consultations were made with specialists in the area, thus validating the model.

The model was checked by means of the variance calculation (difference between the results of simulated and real scenarios, divided by the result of the real scenario) of the variables related to ewes, lambs and the economic results. The hybrid simulation model was associated with both input and output data.

Analysis

As the last step of the method, the simulation model was defined as "non-terminal"; that is, an exact termination time was not set, as what really matters is the development of the study within the period in which the simulation is permanent (Chwif & Medina, 2014). Thus, a seven-year warm-up was performed such that there were ewes of all ages up to culling age, making a stabilised and active herd. An analysis of the results was computed after the warm-up period.

The scenarios involved a productive cycle and an independent mode, which is one in which changing one variable does not imply the systemic alteration of another variable. For each scenario, a parameter variation amplitude was established and sensitivity analyses were performed using the regression method (Table 5).

Table 5. Range of variation of sensitivity analyses for the experiments and scenarios studied in the hybrid simulation model

Scenario		Description	Original values	Range of variation
S1		Increase/decrease in mating rate	Ewes: 89% Ewe lambs: 79%	±10 pp[a], varying for each 1 pp.
S2		Increase/decrease in fertility rate	Ewes: 93% Ewe lambs: 81%	±10 pp, varying for each 1 pp.
S3	Ewe and ewe lamb	Increase/decrease in male:female ratio	1:50	1:50 to 1:400, varying for every 20 ewes
S4		Increase/decrease in single lambing incidence	Ewes: 46% Ewe lambs: 84%	±50 pp, varying for every 5 pp. Ewe lambs do no change
S5		Increase/decrease in abortion incidence	2%	±20 pp, varying for each 1 pp.
S6		Increase/decrease in stillbirth rate	4%	±15 pp, varying for each 1 pp.
S7	Lamb	Increase/decrease in neonatal mortality rate	Eutocic lambing: 3% Assisted lambing: 2.6% Ewe with mastitis: 15%	±20 pp, varying for each 1 pp.
S8		Increase/decrease in lactation mortality rate	4% Ewes with mastitis: 20%	±15 pp, varying for each 1 pp.
S9		Increase/decrease in termination mortality rate	1%	±20 pp, varying for each 1 pp.
S10		No culling of ewes over six years of age	Age > 6 years	No culling
S11	Management	No culling of infertile ewes	Infertility > 2 years in a row	No culling.
S12		Increase/decrease in average daily gain	0.230 kg.day^{-1}	Variation between 0.180 and 0.370 kg.day^{-1}, varying for each 0.010 kg.day^{-1}.

[a]pp: percentage points; S1 to S5: scenarios referring to changes in the productive parameters of ewes and ewe lambs: S6 to S9: scenarios referring to changes in the productive parameters of lambs; S10 to S12: scenarios referring to changes in herd management criteria

According to De Freitas Filho (2008), as a rule, the collection of data to produce a sample from a model simulation can be performed in two ways: by making use of individual observations within each replication, or by performing simulations (replications). In this study, the second option was chosen, and 100 replications were performed for each scenario.

3. Results

The financial year net result simulation average was R$ –3 803.27, with a standard deviation of R$ 3 389.19, and with limit values ranging from R$ –13 475.80 to R$ 3 055.40. The net operational margin (NOM) showed positive financial results, with values between R$ 11 741.80 and R$ 21 389.80, and an average of R$ 14 412.14 ±R$ 3 873.02 (Table 6).

Table 6. Production year profit and loss statement in a simulated meat sheep production system

Profit and loss statement[a]	R$.year^{-1}
Gross operating revenue	
Lamb meat sales	73 233.24
Culling ewe sales	14 080.27
(–) Gross revenue deductions	
Taxes	8 993.29
Net operating revenue	78 320.22
(–) Sales costs	
Slaughter costs	5 208.66
Feed costs	18 488.46
Health costs	815.54
Gross operating results	53 807.56
(–) Operating expenses	
Permanent labour costs	9 814.38
Pasture management costs	10 999.02
Technical assistance costs	2 836.80
Drug costs	1 800.00
Electricity costs	240.00
Maintenance costs	7 232.09
Depreciation costs	6 134.86
Working capital interest costs	338.27
Net profit	14 412.14
(–) Invested capital opportunity cost	18 215.41
Financial year net result	–3 803.27

[a]Average of 100 replications; Exchange rate for December 2015: USD 1.00 = R$ 3.8705, according to BCB

Food had the greatest net profit impact (25.4%) in the yearly profit and loss statement, followed by pasture management (15.1%), permanent labour (13.5%) and taxes (12.3%).

Health costs were relatively low (1.3%) in relation to operating costs. This low percentage can be attributed to the distribution of animals with lower Famacha scores, where the average simulated by the model was 292 cases, that is, one vermifugation for each 0.73 sheep.year-1 (400 ewes and ewe lambs).

