Agricultural Systems 194 (2021) 103247

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Bioeconomic simulation of *Rhipicephalus microplus* infestation in different beef cattle production systems in the Brazilian Cerrado

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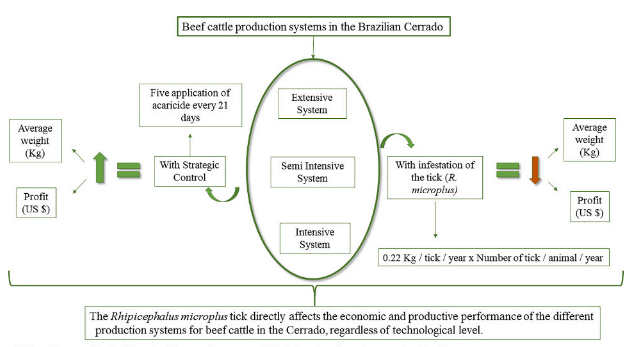
HIGHLIGHTS

- The infestation of *R. microplus* causes great economic damage to the beef cattle production chain.
- A model was adapted that estimated and compared economic losses due to tick infestation in different production systems.
- Total gross revenue, profit and performance indicators values were lower in tick-infested systems.
- Ticks affect the economic and productive performance of production systems regardless of technological level.
- This assessment is an important tool in decision making about tick control for the efficiency of beef cattle.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Jagadish Timsina

Keywords:
Crossbred cattle
Productive indicators
Tick
Strategic control
Technological standard
Economic indicators

ABSTRACT

CONTEXT: Models are important tools to assess the impacts of tick infestation on the economic performance of different beef cattle production systems. The information from these simulations can be used by producers to evaluate, compare and make decisions about strategic measures to control the tick *Rhipicephalus microplus*, which cause significant production losses for the beef cattle production chain.

OBJECTIVE: The aim of this study was to adapt a model to estimate and compare the economic losses related to the infestation of the tick *R. microplus* in cattle production systems under grazing conditions with different technological standards in the Brazilian Cerrado biome.

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https://doi.org/10.1016/j.agsy.2021.103247
Received 22 November 2020; Received in revised form 11 August 2021; Accepted 12 August 2021
Available online 20 August 2021

METHODS: Three production systems were simulated, characterized as extensive, semi-intensive and intensive systems, based on zootechnical indexes and parameters of the production systems under evaluation. To compare the systems, they were divided into systems with tick infestation and strategic control.
RESULTS AND CONCLUSIONS: For the cattle categories intended for replacement and slaughter, each female in the infested systems had an individual loss of 19 kg of live weight (LW), whereas males aged 24, 36, and ≥ 36 months had an individual loss of 39, 68, and 92 kg LW, respectively, compared to the control systems. The economic difference in gross profit between the extensive system with control and with infestation was US $ 22, 619.00. The semi- intensive system with infestation showed a difference in gross profit of US $13, 902.00 relative to the semi-intensive system with control, and the intensive system with infestation showed in gross profit difference of US $28, 290.00 compared to the intensive system with control. Productivity indicators were higher as the technological level increased, but they were lower in systems with infestation.
SIGNIFICANCE: This means that losses in productivity and efficiency associated with *R. microplus* infestation economically impact the livestock production chain in the Brazilian Cerrado.

1. Introduction

Every year, new tick species are documented around the planet, where so far more than 920 species have been described (Garcia et al., 2019). It is important to note that most species have a regional distribution. Cattle in Asia, Australia and Central and South America are affected by members of the tick *R. microplus* complex, whereas cattle across Africa are affected by species from (*Rhipicephalus, Amblyomma* and *Hyalomma*) all three genera (Guglielmone et al., 2010). About 80% of the world's cattle are at risk of ticks and tick-borne diseases both of which cause significant production losses (Burrow et al., 2019). Infestation of cattle by these species has a direct impact on production, such as, weight loss and decreased milk production (Reck et al., 2014; Andreotti et al., 2019; Burrow et al., 2019) as well as indirect effects of diseases caused by tick-borne pathogens (Honer and Gomes, 1990; Burrow et al., 2019; Bonatte Jr et al., 2019). In Brazil, the tick fauna is currently composed of 75 species (Labruna et al., 2020; Muñoz-Leal et al., 2020; Onofrio et al., 2020). One of the species that arouses the most interest in the scientific community and is an important bottleneck faced by ranchers in the cattle production system, whether of beef or dairy cattle, is the tick *R. microplus* (Garcia et al., 2019).

The *R. microplus* tick has a life cycle with two phases: parasitic and free-living, and its development depends on climatic conditions that can vary between regions and seasons (Garcia et al., 2019). In the parasitic phase, its life cycle is approximately 21 days (Pereira and Costa, 2014), and it is the phase in which the main economic losses occur in cattle, which is its main host. Knowledge about the biology, behavior and population dynamics of this tick in the pasture environment (Garcia et al., 2019), where ectoparasite, host and environment generally interact (Pereira, 2008), is of paramount importance, since Gauss and Furlong (2002) reported that the larvae can remain in pasture for almost 90 days.

Regardless of the technological level, beef cattle production systems in Brazil are fundamentally based on the use of pastures, where more than 80% of the slaughtered animals are finished in grazing systems (ABIEC, 2019). Strategic control through the application of acaricides and based on the tick's life cycle, reduces the population of these parasites, is economically viable, and contributes to the improvement of the genetic potential of more sensitive breeds, making the production system more efficient (Andreotti et al., 2019; Calvano et al., 2019). In addition, the cost of chemical control and the emergence of acaricide resistant populations of *R. microplus* in the production system (Jonsson, 2006; Higa et al., 2019; Burrow et al., 2019) have contributed even more to the losses caused by ticks (Jonsson, 2006; Grisi et al., 2014; Calvano et al., 2019). Estimates suggest that the total loss attributed to *R. microplus* infestation of cattle in Brazil is approximately US $3,2 billion per year (Grisi et al., 2014). In beef cattle, infested crossbred animals (*B. taurus* and *B. indicus*) had an economically significant weight loss of 6.8% of their live weight (LW) in the rearing phase, equivalent to an economic loss of US $34.61/animal/year (Calvano et al., 2019).

