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**ECONOMICS, RISK ANALYSIS, AND SUSTAINABILITY OF
MINIMUM MODULE IN PASTURE-BASED BEEF PRODUCTION:
A CASE STUDY OF THE CAMPO GRANDE, MS, BRAZIL**

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ECONOMICS, RISK ANALYSIS, AND SUSTAINABILITY OF MINIMUM MODULE IN PASTURE-BASED BEEF PRODUCTION: A CASE STUDY OF THE CAMPO GRANDE, MS, BRAZIL

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ABSTRACT

This study quantified production risks and economic feasibility in tropical pasture-based beef systems by integrating a rule-based Minimum Module (MM) framework with Monte Carlo simulation (@Risk 8.0) in Excel 365 and Microsoft Visual Basic 6.0 algorithm. Twelve scenarios, low (0.5 animal unit [AU] ha⁻¹), medium (1.0 AU ha⁻¹), and high (1.5 AU ha⁻¹) stocking rates over 2017–2020, were each run with 10 000 stochastic iterations to identify the smallest viable herd size and pasture area ensuring non-negative net present value (NPV ≥ 0). Intensification increased per-hectare productivity from 3.3 to 9.8 arrobas ha⁻¹ yr⁻¹ (P < 0.001) and reduced minimum grazing area by 53–63 percent (P < 0.001). Risk profiles remained favorable, with the probability of negative gross margin below 3 percent (P = 0.02) and total profit loss under 17 percent (P = 0.04). Fixed-cost share declined from 72 percent in low-intensity to 48 percent in high-intensity systems (P < 0.05). Strong co-movement among overhead inputs (ρ > 0.90) and among variable-cost inputs (ρ > 0.80), and a land-for-feed trade-off (ρ ≈ -0.35) were quantified. The MM tool delivers transparent “what-if” scenario testing for herd and land planning without complex optimization, enabling data-driven feed-price hedging and stocking-rate adjustments.

Keywords: beef cattle; intensification; minimum module; Monte Carlo simulation; net present value; tropical grazing systems.

1. Introduction

The global demand for sustainable beef production continues to rise, driving the need for grazing systems that balance economic viability, environmental health, and livestock productivity. In tropical regions such as Brazil, where extensive cattle farming underpins agribusiness, producers confront economic volatility, biophysical constraints, and technological uncertainty (Anderson, 2003; Dickinson, 2001; Moss, 2010; Stockton, 2022; Santos et al., 2024; Taylor et al., 2025).

Brazil's ruminant sector relies almost entirely on forage-based diets, with improved and native pastures covering approximately 180 million ha, 30 percent of which lies in the Cerrado biome, making pasture management a cornerstone of national beef output (Barcellos et al., 2008; McManus et al., 2016; Cordeiro et al., 2023; Parente et al., 2019; Sano et al., 2019; Santos et al., 2024). Mato Grosso do Sul exemplifies this dynamic, hosting 18.9 million cattle over 14.6 million ha of grazing land, and the Campo Grande microregion alone supports 1.75 million head (9.2 percent of the state total) with strategic access to soybean, corn, and processing hubs (de Azevedo et al., 2023; Lapig, 2023; Moore et al., 1999; Tambara et al., 2021).

Despite these assets, pasture-based beef systems face mounting pressures—deforestation, greenhouse-gas emissions, land-use conflicts, and financial risks—underscoring the need for integrated sustainability indicators in production models (Lorencowicz et al., 2024; Chapman et al., 2024). Sustainability frameworks operationalize economic, environmental, and social goals, guided by indicators that inform evidence-based management and align with SDGs 2, 12, and 15 (Mukherjee, 1998; Dumanski et al., 1998; Barry and Hoyne, 2021; Nadaraja et al., 2021; ONU, 2015).

Current economic and agronomic models often omit stochastic elements or lack usability, limiting their adoption in commercial herds (Moss, 2010; Stockton, 2022; Taylor et al., 2025; McManus et al., 2016; Gomes et al., 2015; McKendree et al., 2021; Tedeschi et al., 2024; Hardaker and Lien, 2010a,b; Hardaker et al., 2015a,b). Moreover, most mathematical models remain confined to academic research, offering limited decision-support for producers and policymakers (Stygar and Makulska, 2010; Jones et al., 2017). To bridge these gaps, Jorge (2019) developed the Minimum Module (MM), a modular deterministic-stochastic framework that links a rancher's target net income to endogenous adjustments in herd size and pasture area—defining the minimum viable scale as the point where the removal of one breeding cow causes net present value (NPV) to fall below zero. This study applies to the MM with Monte Carlo simulation to (i) quantify market-driven production risks, (ii) evaluate economic feasibility under low, medium, and high intensification strategies, and (iii) deliver a practical decision-support tool that guides land-use and herd-scaling decisions to balance profitability and sustainability in tropical grazing systems.

2. Material and methods

2.1 Study Design

We applied the rule-based Minimum Module (MM) framework, a deterministic-stochastic simulation model, to determine the smallest viable herd size and pasture area that sustain non-negative net present value ($NPV \geq 0$) under three stocking-rate intensification levels: low (0.5 animal unit [AU] ha⁻¹), medium (1.0 AU ha⁻¹), and high (1.5 AU ha⁻¹). The MM overcomes limitations of conventional economic models by embedding zootechnical and financial uncertainties within a single decision-

support structure that mirrors on-farm management rules, rather than relying on mathematical optimization alone (Jorge, 2019; Lampert et al., 2020). We conducted simulations for the Campo Grande microregion (20°26' S, 54°38' W) in Mato Grosso do Sul, Brazil—a representative pasture-based beef system characterized by *Urochloa brizantha* spp. pastures, annual rainfall of approximately 1,400 mm, and bimodal wet–dry seasons. We ran twelve scenarios combining three intensification levels and four production years (2017–2020), each spanning a 20-year horizon (20 annual cycles) to capture inter-annual climate variability and typical ranch investment amortization periods. For each scenario, we fixed an annual net-income requirement ($Rr_1 = \text{USD } 70,725.93$), informed by regional cost–return data (CEPEA, 2020), and identified the MM threshold by reducing herd size incrementally until removing one breeding cow caused NPV to drop below zero. To quantify production risk, we reserved a detailed Monte Carlo simulation for Section 2.7.

2.2 Modeling of the Minimum Module (MM)

We developed the Minimum Module (MM) as a modular, deterministic–stochastic simulation framework that quantitatively represents pasture-based beef production by linking three interconnected submodels: Animal Production Module (Animal Module), Plant Production Module (Plant Module), and Economic Module (Pidd 1997; Jorge 2019) (Figure 1). [Suggested placement: insert Figure 1 here] Thus, we implemented all submodels and automated calculations in Microsoft Excel® 365 (build 2504, compilation 18730.20168) using a Microsoft Visual Basic 6.0 algorithm comprising eleven subroutines and totaling 3,867 lines of code, alongside the @Risk 8.0 (Palisade Corp., Ithaca, NY) add-in to generate correlated

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113 random variates, construct the risk-correlation matrix, and execute Monte Carlo
114 simulations.

115 **2.3 Animal Module**

116 In the Animal Module, we tracked herd composition and performance across 16
117 animal categories, defining average live weight (W_i , kg head⁻¹), carcass yield (R_i , kg
118 carcass kg live weight⁻¹), and selection pressure (Ps_i , %) for under-threshold
119 animals. We specified weight thresholds—180 kg for male weaners, 160 kg for
120 female weaners, 195 kg for bull calves, 180 kg for female calves, 285 kg for 18-
121 month-olds, and 360 kg for lean bulls—and directed animals failing to meet these
122 thresholds into replacement markets (i.e., sold from one producer to another), while
123 applying category-specific (Ps_i) rates to all others for slaughter (Table 1). [Suggested
124 placement: insert Table 1]

125 Furthermore, we standardized Animal Units at 450 kg live weight, imposed a bull-
126 to-cow ratio of 1:25, set annual replacement rates at 20 %, and targeted a calving
127 rate of 70–90 % (Table 2). [Suggested placement: insert Table 2]

128 Nutritional management incorporated daily mineral-salt and protein/energy
129 supplementation, creep feeding, and semi-confinement diets yielding 1.3 kg day⁻¹
130 gains, while health protocols included annual vaccinations for foot-and-mouth
131 disease, blackleg, and brucellosis plus systematic deworming. We simulated
132 replacement purchases of 170 cow-calf pairs and six breeding bulls per year, with
133 younger replacements set to zero in core scenarios (Table 3). [Suggested placement:
134 insert Table 3]

135 **2.4 Plant Module**

136 In the Plant Module, we modeled pasture over a ten-year lifespan, beginning with
137 land preparation—stump removal (5 h ha⁻¹), disking (1 h ha⁻¹), plowing (1.5 h

138 ha^{-1}), liming with 2 t ha^{-1} of dolomitic limestone, NPK fertilization at 300 kg ha^{-1} ,
139 and seeding at 18 kg ha^{-1} —and followed by uniform annual maintenance
140 comprising lime spreading (1 h ha^{-1}), disking (1 h ha^{-1}), fertilizer application (0.35
141 h ha^{-1}), and selective herbicide use (4.4 L ha^{-1} of 2,4-D/Picloram) (Table 4).