When the economic results of the model were analysed, the productive system was found to have operated profitably; that is, the operating breakeven point (BEP) was obtained before 100%, with a surplus over operating costs. The average number of slaughtered lambs verified by the model was in 240 animals, with a minimum of 199 and a maximum of 291 animals under the patterned parameters, and an average slaughter rate of 68.4 ±3.9%. However, when calculations included the total cost of production, the BEP exceeded 100%, i.e. production was not sufficient to compensate for all production costs, even with a slaughter rate close to 70% of production. The average production operating cost per kilogram of marketed carcass was R$ 13.77, having reached an operational balance at 84.1% of production.

When analysing the proposed ewe-related variable scenarios (scenarios S1 to S5) in relation to the slaughter rate, a greater linear response was observed for the abortion rate, with the fertility rate being another important component (Table 7). In the scenarios referring to lamb-related variables (S6 to S9), a greater linear response was observed for the termination and neonatal mortality rate, as described in Table 7.

Table 7. Analysis of proposed scenarios in relation to ewe (S1 to S5) and lamb (S6 to S9 and S12) slaughter rate variables

Scenario	Equation	R^{2*}(%)	*t* (a)	*t* (x)
S1	Slaughter rate (%) = 0.4793 + 0.2365 * mating rate	89.5	32.3	13.4
S2	Slaughter rate (%) = 0.4410 + 0.2592 * fertility rate	92.5	29.7	15.7
S3	Slaughter rate (%) = 0.6960 – 0.0002 * male:female ratio	61.5	70.5	–5.6
S4	Slaughter rate (%) = 0.7136 – 0.0008 * single lambing	95.1	288.9	–20.2
S5	Slaughter rate (%) = 0.6949 – 0.7731 * abortion	99.1	351.7	–50.2
S6	Slaughter rate (%) = 0.7148 – 0.8697 * stillborns	99.4	436.9	–59.0
S7	Slaughter rate (%) = 0.7255 – 1.5931 * neonatal mortality	99.5	232.1	–68.4
S8	Slaughter rate (%) = 0.7154 – 0.8827 * lactation mortality	99.2	269.2	–50.6
S9	Slaughter rate (%) = 0.6894 – 0.8507 * termination mortality	99.6	480.3	–72.7
S12	Slaughter rate (%) = 0.6599 + 0.0917 * average daily gain	72.4	182.8	7.1

S1 evaluates changes in ewe mating rates; S2 evaluates changes in ewe fertility rates; S3 evaluates changes in the male:female ratio; S4 evaluates changes in the incidence of single births; S5 evaluates abortion rate changes; S6 evaluates changes in stillborn lamb rates; S7 evaluates changes in neonatal mortality rates; S8 evaluates changes in mortality rates in the lactation period; S9 evaluates changes in mortality rates at termination; S12 evaluates changes in lamb average daily gain. * R^2-adjusted; T: Student's t-test.

Upon analysing ewe performance, the abortion rate showed a higher linear response, as contrasted to the birth rate (birth rate = 1.0992 – 1.2848 * abortion, adjusted coefficient of determination R^2 = 99.7%) and the net operating margin (NOM R$ = 14 529.7414 – 59 672.5337 * abortion, adjusted coefficient of determination R^2 = 95.7%). However, neonatal mortality had the greatest impact on NOM (NOM R$ = 17 782.2975 – 140 473.3895 * neonatal mortality, adjusted R^2 = 99.6%), and on general lamb mortality (Mortality % = 0.0965 + 1.74 * neonatal mortality, adjusted R^2 = 99.2%).

Ewe mating failure was not attributed to male sexual performance, inasmuch as when scenario S3 was performed, alterations were only perceived when occurring in scenarios that did not correspond to reality, such as the 1:200 ratio. It is believed the ease of modeling this variable may have caused the loss of other information, which in turn could better explain the effect of the male and female ratio within the productive system. However, it is believed that the presence of lambs in the herd may have negatively influenced the mating rate, as data showed a 10% ewe reduction. Thus, mating rate failure occurred due to the sheep.

As for management standards, scenarios S10 and S11 (which simulated ewe culling or not according to age and/or consecutive infertility, respectively) showed a 52% NOM increase in relation to the base scenario when culling was not performed (six years); it was economically more interesting than the slaughter of ewes due to infertility. These results can be accounted for by the fact that there was a greater number of ewes, as compared to ewe lambs, in the herd (309 and 91 versus 255 and 145 in the baseline scenario), increasing the reproductive parameter averages, such as the mating rate, fertility rate and number of multiple births, resulting in a higher number of lambs in the herd.

Reproductive trait improvement did not have a greater economic impact than that of lamb growth. Neonatal mortality was the ewe- and lamb-related variable that most affected the slaughter rate (Table 7), birth rate and NOM; that is, the main critical period for production is the first five days of lamb life.

Considering the variables that can influence the slaughter rate within the ewe performance parameters, the abortion rate was the main cause of the slaughter rate, birth rate and the NOM reduction.

