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Bioeconomic evaluation of pasture sheep finishing using castor bean cake

Avaliação bioeconômica da terminação de ovinos sob pastejo utilizando torta de mamona

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Abstract
This study evaluates the economic viability of sheep finishing systems on irrigated Tamani grass pasture under continuous stocking, using castor bean cake. Four production systems were simulated: sheep supplemented with soybean meal on pasture fertilized with urea (SMUR), sheep supplemented with detoxified castor bean cake on pasture fertilized with urea (CCdUR), sheep supplemented with soybean meal on pasture fertilized with *in natura* castor bean cake (SMCC) and sheep supplemented with detoxified castor bean cake on pasture fertilized with *in natura* castor bean cake (CCdCC). A minimum unit of 3 hectares and an average slaughter weight of 28 kg were considered. A minimum selling price, at which the least profitable system would become profitable, was stablished: US$ 2.38 and US$ 4.45/kg per kilogram of body weight and carcass weight equivalent, adopting a minimum rate of return of 3.5% per year, based on the Selic rate. The costs for organic fertilization were 46.01% higher than in systems using chemical fertilization. The selling of live animals was not attractive in any of the systems evaluated, and the opposite was observed for the selling of carcasses and non-carcass components. System SMUR proved to be more profitable, with a gain of US$ 0.53 per kg carcass.
Keywords: concentrated supplementation; internal rate of return; profitability; *Ricinus communis* L; Santa Inês.

Resumo
Objetivou-se avaliar a economicidade de sistemas de terminação de ovinos em pastagem irrigada de capim-tamani sob lotação contínua, utilizando torta de mamona. Foram simulados quatro sistemas de produção: ovinos suplementados com farelo de soja e o pasto adubado com ureia (FSUR), ovinos suplementados com torta de mamona destoxificada e o pasto adubado com ureia (TMdUR), ovinos suplementados com farelo de soja e o pasto adubado com torta de mamona *in natura* (FSTM) e ovinos suplementados com torta de mamona destoxificada e o pasto adubado com torta de mamona *in natura* (TMdTM). Foi considerada a unidade mínima de 3 hectares e determinado um peso médio ao abate de 28 kg de peso corporal. Estabeleceu-se um preço de venda mínimo, no qual o sistema de criação menos lucrativo se tornasse rentável de 2,38 e 4,45 dólares por quilograma de peso corporal e por equivalente de peso da carcaça, dotando uma taxa mínima de atratividade de 3,5% ao ano, com base na taxa Selic. Os custos com adubação orgânica, em média, são 46,01% superiores aos sistemas que utilizam adubação química. A venda de animais vivos não é atrativa em nenhum dos sistemas avaliados, sendo o contrário observado para a comercialização de carcaças e dos não componentes da carcaça de ovinos. O sistema de produção FSUR se mostrou mais lucrativo, com ganho de US$ 0.53 centavos por kg de carcaça.
Palavras-chave: rentabilidade; *Ricinus communis*; Santa Inês; suplementação concentrada; taxa interna de retorno.

1. Introduction

Sheep farming is an important activity in the global agricultural context. Sheep are cosmopolitan animals and adapt to different soil and climatic conditions[(1)], besides presenting good productive performance on pasture[(2)] and in confinement, which makes them a source of income with market potential. In Brazil, ruminant farming has enormous potential, mainly due to the large territory and tropical climate of the country, allowing the production of animals at low cost.

Globally, pastures are the main and cheapest source of feed for ruminants, and in Brazil, this production is predominantly extensive. Grazing sheep farming is limited by gastrointestinal parasitism, which causes reduced animal performance, weight loss, low fertility, and high mortality rates[(3)]. The species *Haemonchus contortus* is the main parasite found in small ruminant herds. It has a

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hematophagous habit and causes great losses due to the high rate of contamination and animal mortality[4].

The use of feed supplements, fertilizers, and anthelmintics allows maximizing animal production per area; however, it can burden the production system and, in some cases, compromise economic viability. In this scenario, the use of agroindustry by-products can contribute to the reduction of costs in livestock, either in the form of supplements, organic fertilizers, or the control of gastrointestinal parasites[5-7].

Among the by-products, there are those generated by the ricin-chemical industry chain, such as castor bean cake, which is obtained via oil extraction. It has high levels of crude protein and total digestible nutrients, and can be used as input to decrease the costs of animal production[5]. Although for a long time its use was limited by the presence of toxic anti-nutritional factors, today, there are safe and economically feasible detoxification methods, such as the alkaline chemical method proposed by Andrade et al.[8], with good results in livestock[9,5].

The use of castor bean cake, with nematicide action, as organic fertilizer assists in the control of the free-living phase of gastrointestinal parasites in sheep[7] and phytonematodes in the soil[10]. In addition, it is an excellent source of nutrients such as nitrogen, phosphorus, calcium, and micronutrients for plants[11]. In this sense, the economic feasibility and application of castor bean cake in production systems are important for the recommendation of its use to reduce production costs, either as a feed input, fertilizer, or for the control of gastrointestinal parasites of grazing sheep.

In this context, the purpose of this study was to analyze the bioeconomic feasibility of using detoxified castor bean cake replacing soybean meal in concentrated feed, as well as the use of *in natura* castor bean cake as organic fertilizer replacing urea in the finishing of sheep on irrigated Tamani grass pasture under continuous stocking.

2. Material and methods

2.1. Description of the experimental area

All procedures were approved by the Ethics Committee on the Use of Animals (CEUA) of Embrapa Goats and Sheep, under protocol No. 001/2017. The study was carried out from October 2019 to February 2020 at Três Lagoas Farm, which belongs to Embrapa Goats and Sheep, and is located in the city of Sobral - CE, Brazil, at latitude 3º44'50" South and longitude 40º21'28" West. The climate of the region is classified as BSh, warm semi-arid[12]. During the evaluation period, climate data were collected from a weather station installed in the experimental area. Average values of 29.57ºC, 66.54%, 1881.03 μmol m^2/s, and 7.75 mm/day were recorded for air temperature, air relative humidity, solar radiation, and rainfall precipitation, respectively.