142 [Suggested placement: insert Table 4]

143 As well as, we enforced a 20 % legal reserve as required by Article 12 of the
144 Brazilian Forest Code (Law 12.651/2012) and assumed a uniform 10 % permanent
145 preservation area per Article 4, recognizing that actual preservation percentages
146 vary by property (1 %–25 %, approximately), to maintain consistency across
147 comparative intensification scenarios.

148 **2.5 Economic Module**

149 We integrated the Economic Module into the simulation to capture the financial
150 dynamics of pasture-based beef production under varying environmental
151 conditions. We incorporated both fixed and variable inputs, with variable inputs
152 reflecting site-specific conditions to ensure a localized economic representation.

153 Fixed inputs, including operational costs such as labor, general expenses, rural
154 inventory, tractor operators' and ranch hands' monthly labor hours, internal
155 transportation, technical assistance (veterinary, animal science, and agronomy
156 consultations), accounting, electricity, machinery, equipment, and infrastructure
157 costs and depreciation (e.g., seed/fertilizer spreaders, disc plows, leveling harrows)
158 (Table 5), were incorporated into the simulation.

159 [Suggested placement: insert Table 5]

160 Variable inputs were presented in two parts. We outlined revenue sources—
161 including local sale prices per unit for each cohort (cull cows, male and female
162 weaned calves, bulls, and heifers at various growth stages) and early-slaughter

bonuses to reflect market incentives (Table 6). [Suggested placement: insert Table 6] We adjusted these prices for seasonal fluctuations, Rural Workers Assistance Fund (Funrural) tax obligations, and the regional market context. We detailed site-specific production costs—including labor, general expenses, pasture operations (stump removal, plowing, seeding/fertilizing, herbicide application, and annual lime spreading), nutritional inputs (mineral salts, protein supplements, creep feeding), and animal health expenses (vaccinations, deworming) (Table 7)—to ensure that we captured both direct and indirect costs under the local conditions of the Campo Grande microregion. [Suggested placement: insert Table 7] By incorporating environment-dependent cost and price data, we enabled the Economic model to reflect specific regional market conditions, cost structures, and production strategies. This approach allowed us to simulate, and accurately evaluate, the economic performance of pasture-based beef systems across different intensification scenarios under real-world variability.

2.6 Simulation Scenarios

We configured twelve scenarios by combining user-selected settings in the Simulation Panel with fixed biological, economic, and intensification parameters (Table 8). [Suggested placement: insert Table 8] First, users specified their rancher profile (sole proprietor), land-ownership status (owned), annual net-income target (Rr1), cohort prices (Pi) and cost components (Ci) for the chosen year (Sim2: 2017–2020), stocking rate (Sr2: 0.5, 1.0, or 1.5 AU ha⁻¹), land constraints (20 % legal reserve, Ar1, per Law 12 651/2012, Art. 12; 10 % permanent preservation area, Ar2, per Art. 4), geographic focus (Campo Grande microregion), and intensification level (Ni3).

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3 187 After panel configuration, we applied the Animal Production assumptions. We set a
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5 188 November–January breeding season with first-exposure conception rates of 50 %–
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7 189 85 % and subsequent annual rates of 75 %–92 %, a 2 %–5 % pregnancy loss rate,
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9 190 and an August–October calving window. Herd dynamics used a bull-to-cow ratio of
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11 191 1:25, 20 % annual replacement, a 70 %–90 % calving rate, an Animal Unit of 450 kg,
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13 192 daily gains of 1.3 kg per head, and standard health and nutrition protocols
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15 193 (vaccinations, deworming, mineral and protein supplements, and creep feeding)
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17 194 (Table 9). [Suggested placement: insert Table 9]
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19 195 Next, we applied the Economic and Macroeconomic parameters. We used a federal
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21 196 income tax rate of 27.5%, a Rural Workers Assistance Fund (Funrural) tax rate of
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23 197 1.5%, a minimum acceptable rate of return (MARR) and real discount rate of 6%, an
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25 198 annual inflation rate of 4.5%, a capital structure of 40% equity and 60% debt with a
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27 199 10-year financing term and 2-year grace period, a nominal interest rate of 7%, and
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29 200 a bare-land value of USD 1,500 per hectare. These inputs drove fixed and variable
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31 201 cost calculations and revenue deflation (Table 10). [Suggested placement: insert
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33 202 Table 10]
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35 203 We then enforced the intensification-level parameters across all 20 annual cycles.
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37 204 We applied fertilizer at rates ranging from 40 kg ha⁻¹ under low intensification to
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39 205 180 kg ha⁻¹ under high intensification; we varied pasture maintenance hours and
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41 206 lease rates; accordingly, and we fixed stocking rates at 0.5, 1.0, or 1.5 AU ha⁻¹ (Table
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43 207 11). [Suggested placement: insert Table 11]
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45 208 With all inputs defined, the Minimum Module was determined for each scenario by
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47 209 reducing herd size and pasture area until removing one breeding cow caused net
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49 210 present value to fall below zero. The model then recorded fixed and variable costs,
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gross and net revenues, operating and net margins, total profit, and per-hectare profitability for each intensification level and year.

Hence, we structured the simulation workflow to maintain transparency and reproducibility and to allow us to isolate the effects of intensification level and production year on system resilience and land-use efficiency.

2.7 Data Sources and Parameterization

We sourced all price and cost data from regional public databases and standardized values to December 2020 using the General Price Index – Internal Availability (Índice Geral de Preços – Disponibilidade Interna IGP-DI; FGV, 2020). Beef-cattle production costs for Campo Grande municipality were obtained from the Center for Advanced Studies in Applied Economics (CEPEA) database (2020), and we downloaded daily price series for 15 animal categories from the Corrêa da Costa auction website (2021) covering January 2010–December 2020. We provide the complete monthly aggregates and deflated time-series plots in the Results (Section 3.5). Lease rates for pastureland reflected prevailing local values.

To capture biological and replacement uncertainty in the Animal Module, we parameterized each input variable by sampling from a uniform distribution bounded by minimum and maximum values reported in subtropical and tropical studies. We selected a uniform distribution to avoid bias where stronger empirical priors were unavailable. These ranges—drawn from Scarnecchia (1998); Euclides Filho et al. (2002); Abreu et al. (2003); Abreu and Lopes (2005); Costa et al. (2005); Pereira et al. (2005); Barione et al. (2006); Fernandes et al. (2010); Allen et al. (2011); Porto et al. (2011); Pereira et al. (2014); Jorge (2019); Lampert et al. (2019); Moriel et al. (2020); and Dick et al. (2021)—ensured that simulated herd dynamics

235 reflected full-cycle, pasture-based beef production conditions in the study region
236 (Table 12). [Suggested placement: insert Table 12]
237 For the Plant Module, we parameterized machinery-hour requirements and input
238 rates for land preparation and maintenance using data from Pacheco (2000) and
239 Peres et al. (2013, 2014). These values informed simulated labor, fuel, and
240 equipment needs across low, medium, and high intensification scenarios in the MM.
241 All deflation and data cleaning were performed in Microsoft Excel 365, ensuring
242 consistency with the simulation environment.

2.8 Mathematical Formulation of the Minimum Module

2.8.1 Discounted Cash Flow Components and Economic Metrics

245 We calculated annual economic outputs using the discounted cash-flow (DCF)
246 component equations (Table 13). [Suggested placement: insert Table 13] First, we
247 computed total revenue (TR) as the sum across all animal categories of quantity
248 sold, average live weight, carcass yield, selection pressure, and carcass price (Jorge
249 2019, p. 124; 2024, p. 127). From TR, we derived net income (NI) by subtracting the
250 Rural Workers Assistance Fund (Funrural) social security tax ($\alpha = 1.5\%$)
251 (Damodaran 2010, 2020).

252 Next, we calculated total operating cost (TOC) as the sum of fixed operating cost
253 (FOC) and variable operating cost (VOC) streams (Matsunaga et al. 1976; Jorge 2019,
254 p. 124). We estimated opportunity cost (OC_p) at $Z\%$ of potential beef production
255 value, market arroba price multiplied by grazing area, annualized following Ross et
256 al. (2013, p. 172) and Jorge (2019, p. 124; 2024, p. 127). Summing TOC and OC_p
257 yielded total cost (TC).

258 We defined earnings before interest, taxes, depreciation, and amortization
259 (EBITDA) as NI minus TC (Damodaran 2010, 2020). We calculated annual

260 depreciation (Dep) on original asset costs using straight-line schedules with an 80
261 % salvage value over 10 years for movable assets and 90 % over 20 years for
262 buildings (Damodaran 2000, 2010; Kay et al. 2023, p. 75; Jorge 2019, p. 124; 2024,
263 p. 127). Earnings before interest and taxes (EBIT) resulted from subtracting Dep
264 from EBITDA.

265 We computed annual rural land tax (RLT) by multiplying the average bare-land
266 value (VTN) by an 80 % land-use coefficient (Jorge 2019; 2024). We applied
267 progressive income-tax rates up to 27.5 % to each EBIT segment in accordance with
268 Brazilian Federal Revenue Service guidelines (2019; Jorge 2019, p. 139). We
269 aggregated annual reinvestment outlays (R) for livestock replacement, machinery,
270 and infrastructure upgrades (Damodaran 2000, 2010, 2020).