According to data from the Brazilian Institute of Geography and Statistics (IBGE – Instituto Brasileiro de Geografia e Estatística, 2017), the Brazilian cattle herd reached 216 million head in the year 2016. This represents an exponential growth of 400% over recent decades and an accelerating trajectory of beef production. Thirty-two percent of this growth took place in the Central-West Region of the country that includes the Cerrado biome (Bonatte Jr et al., 2019). Climatic conditions in the Cerrado are favorable for the maintenance of *R. microplus* populations in pastures during the year, which leads to high rates of infestation in cattle, particularly in the taurine breeds and their crosses (Furlong and Evans, 1991).

Livestock farming is one of the most important commodities in Brazil (Bernardino de Carvalho and De Zen, 2017). Given its importance in Brazil and the need to increase cattle productivity in the same production area, there is a need for technification of production systems (Bonatte Jr et al., 2019). Technification is related to the quantity and quality of technologies adopted, ranging from more intensive livestock farming, the growth of high-productivity pastures, and feed supplementation of the pasture and feedlot to the use of crosses between European breeds (*B. taurus)* and Zebu breeds (*B. indicus*), which have higher precocity, better weight gain, better carcass finishing and better meat quality, and it aims to increase the profitability per animal (Igarasi et al., 2008). Often such "technifications" can be an obstacle in the cattle production chain because introducing crossbred animals can also change the genetic sensitivity to parasites, which will reflect on the economic aspects of extensive livestock farming (Andreotti et al., 2018). All technological changes are complex activities, presenting great flexibility in the combination of production factors, and as a result, there is great diversity in the production systems used by producers, even within the same biome, imposed by edaphoclimatic, social, and economic factors associated with a wide range of technological standards (Pereira and Costa, 2014; Costa et al., 2018).

Models are important tools to evaluate the impacts of tick infestation on the economic performance of different beef cattle production systems for the evaluation, comparison, and decision making on strategic tick control by producers. Thus, this study aimed to adapt a model to estimate and compare the economic losses related to infestation with the tick *R. microplus* in cattle production systems under grazing conditions with different technological standards in the Brazilian Cerrado biome.

2. Materials and methods

2.1. Characteristics of the cattle herd structure

The matrix of simulated data represents, in an adapted way, properties defined by Corrêa et al. (2006), who proposed five improved systems as alternatives to the systems used by most producers in the central-western region of Brazil, whose predominant biome is the Cerrado, which has a predominantly hot climate with well-defined dry and rainy seasons. To define the systems proposed by Corrêa et al. (2006), participated in the research producers in the region, researchers from Embrapa beef cattle and field technicians.

2.2. Description of the improved systems

The data used for the simulation were obtained from the studies by Gaspar et al. (2018), which compared the economic-financial efficiency of the renovation and maintenance of pastures in three different beef cattle production systems in the Cerrado biome: extensive, semi-intensive, and intensive. There was a total farm size of 1500 ha, of which 20% was used as an environmental reserve, leaving 1200 ha for production. Table 1 shows the productive indices of each system and its technological standards.

To distinguish the different technological levels and their respective zootechnical indices, the present study adopted the levels of annual rates of renovation and maintenance of pastures between the production systems (Table 1), i.e., as the renovation and maintenance rates of pastures increase, the technological level also increases.

2.3. Description of the different production systems

Economic losses due to tick infestation by *R. microplus* in beef cattle were evaluated in relation to the possible weight loss (kg) of cattle destined for slaughter and the sale of females for replacement according to the average number of ticks infesting cattle in different production systems.

The value of weight loss, which is directly linked to loss of revenue and profit, was 22.4 kg/animal/year, estimated in the studies by Calvano et al. (2019) through the following formula (Honer and Gomes, 1990):

$$W = w\ x\ n \tag{1}$$

where W is the total weight loss (kg), w is the weight loss (kg) per tick (0.22 kg/tick/year, according to Honer and Gomes, 1990), and n is the number of ticks/animal (102 ticks/animal/year, according to Andreotti et al. (2018).

The study simulated two different scenarios: with Infestation (wI) and with Control (wC), in the three different production systems that were improved according to different technological levels. Thus, the study simulated six different production systems for beef cattle in the Cerrado biome: extensive system with infestation (EwI); extensive system with control (EwC); semi-intensive system with infestation (SIwI); semi-intensive system with control (SIwI); intensive system with infestation (IwI) and intensive system with control (IwC). The infested systems (wI) had a herd of crossbred animals (*B. taurus* and *B. indicus*) with high tick infestation, that is, 102 ticks/animal/year (Andreotti et al., 2018), and systems with control (wC) had a herd of crossbred animals (*B. taurus* and *B. indicus*) and the adoption of strategic control, with five applications every 21 days, in the least favorable period for the population growth of ticks, as recommended by Andreotti et al. (2016), and the application doses were according to the manufacturer for all wC systems. This can prevent the appearance of larvae for 105 days, removing a large proportion of the larvae population from pasture and therefore reducing infestation in animals. The values of weight loss were attributed only to systems called wI and the cost of strategic control was attributed only to systems called wC.

Table 1
Zootechnical indices and parameters for beef cattle production systems.

Variables	Extensive	Semi-intensive	Intensive
Total area (ha)	1500	1500	1500
Mean fertility (%)	65%	80%	90%
Age at first calf (months)	36	24	24
Mean age at slaughter (months)	48	36	24
Mortality at weaning (%)	7%	5%	3%
Mortality after weaning (%)	1%	0.50%	0.50%
Stocking rate (UA/ha)	0.95	1.20	1.77
Annual rate of pasture renovation*	0%	7%	10%
Annual rate of pasture maintenance*	25%	33%	40%

Source: Modified from Corrêa et al. (2006). * Source: Gaspar et al. (2018).