2.2. Pasture establishment and castor bean cake detoxification

A soil sample was collected from the 0 - 20-cm layer for the evaluation of physical and chemical attributes. The soil of the experimental area was classified as Ortic Chromic Luvisol[13] and presented the following characteristics: pH=6.8; organic matter=17.27 $g.kg^{-1}$; P = 23.0 $g.kg^{-1}$; K = 0.2 $cmol_c/kg^{-1}$; Ca = 11.5 $cmol_c/kg^{-1}$; Mg = 3.4 $cmol_c/kg^{-1}$; H+Al = 1.98 $cmol_c/kg^{-1}$; Al = 0.0 $cmol_c/kg^{-1}$; sum of bases (SB) = 15.1 $cmol_c/kg^{-1}$; cation exchange capacity (CEC) = 17.08 $cmol_c/kg^{-1}$; and V = 89 %. The S, Na, Cu, Fe, Zn, Mn, and B values were 153.0, 23.0, 40.0, 80.0, 13.0, 159.0, and 1.3 $cmol_c/kg^{-1}$, respectively. Th values obtained for clay, silt, coarse sand and fine sand were 161.0, 219.0, 327.0, and 293.0 g/kg^{-1}, respectively.

Based on the soil analysis, base fertilization was carried out with the formulation 06:28:16 to meet the recommendation of 40:70:40 kg of NPK, in addition to 40 kg/ha of micronutrient FTE BR-12[14]. Initially, ammonium sulphate was used as an N source. Prior to the experiment, the area was subjected to mechanized crop treatments: stump removal, ploughing and harrowing. The Tamani grass pasture was implemented on July 12, 2019, with the aid of a four-row hydraulic planter. An amount of seeds equivalent to 20 kg/ha was used, and sowing was performed with a distance of 40 cm between rows and a depth of 2 cm.

The area was provided with a low-pressure fixed sprinkler irrigation system, with service pressure < 2.5 kgf/cm^2, and irrigation was carried out daily, over the night. The supplied amount of water corresponded to an average crop evapotranspiration of 6.9 mm/day, with an application efficiency of 75%. Evaluation of the uniformity of water distribution by the system was performed with the aid of rain gauges spaced at distances of 3.0 x 3.0 m, at a height of 0.5 m from the ground, in two diagonally alternated paddocks.

The castor bean cake was purchased from Bioenergy Brazil Industry and Trade LTDA, in the city of Monsenhor Tabosa, Ceará, and was a by-product of the mechanical extraction (pressing) of the seed oil, at temperatures between 90 and 100ºC. It was stored in raffia polypropylene containers with a capacity of 50 kg and kept on wooden platforms in a closed shed until being used in the experiment. The *in natura* castor bean cake used as organic fertilizer had the following values for N, P, K, Ca, Mg, and S: 55.02, 12.0, 15.7, 6.5, 8.7, and 1.60 g/kg, respectively, with a C:N ratio of 5.2. The values for Cu, Fe, Zn, Mn and B were 26.0, 532.0, 168.0, 62.0, and 7.0 mg/kg, respectively. The castor bean cake destined for animal supplementation, was detoxified with calcium oxide (CaO) in the proportion of 90 g (CaO) per kilogram of cake and dissolved in 2.5 L of water[8]. Detoxification was confirmed after electrophoretic characterization (SDS-PAGE) of the samples of castor bean cake extract (CC), detoxified castor bean cake (CCd) and diet containing CCd (CCdD), in addition to the analysis of the hemagglutinating activity of toxic lectins, according to Andrade et al.[8].

2.3. General management of pasture, animals, treatments, and diet

The animal performance data used in this economic analysis were obtained from a study using 64 Santa Inês sheep, 32 castrated males and 32 females, aged of 3.6 ± 0.6 months and with an initial body weight (BW) of 19.42 ± 3.6 kg. Each treatment contained four animals, with four replications (paddocks). Thirty ewes were used as balance animals, with a BW of 35 ± 3.53 and approximately 5 years old, also managed under continuous stocking, receiving the same concentrate supplementation as the test animals. The treatments were as follows: sheep supplemented with soybean meal and pasture fertilized with urea (SMUR); sheep supplemented with detoxified castor bean cake and pasture fertilized with urea (CCdUR); sheep supplemented with soybean meal and pasture fertilized with *in natura* castor bean cake (SMCC); and sheep supplemented with detoxified castor bean cake and pasture fertilized with *in natura* castor bean cake (CCdCC).

Regarding the N fertilizers (mineral or organic), the experimental plots of Tamani grass pasture were fertilized according to the treatments, using urea (45% N) or *in natura* castor bean cake (5% N) as N sources. The recommendation of 450 $kg.ha^{-1}.year^{-1}$ was followed, according to Vasconcelos et al.[15] and the pasture was managed at an average height of 22 cm. Both applications were equally fractioned, being applied at the beginning and in the middle (12 days) of the crop production cycles, which lasted for 24 days each. The pasture was managed under continuous stocking with variable stocking rates[16]. The total area corresponded to 1 hectare, divided into 16 paddocks of 500 m² each for grazing by the experimental animals and two paddocks for the allocation of balance animals. All paddocks were delimited by wire mesh fence and provided with feeders, drinking troughs, salt troughs and 2.0 x 3.0-m shading screens with 50% light transmittance.

The male animals were castrated with a "burdizzo" castrator at the beginning of the experiment, according to CFMV Resolution No. 877 of February 2008[17]. Before being allocated to the paddocks, the animals were treated with antiparasitic agents based on 10% closantel sodium (10 $mg.kg^{-1}$) and 5% levamisole hydrochloride (5 $mg.kg^{-1}$), and the absence of infection by gastrointestinal parasites was confirmed through the count of eggs per gram (EPG) of feces.

The finishing diets, based on ground corn, soybean meal, and detoxified castor bean cake, were formulated for average daily live weight gains of 200 $grams.day^{-1}$, with 14% crude protein (CP) and 67.9% total digestible nutrients (TDN)[18]. The ratio CP:TDN of the feed provides greater parasite resilience to grazing sheep, reducing the effects caused by haemoncosis. The chemical composition of the ingredients and their proportions are shown in Tables 1 and 2. The supplement was provided at the rate of 1.8% of BW, considering a daily dry matter intake equivalent to 3.6% of BW[19]. Mineral salt was supplied at will in the morning, and the concentrated supplement was supplied daily, at 5:30 pm, which was the best time because of the lower activity of African bees (*Apis mellifera*) in the troughs. The lambs were weighed fortnightly, always in the morning, in a digital scale model BL300pro Laboremus, from birth (June/2019) until reaching the average body weight for slaughter of 28 kg[20, 21].