271 We determined free cash flow to equity (FCFE) as EBIT minus RLT, reinvestment,
272 and debt service (principal plus interest) (Damodaran 2000, 2010; Ross et al. 2013,
273 p. 29). We accumulated FCFE over the 20-year horizon, offsetting the initial
274 investment (I_0) as an outflow, to obtain accumulated FCFE ($FCFE_a$) (Jensen 1986;
275 Damodaran 2000, 2010, 2020). Finally, we expressed the annual economic result
276 (ER) per hectare of grazing area by dividing FCFE by available grazing area (AgA)
277 (Jorge 2019, p. 124; 2024, p. 129).

278 **2.8.2 Minimum Module Outputs and Indicator Calculations**

279 We generated annual performance indicators by applying the formulas summarized
280 in Tables 14–17 to our discounted cash-flow projections and herd-dynamics
281 outputs.

282 We first assessed financial viability metrics (Table 14). We calculated net present
283 value (NPV; USD) by discounting each year's free cash flow (FCF_t) at the real
284 discount rate, summing the present values, and subtracting the initial investment

(K_0); we identified the minimum module when removing one breeding cow caused NPV to fall below zero (Damodaran 2000, 2010, 2020; Ross et al. 2013; Jorge 2019, 2024). We derived the modified internal rate of return (MIRR; %) by compounding positive cash flows at the reinvestment rate and discounting negative cash flows at the financing rate (Damodaran 2000, 2010, 2020; Ross et al. 2013; Jorge 2019, 2024). We determined the discounted payback period (years) as the smallest t for which cumulative discounted FCF_t met or exceeded K_0 (Ross et al. 2013). Next, we calculated economic-performance and herd-value indicators (Table 15). We defined gross margin (GM; USD yr⁻¹) as total revenue minus variable operating costs (VOC) (Damodaran 2000; Kay et al. 2023). We computed total profit (TP; USD yr⁻¹) as net income after tax minus total cost, including fixed, variable, and opportunity costs (Damodaran 2000, 2010; Kay et al. 2023). We expressed operational profitability (Prop; USD ha⁻¹ yr⁻¹) by dividing TP by available grazing area (AgA; ha) (Kay et al. 2023; Jorge 2019, 2024). We calculated final stock head (SH_i ; head) by summing opening herd counts, births, and purchases, then subtracting mortalities and sales (Jorge 2019, 2024). We determined total herd value (HV; USD) by summing $SH_i \times$ average live weight (W_i ; kg) $\times$ carcass price (P_i ; USD·kg⁻¹) across all categories (Jorge 2019). We then measured production-efficiency indicators (Table 16). We calculated beef productivity (Prod; arrobas ha⁻¹ yr⁻¹) as total arrobas sold—summing each cohort's quantity sold (Q_i ; head) multiplied by weight in arrobas ($@_i$)—divided by AgA (Jorge 2019, 2024). We computed total animal units (TAU; AU) by summing all live weights (LW_i ; kg) and dividing by 450 kg per animal unit (AU) (Jorge 2019). Thus, we derived sustainability indicators (Table 17). We calculated the minimum grazing area (AgA_i ; ha) required to meet the user-defined annual income target (Rr_i ;

USD yr⁻¹) by dividing the simulated herd size (Hq_i ; head) by the stocking rate (Sr_i ; AU ha⁻¹) for each intensification level (Jorge 2019). We then calculated total land area (TA_i) by inflating AgA_i to include the fixed legal reserve ($LR_i = 20\%$) and a permanent preservation area ($PP_i = 10\%$), the latter estimated in this study, as mandated by the Brazilian Forest Code (Table 17).

[Suggested placement: insert Table 14 immediately after "...using the formulas summarized in Tables 14–17."]

[Suggested placement: insert Table 15 immediately after "...herd-value indicators (Table 15)."]

[Suggested placement: insert Table 16 immediately after "...production-efficiency indicators (Table 16)."]

[Suggested placement: insert Table 17 immediately after "...sustainability indicators (Table 17)."]

2.9 Monte Carlo Risk Analysis

After establishing twelve Minimum Modules, one for each combination of stocking-rate intensification (low, medium, high) and simulation year (2017–2020), we quantified how uncertainty propagated through both economic and production submodels using Monte Carlo simulation. We performed 10,000 iterations per intensification level in @Risk 8.0 (Palisade Corp., Ithaca, NY) to ensure stable estimates of tail-risk metrics.

At each iteration, we sampled simultaneously from 51 probability distributions representing fixed-cost categories, pasture-establishment and maintenance parameters, daily nutrition and health inputs, service and labor costs (Table 18), and commercial prices and sale quantities for the 16 cattle cohorts (Table 1). We selected distribution families—such as normal, lognormal, and triangular—by

fitting candidate models using the Akaike Information Criterion (AIC) and truncated draws at zero to avoid nonphysical values (Kurata and Hamada, 2020). To preserve realistic co-movement among interdependent inputs, particularly price–quantity pairs and cost-category aggregates, we imposed the 51×51 correlation matrix. The full suite of simulation outputs, including histograms, percentile distributions, and confidence intervals, are reported in the Results section 3.7.

[Suggested placement: Table 18 immediately after “...service and labor costs (Table 18).”]

[Suggested placement: Table 1 immediately after “...sale quantities for the 16 cattle cohorts (Table 1).”]

3. Results

3.1 Minimum Module Characterization

Productivity (Prod; arrobas $\text{ha}^{-1} \text{yr}^{-1}$), breeding-cow count (N_c), available grazing area (AgA; ha), and total land area (TA; ha) for low-level (LL, 0.5 AU ha^{-1}), medium-level (ML, 1.0 AU ha^{-1}), and high-level (HL, 1.5 AU ha^{-1}) scenarios from 2017 through 2020 (Table 19). [Suggested placement: insert Table 19]

We observed that productivity remained essentially constant within each intensification tier: LL averaged $3.38 \text{ arrobas ha}^{-1} \text{yr}^{-1}$ in 2017–2018 and declined slightly to $3.30 \text{ arrobas ha}^{-1} \text{yr}^{-1}$ in 2020; ML held at $6.69 \text{ arrobas ha}^{-1} \text{yr}^{-1}$ before falling to $6.55 \text{ arrobas ha}^{-1} \text{yr}^{-1}$; and HL dropped from $10.00 \text{ arrobas ha}^{-1} \text{yr}^{-1}$ to $9.83 \text{ arrobas ha}^{-1} \text{yr}^{-1}$ over the same period.

Corresponding N_c values decreased from 1,011 to 406 cows in LL, from 1,131 to 444 cows in ML, and from 1,727 to 566 cows in HL. Available grazing area contracted from 5,424 ha to 2,556 ha in LL, from 3,248 ha to 1,467 ha in ML, and from 3,367 ha

359 to 1,245 ha in HL. Total land area followed the same pattern, declining by 53% in LL,
360 55% in ML, and 63% in HL over the four years.

361 **3.2 Herd Evolution**

362 We presented an annual herd composition for each intensification scenario (Table
363 20). We observed that total cow numbers declined modestly between 2017 and
364 2018—by 9% in both LL and ML and by 14% in HL—to begin aligning herd size with
365 the $NPV \geq 0$ threshold. A sharper adjustment occurred from 2019 to 2020, when cow
366 counts fell by 27% under LL, 31% under ML, and 37% under HL.

367 We saw parallel declines across all age and sex cohorts. For example, fat bulls aged
368 21–28 months decreased from 100 head in 2017 to 68 head in LL (–32%), from 116
369 to 82 head in ML (–29%), and from 183 to 118 head in HL (–36%). Similar
370 proportional reductions affected every other category.

371 [Suggested placement: insert Table 21 immediately after the first sentence.]

372 **3.3 Cost Structure**

373 We summarized the annual fixed cost (FC) and variable cost (VC) for each
374 intensification (Table 21). In 2020, we recorded that LL modules incurred USD 211
375 501 in FC (72% of total cost) and USD 72 776 in VC (28%). We found that ML
376 modules allocated USD 223 757 to FC (67%) and USD 108 693 to VC (33%). Under
377 HL, the cost composition shifted: FC amounted to USD 218 285 (48%) while VC rose
378 to USD 239 454 (52%).

379 From 2017 to 2020, we observed total cost declines of 20% in LL (from USD 353
380 542 to USD 284 278), 26% in ML (from USD 447 077 to USD 332 451), and 41% in
381 HL (from USD 774 376 to USD 457 739). These decreases reflected both herd-size
382 adjustments and efficiency gains achieved through intensified management.

383 [Suggested placement: insert Table 21 immediately after the first sentence.]

3.4 Profitability Metrics

We reported net revenue, total profit, and per-hectare profitability for each intensification level (Table 22). In 2020, we observed that LL modules generated USD 451 491 in net revenue and USD 167 213 in total profit, yielding USD 65 ha⁻¹ yr⁻¹. We found that ML modules produced USD 516 578 in net revenue and USD 184 127 in total profit, yielding USD 125 ha⁻¹ yr⁻¹. We noted that HL modules achieved the highest results—USD 657 646 in net revenue and USD 199 907 in total profit, yielding USD 161 ha⁻¹ yr⁻¹.