2.4. Economic data for the cost and revenue control center

The simulation used the interaction of three large calculation centers: the herd simulator, the productivity indices, and the cost and revenue control centers. In the production systems with infestation, the value of 22.4 kg, which corresponded to the amount of weight loss caused by tick infestation per tick per year (Calvano et al., 2019), was subtracted from the body weight of the herd animals, regardless of sex and animal category; for the calculation of the values used for revenue calculations, that value was assigned only to animals destined for slaughter and the sale of females for replacement.

To estimate the dollar value (US $) and the Weight Unit[1] (WU) value of fattened cattle, an average value between 2016 and 2019 were obtained from the Center for Advanced Studies in Applied Economics - CEPEA/Esalq USP.

Due to the productive gain of scale, the herd is altered, and consequently, the productive costs as well, in the different production systems. Administrative costs suffer proportional dilution, according to scale gains.

The use of acaricide is an important tool in the strategic control process (Andreotti et al., 2019). According to Higa et al. (2019), there are several acaricides on the market, which differ in their active principles, effectiveness and ways of application (spraying and spilling). For this study, the spray method (organophosphate and pyrethroids) was used. The model assumes the maximum effectiveness of the treatment due to the lack of resistance to acaricides among the tick population. The commercial values of the acaricides were quoted in the local market of Campo Grande, State of Mato Grosso do Sul, Brazil, and converted to values in US$.

2.5. Equations for herd simulation

Based on the work of Brumatti et al. (2011) and Gaspar et al. (2018), the bioeconomic model used uses the formulas to obtain the structure of the herd, considering that such formulas are derived for intermediate categories, however in structural terms, as described below:

$$BC = [(TNBC - CBC) - (NCPY\ x\ CM) - (NHBPY)] + [(NHPY\ x\ FCM)] + [(NH24m\ x\ F24m + NCC)] \tag{2}$$

where BC = number of breeding cows; TNBC = total number of breeding cows; CBC = culled breeding cows; NCPY = number of cows from the previous year; CM = cow mortality; NHBPY = number of heifers in breeding from the previous year; NHPY = number of heifers from the previous year; FCM = first cows' mortality; NH24m = number of heifers at 24 months; F24m = females at 24 months; NCC = numbers culled cows.

$$BuN = (NBC/NCpB) \tag{3}$$

where BuN = number of bulls; NBC = number of breeding cows; NCpBu = number of cows per bull.

$$BiN = [(NC\ x\ \mathrm{CF}) + (NCFC\ x\ FCFC) + (NH24m\ x\ HF24m)] \tag{4}$$

where BiN = number of births; NC = numbers cows; CF = cows' fertility; NCFC = numbers of cows first calf; FCFC = fertility of cows the first calf; NH24m = number of heifers at 24 months; HF24m = heifer fertility 24 months.

$$NF = [(NBi\ x\ RMW)] \tag{5}$$

where NF = numbers feeder; NBi = number of born; RMW = rate mortality at weaning.

$$NC = [(NFC\ x\ MR)] \quad (6)$$

where NC = number calves; NFC = number of feeder calves; MR = mortality rate.

$$CWC = [(PCW\ x\ WGCQ\ x\ NDBC)] \quad (7)$$

where CWC = calculation of weight (Kg) calves; PCW = Previous category weight; WGCQ = average weight gain of the category in question; NDBC = number of days between categories.

$$FN = [(NAC\ x\ MR)] \quad (8)$$

where FN = fattening numbers; NAC = numbers of animals' calves; MR = mortality rate.

$$CWF = [(PCW\ x\ AWGC\ x\ NDBC)] \quad (9)$$

where CWF = calculation of weight (Kg) fattening; PCW = previous category weight; AWGC = average weight gain of the category in question; NDBC = number of days between categories.

$$SWC = [(NA\ x\ FW\ x\%PECY)] \quad (10)$$

where SWC = slaughter weight calculation; NA = number of animals; FW = final weight; %PECY = percentage of estimated carcass yield.

2.6. Bioeconomic model

The bioeconomic model described by Brumatti et al. (2011), is a deterministic model, and was used in this analysis considering the two proposed scenarios: wI and wC. This model can interpret and interact with the zootechnical indexes and the structure of the herd through cost and revenue centers, describing the livestock production systems in terms of the complete cycle, including creation and termination of animals for fattening in pastures and feedlots. For the complete cycle system, our simulator used a deterministic system that simulated a herd of a fixed number of breeding cows, integrating costs and annual revenues from several simulated scenarios.

With user information on reproductive, health and zootechnical indexes, the model estimated the number of animals in the herd and their respective weights in kilograms. These numbers influenced the actual stocking rate, comparing it and adjusting to the desired stocking rate. These calculations were necessary to determine the total value and the average weights of each category in the initial herd until reaching stability, which occurred in the sixth year after the system was implemented (Brumatti et al., 2011).

For all categories of animals evaluated in this study, their respective zootechnical indexes were applied, such as mortality rates and weight gain, inserted by the user in the respective control centers (Fig. 1). For breeding categories, the fertility rate was applied as described in each scenario. Thus, the number of animals obtained for each category was conditioned to the respective zootechnical indexes. Once the herd was stable, the model provided the number of animals necessary to simulate a fully active property. A value of 102 ticks/animal al was assigned, an average value of tick infestation in crossbred animals in the Brazilian cerrado (Andreotti et al., 2018), in wI systems, regardless of the technological level, thus providing the weight loss values. Consequently, the model provided the economic results, which served as basis for comparing the systems.