Table 1. Chemical composition of the ingredients of the experimental diets.

Items (g/kg^{-1} of Dry matter)	Ingredients				
	TGu	TGc	GC	SM	CCd
Dry Matter	954.80	956.80	889.90	902.40	931.20
Organic matter	877.50	874.30	932.10	985.10	846.40
Mineral matter	122.50	125.70	18.50	14.90	153.60
Crude protein	101.30	101.40	101.50	489.40	301.30
Neutral detergent insoluble protein	38.10	40.30	25.00	30.50	129.40
Acid detergent insoluble protein	10.00	7.30	20.60	33.10	81.30
Ether extract	36.40	31.60	58.00	43.80	78.30
Total carbohydrates	739.80	741.30	822.00	451.90	466.80
Non-fiber carbohydrates	16.80	3.80	659.60	271.4	136.60
Structural carbohydrates	720.30	737.50	163.00	180.50	330.20
Neutral detergent fiber	758.10	764.70	191.90	192.90	355.20
NDF corrected for ash and protein	723.00	737.50	163.00	180.50	330.20
Acid detergent fiber	366.70	372.00	54.00	39.70	328.50
Lignin	13.30	15.70	6.10	1.30	36.00
Hemicellulose	391.40	392.70	137.90	153.20	26.70
Total digestible nutrients	574.70	565.20	861.30	853.60	695.20

TGu - Tamani grass fertilized with urea; TGc - Tamani grass fertilized with *in natura* castor bean cake; GC - ground corn; SM - soybean meal; CCd - detoxified castor bean cake.

Table 2. Proportions of the ingredients and chemical composition of the experimental diets.

Item (% Dry matter)	Proportions of ingredients	
	Standard Feed	Alternative Feed
Tamani grass	51.13	46.95
Ground corn	39.10	33.42
Soybean meal	9.77	----
Detoxified castor bean cake	----	16.45
Soybean oil	----	3.18
Mineral salt[1]	At will	
Total	100	100
Items (g.kg^{-1} Dry matter)	Chemical composition of the diet	
Dry Matter	924.80	931.00
Organic matter	908.50	862.00
Mineral matter	72.10	89.70
Crude protein	139.30	131.10
Neutral detergent insoluble protein	32.80	48.00
Acid detergent insoluble protein	16.40	20.40
Ether extract	44.30	79.70
Total carbohydrates	744.20	699.20
Non-structural carbohydrates	289.50	247.50
Structural carbohydrates	454.70	451.60
Neutral detergent fiber	483.20	480.00
NDF corrected for ash and protein	454.70	451.60
Acid detergent fiber	213.80	245.50
Lignin	9.90	14.80
Hemicelluloses	269.30	234.50
Total digestible nutrients[19]	711.60	735.60

Source: Research data.

Standard feed: based on ground corn and soybean meal; alternative feed: based on ground corn and castor bean cake. [1]Composition: phosphorus - 65.00 g; calcium - 177.50 g; sulfur - 20.00 g; magnesium - 8.00 g; sodium - 162.00 g; cobalt - 0.04 g; zinc - 1.90 g; manganese - 1.35 g; iodine - 0.071 g; selenium - 0.02 g; fluorine - 0.76 g; copper - 0.20 g and vehicle - 1,000 g.

2.4. Data for the bioeconomic assessment

The economic analysis was based on the simulation of the selling of 3.5-month-old Santa Inês lambs, with an initial weight of 19.42 kg, finished on irrigated Tamani grass pasture and subjected to four treatments (SMUR, CCdUR, SMCC, and CCdCCTM) from August to December, which corresponds to the dry season of the year. A minimum unit of 3 hectares was considered, which is the maximum area that a fixed paid employee could manage, according to experimental data. A body weight at slaughter of 28 kg BW was determined for the animals, which is the weight for the Santa Inês breed at which the amount of muscle in the carcass ceases to increase [21]. The animal performance data used in the economic analysis of the study are presented in Table 3. The same salt intake was considered for all treatments, which was on average 30 grams.sheep.day^{-1}.

Table 3. Animal performance indices of sheep on irrigated Tamani grass pasture, managed under continuous stocking, using castor bean cake as supplement replacing soybean meal or as organic fertilizer replacing urea

Variable	**Production systems evaluated**			
	SMUR	**CCdUR**	**SMCC**	**CCdCC**
Average daily gain (g.day^{-1})	103.00	88.00	105.00	86.00
Stocking rate (sheep.ha^{-1})	82.11	90.88	87.40	81.47
Finishing time (days)	83.00	97.00	81.00	99.00
Carcass yield (% BW)	52.79	51.58	51.17	52.46
Dry matter yield (% BW)	3.84	3.43	3.74	3.33
Dry matter intake (g.sheep^{-1}.day^{-1})	1,034.04	969.34	1,040.17	940.46

SMUR - animals supplemented with soybean meal and pasture fertilized with urea; CCdUR - animals supplemented with detoxified castor bean cake and pasture fertilized with urea; SMCC - animals supplemented with soybean meal and pasture fertilized with *in natura* castor bean cake; and CCdCC - animals supplemented with detoxified castor bean cake and pasture fertilized with *in natura* castor bean cake.

For the purpose of comparison among treatments, the selling price of the animals was determined as the minimum value for the least profitable production system to present a minimally positive net present value, in the 10-year horizon of the analysis, and depreciation of Fixed Assets (FA), based on the Normative Instruction of the Brazilian Federal Revenue Organ, No. 1700/2017. For analysis purposes, the dollar price of R$ 5.23 from August

9, 2021, was used. The cost composition used was the same as that observed in the Integrated System of Agricultural Costs - CUSTAGRI[22], developed by the Institute of Agricultural Economics (IEA), in partnership with the National Center for Technological Research in Information Technology for Agriculture (EMBRAPA-CNPTIA). The analysis horizon comprised 10 years, corresponding to the useful life of most of the investments (irrigation system, machinery, fences, among others).