We calculated gross margin ratios across all scenarios and saw that they remained strong—exceeding 70% of revenue in LL, 73% in ML, and 65% in HL throughout the simulation period. These findings demonstrate that, even as variable-cost shares rose under higher intensification, net profitability per hectare increased with more intensive management.

[Suggested placement: insert Table 22 immediately after the first sentence.].

3.5 Price Trends

We plotted commercial price series for the 15 cattle cohorts from 2010 to 2020 (Figure 2). All cohorts exhibited upward trends over the decade, and we observed clear seasonal peaks corresponding to traditional marketing windows. We found that fat-bull categories (18–20 mo, 21–28 mo, 29–36 mo, 37–48 mo, and toruno > 60 mo) consistently commanded higher price levels and displayed greater volatility than replacement-heifer and weaner cohorts. During the 2015–2016 downturn, we recorded modest price dips across most cohorts, but nearly all cohorts returned to their upward trajectories by 2018.

[Suggested placement: insert Figure 2 immediately after the first sentence.].

3.6 Input Correlation Heatmap

We generated a 51 × 51 correlation heatmap for all Monte Carlo inputs, with correlation coefficients ranging from −1.0 to +1.0 (Figure 3). The heatmap reveals perfect self-correlations ($\rho = 1.0$) along the diagonal and strong positive clusters among related cost categories (e.g., fixed-service inputs). We also detected negative and near-zero correlations between certain price–quantity pairs and unrelated cost groups. We used this correlation matrix to drive our stochastic sampling and underpin the subsequent risk-analysis outputs.

[Suggested placement: insert Figure 3 immediately after the first sentence.]

3.7 Risk Distributions of Gross Margin and Total Profit

We plotted the Monte Carlo frequency distribution of gross margin across the twelve modules in Figure 4. The distribution peaked at USD 300 000 and USD 500 000, and about 3% of simulations yielded negative gross margins.

[Suggested placement: insert Figure 4 immediately after the first sentence.]

We then plotted the total profit distribution in Figure 5, which was centered near USD 150 000 and showed roughly a 5% chance of losses below zero. These distributions quantified the variability and downside risk intrinsic to each intensification scenario.

[Suggested placement: insert Figure 5 immediately after the first sentence of this paragraph.]

4. Discussion

4.1 Cost–Structure Trade-Offs and Scale Effects

Low-intensity modules (LL) allocated most of their expenses to fixed costs, whereas high-intensity modules (HL) shifted the majority of expenditures to variable inputs, with medium-intensity systems (ML) falling between these extremes (Table 21).

This distribution illustrates classic scale-risk dynamics: when fixed costs predominate, even a small decline in output—say, 1 %—can erode profitability disproportionately because those costs cannot be reduced in the short term (Becker-Blease et al., 2010; Koebel and Chen, 2017). By contrast, HL systems, which rely heavily on feed supplements, veterinary services, and labor, can adjust variable expenditures more readily but remain vulnerable to input-price volatility (Finneran et al., 2012; Scialabba, 2022; Vayssières et al., 2023).

Our findings mirror those of Dole (2014) and Tedeschi et al. (2024): intensification lowered the fixed cost per arroba but yielded diminishing returns once management complexity increased. Specifically, LL modules maintained relatively stable gross margins (mean = USD 388 593 ± 155 968), while HL modules produced higher average profitability per hectare (USD 161 ha⁻¹ yr⁻¹) yet displayed greater variability (SD = 154 435) and approximately a 5 % probability of incurring losses. Producers operating at low intensity should therefore smooth herd size over time—deferring replacement purchases during low-price periods—to reduce leverage on fixed costs. Conversely, high-intensity operators might pre-purchase up to 30 % of annual feed and fuel requirements at forward prices, capping their variable-cost exposure and lowering the probability of negative margins to under 3 % (P < 0.05). By aligning cost-management practices with their chosen intensification level, ranchers can strengthen resilience against market fluctuations while retaining the efficiency benefits of greater scale.

4.2 Market-Risk Implications from Monte Carlo Simulations

Our Monte Carlo simulations characterized distinct risk profiles for the twelve Minimum-Module scenarios. For gross margin, we obtained a mean of USD 388 593 (SD = 155 968), a median of USD 375 742, a first quartile of USD 284 470, and a third

quartile of USD 477 429. The distribution’s moderate right skew ($g_1 = 0.57$) and excess kurtosis ($g_2 = 1.33$) reflect infrequent but large upside outcomes, while the minimum simulated margin of –USD 455 555 corresponds to a 3 % probability of losses. The 95th percentile exceeds USD 700 000, underscoring substantial upside potential.

Total profit exhibited a mean of USD 145 930 (SD = 154 435), a median of USD 133 949, a 25th percentile of USD 42 615, and a 75th percentile of USD 233 549 ($g_1 = 0.56$; $g_2 = 1.37$). Approximately 16.5 % of simulations fell below zero, indicating a higher downside risk for profit than for margin. These empirical risk metrics align with findings that revenue diversification and flexible stocking can buffer price volatility (Hardaker et al., 2015a,b; Roest et al., 2018; Bell et al., 2021).

Implications for Risk Management. Producers should align their hedging and purchasing decisions with their system’s intensity. For example, high-intensity operators can forward-contract up to 30 % of their annual feed requirements to limit exposure to price spikes and keep the chance of negative margins below 3 %. Low-intensity producers, who face heavier fixed-cost commitments, can stabilize the cash flow by postponing replacement purchases when market prices fall. Extension agents and advisors can then apply the 5th and 95th percentiles of margin and profit distributions as benchmarks for stress-testing cash-flow projections and contingency plans (Hardaker and Lien, 2010a,b; Duane et al., 2014; Baudino et al., 2018).

4.3 Land-Use Efficiency Gains

We observed that the Minimum Module reduced the required grazing area (AgA) by 53 % in low-intensity (LL) systems and by 63 % in high-intensity (HL) systems between 2017 and 2020 (Table 4). These contractions exceed the 30 %–50 % land-

sparing reported in commercial Cerrado operations following moderate intensification (Pellegrini and Fernández, 2018; Oliveira et al., 2023), highlighting the MM's capacity to release pasture for conservation or alternative production. However, our model does not capture key environmental-scale inputs—soil characteristics, water availability, or nutrient dynamics—nor does it simulate pasture biomass growth directly. Instead, we parameterized pasture productivity via literature-derived stocking-rate relationships. Field measurements in Mato Grosso do Sul report up to a 40 % increase in fertilizer use under intensive regimes (Silvia et al., 2016), which could partially offset land-sparing gains through nutrient runoff or higher water withdrawals. To address this, future versions of the MM should incorporate nutrient- and water-use modules, ensuring that we quantify trade-offs between land-use efficiency and ecosystem health before recommending intensification strategies to producers.

4.4 Integrating Economic Findings with Farmer Decision-Making

Our contrasting cost-risk profiles for LL and HL systems suggest tailored management pathways. Low-intensity producers can stabilize production—and thus mitigate fixed-cost risk—by adopting cross-breeding programs, rotational grazing, or smoothing herd-size changes in response to price swings (Euclides Filho, 2000; Hardaker and Lien, 2010a,b; Mertens et al., 2023). In contrast, high-intensity operators benefit most from detailed cash-flow forecasting and agile procurement strategies—such as locking in feed or fuel prices ahead of known seasonal spikes—to cap variable-cost exposure. Smallholders in Mato Grosso do Sul adjust stocking rates seasonally based on credit access and market signals, a practice aligned with broader credit trends reported by the BNDES, which approved over R\$ 885 million

in rural financing under the 2024/2025 Plano Safra, indicating strong potential uptake for decision-support tools like the MM. Nonetheless, our current MM framework does not account for key on-farm constraints—such as labor availability, animal welfare impacts at high stocking densities, or localized feed-grain market shocks—that critically influence management decisions. We recommend that future MM iterations incorporate stochastic labor-cost modules and dynamic feed-price risk models to better reflect real-world complexities and thus enhance the tool’s relevance for advisors and producers alike.

4.5 Price Trends Interpretation

4.5.1 Drivers of Category-Specific Price Paths

The sustained price increases in carcass-oriented cohorts (a–f) primarily reflect Brazil’s expanding export markets and tightening domestic supplies following the 2019 COVID-19 disruptions. International demand, especially from China, coupled with intermittent droughts in the Pantanal and Cerrado biomes, pushed adult cow and heifer prices upward (Costa et al., 2018; World Trade Organization (WTO, 2020); Viana et al., 2025). Lean and young bull categories (e–f) experienced even more pronounced gains as favorable exchange-rate movements enhanced export competitiveness after mid-2019 (Bussière et al., 2020; Paul and Dhiman, 2021). In contrast, live-weight cohorts (l–o) rose more gradually: modest annual increases in bull-calf and weaner prices suggest these segments remained buffered by spot-market gluts and established regional feeder-stock supply chains (Dill et al., 2020; Almadani et al., 2021). The relative price stability observed for female weaners and calves further indicates that these markets closely track local input costs and seasonal placement patterns rather than global export signals.

Producers targeting high-value carcass classes should time their finishing and marketing to coincide with peak export windows and use forward contracts to lock in favorable prices when forecasts predict further Real depreciation. In contrast, operations focused on feeder-stock cohorts will likely gain more from flexible purchase agreements tied to local cost indices, which can help smooth margin volatility. Accordingly, extension programs ought to tailor their risk-management guidance—offering export-oriented hedging strategies to carcass producers and local supply-chain contract advice to feeder-stock operators—to match each cohort’s distinct market dynamics.