2.6.1. Bioeconomic equations

For economic calculations, in the proposed model, two scenarios were considered: wI and wC, which may or may not lead to loss of efficiency, using the following equations:

$$FP = FC + PheiS + PC + PCB \quad (11)$$

where FP = farm profit, FC = profit per fattened cattle, PheiS = profit per heifer, PC = profit per cow, and PCB = profit per culled bull.

$$FC = N\ x\ ((NPC\ x\ (CW\ x\ CY\ x\ U\$/Kg))-((NPC\ x\ CS) + Erat)) \quad (12)$$

where N = number of breeding cows, NPC = number of products per cow, CW = carcass weight (kg), CY = carcass yield (%), US $/kg = price per kilo of steers (US $), CS = cost per heifer (US $), and Erat = total administrative expenses x percentage of herd category.

$$CS = ((NPC\ x\ DCS) + (NPC\ x\ ICS) \quad (12.1)$$

where NPC = number of products per cow; DCS = direct costs of the category; and ICS = indirect costs of the remaining categories.

$$PheiS = N\ x\ ((NPC\ x\ (LW\ x\ U\$/Kg))-((NPC\ x\ CH) + Erat \quad (13)$$

where N = number of breeding cows; NPC = number of products per cow; LW is in kg; US $/kg = price per kilo (US $); CH = cost of the heifer sold (US $); Erat = total administrative expenses x percentage of herd category;

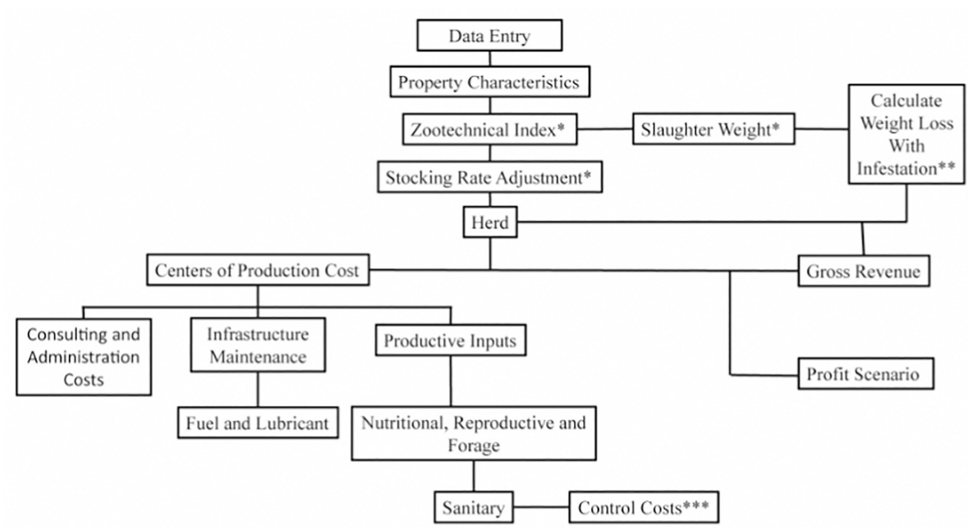


Fig. 1. Bioeconomic model flowchart. * Values according to Table 1; ** Values determined using the formula W = w x n (Calvano et al., 2019), and used only in Systems called With Infestation; *** Control cost values used only in Systems called no Infestation.

$$CH = (NPC\ x\ DCSHei) + (NPC\ x\ ICSHei) \tag{13.1}$$

where DCSHei = direct cost of sold heifer; ICSHei = indirect cost of the remaining categories over the category heifers sold;

$$PC = N\ x\ ((CCull\ x\ (CW\ x\ CV\ x\ U\$/Kg)) - ((CCull\ x\ Erat)) \tag{14}$$

where N = number of breeding cows; CCull = percentage of culled cows; CW = carcass weight (kg); CY = carcass yield (%); US $/kg = price per kilo of live cow; CCull = cost of each live cow culled (US $); Erat = total administrative expenses × percentage of herd category.

$$CCull = ((NCull\ x\ DCCull) + (NCull\ x\ ICCcull)) \tag{14.1}$$

where NCull = number of culled cows; DCCull = direct cost of the culled cow's category; ICCcull = indirect cost of the other categories relative to culled cows.

$$PCB = N\ x\ ((BCull\ x\ (CW\ x\ CY\ x\ U\$/Kg)) - (CB + Erat)) \tag{15}$$

where N = number of breeding cows; BCull = percentage of culled bulls; CW = carcass weight (kg); CY = carcass yield (%); US $/kg = cost per kilo of live bull (US $); CB = cust of each bull; Erat = total administrative expenses x percentage of herd category.

$$CB = (NBcull\ x\ DBCCull) + (NBcull\ x\ ICBDull) \tag{15.1}$$

where NBcull = number of culled bulls; DBCCull = culled bulls by direct cost category; ICBDull = indirect cost of the remaining categories on culled bulls.

3. Results

3.1. Structure of the cattle herd

As the technological level of the systems increased, so did the total number of animals in the herd, as shown in Table 2. This connection was due to the increase in the number of breeding cows in the different production systems: The extensive system had 561 breeding cows, the semi-intensive system had 635 breeding cows, and the intensive system had 1010 breeding cows. Similar data were found by Gaspar et al. (2018). Corrêa et al. (2006) explained that this increase in the number of breeding cows relative to the amount of fertilizers and correctives is intended to improve the quality and efficiency of pasture use.

Table 2
Physical results of the cattle herd in the different production systems.

	Production systems		
Herd structure	Extensive	Semi-intensive	Intensive
Categories	Head count	Head count	Head count
Breeding cows	561	635	1010
Bulls	16	8	7
Calves	339	483	882
Feeder Calves - 12 to 24 Months	168	350	770
Feeder Calves - 24 to 36 Months	163	201	70
Feeder Calves - > 36 Months	162	42	12
Fattened cattle 24 Months	3	32	298
Fattened cattle 36 Months	23	163	59
Fattened cattle >36 Months	139	38	9
Steers for sale	–	–	–
Heifers for sale	49	110	331
Culled cows	112	127	101
Culled bulls	3	1	0
Breeding cows and bulls purchased	3	1	0
Total *	1574	1953	3117

* Does not consider culled animals or purchases

3.2. Productive performance of the herd

The systems with high tick infestation showed lower productive performance than systems with control of ticks, regardless of the technological level (Tables 3–5).

When analyzing the categories destined for slaughter, there was a difference in the average weight (kg) in the wI systems compared to the wC systems. For the EwI, the average weight for heifers was 362 kg, while for EwC, the average weight was 381 kg. For the male category, the EwI had an average of 481, 431, and 431 kg for animals of 24, 36, and > 36 months, respectively. Conversely, the EwC had an average of 477, 499, and 523 kg for animals of 24, 36 and > 36 months of age (Table 3).