The investments related to the implementation of the production systems were as follows: management center (110 m^2) with concrete floor, wooden roof with colonial type tiles, and countryside screen (100 m^2 waiting room), sized to allow 1 m^2.animal^{-1}. Coupled to the management center, there was a warehouse (20 m^2) used for storing feed, medication, among others, a grinder used in the production of concentrate, and a mobile scale for weighing the animals. The grazing area totaled 30,000 m^2 and contained: drinking troughs and plastic troughs, obtained from longitudinally sectioned buckets (25 cm.animal^{-1}), as well as artificial salt troughs and shades (2 m^2.animal^{-1}), bordered by a field-type fence (Table 4).

Table 4. Cost of establishing three hectares of irrigated Tamani grass pasture for grazing sheep managed under continuous stocking

Investments	Costs (US$)
Management center (210.00 m^2)	
Mobile weighting scale	1,108.99
Drinkers	138.70
Feeding troughs	235.18
Warehouse and management center	4,006.46
Grinder/chopper	1,089.87
Subtotal	6,579.20
Pasture implantation (3.00 hectares)	
Field screen fences	3,523.90
Pasture implantation	1,881.45
Irrigation	7,434.55
Irrigation pump and magnetic key kit	682.60
Subtotal	13,522.50
Other (5% of investment expenses)	
Subtotal	1,005.09
Total	21,106.79

To quantify the labor costs, in the production systems that used urea as fertilizer, only one effective employee was considered to perform management activities such as feeding, cleaning water troughs, applying medicines and fertilizers. For the production systems that used *in natura* castor bean cake as fertilizer, two extra day payments per cycle were used to ensure the functionality of the system, paid at the beginning and middle of each 24-day production cycle of Tamani grass. The salary was based on the minimum Brazilian wage of $210.33 in effect in August 2021, with all social charges paid. Feed costs were composed of protein-energy supplementation and mineral salt.

The costs of electric energy from the energy consumption of the forage chopper (0.08 cents US$/kWh) and irrigation (0.0081 cents US$/kWh), referring to the intermediate and cheap electric tax, were calculated for consumers of subgroup A4, according to ANEEL's Ordinance No. 2.568, of July 2, 2019. The price of US$ 1.46 per kg of BW was considered for the purchase of animals with an average weight of 19.42 kg BW, which was the local market value (Sobral/CE). Other costs were also estimated, such as: machinery operation (worked hour), medication (vaccination, deworming and antibiotics, in preventive use), as well as the cost of miscellaneous materials (formicide, syringes, gloves, and gauze).

The following economic and financial indicators were used: gross revenue (GR): total production in kilograms of product x market selling price; effective operational cost (EOC): expenses with operations (labor, food, equipment maintenance, purchase of animals and fuel); total operational cost (TOC): EOC + other operational costs (depreciation of facilities and machinery, technical assistance, social charges) and total production cost (TPC): TOC + other fixed costs (return on capital invested in facilities, machinery and land). For the calculation of depreciation, the linear or fixed quotas method was used, in which the value is determined by the following equation: (d): (vi - vf)/n, where (vi): initial value of the asset, (vf): final value, which corresponds to the value of the capital asset after its useful life and (n): number of years of capital duration (useful life).

Gross Margin (GM): GR - EOC; Net Margin (NM): GR - TOC, and Profit (L): GR - TPC, according to Oliveira et al.[23]. All economic indicators were also expressed in US$ per kg of product, either body weight (BW) or carcass. The benefit/cost ratio (B/C) was estimated by the ratio between the GR and the TPC, and represents how many dollar units would be received for each unit of real applied in the activity[24].

For the remuneration of the invested capital, we selected the interest rate of the Special System for Amortization and Custody (Selic), set at 3.5% per year in August 2021, which is understood as the minimum rate of return, i.e., the best available in the market for the application, but with the lowest associated risk[25]. The rate of return on invested capital (RRIC) was obtained by the quotient of net margin by investment costs[26]. The net present value (NPV) was obtained from the equation proposed by Sousa Neto & Martins[27], wereas the internal rate of return was determined according to Copeland et al.[28]. All costs used in the simulations were budgeted using the local market prices of Sobral, Ceará.

3. Results and discussion

The initial investment was the same for all systems analyzed (US$ 21,106.79), where the cost for the implementation of the pasture corresponded to 64.06% of the investment costs, highlighting irrigation costs, which were approximately US$ 7,434.55 (Table 4). Irrigation is an important technology for production systems in semi-arid regions because it ensures the production of annual forage, minimizing the seasonality of production and allowing a greater number of animal consignments per year and, consequently, a higher annual income.

In the evaluated scenarios, animal acquisition, feed, and fertilization were the items that most contributed to the increase in effective operational costs (EOC), and their sum represented values of 89.7%, 90.03%, 90.04%, and 89.19%, for SMUR, CCdUR, SMCC and CCdCC, respectively, followed by labor, machinery operation, diverse materials, medication and energy consumption (Table 5).

Table 5. Effective operational cost of 3 hectares of irrigated Tamani grass pasture for grazing sheep, managed under continuous stocking using castor bean cake as supplement replacing soybean meal or as organic fertilizer replacing urea

Serv. and supplies	Production systems evaluated							
	SMUR	CCdUR	SMCC	CCdCC				
	US$.year^{-1}	%year	US$.year^{-1}	%year	US$.year^{-1}	%year	US$.year^{-1}	%year
Labor	1,714.15	4.24	2,014.91	4.41	1,878.01	4.27	2,282.22	5.20
Feeding	13,338.13	32.99	15,597.57	34.16	13,667.30	31.05	13,909.52	31.72
Equ. Main.	1,518.95	3.76	1,522.18	3.33	1,520.94	3.46	1,518.70	3.46
Fert.	1,934.08	4.78	2,273.44	4.98	3,598.55	8.18	4,379.28	9.99
Div. mat.	548.91	1.36	606.93	1.33	584.62	1.33	544.45	1.24
Med.	268.11	0.66	296.44	0.65	285.54	0.65	265.93	0.61
Energy	115.51	0.29	134.98	0.30	114.99	0.26	132.06	0.30
Anim. acq.	20,994.90	51.93	23,213.87	50.84	22,360.42	50.81	20,824.21	47.48
EOC/Total	40,432.74	100.00	45,660.33	100.00	44,010.37	100.00	43,856.37	100.0

SMUR- animals supplemented with soybean meal and pasture fertilized with urea; CCdUR - animals supplemented with detoxified castor bean cake and pasture fertilized with urea; SMCC - animals supplemented with soybean meal and pasture fertilized with *in natura* castor bean cake; and CCdCC - animals supplemented with detoxified castor bean cake and pasture fertilized with *in natura* castor bean cake. Serv. and supplies - services and supplies; Equ. main.- equipment maintenance; Fert. - fertilization; Div. mat. - diverse materials; Med.- medicines; Anim. acq. - animal acquisition; EOC/Total - total effective operational cost.