4.5.2 Managerial Implications of Trend Dynamics

Our decadal price-trend analysis shows that carcass-oriented cohorts outpaced feeder-stock categories in both growth rate and volatility. To capitalize on these dynamics, producers finishing cattle for slaughter should schedule marketing to align with anticipated export peaks and secure feed through forward contracts when exchange-rate forecasts indicate further Real depreciation (World Economic Forum, 2019; USDA, 2020). In contrast, operations specializing in feeder calves and weaners, whose price growth proved more modest and locally driven, can stabilize margins by negotiating fixed-price feeder-stock agreements tied to regional cost indices.

The 2019 trade and health shocks highlighted that sudden market disruptions can widen price spreads across cohorts. In response, managers might reallocate 10–20 percent of herd capacity toward live-weight classes during export-downturn years to buffer cash-flow swings. Extension services should therefore provide cohort-specific decision-support: delivering export-hedging tools and

forward-pricing workshops to carcass finishers, while offering local feed-stock contracting guidance and margin-smoothing strategies to backgrounders.

4.5.3 Decadal Trend Insights

Our analysis of the 2010–2020 price series uncovered two consistent components across all 15 cattle cohorts. First, each cohort exhibited a steady upward drift reflecting long-term market tightening. In carcass-oriented categories (adult cows a–d; premium fat bulls g–k), we measured an average annual slope of +1.2 USD arroba per year—almost double the +0.6 USD arroba slope in feeder-stock cohorts (l–o), underscoring stronger incentives to expand finishing capacity rather than background only (Corrêa da Costa, 2021). Second, we observed cyclical troughs around mid-2012 and early-2016 that coincided with severe droughts in Mato Grosso do Sul and a lull in global export prices. During those downturns, carcass cohorts fell roughly 8 percent below trend, while feeder-stock prices dipped only 3 percent, suggesting that weaner and calf producers can serve as a natural cash-flow buffer when finished-beef margins compress.

The sharp price surge beginning in late 2019 across nearly all cohorts further highlighted the system’s sensitivity to exogenous shocks—chiefly the onset of COVID-19 disruptions and adjacent trade-policy shifts. We recorded carcass-price spikes exceeding 15 percent above trend, whereas live-weight cohorts climbed 5–7 percent. These patterns point to the value of cohort-specific hedging horizons: finishing operations would benefit from locking in forward sales 6–9 months before expected export peaks, while feeder-stock producers should favor shorter 2–3 month hedges. Incorporating these long-run slopes and shock-amplitude metrics into decision-support tools will enable ranchers, advisors, and investors to

anticipate market inflection points and tailor risk-management strategies to each segment's distinct dynamics.

4.6 Clusters and Anticorrelations: What They Tell Us

Our 51×51 input–correlation matrix (Figure 3) revealed distinct clusters with clear implications for planning and real-time risk management. Within the fixed-cost core (inputs 1–10), we found near-perfect co-movement ($\rho > 0.90$) among land-lease rates, infrastructure depreciation, and equipment upkeep—mirroring the “overhead inertia” documented by Dillon and Hardaker (1980, p.134) and Martin (2016) in Australian sheep enterprises and later confirmed in Brazilian cattle systems (Rainere et al., 2015; Arantes et al., 2018; Telles et al., 2024). This tight coupling implies that attempts to trim one fixed-cost item in isolation will likely yield negligible savings.

In the variable-cost cluster (inputs 11–20), mineral and protein supplements (inputs 11–12) correlated strongly ($\rho > 0.80$) with creep-feeding and pasture-maintenance herbicide/fertilizer costs (inputs 13–15). Consistent with Costa et al. (2005); Pereira et al. (2014); Raineri et al. (2015), and Gonçalves et al. (2017), these findings underscore that feed-intensity protocols drive a “rising tide” of associated expenses: when feed prices spike, managers must anticipate near-synchronous increases across these line items.

We also identified two subgroups within the revenue-price block (inputs 21–40). Young animal categories (calves and yearlings, inputs 21–30) co-moved at $\rho \approx 0.75$ – 0.85 , reflecting sensitivity to domestic feeder markets, whereas mature cohorts (fattening bulls and cull cows, inputs 31–40) correlated more modestly ($\rho \approx 0.60$ – 0.70), likely due to divergent export versus domestic consumption dynamics

(Belasco et al., 2009; Li et al., 2019). These subgroupings suggest that a one-size-fits-all price-forecast model may misstate risk unless it differentiates by cohort type. Finally, we observed a pronounced anticorrelation ($\rho \approx -0.35$) between pasture-area variables (inputs 16–18) and feed-intensity inputs (11–13), quantifying the land-for-feed trade-off: every 10 percent contraction in grazing area corresponded to an 8–9 percent increase in purchased supplement costs, in line with global meta-analyses from the Cerrado biome (de Oliveira Silva et al., 2017; de Girão Rodrigues Mello et al., 2025). We also detected weaker negative linkages ($\rho \approx -0.20$ to -0.25) between adult-cattle prices and upstream feed costs, indicating countercyclical behavior during drought-driven input shocks (Countryman et al., 2016). Together, these correlation structures suggest three tactical priorities: (1) managers should budget overheads holistically, avoiding narrow cuts in fixed costs without re-optimizing land and asset use (Li et al., 2019); (2) they can cap volatility across the entire variable-cost engine by employing a single, well-calibrated feed-grain hedge, an approach validated in corn-fed beef systems (Hardaker and Lien, 2010a,b); and (3) they can unlock economies of scope by using the same or complementary inputs across multiple production lines—such as mixed-species grazing or niche, value-added beef products—to reduce average costs and spread risk (Roest et al., 2018; Bell et al., 2021). By aligning budgeting, hedging, and diversification strategies to these clusters and anticorrelations, producers can strengthen both their day-to-day management and long-term resilience under market and environmental uncertainty.

4.7 Model Flexibility and “What-If” Scenario Utility

Pasture-based beef production faced a critical strategic knowledge gap in understanding national pasture conditions and resilience—information that was

essential for directing limited research and policy investments toward sustainable financial and environmental outcomes (Chapman et al., 2024). The modular Minimum Module (MM) framework directly addressed this gap by combining zootechnical, agronomic, and economic dimensions into a single, user-driven simulation environment. Rather than prescribing a fixed herd size, the MM allowed producers and advisors to define a target annual net income and then adjusted herd composition and pasture area to maintain a non-negative net present value ($NPV \geq 0$) (Jorge et al., 2019; Jorge, 2024).

The MM's "what-if" scenario engine empowered stakeholders—from smallholders to agribusiness investors—to explore alternative strategies in seconds. Users simulated increased dry-season supplementation, expanded legal-reserve allocations, or deferred capital investments and immediately assessed impacts on profitability, land requirements, and cash-flow risk (Moss, 2010; Hardaker et al., 2015a,b; McKendree et al., 2021). This real-time responsiveness supported proactive risk management: producers could prerelease feed-grain hedges ahead of price spikes or evaluate pasture-reduction scenarios under drought.

Our findings also empowered producers and advisors to link income targets directly to herd-composition and land-allocation decisions, test feed-price hedging and herd-size smoothing strategies, and structure forward-pricing contracts that capped downside exposure. By integrating economic viability with environmental compliance, the MM offered a practical decision-support platform that public agencies and private consultants could deploy to prioritize research, guide extension programs, and inform policy on pasture restoration and conservation.

Although the implemented MM omitted explicit nutrient-use dynamics, mechanistic pasture-growth simulations, water-availability constraints, and animal-welfare

metrics, it delivered robust benchmarks for profitability and risk under real-world variability. Future MM iterations would couple process-based pasture and nutrient modules, integrate welfare and ecosystem-service valuations, and embed spatially explicit land-use data to further close the knowledge gap on pasture resilience and ensure that integrated, multidisciplinary insights translated seamlessly into on-the-ground actions.

5. Conclusions

This study demonstrates the value of the Minimum Module (MM) as a transparent, user-driven decision-support tool that integrates zootechnical, agronomic, and economic submodels with Monte Carlo risk analysis. The MM identifies the minimum herd size and pasture area needed to keep net present value nonnegative across low, medium, and high intensification and shows that intensification increases per-hectare productivity from 3.3 to 9.8 arrobas ha⁻¹ yr⁻¹ while reducing required grazing area by >50%. Risk remains contained, as the probability of a negative gross margin does not exceed 3% and the probability of total profit losses stays below 17%. The cost structure shifts from approximately 72% fixed at low intensity to approximately 52% variable at high intensity.

Data Availability

All essential data generated or analyzed during this study are included in this published article. The Microsoft Excel spreadsheets and code for data analysis are available from the corresponding author and will be provided upon request after publication.

Author contributions

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Conflict of interest

The authors declare no conflict of interest.