The data show that when analyzing the weight produced by each system, EwI produced 71,242 kg, while the EwC produced 79,060 kg (Table 3), for a difference of 7818 kg between the systems. The EwI system produced 59.37 kg/ha, while the EwC produced 65.88 kg/ha (Table 3), a difference of 6.51 kg/ha.

As the technological level of the systems increased, the average weight of the animals in the different categories increased. In the SIwI, the heifers had an average weight of 405 kg, while the SIwC had a weight of 424 kg. Males aged 24, 36 and > 36 months had weights of 511, 532, and 533 kg, respectively, under the SIwI. The SIwC had higher weights for males, with 550, 600, and 625 kg for animals of 24. 36 and > 36 months of age, respectively (Table 4). Even the SIwC had a smaller herd (1953 animals) than the SIwI (2020 animals). The weight produced was higher for SIwC, totaling 127,836 kg, while SIwI produced 122,534 kg (Table 4), a difference of 5302 kg. The difference between the weight in kg/ha was 4.4 kg: SIwI produced 102.1 kg/ha, while SIwC produced 106.5 kg/ha (Table 4).

The intensive system had more animals (Table 5) than the extensive and semi-intensive systems. The weight in the heifer category was 447 kg in IwI and 466 kg in IwC. The males for slaughter in IwI were 486, 507, and 508 kg for animals aged 24, 36 and > 36 months, respectively. In the IwC, the males had weights of 525, 574, and 599 kg for animals aged 24, 36 and > 36 months, respectively. The total weight produced by IwI was 200,616 kg and by IwC was 212,793 kg (Table 5), a difference of 12,177 kg. The highest kg/ha value was in IwC, with a production of 177.3 kg/ha, while IwI had a production of 167.2 kg/ha, a difference of 10.1 kg/ha.

3.3. Economic results obtained

3.3.1. Production costs

When analyzing production costs, which varied between 23% and 43% of the effective operating costs, specifically the sanitary costs, the values were higher for the systems that adopted the strategic control, but the difference between the systems with *R. microplus* tick infestation was small, at 2.4% to 4.1% (Table 6). The sanitary costs represented, in this study, a small value relative to the other production costs.

3.3.2. Revenue and profits

The lowest total gross revenue and profit was obtained under the EwI system, totaling US $235,992.00 and a profit of US $83,751.00. The IwC presented a revenue value of US $790,454.00 and a profit of US $336,060.00 (Table 6).

When comparing the total gross revenue values between the same systems (wI and wC), the values were higher for the systems that adopted strategic control. The difference between the wI and wC systems was quite significant, with a US $26,874.00 difference between EwC and EwI, US $18,511.00 between SIwC and SIwI, and US $44,349.00 between IwC and IwI.

The profit showed an economic difference between the systems: EwC had an economic difference of US $22,619.00 compared to EwI, SIwC presented an economic difference of US $13,902.00 relative to SIwI, and IwC presented an economic difference of US $28,290,00 relative to IwI.

Table 3
Structure of the cattle herds and the productive performance compared the extensive system with tick infestation to the extensive system with tick control.

	Extensive with infestation				Extensive with control			
Categories	Head count	Average weight (kg)	Kg[1]	kg/ha[1]	Head count	Average weight (kg)	Kg[1]	kg/ha[1]
Breeding cows	561	378	103,750	86.5	561	385	105,846	88.2
Bulls	16	650	5304	4.4	16	650	5304	4.4
Calves	339	169	29,275	24.4	339	169	29,275	24.4
Feeder calves - 12 to 24 Months	168	341	29,154	24.3	168	361	30,864	25.7
Feeder calves - 24 to 36 Months	163	369	30,666	25.6	163	402	33,368	27.8
Feeder calves - > 36 Months	162	409	33,747	28.1	162	475	39,241	32.7
Fattened cattle 24 Months[2]	3	438	780	0.7	3	477	849	0.7
Fattened cattle 36 Months[2]	23	431	4970	4.1	23	499	5750	4.8
Fattened cattle >36 Months[2]	139	431	30,657	25.5	139	523	37,161	31.0
Steers for sale	–	–	–	–	–	–	–	–
Heifers for sale [B]	49	362	9052	7.5	49	381	9518	7.9
Culled cows [2]	112	450	24,722	20.6	112	450	24,722	20.6
Culled bulls [2]	3	650	1061	0.9	3	650	1061	0.9
Breeding cows and bulls	3	450			3	463		
Total produced			71,242	59.4			79,060	65.9
Total *	1574		30,3139	252.6	1574		322,957	269.1

* Does not consider culled animals or purchases; 1 = Produced + Sold; 2 = animals destined for sale (slaughter and replacement).

Table 4
Structures of the cattle herds and the productive performance comparing the semi-intensive system with tick infestation to the semi-intensive system with tick control.

	Semi-intensive with infestation				Semi-intensive with control			
Categories	Head count	Average weight (kg)	Kg[1]	kg/ha[1]	Head count	Average weight (kg)	Kg[1]	kg/ha[1]
Breeding cows	657	395	132,444	110.4	635	403	130,448	108.7
Bulls	9	650	2989	2.5	8	650	2889	2.4
Calves	499	195	51,612	43.0	483	195	49,884	41.6
Feeder calves - 12 to 24 Months	362	399	76,615	63.8	350	419	77,760	64.8
Feeder calves - 24 to 36 Months	208	442	48,867	40.7	201	475	50,706	42.3
Feeder calves - > 36 Months	44	500	11,574	9.6	42	566	12,675	10.6
Fattened cattle 24 Months[2]	34	511	9110	7.6	32	550	9472	7.9
Fattened cattle 36 Months[2]	169	532	47,545	39.6	163	600	51,789	43.2
Fattened cattle >36 Months[2]	39	533	10,968	9.1	38	625	12,419	10.3
Steers for sale	–	–	–	–	–	–	–	–
Heifers for sale [2]	114	405	24,446	20.4	110	424	24,712	20.6
Culled cows [2]	131	450	30,157	25.1	127	450	29,147	24.3
Culled bulls [2]	1	650	308	0.3	1	650	297	0.2
Breeding cows and bulls	1	479			1	492		
Total produced			122,534	102.1			127,836	106.5
Total *	2020		446,635	372.2	1953		452,197	376.8

* Does not consider culled animals or purchases; 1 = Produced + Sold; 2 = animals destined for sale (slaughter and replacement).