Animal acquisition costs was most expensive, representing an annual expense of 51.93%, 50.84%, 50.81%, and 47.48% of the EOC for SMUR; CCdUR; SMCC and CCdCC, respectively. The purchase price of the animals was $1.46 per kg BW (Table 6). Annual feed costs varied between 31.05% and 32.99%, being more influenced by the stocking rate as the price per kilogram of concentrate was similar among diets, presenting values of US$ 0.37 and 0.37 per kg for the supplement containing soybean meal (SM) and detoxified castor bean cake (CCdCC), respectively.

Table 6. Productive and economic indices of sheep finished on irrigated Tamani grass pasture managed under continuous stocking, using castor bean cake as supplement or organic fertilizer

Variables	Production systems evaluated							
	SMUR		CCdUR		SMCC		CCdCC	
		US$ kg BW		US$ kg BW		US$ kg BW		US$ kg BW
Animals per year	246.00	1.46	272.00	1.46	262.00	1.46	244.00	1.46
Consignment days	247.92	-	291.42	-	243.97	-	296.90	-
Nº consign. per year	3.00	-	3.00	-	3.00	-	3.00	-
Revenue (US$ year)	49,111.57	-	54,302.53	-	52,305.82	-	48,712.29	-
EOC (US$ year)	40,432.74	1.96	45,660.33	2.00	44,010.37	2.00	43,856.37	2.14
TOC (US$ year)	43,558.43	2.11	49,000.64	2.14	47,119.44	2.14	47,218.78	2.30
TPC (US$ year)	44,297.16	2.14	49,740.29	2.18	47,858.73	2.17	47,957.45	2.34
GM (US$ year)	8,678.83	0.42	8,641.90	0.38	8,295.45	0.38	4,855.92	0.24
NM (US$ year)	5,553.14	0.27	5,301.59	0.23	5,186.38	0.24	1,493.51	0.07
Profit (US$ year)	4,814.41	0.23	4,561.93	0.20	4,447.09	0.20	754.84	0.04
(B/C) (years)	1.11	-	1.09	-	1.09	-	1.02	-
RRIC (%)	26.31	-	25.09	-	24.55	-	7.08	-
NPV (US$)	33,895.74	-	31,788.43	-	30,836.19	-	134.52	-
IRR (%)	18.66	-	17.48	-	16.96	-	0.07	-
(B/C) (10 years)	1.09	-	1.07	-	1.07	-	1.00	-
MSP (US$ kg^{-1} BW)	2.18	-	2.21	-	2.21	-	2.38	-

EOC - effective operational cost; TOC - total operational cost; TPC - total production cost; GM - gross margin; NM - net margin; (B/C) - benefit/cost ratio; RRIC - rate of return on invested capital; NPV - net present value; IRR - internal rate of return; MSP - minimum selling price; SMUR - animals supplemented with soybean meal and pasture fertilized with urea; CCdUR - animals supplemented with detoxified castor bean cake and pasture fertilized with urea; SMCC - animals supplemented with soybean meal and pasture fertilized with *in natura* castor bean cake; and CCdCC - animals supplemented with detoxified castor bean cake and pasture fertilized with *in natura* castor bean cake. For IRR and (B/C) ratio, the horizon of analysis was annual and 10 years.

The feed is one of the most expensive components in ruminant farming, with negative impacts on total production costs (TPC)[29]. The highest annual feed expenses were observed in the systems CCdUR and CCdCC in the order of US$ 15,597.57 and 13,909.52 per year, whereas the lowest costs were calculated for SMUR and SMCC, which were US$ 13,338.13 and 13,667.30 per year, respectively (Table 20). This can be explained by the stocking rate and staying time of the animals in the production system, i.e., the longer the time of the finishing phase, the higher are the costs with feed inputs, reducing the efficiency of the enterprise.

The low performances observed in the systems CCdUR and CCdCC were due to the average daily weight gain (ADG) of the sheep, which were 88.0 and 86.0 g.sheep^{-1}.day^{-1}, respectively, since a low ADG leads a to longer staying time of the animal in the production system. For SMUR, CCdUR, SMCC and CCdCC, minimum finishing times of 83, 97, 81, and 99 days, respectively, were estimated (Table 3). Animals supplemented with feed containing soybean meal (SM) in its composition showed better ADG responses, with values of 103.0 and 105.0 grams.sheep^{-1}.day^{-1}, significantly reducing the time spent in the finishing phase and, consequently, the feed costs.

To meet the energy recommendations regarding the diet containing CCd, soybean oil was added, which was the main factor responsible for the increase in the cost of this diet, corresponding to 23.01% of the costs. The expenses for the energy sources (corn and soybean oil) of the supplements containing SM and CCd corresponded to 71.31% and 79.67% of the total price of the supplements. Normally, the protein sources that compose the animal feed are the most expensive ingredients of the diets; however, the energy sources, due to the proportion of inclusion in the formulations of the diets, become a major obstacle in the manufacturing of the supplements. In this scenario, it is necessary to look for alternative products that can replace them, making the production more economically viable.

The costs for organic fertilization in the treatments SMCC and CCdCC presented values of US$ 3,598.55 and 4,379.28 per year, being on average 46.01% higher than the average of systems that were chemically fertilized with urea (SMUR and CCdUR) (Table 5). The purchase prices of inputs used for fertilization, such as the *in natura* castor bean cake and urea, were US$ 0.24 and 0.91 per kg. To meet the N demand of Tamani grass of 450 kg N.ha.year^{-1}, it was necessary to apply nine times more *in natura* CC, since it contained approximately 5% N, whereas UR had an N content of 45%. In addition, two day payments were added per crop production cycle to ensure the distribution of castor bean cake in the area of the systems SMCC and CCdCC, contributing to the increase in organic fertilizer costs.