4. Discussion

Lamb feed costs in Brazil have played a major role in the production of meat sheep (Barros et al., 2009a; Barros et al., 2009b; Paim et al., 2011; Raineri et al., 2015a; Stivari et al., 2013; Ziguer et al., 2011). Raineri et al. (2015a), upon analysing the elasticity of meat sheep production costs in a feedlot in Brazil, reported higher contribution margins (63%) and an elastic, positive feed increase. In Turkey's provinces, Demirhan (2019), through a questionnaire, found that the main problems identified by sheep producers were the cost of feed. Thus, the adequate management of feed costs seems to be relevant for sheep production.

The significant tax contribution on sheep production in this study is in accordance with the findings of Raineri et al. (2015b), Sorio & Rasi (2010) and Souza et al. (2008). These authors stated that informality is present in the production, slaughter, marketing and carcass processing of Brazilian sheep, in which 55% of farmers perform the slaughter and marketing on their own farms, both because of the possibility of achieving higher sales figures and evading taxes. This practice is of great concern to the Brazilian sheep industry, not only because of the exclusion of the health surveillance system, but also because of the disruption of the entire production chain.

The low herd health contribution to production costs is a reality in the LAPOC/UFPR sheep production environment, which has satisfactory standards and herd health control. Health protection programmes are sometimes understood as extra costs related to sheep production; however, an increase in lamb deaths can lead to higher losses (Demirhan, 2019). In a study carried out on representative commercial farms with respect to meat lamb production, Raineri et al. (2015b) noted the use of anthelmintics as one of the factors that least impacted the production costs of sheep farming, which is in agreement with our findings. It is believed that submodels, which can add information on genetic selection by resistant animals, can be more sensitive to the effects of age and differences in pasture management; therefore, the impact of the health variable could be refined, its behaviour better understood and its analysis improved.

Producers who want to obtain or modify production costs need to pay attention to the productive performance of the herd. The slaughter rate directly influences costs per kilogram of live weight, in which the production costs are inversely proportional to the slaughter rate of the herd: the higher the slaughter rate, the more kilograms of meat are marketed and the lower the costs per kilogram of meat produced (Viana & Silveira, 2009).

Wang & Dickerson (1991) stated that reproductive trait improvement has a greater economic impact than that of lamb growth. Although these results were not found in our research, this assumption was only observed when the effect of the average daily gain on the slaughter rate was analysed, and was unrelated to lamb mortality.

According to Simplício & Azevedo (2014), high prolificacy selection is important because birth is associated with the survival of a large number of lambs, and because it favours the genetic improvement of the herd. Despite the results presented by these authors, the scenario results showed that a reduction in the number of single births was not a major contributor to an increase in the slaughter rate, birth rate and/or net operating margin.

Alterations to the fertility and mating rates of ewes did not result in big economic gains, as compared to the management of lambs in their first days of life. This reinforces the necessity for special attention to this phase in the production system, without neglecting the role of embryonic survival, stillbirths and postnatal mortality (Gouveia, 2006).

Knowing that the average operating cost of maintenance ewes was approximately R$ 136.83 ewe.year^{-1}, which was higher than that of R$ 66.10 found by Paim et al. (2011) – unmated females added approximately R$ 64.00 to the cost per ewe to the system – an equivalent to approximately 1 355 kg of lamb meat, not generating an additional revenue of approximately R$ 23 000.00 . Of the mated sheep (273), 26 did not get pregnant (9.5%), and 5 $\pm$ 2 sheep proved to be infertile for two consecutive years; that is, infertility caused a loss of approximately R$ 11 000.00 to the system.

These results are in agreement with those published by Simplício & Azevedo (2014), who emphasised that the profitability by ewes and area unit exploration is influenced by the number of offspring marketed and incorporated into the herd as replacement animals. Bohan et al. (2018) found that the main drivers of profitability were the number of lambs weaned per ha, related to the growth and utilisation of pastures, since the animals of this simulation were also considered to be grazing.

In non-stabilised herds with health control weaknesses, an increase in the number of abortions is usually associated with outbreaks of infectious diseases, such as Toxoplasma gondii (toxoplasmosis), Chlamydia psittach (enzootic abortion) and Campylobacter fetus (vibriosis) (Pereira et al., 2013). When the infectious component is not the causative agent, the incidence of abortions is usually sporadic and due to blows, high stress during prepartum shearing , the administration of contraindicated drugs during the gestation period, incorrect nutritional management and fights between animals (Alves et al., 2014; Eales & Small, 2008). These factors are closely related to a low quality workforce and technification, as well as inadequate shelter (location, size) in prepartum, which can lead to overcrowding, increasing the probability of fights between animals.

5. Conclusions

The simulation model identified that the reproductive characteristics were not the variables that most influenced the productive and economic results as many believe, but rather those related to the first day's life care of lamb.

The assignment of individual characteristics of the animals (the agent-based approach) and the use of a complete and detailed database provided the development of a more robust and adequate simulation model for representation of the productive system. This allows the study and analysis of different technological combinations without the need of field experiment, aiming to guide scientists' efforts towards the development of further research in animal science.

Simulation modelling can also be used as a didactic and practical tool to demonstrate the cause-effect relationships in livestock for the non-scientist public, as farmers and policymakers, for example. Similar approach can be applied for other important livestock systems.

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