Table 5
Structures of the cattle herds and the productive performance comparing the intensive system with tick infestation to the intensive system with tick control.

	Intensive with infestation				Intensive with control			
Categories	Head count	Average weight (kg)	Kg[1]	kg/ha[1]	Head count	Average weight (kg)	Kg[1]	kg/ha[1]
Breeding cows	1010	401	210,810	175.7	1010	405	212,836	177.4
Bulls	7	650	2413	2.0	7	650	2413	2.0
Calves	882	241	114,812	95.7	882	241	114,812	95.7
Feeder calves - 12 to 24 Months	770	416	173,093	144.2	770	436	181,408	151.2
Feeder calves - 24 to 36 Months	70	417	15,822	13.2	70	450	17,057	14.2
Feeder calves - > 36 Months	12	474	3048	2.5	12	541	3475	2.9
Fattened cattle 24 Months[2]	298	486	78,083	65.1	298	525	84,312	70.3
Fattened cattle 36 Months[2]	59	507	16,241	13.5	59	574	18,407	15.3
Fattened cattle >36 Months[2]	9	508	2513	2.1	9	599	2966	2.5
Steers for sale	–	–	–	–	–	–	–	–
Heifers for sale [2]	331	447	80,021	66.7	331	466	83,351	69.5
Culled cows [2]	101	450	23,634	19.7	101	450	23,634	19.7
Culled bulls [2]	0	650	123	0.1	0	650	123	0.1
Breeding cows and bulls	0	507			0	520		
Total produced			200,616	167.2			212,793	177.3
Total *	3117		720,615	600.5	3117		744,796	620.66

* Does not consider culled animals or purchases; 1 = Produced + Sold; 2 = animals destined for sale (slaughter and replacement).

3.4. *Results of productive indicators × economic indicators*

Analysis of the production indicators, unit of weight produced (UW) and Kg/year, revealed that the profit values were very close among the systems analyzed (Fig. 2). These indicators are related the animals LW due to tick infestation.

Table 6
Economic statement of the different production systems.

	Production systems											
	EwI		EwC		SIwI		SIwC		IwI		IwC	
Items	Year		Year		Year		Year		Year		Year	
Revenue	Total (US $)	Margin (%)	Total (US $)	Margin (%)	Total (US $)	Margin (%)	Total (US $)	Margin (%)	Total (US $)	Margin (%)	Total (US $)	Margin (%)
Fattened cattle	124,132	52.6	149,542	56.9	238,505	56.6	259,474	59.0	398,188	53.4	431,516	54.6
Heifers	28,990	12.3	30,453	11.6	84,739	20.1	85,560	19.5	271,557	36.4	282,578	35.7
Culled cows	79,461	33.7	79,461	30.2	96,929	23.0	93,683	21.3	75,964	10.2	75,964	9.6
Calves	–	0.0	–	0.0	–	0.0	–	0.0	–	0.0	–	0.0
Culled bulls	3410	1.4	3410	1.3	989	0.2	956	0.2	396	0.1	396	0.1
Steers	–	0.0	–	0.0	–	0.0	–	0.0	–	0.0	–	0.0
Total gross revenue	235,992	100	262,866	100	421,162	100	439,673	100	746,105	100	790,454	100
Production costs												
Productive inputs												
Animals for fattening	–	0.0	–	0.0	–	0.0	–	0.0	–	0.0	–	0.0
Nutritional	25,178	10.7	26,311	10	128,931	30.6	131,063	29.8	263,376	35.3	273,394	34.6
Reproductive	1012	0.4	1012	0.4	13,397	3.2	12,949	2.9	23,002	3.1	23,002	2.9
Sanitary	7596	3.2	10,717	4.1	10,233	2.4	14,006	3.2	15,056	2.0	21,095	2.7
Forages	22,743	9.6	22,743	8.7	22,743	5.4	22,743	5.2	22,743	3.0	22,743	2.9
Subtotal productive Inputs	56,529	24.0	60,783	23.1	175,303	41.6	180,761	41.1	324,176	43.4	340,235	43.0
Payroll	75,913	32.2	75,913	28.9	80,473	19.1	79,698	18.1	93,045	12.5	93,045	11.8
Infrastructure												
Maintenance, fuel and lubricants	10,677	4.5	10,677	4.1	10,677	2.5	10,677	2.4	10,677	1.4	10,677	1.4
Consultancy and Administration costs	9123	3.9	9123	3.5	9328	2.2	9328	2.1	10,438	1.4	10,438	1.3
Effective operating cost	152,241	64.5	156,496	59.5	275,782	65.5	280,390	63.8	438,335	58.7	454,394	57.5
Gross profit	83,751		106,370		145,381		159,283		307,770		336,060	
Gross margin		35.5		40.5		34.5		36.2		41.3		42.5

* EwI = extensive system with infestation; EwC = extensive system with control; SIwI = semi-intensive system with infestation; SIwC = semi-intensive system with control; IwI = intensive system with infestation; IwC = intensive system with control.

When comparing the productive indicators UW produced between the same systems (wI and wC), the values were higher for the systems that adopted strategic control, and as the technological level increases, the amount of UN produced also increases (Table 7). The difference between EwI and EwC was 1321.22 UW, between SIwI and SIwC was 370.85 UW and between IwI and IwC was 1612.09 UW.

Productive indicators that are related to the intensification of systems (wI and wC), found greater economic value for systems that used strategic control (EwC, SIwC and IwC). In Fig. 2 – A, profit values per AU/year produced, the difference was US $ 13.10 for EwC and EwI, US $ 6.80 for SIwC and SIwI, and US $ 6.70 for IwC and IwI. When analyzing Ha/year produced (Fig. 2 – D), the difference in profit values were US $15.1 for EwC and EwI, US $ 9.3 for SIwC and SIwI, and US $ 18.8 for IwC and IwI.