However, the importance of organic fertilization for the soil to supply the plants with nutrients should be emphasized. Castor bean cake presents nutrients such as N, P, K, Ca, and micronutrients, besides a low C: N ratio, which favors the mineralization of the input by soil microorganisms and the availability of nutrients to plants. It is therefore, widely employed in vegetable production, with good results and improved chemical and physical soil attributes[11]. In addition, because of its nematicidal effect, it controls gastrointestinal parasites in grazing sheep[6,7], reducing the anthelmintic costs.

The annual labor cost was higher for the system CCdCC (5.2%) (Table 5), which is attributed to the longer stay of the animals in this system (99 days), due to the lower weight gain and the higher cost for organic fertilizer application (US$ 229.45 per year). The opposite result was observed for the system SMUR (4.24%), which is explained by the shorter finishing phase and lower fertilization costs.

A value equivalent to 13% of the initial investment cost was considered to guarantee the maintenance of machinery and equipment, which was similar among the treatments. The values of US$ 1,518.95, 1,522.18, 1,520.94, and 1,518.70 per year for this variable in the systems SMUR, CCdUR, SMCC, and CCdCC (Table 5) are due to the numbers of drinkers and feeders, which varied according to the animal stocking rate (Table 3). Expenditures for miscellaneous materials and medications were more associated with the number of animals that pass through the production system, being higher in the systems CCdUR and SMCC, whereas energy intake, related to the duration of the finishing phase, presented higher values, which were US$ 134.98 and US$ 132.06 per year for CCdUR and CCdCC (Table 5).

According to Vieira et al.[30], the cost for animal health inputs was around 5.1% per year in a study that evaluated helminth control measures in sheep in irrigated pasture managed under rotational stocking, which is a value higher than those found in the present study, with an average among treatments of 0.64% per year. In the present study, there was no need for antiparasitic treatment during the experimental period, which contributed to the reduction of drug costs, showing that both feeds containing SM and CCd, as the *in natura* CC with organic fertilizer were effective in controlling gastrointestinal parasites in sheep, corroborating with the findings of Miranda[18], Salles et al.[6], and Maranguape et al[7].

System CCdUR presented the highest effective operational cost (EOC), which negatively impacted the total operational cost (TOC), with a value of US$49,000.64 per year (Table 6). The TOC is composed of the EOC plus other operational costs such as: depreciation of machinery, financial charges, administration expenses, technical assistance, insurance, among others[22], which were more expressive in the systems CCdCC and CCdUR, showing values of US$ 1,436.94 and 1,410.44 per year. The lowest and highest total production costs (TPCs), which were US$ 2.14 and 2.34 per kg BW^{-1}, were observed in the systems SMUR and CCdCC (Table 6). Overall, TOC and TPC were most affected by animal acquisition, feed, fertilization, and labor and influenced by stocking rate and duration of the finishing phase.

Gross revenue (GR) was calculated considering the sales price of $2.38 per kg of BW (Table 6), in which the least profitable supplementation-fertilization system becomes profitable, multiplied by the total kilogram of sheep BW produced. The GR was affected by the stocking rate, presenting values of $49,111.57; 54,302.53; 52,305.82 and 48,712.29 per year for the systems SMUR, CCdUR, SMCC, and CCdCC, respectively.

The gross margin (GM) is obtained by the difference between GR and EOC and is an important index of the economic situation of the activity; if the GM is greater than zero, the activity survives in the short term[23]. Considering a possible adverse scenario, with high input prices or water shortage or some other factor, for the systems SMUR, CCdUR, SMCC, and CCdCC, the producer could sell 1 kg of animal body weight for US$ 1.95, 2.00, 2.00, and 2.14, respectively, which would cover the EOC expenses. However, in the medium term, the producer could use the results of the net margin (NM) to analyze the economic situation of the activity. Therefore, if the NM is positive, the activity is economically stable, with possibilities of expansion and maintenance in the long term, assuring the expenses for TOC[23]. The profit of US$ 4,814.41 per year, obtained in the system SMUR, was higher by 5.26%, 7.63%, and 84.32% when compared to the systems CCdUR, SMCC, and CCdCC.

In the 10-year analysis horizon, the benefit/cost ratio (B/C) showed that the present value of the benefits in the system CCdCC was equal to the costs, that is, the investment generated only US$ 1.02 of revenue for each dollar applied, whereas in the system SMUR, the value was US$ 1.11, representing gains of US$ 0.02 and 0.11 cents for each dollar applied, respectively. The B/C ratio expresses how many dollar units would be received for each dollar unit applied[24]. Thus, the higher the ratio, the more attractive the activity is for the investor. A similar behavior was found for the rate of return on invested capital (RRIC), which showed values of 26.31% and 7.08%, referring to the systems that presented the best (SMUR) and worst indicators (CCdCC).

The net present value (NPV) and the internal rate of return (IRR) were higher in the system SMUR, with estimated values of $33,895.74 and 18.66% per year, respectively. The NPV is the sum of all net revenues updated at an appropriate discount rate[25], whereas IRR represents the percentage of a project's economic return in relation to what was invested and is considered the interest rate that makes NPV equal to zero, allowing the comparison between the profitability of a project and other activities or investments[31]. With the exception of the system CCdCC, all systems showed values above the interest rate of the opportunity of capital (3.5%) since the minimum selling price considered was that of the supplementation-fertilization system of lower profitability, still becoming profitable (lower positive NPV). Systems SMUR, CCdUR, SMCC, and CCdCC presented economic viability when animal body weight kilograms were traded at values of US$ 2.18, 2.21, 2.21, and 2.38 per kg BW, respectively (Table 6). However, it is important to emphasize that the values obtained in the simulation are higher than those observed at the local market (US$ 1.46 per kg of BW^{-1}), showing that the sale of live animals for the adopted systems is not economically attractive to the producer. In any intensive system, whether in pasture or in feedlot, the selling price of animals should compensate the production costs, because animals are finished at a younger age, reflecting carcasses with higher quality. Therefore, the producer needs to seek more selective market niches, where payment must be made for the quality of the product. The use of specialized breeds (Dorper or Santa Inês) or their crossbreeds can be an alternative to make these systems more viable.