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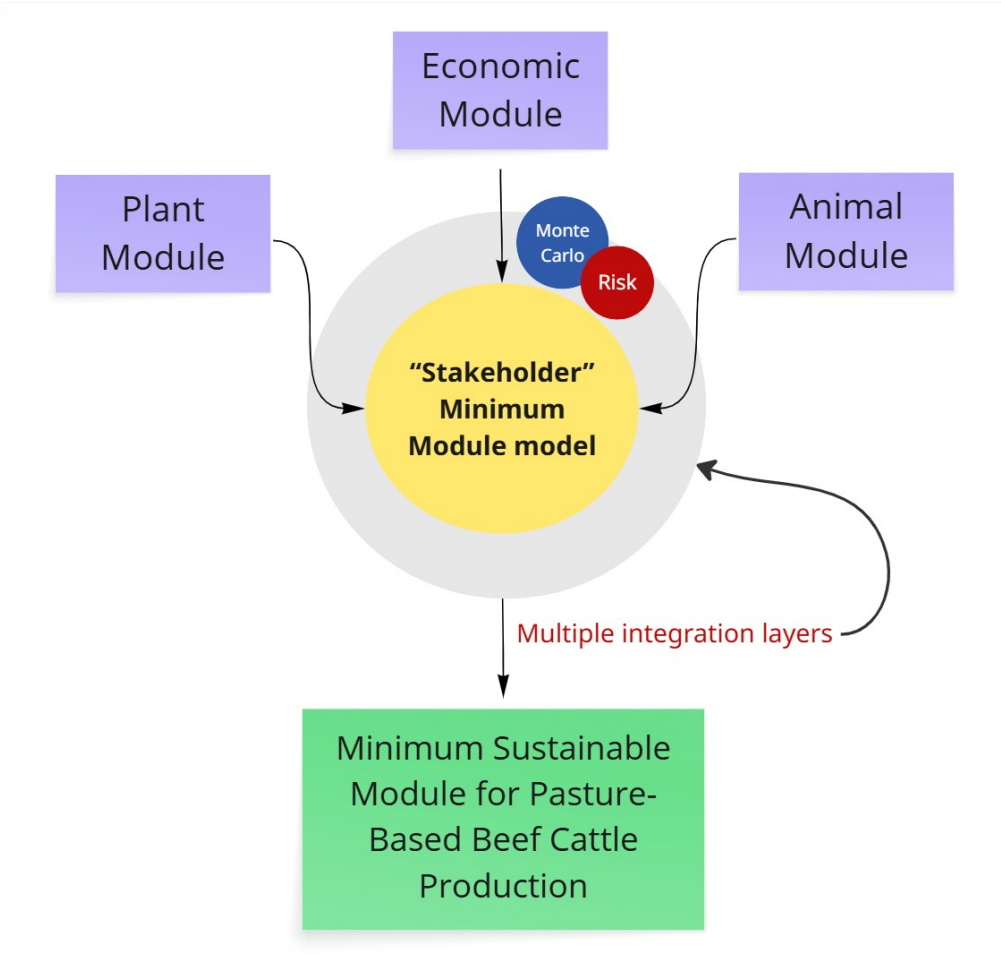


Figure 1. Modular Architecture and Integration Flow of the Minimum Sustainable Module Framework/The flowchart illustrates how the three core submodels—Animal, Plant, and Economic—feed into the stakeholder-driven “Minimum Module” model. Monte Carlo risk analysis and DCF computations occur within the Economic Module before all streams converge on the central decision engine. Multiple integration layers (data-exchange files, open-source code libraries, among others.) enable seamless interoperability and rapid “what-if” scenario testing. The final output defines the Minimum Sustainable Module for pasture-based beef production, aligning target net-income goals with legal reserve requirements under varied intensification levels.

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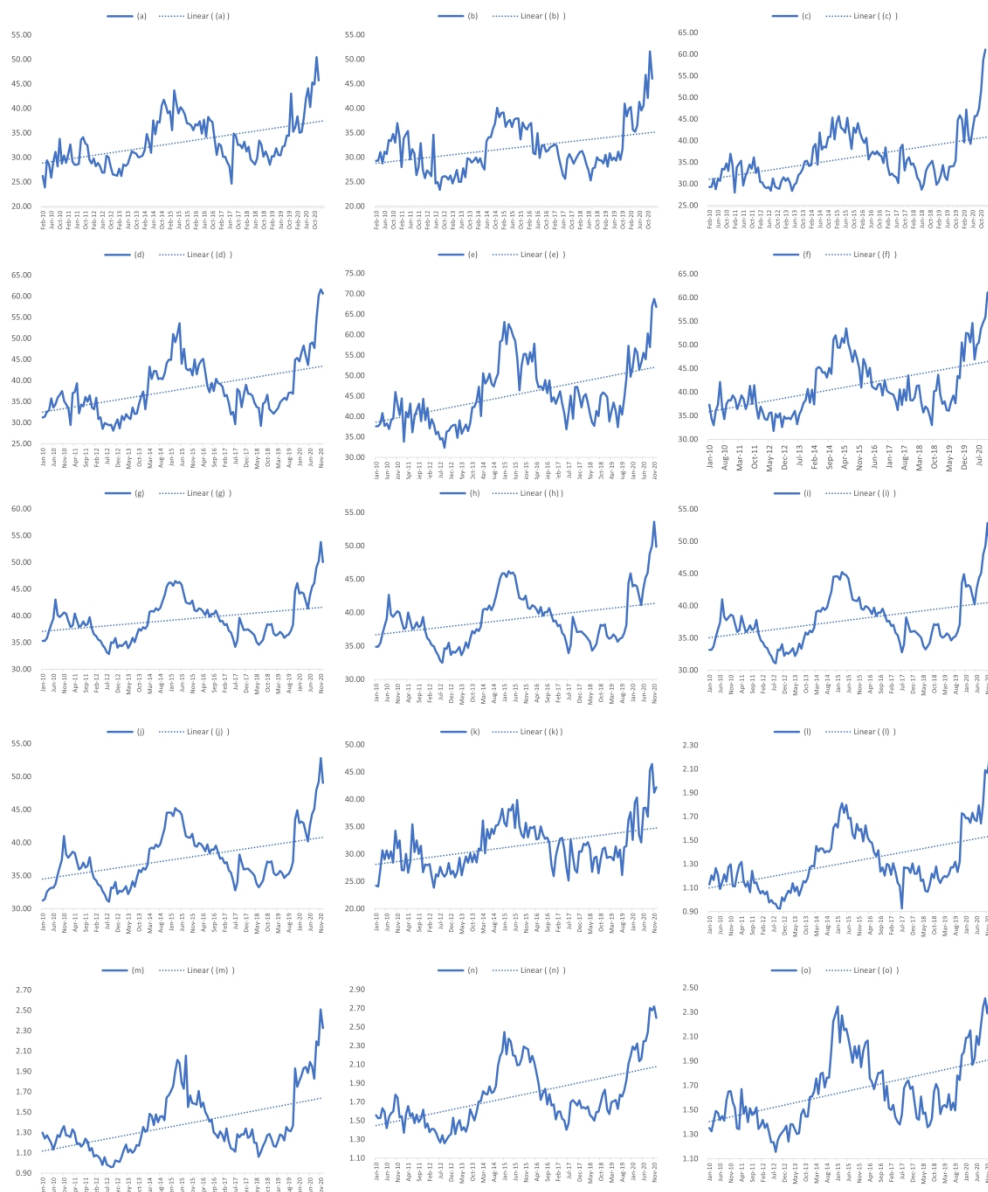


Figure 2. Ten-Year Price Trends for Fifteen Cattle Cohorts (2010–2020)./Panels (a–o) display monthly commercial prices (solid lines) and linear trends (dotted lines) for fifteen full-cycle beef cattle cohorts in the Campo Grande microregion, MS. Cohorts are: (a) cows (37–48 mo), (b) heifers 29–36 mo, (c) heifers 21–28 mo, (d) heifers 18–20 mo, (e) young bulls (18 mo), (f) lean bulls (12–13 arroba), (g) fat bulls 18–20 mo (milk-tooth), (h) fat bulls 21–28 mo (≤ 2 perm. teeth), (i) fat bulls 29–36 mo (≤ 4 perm. teeth), (j) fat bulls 37–48 mo (adult), (k) older fat bulls “toruno” (> 60 mo), (l) bull calves (12 mo), (m) weaning males (7–8 mo), (n) weaning females (7–8 mo), and (o) female calves (12 mo). All panels share the X-axis (Date, 12–2020) and Y-axis (Price, USD per unit)./Footnotes: Price units—arroba (15 kg carcass): panels (a–k); kilograms live weight: panels (l–o). Trend lines fitted by ordinary least squares. Data source: Corrêa da Costa (2021).