4. Discussion

The data presented in this article, based on simulation results, support several studies that emphasize that tick infestation in cattle causes economic losses in animal production (Honer and Gomes, 1990; Jonsson, 2006; Grisi et al., 2014; Wang et al., 2017; Andreotti et al., 2018; Bonatte Jr et al., 2019; Burrow et al., 2019; Calvano et al., 2019).

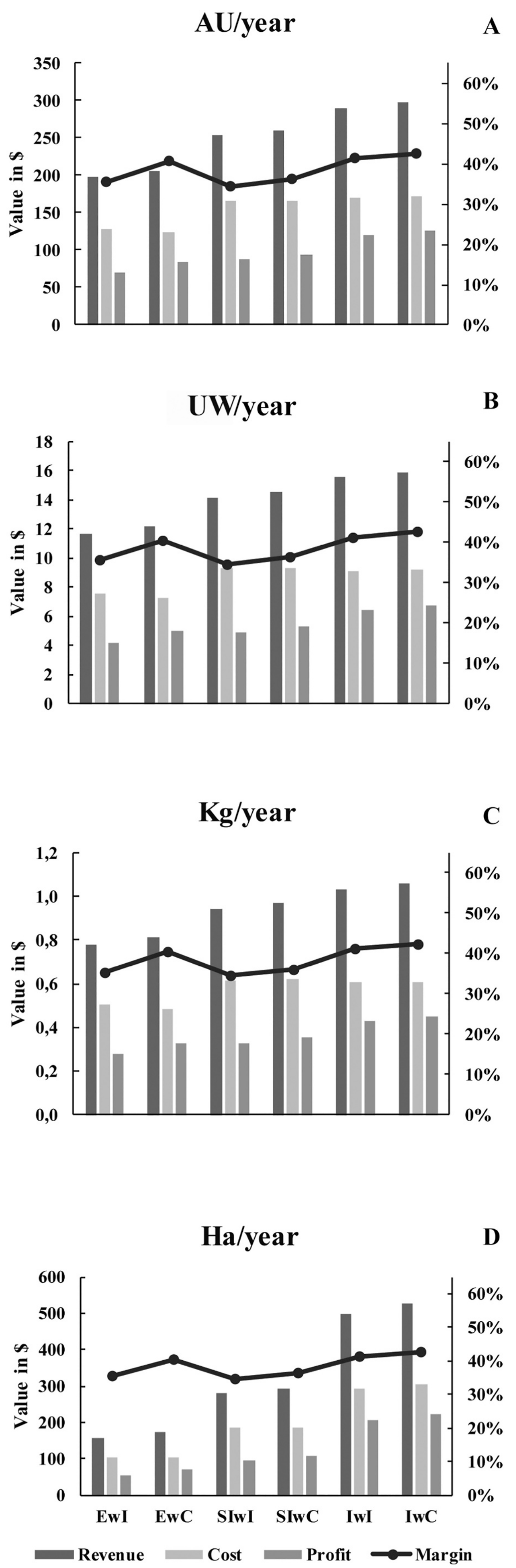
The evaluation of data from representative rural properties of the Cerrado biome allowed us to identify how much the tick *R. microplus* affects the production system, the economic system and the productive performance of the animals.

Brazilian livestock is characterized by its diversity in relation to different types of soil, climate, temperature, relief, and also by socio-economic issues, related to producer income, different levels of education, adoption or not of technologies, which Costa et al. (2018) characterize this diversity as edaphoclimatic, social and economic factors in production systems, which implies great uncertainty as to the productive and economic result.

When it comes to sanitary issues, and Brazil being an endemic territory for *R. microplus*, the results of this work, which compare a production system with tick-infested cattle and control, allow the producer to visualize bottlenecks and make decisions that enable the increased production in beef cattle. Another study, using a probabilistic model (BBN) to estimate whether a farm's herd can become infested with *R. microplus*, making it possible to assess the impact that biosafety measures, proposed by Miraballes et al. (2019), have about the probability of introducing animals infested by the parasite and, thus, guide the decision-making on the control or elimination of *R. microplus* from the farms.

These simulations allow for the integration and evaluation of scenarios with varying conditions and can provide production and economic data over time (Ash et al., 2015; Lopes et al., 2019). The modernization of livestock farming involves the creation of economic and financial indicators, zootechnical indicators and an increase in the technological level of production systems (Wedekin, 2017; Costa et al., 2018).

Since the beginning of the 20th century, the main form of tick control has been the use of chemical products (Angus, 1996; Rodrigues et al., 2018; Andreotti et al., 2019; Higa et al., 2019), even though they are not the most effective (Rodrigues et al., 2018; Higa et al., 2019), and even though it is a major concern among environmentalists and public health, as they can lead or lead to contamination in soil, water, air, and also in meat, milk and its derivatives (Graham and Hourrigan, 1977; Rodrigues et al., 2018; Braga et al., 2020; Vicente and Guedes, 2021). There are several alternatives for the control of bovine ticks, such as vaccines (Patarroyo and Lombana, 2004; Guerrero et al., 2014), herbal medicines (Adenubi et al., 2016; Medeiros et al., 2019), biological agents (Garcia et al., 2011), pasture management (Andreotti et al., 2019; Hüe and Fontfreyde, 2019), selection of animals less sensitive to the ectoparasite,



(caption on next column)

Fig. 2. Economic indicators and productive indicators of the different production systems. Productive indicators = A = AU (animal unit) = 450 kg LW of the animal; B = Kg/year = kilos produced per year; C = UW/year = unit of weight = 15 kg LW of the animal; D = Ha/year = production per hectare per year (Cardoso et al., 2016; Costa et al., 2018; Centro de Estudos Avançados em Economia Aplicada, 2021).

(Naves et al., 2016; Andreotti et al., 2018).

The rural property manager needs to be aware of these aspects when selecting acaricidal products that should be used according to label instructions. The choice of product used and the form of control are totally related to the rural property manager (Rodrigues et al., 2018), but it is important to demonstrate the economic impact when the infestation is not controlled. Being aware of the costs related to health issues is one of the keys to the success of the activity (Wolf, 2005).