Another way to reduce TPC and increase the property's income would be to optimize the area for the production of roughage during the rainy season (March - July) and preserve it in the form of silage, aiming at its use for feeding other categories of animals or even for selling, generating extra income for the system. However, the commercialization of this grass (Tamani grass) in the preserved form (hay or silage) is not common, requiring a prior assessment of the market. Another alternative may be to lease the grazing area in the rainy season for use by other animal species, such as cattle, which are more adapted and resilient to worm infection.[32]

Regarding the systems for the marketing of sheep carcasses, the slaughter expenses were around US$ 5,282.77, 5,841.11, 5,626.36, and 5,239.82 for SMUR, CCdUR, SMCC, and CCdCC, respectively, representing 11.56%, 11.33%, 11.34%, and 10.66% of the annual EOC (Table 7) and were influenced by the number of animals slaughtered. Considering the inclusion of slaughter costs in the simulation, in order of importance, the most relevant expenses in the effective operational cost were animal acquisition, feed, and slaughter, representing 84.75% of the EOC. In this scenario, the implementation of public policies, such as: ensuring the purchase of meat by the state government for use in public institutions (schools, hospitals, prisons, others), would ensure a minimum remuneration to producers, maximizing their profitability, as it would reduce the role of middle-men and thus strengthen and stimulate the regional sheep farming activity.

Table 7. Effective operational costs for commercialization of carcasses of sheep finished on irrigated Tamani grass pasture, managed under continuous stocking, using castor bean cake as supplement or organic fertilizer.

Serv. and supplies	Production systems evaluated							
	SMUR		CCdUR		SMCC		CCdCC	
	US$.year^{-1}	%year	US$.year^{-1}	%year	US$.year^{-1}	%year	US$.year^{-1}	%year
Labor	1,714.15	3.75	2,014.91	3.90	1,878.01	3.78	2,282.22	4.64
Feeding	13,338.13	29.18	15,597.57	30.42	13,667.30	27.53	13,909.52	28.46
Equ. Main.	1,518.95	3.32	1,522.18	2.95	1,520.94	3.06	1,518.70	3.09
Fert.	1,934.08	4.23	2,273.44	4.41	3,598.55	7.25	4,379.28	8.90
Div. mat.	548.91	1.20	606.93	1.18	584.62	1.18	544.45	1.11
Med.	268.11	0.59	296.44	0.57	285.54	0.58	265.93	0.54
Energy	115.51	0.25	134.98	0.26	114.99	0.23	132.06	0.27
Anim. acq.	20,994.90	45.93	23,213.87	44.99	22,360.42	45.05	20,824.21	42.34
Cost/slaug.	5,282.77	11.56	5,841.11	11.32	5,626.36	11.34	5,239.82	10.65
EOC/Total	45,715.51	100.00	51,601.53	100.00	49,636.73	100.00	49,184.98	100.00

SMUR- animals supplemented with soybean meal and pasture fertilized with urea; CCdUR - animals supplemented with detoxified castor bean cake and pasture fertilized with urea; SMCC - animals supplemented with soybean meal and pasture fertilized with *in natura* castor bean cake; and CCdCC - animals supplemented with detoxified castor bean cake and pasture fertilized with *in natura* castor bean cake. Serv. and supplies - services and supplies; Equ. main.- equipment maintenance; Fert. - fertilization; Div. mat. - diverse materials; Med.- medicines; Anim. acq. - animal acquisition; Cost/slaug. - cost for slaughter; EOC/Total - total effective operational cost.

To calculate the gross revenue (GR) from the sale of carcasses, the selling price at which the least profitable system would become profitable, US$ 4.45 per kg of animal carcass, multiplied by the total kg of sheep carcass produced, was considered. The GR was influenced by stocking rate and animal carcass yield, obtaining values of US$ 55,350.59, 59,969.52, 57,362.94, and 54,559.38 per year for SMUR, CCdUR, SMCC, and CCdCC, respectively (Table 8).

Table 8. Productive and economic indices of commercialization of carcasses of sheep finished on irrigated Tamani grass pasture, managed under continuous stocking, using castor bean cake as supplement or organic fertilizer

Variables	Production systems evaluated							
	SMUR		CCdUR		SMCC		CCdCC	
		US$. kg BW^{-1}		US$. kg BW^{-1}		US$. kg BW^{-1}		US$. kg BW^{-1}
Animals per year	246.00	-	272.00	-	262.00	-	244.00	-
Consignment days	247.92	-	291.42	-	243.97	-	296.90	-
Nº consign. per year	3	-	3	-	3	-	3	-
Revenue (US$ year)	55,350.59	-	59,969.52	-	57,362.94	-	54,559.38	-
EOC (US$ year)	45,715.51	3.68	51,601.53	3.83	49,636.73	3.85	49,184.98	4.01
TOC (US$ year)	48,841.19	3.93	54,941.84	4.08	52,745.80	4.09	52,547.38	4.29
TPC (US$ year)	49,579.93	3.99	55,681.49	4.13	53,485.10	4.15	53,286.05	4.35
GM (US$ year)	9,635.08	0.78	8,367.99	0.62	7,726.21	0.60	5,414.41	0.44
NM (US$ year)	6,509.39	0.52	5,027.68	0.37	4,617.14	0.36	2,052.00	0.17
Profit (US$ year)	5,770.65	0.46	4,288.03	0.32	3,877.84	0.30	1,313.33	0.11
(B/C) (years)	1.12	-	1.08	-	1.07	-	1.02	-
RRIC (%)	30.84	-	23.79	-	21.86	-	9.72	-
NPV (US$)	37,046.79	-	24,201.31	-	20,998.06	-	16.63	-
IRR (%)	21.17	-	14.83	-	12.87	-	0.01	-
(B/C) (10 years)	1.09	-	1.05	-	1.05	-	1.00	-
MSP (US$ kg^{-1} BW)	4.05	-	4.21	-	4.23	-	4.45	-

EOC - effective operational cost; TOC - total operational cost; TPC - total production cost; GM - gross margin; NM - net margin; (B/C) - benefit/cost ratio; RRIC - rate of return on invested capital; NPV - net present value; IRR - internal rate of return; MSP - minimum selling price; SMUR - animals supplemented with soybean meal and pasture fertilized with urea; CCdUR - animals supplemented with detoxified castor bean cake and pasture fertilized with urea; SMCC - animals supplemented with soybean meal and pasture fertilized with *in natura* castor bean cake; and CCdCC - animals supplemented with detoxified castor bean cake and pasture fertilized with *in natura* castor bean cake. For IRR and (B/C) ratio, the horizon of analysis was annual and 10 years.