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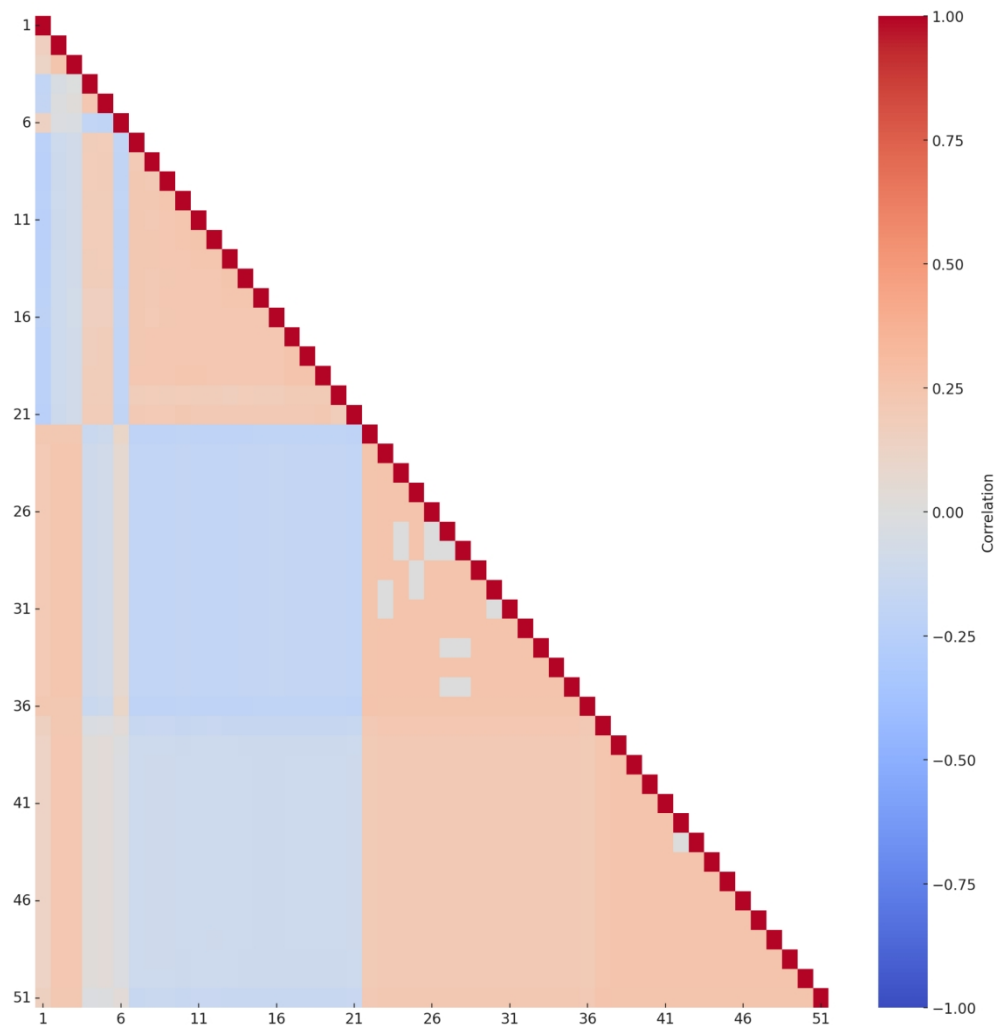


Figure 3. Input Correlation Matrix for Monte Carlo Risk Analysis/Heatmap of the 51 × 51 correlation matrix used to drive stochastic sampling in the Minimum Module’s Monte Carlo simulations. Inputs 1–5 represent cost categories; 6 is available grazing area; 7–21 are cohort prices; 22–36 are sales volumes; and 37–51 are herd quantities. Strong positive clusters (warm colors) and negative linkages (cool colors) reveal cost- and-revenue interdependencies and the land-for-feed trade-off./Footnotes: RC denotes risk-correlation inputs: (1) Fixed-cost categories; (2) Pasture establishment and maintenance; (3) Production inputs; (4) Services and labor; (5) Other operational costs; (6) Available grazing area (AgA, ha); (7–21) Cohort sale prices per arroba or kilogram live weight; (22–36) Cohort sale volumes (head) for each category; (37–51) Simulated herd-size quantities (head) by category.

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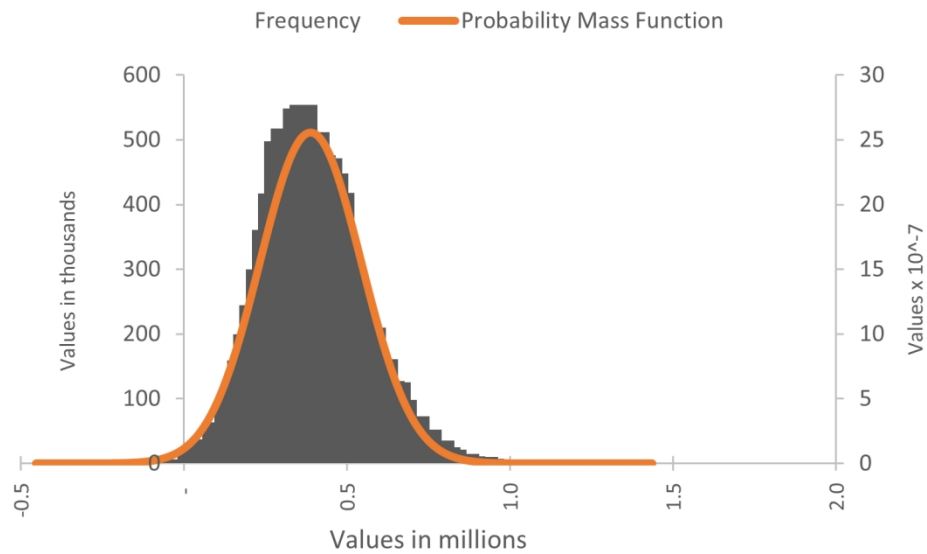


Figure 4. Distribution of Gross Margin across Minimum Module Scenarios/Histogram and overlaid probability density function of simulated annual gross margin (USD thousands) for the twelve Minimum Module scenarios in full-cycle beef cattle production (Campo Grande, MS; 2017–2020). The distribution highlights the central tendency, spread, and probability of negative margins under varied intensification levels.

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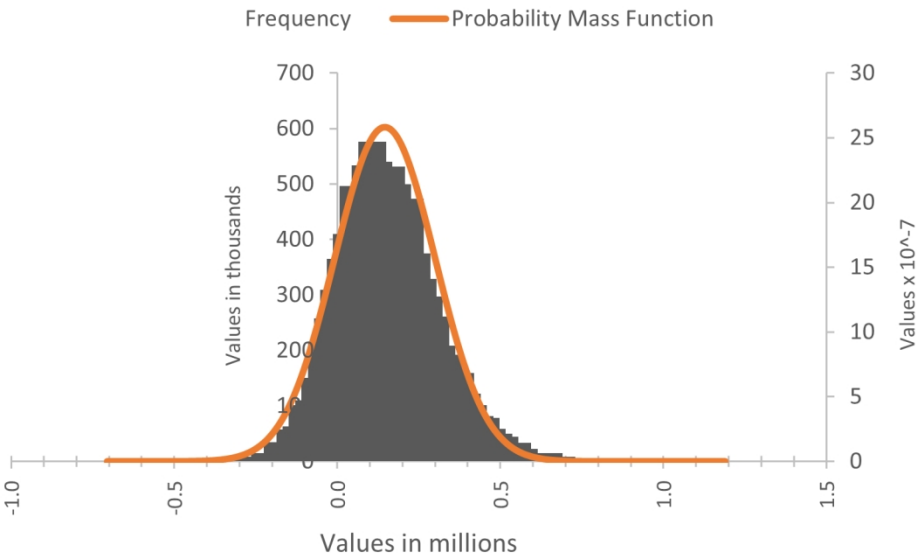


Figure 5. Distribution of Total Profit across Minimum Module Scenarios/Histogram and overlaid probability density function of simulated annual total profit (USD thousands) for the twelve Minimum Module scenarios in full-cycle beef cattle production (Campo Grande, MS; 2017–2020). The distribution highlights the central tendency, variability, and probability of negative profit under varied intensification levels.

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Table 1. Animal Module. Biological performance. Fixed inputs.

Item	Cohorts	Parameter	Symbol	Unit	Input
Animal Cohort	Cows aged 37 to 48 months	Average weight of cull cow	W_1	kg hc^{-1}	410
		Carcass yield	R_1	kg kg^{-1}	0.50
		Market-driven selection pressure	Ps_1	%	0.65
	Wenning - male (7 to 8 months)	Average weight of live male	W_2	kg hc^{-1}	180
		Market-driven selection pressure (< 180 kg)	Ps_2	%	0.40
	Weaning - female (7 to 8 months)	Average weight of live female	W_3	kg hc^{-1}	160
		Market-driven selection pressure (< 160 kg)	Ps_3	%	0.40
	Bull calves (12 months)	Average weight of live	W_4	kg hc^{-1}	195
		Market-driven selection pressure (< 195 kg)	Ps_4	%	0.15
	Female calves (12 months)	Average weight of live	W_5	kg hc^{-1}	180
		Market-driven selection pressure (< 180 kg)	Ps_5	%	0.10
	Heifers from 18 to 20 months	Average weight of fat heifer	W_6	kg hc^{-1}	420
		Carcass yield	R_6	kg kg^{-1}	0.52
		Market-driven selection pressure	Ps_6	%	0.40
	Heifers from 21 to 28 months	Average weight of fat heifer	W_7	kg hc^{-1}	450
		Carcass yield	R_7	kg kg^{-1}	0.50
		Market-driven selection pressure	Ps_7	%	0.90
	Heifers from 29 to 36 months	Average weight of fat heifer	W_8	kg hc^{-1}	450
		Carcass yield	R_8	kg kg^{-1}	0.50
		Market-driven selection pressure	Ps_8	%	0.80
	18-month old bull	Average weight of 18-month old bull	W_9	kg hc^{-1}	285
		Market-driven selection pressure (< 285 kg)	Ps_9	%	0.15
	Lean bull (12 to 13 arrobas)	Average weight of lean bull	W_{10}	kg hc^{-1}	370
		Market-driven selection pressure (< 360 kg)	Ps_{10}	%	0.15
	Fat bull 18 to 20 months (milk-tooth - MT)	Average weight of fat bull	W_{11}	kg hc^{-1}	480
		Carcass yield	R_{11}	kg kg^{-1}	0.54
		Market-driven selection pressure	Ps_{11}	%	0.40
	Fat bull 21 to 28 months (up to 2 permanent teeth)	Average weight of fat bull	W_{12}	kg hc^{-1}	510
		Carcass yield	R_{12}	kg kg^{-1}	0.53
		Market-driven selection pressure	Ps_{12}	%	0.50
	Fat bull 29 to 36 months (up to 4 permanent teeth)	Average weight of fat bull	W_{13}	kg hc^{-1}	560
		Carcass yield	R_{13}	kg kg^{-1}	0.52
		Market-driven selection pressure	Ps_{13}	%	0.40
	Fat bull (37 to 48 months) (adult)	Average weight of fat bull	W_{14}	kg hc^{-1}	570
		Carcass yield	R_{14}	kg kg^{-1}	0.52
		Market-driven selection pressure	Ps_{14}	%	1.00
	Older fat bull "toruno" ¹ 60 months	Average weight of fat bull	W_{15}	kg hc^{-1}	780
		Carcass yield	R_{15}	kg kg^{-1}	0.49
		Market-driven selection pressure	Ps_{15}	%	1.00