It is important to emphasize that the strategic control of the bovine tick aims to use acaricides (in the Brazilian cerrado), considering the tick's life cycle and its relationships with environmental variations (temperature and humidity), population dynamics, especially seasonality, to identify when the population of ticks is at the most vulnerable stage to control (Andreotti et al., 2016), and the doses of acaricides were used according to the manufacturer's recommendation. Scientific evidence indicates that the indiscriminate use of acaricides has resulted in populations of *R. microplus* resistant to chemical treatment (Rodrigues et al., 2018; Higa et al., 2019; Valsoni et al., 2020). The values of health costs increase, in different systems, due to the fact that as the technological level of the systems increases, so does the number of animals and, consequently, the amount of acaricides in the different systems.

Our data showed that cattle with high tick infestation, regardless of the production system, produced lighter animals compared to the control systems. For the categories destined for slaughter adopted in this study, in the systems with infestation, the animals had a weight difference in heifers of 19 kg LW, whereas in males aged 24, 36 and > 36 months, the difference was 39, 68, and 92 kg/LW, respectively, compared to in the control systems. In the studies by Calvano et al. (2019), when quantifying this loss in kg/year, crossbred animals in the rearing phase lost 22.44 kg LW. The difference between weight losses between breeding animals, mentioned above, is in the category, as males have greater weight gain than females.

When the systems that adopted the strategic control of ticks were analyzed, regardless of the technological level, the animals could realize their genetic potential, with a greater weight gain than the animals of the infested systems. Grisi et al. (2014) reported that parasitism caused economic losses due to negative effects on the productivity of untreated Brazilian cattle herds, and Bonatte Jr et al. (2019) reported that Brangus animals without tick treatment showed lower weight gain, greater tick counts, and higher costs compared to animals that received prophylactic treatment against the bovine babesiosis and anaplasmosis complex and curative treatment against myiasis. The more ticks that infest an animal, the greater the load of transmitted pathogens, which increases the risk of being affected by the bovine babesiosis and anaplasmosis complex and the consequent loss of animals, and this risk increases when the animals are crossbred (Gicliotti et al., 2018). Losses due to those factors were not computed in this evaluation because no regional data was available in the literature. In several countries where cattle fever ticks remain endemic, bovine babesiosis-anaplasmosis complex is detrimental to cattle health and results in a significant economic cost to the livestock industry due to several tick species that can transmit different pathogenic agents to cattle and are dependent of climatic and cattle management systems (Guglielmone et al., 1992; Kivaria, 2006; Abdela et al., 2018; Esteve-Gasent et al., 2020; Ozubek et al., 2020).

The sanitary costs had a low value relative to the other production costs, regardless of the adopted system. This reinforces the importance of adopting strategic control of ticks to assist both in decreasing the population of these parasites in pastures and in increasing the

Table 7
Productivity indicator of the different production systems*.

	EwI	EwC	SIwI	SIwC	IwI	IwC
UW Produced	20,209.26	21,530.48	29,775.65	30,146.50	48.040,98	49,653.07
UW Produced/Ha	16.84	17,94	24.81	25.12	40.03	41.38

* Productivity indicator = UW = unit of weight = 15 kg LW of the animal (Cardoso et al., 2016; Costa et al., 2018; Centro de Estudos Avançados em Economia Aplicada, 2021).

productive performance of animals. Some 95% of ticks in a cattle production system are found in pastures, and only 5% of the population is found in the animal (Campos Pereira and Labruna, 2008). Jonsson et al. (2001) reported that its likely that the greatest sources of error are in the farmers estimates of the peak number of ticks seen and in the assumption that there is a constant relationship between peak tick number and the total annual infestation. Calvano et al. (2019), when analyzing the relationship between the cost of spraying treatment and the economic losses due to infestation, found values of 6.4% and 5.64% for the rearing and fattening categories, respectively, in crossbred breeds and emphasized that it is important to determine the relationship between treatment cost and productivity loss to demonstrate that control can be an economically efficient procedure. When analyzing the technical performance indicators, the systems with infestation showed a worse economic and productive performance. These analyzes allow us to be in a range of production aligned with economic gain within each system. It is interesting that all production systems are profitable, and that every investment needs to be put to good use.

These indicators can help minimize the great uncertainties in the productive and economic results within a production system configured to meet specific and diversified objectives (Costa et al., 2018). The data show that as the technological level of the systems increases, so does the performance of the technical indicators, as demonstrated by several authors who have used indicators to evaluate different production systems (Corrêa et al., 2006; Cardoso et al., 2016; Gaspar et al., 2018), but the indicators decrease under a given system when *R. microplus* tick infestation is present.

The damage caused by the tick to the productive performance of the systems is directly reflected in the economic performance, as shown in the data of this simulation. When analyzing the economic statement, the values for total gross revenue were lower in the systems with tick infestation because these systems had the lowest LW production. This led to a decrease in revenue. Calvano et al. (2019) observed a loss in revenue of US $4713.03 in crossbred cattle in the rearing phase with tick infestation.

The health status of the animal combined with genetics and a good diet help improve productive efficiency in beef production. According to Wedekin (2017), these factors are termed the tripod of technological development—breeding, rearing, and fattening—and have always been important in research and development activities in beef cattle production.

5. Conclusion

The *R. microplus* tick directly affects the economic and productive performance of the different beef cattle production systems in the Cerrado, regardless of the technological level. This simulation showed that the adoption of strategic control directly benefits the productive and economic performance of farms in all systems. Crossbred animals, even those that are more susceptible to ticks, demonstrate a productive performance that contributes to the economic efficiency of the production systems analyzed in this simulation. Production increases as the technological level increases and with the adoption of parasite control. Thus, crossbred cattle need a conducive environment where the impact of ectoparasitism by *R. microplus* and associated diseases are managed sustainably to realize their genetic potential for optimal beef production.

Declaration of Competing Interest

There were no conflicts of interest that may have biased the work reported in this paper.

Acknowledgments

The authors thank the Coordination for the Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico), and the Mato Grosso do Sul State Foundation for the Support and Development of Education (Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia) - Governo do Estado de Mato Grosso do Sul, Brazil.

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