The value suggested in the simulation of the present study is lower than the price paid by the final consumer (US$ 4.58 per kg of carcass) on the local market (Sobral/CE), which makes all systems analyzed feasible, considering direct selling (producer-consumer). Therefore, to ensure profitability, public measures are needed to support the link (producer-consumer), such as the consolidation of open fairs, where such products are traded.

For the systems SMUR, CCdUR, SMCC, and CCdCC, simulating the present study in a possible adverse scenario that compromises production, considering GM, in the short term, the producer could sell 1 kg of animal carcass for US$ 3.68, 3.83, 3.85, and 4.01, thus guaranteeing the expenses of EOC. In the medium term, taking into account the NM, the sale per kilogram of animal carcass would be US$ 3.93, 4.08, 4.09, and 4.29, which would guarantee the TOC. Profits of US$ 5,770.65, 4,288.03, 3,877.84, and 1,313.33 per year were observed for the systems SMUR, CCdUR, SMCC, and CCdCC. The higher profit observed for the system SMUR was due to the higher carcass yield (52.79%), and, partly, the ADG (103.0 g.day^{-1}) and stocking rate (82.11 sheep.ha^{-1}). The carcass yield expresses the percentage ratio between carcass weight and the animal's BW, which can vary between 45% and 60% in Santa Inês sheep, being more expressive in younger animals because of the smaller size of the gastrointestinal tract[33].

Analyzing the B/C ratio in the 10-year horizon, considering carcass selling, the most profitable ratio was observed in the treatment SMUR, with a value of 1.09 and an RRIC of 30.84%, whereas the system CCdCC was the least profitable, with values of 1.00 and 0.01%, respectively (Table 8). Similarly, the highest NPV and RRIC values were found in system SMUR, with $37,046.79 and 21.17%, respectively and the lowest in system CCdCC, with $16.63 and 0.01%. By simulation, in all evaluated systems, the selling of animal carcasses was profitable, with better results in the system where sheep were supplemented with diets containing SM and the pasture was fertilized with UR.

Considering the selling of live animals and the marketing of carcasses and non-carcass components, according to the sensitivity analysis in the systems that used urea as standard fertilizer, simulating variations in the price of soybean meal, C*oeteris paribus*, we found that when the price of castor bean cake corresponds to up to 38.05% and 29.81% of the price of soybean meal, respectively, the substitution of soybean meal by the by-product becomes feasible (Fig. 1Aand B).

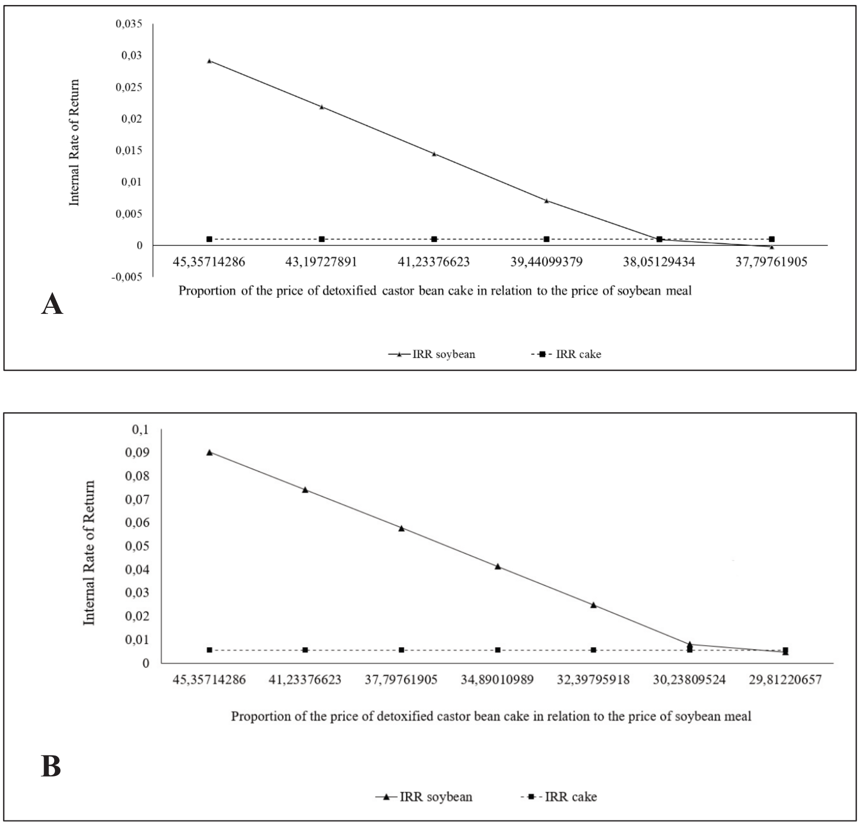

Figure 1. Sensitivity analysis of the castor bean cake price in comparison to the price of soybean meal, *Coeteris paribus*, for the selling of live animals and the commercialization of carcasses and non-carcass components of sheep.

4. Conclusions

For the evaluated systems, the sale of live animals was not attractive, whereas the opposite was observed for the sale of carcasses and non-carcass components. The substitution of soybean meal by detoxified castor bean cake and urea via the use if *in natura* castor bean cake is less profitable, requiring an analysis of the price and availability of inputs on the market to define a better possibility of its use. More studies are needed to validate the use of castor bean cake as supplement or organic fertilizer in sheep pasture-based production systems.

Declaration of conflicts of interest

The authors declare that there are no conflicts of interest.

Author contributions

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