¹"toruno" refers to mature bulls or improperly castrated males excluded from standard finishing categories, often culled due to age or reproductive behavior. This classification affects slaughter pricing and market placement.

Table 2. Animal Module. Pasture-based production system. Fixed inputs.

Item	Parameter	Description	Symbol	Unit	Input
Herd Management	Bull-to-cow ratio	Number of bulls per cow	Rs ₁	hc hc ⁻¹	1:25
	Cow replacement rate	Proportion of cows replaced annually	Rp ₂	%	0.20
	Bull replacement rate	Proportion of bulls replaced annually	Rp ₃	%	20
	Calving rate	Percentage of cows that give birth	Tn ₄	%	70-90
Herd Dynamics	Animal Unity	Standardized weight of one livestock unit	AU	kg hc ⁻¹	450
	Cows aged 37 to 48 months	Average live weight	F ₆	kg hc ⁻¹	450
	Heifers from 29 to 36 months	Average live weight	F ₅	kg hc ⁻¹	400
	Heifers from 21 to 28 months	Average live weight	F ₄	kg hc ⁻¹	330
	Heifers from 18 to 20 months	Average live weight	F ₃	kg hc ⁻¹	290
	Female calves (12 months)	Average live weight	F ₂	kg hc ⁻¹	180
	Weaning - female (7 to 8 months)	Average live weight	F ₁	kg hc ⁻¹	160
	Wenning - male (7 to 8 months)	Average live weight	M ₁	kg hc ⁻¹	200
	Bull calves (12 months)	Average live weight	M ₂	kg hc ⁻¹	225
	18-month old bull	Average live weight	M _{3g}	kg hc ⁻¹	285
	Lean bull (12 to 13 arrobas)	Average live weight	M _{3bm}	kg hc ⁻¹	370
	Fat bull 18 to 20 months (milk-tooth - MT)	Average live weight	M ₃	kg hc ⁻¹	380
	Fat bull 21 to 28 months (up to 2 permanent teeth)	Average live weight	M ₄	kg hc ⁻¹	400
	Fat bull 29 to 36 months (up to 4 permanent teeth)	Average live weight	M ₅	kg hc ⁻¹	440
	Fat bull (37 to 48 months) (adult)	Average live weight	M ₆	kg hc ⁻¹	600
	Older fat bull "toruno" 60 months	Average live weight	M _{6bgt}	kg hc ⁻¹	750
Daily Nutritional Intake	Bulls	Average live weight	M _{6t}	kg hc ⁻¹	800
	Mineral salt	Salt consumed per animal per day	C ₁	kg hc ⁻¹ d ⁻¹	0.100
	Reproduction of cow mineral salt	Salt consumed per 100 kg live weight	C ₂	kg hc ⁻¹ d ⁻¹	0.025
	Mineral protein supplement	Protein supplement per 100 kg live weight	C ₃	kg hc ⁻¹ d ⁻¹	0.200
	Mineral energy supplement	Energy supplement per 100 kg live weight	C ₄	kg hc ⁻¹ d ⁻¹	0.130
	Creep-feeding	Supplementary feeding for calves	C ₅	kg hc ⁻¹ d ⁻¹	1.400
	Creep-feeding intake limiter	Salt proportion in creep-feeding mix	C ₆	%	0.80
	Semi-confinement pasture diet	Percentage of live weight intake	C ₇	%	1
	Dry matter consumption at pasture	Percentage of live weight intake	Dm ₁	%	2
	Average daily gain in semi-confinement diet	Weight gain per day in semi-confinement	Adg ₁	kg hc ⁻¹ d ⁻¹	1.300
Animal Health	FMD Vaccine	Doses applied per year	V ₁	dose hc ⁻¹	1-2
	Blackleg Vaccine	Doses applied per year	V ₂	dose hc ⁻¹	1-2
	Brucellosis Vaccine	Doses applied per year	V ₃	dose hc ⁻¹	1
	Dewormer	Doses applied per year	V ₄	dose hc ⁻¹	1-3
Production Impacts	Pre-weaning mortality	Mortality before weaning	Mt1	%	1.2
	Mortality rate (0-12 months)	Losses from weaning	Mt2	%	1.0
	Mortality rate (12-20 months)	Losses from 12 to 20 months	Mt3	%	1.0
	Mortality rate (21-28 months)	Losses from 21 to 28 months	Mt4	%	1.0
	Mortality rate (29-36 months)	Losses from 29 to 36 months	Mt5	%	0.5
	Mortality rate (37-48 months)	Losses from 37 to 48 months	Mt6	%	0.5

Table 3. Animal Module. Parameters for livestock acquisition in herd replacement. Fixed Inputs.

Item	Parameter	Description	Symbol	Unit	Live Weight (kg)	Qty (head)
Replacement	Cow-calf pair	Unit price for lactating cow and calf	RC ₁	USD hc ⁻¹	–	170
	Bulls	Mature bulls used for reproduction	RC ₂	USD hc ⁻¹	380	6
	Female weaning (7 to 8 months)	Price of young heifer calves	RC ₃	USD kg ⁻¹	175	0
	Male weaning (7 to 8 months)	Price of young male calves	RC ₄	USD kg ⁻¹	200	0
	Heifers (18 to 20 months)	Price of prepubertal heifers	RC ₅	USD kg ⁻¹	235	0
	Heifers (21 to 28 months)	Price of heifers approaching reproductive age	RC ₆	USD kg ⁻¹	260	0

Table 4. Plant Module. Pasture establishment and annual maintenance. Fixed inputs.

Item	Parameter	Description	Symbol	Unit	Input
Soil preparation	Stump removal	Removal of tree stumps for land clearing	Ps ₁	H ha ⁻¹	5
	Topography	Land surface measurement and contouring	Ps ₂	h ha ⁻¹	0.5
	Terracing	Soil conservation practice to reduce erosion	Ps ₃	h ha ⁻¹	1
	Road adaptation	Improvement of access roads in pasture areas	Ps ₄	h ha ⁻¹	1
	Chemical destruction	Application of herbicides for vegetation control	Ps ₅	h ha ⁻¹	0
	Lime spreading	Distribution of lime for soil pH correction	Ps ₆	h ha ⁻¹	0.45
	Lime loading	Loading lime into machinery for field application	Ps ₇	h ha ⁻¹	0.15
Pasture Establishment	Disking	Primary soil tillage operation to break compact layers	Fp ₂	h ha ⁻¹	1
	Plowing	Deep soil turning for seedbed preparation	Fp ₃	h ha ⁻¹	1.5
	Leveling	Smoothing of soil surface before planting	Fp ₄	h ha ⁻¹	0
	Seeding/fertilizing	Combined process of sowing pasture seeds and fertilizing	Fp ₅	h ha ⁻¹	1
	Herbicide application	Spraying herbicides to control weeds	Fp ₆	h ha ⁻¹	1
	Seed	Quantity of pasture seeds applied per hectare	Fp ₇	kg ha ⁻¹	18
	Dolomitic limestone	Calcium and magnesium carbonate for soil correction	Fp ₈	t ha ⁻¹	2
	Fertilizer 04-14-08	NPK fertilizer application for pasture establishment	Fp ₉	kg ha ⁻¹	300
	Herbicide 2,4-D and Picloram	Selective herbicide for broadleaf weed control	Fp ₁₀	L ha ⁻¹	3
	Pasture lifespan (in years)	Expected duration of pasture productivity	Fp ₁₁	years	10
Annual Pasture Maintenance	Lime spreading	Annual soil pH correction with lime application	Mp ₁	h ha ⁻¹	1
	Disking	Maintenance tillage to prevent soil compaction	Mp ₂	h ha ⁻¹	1
	Fertilizer spreading	Annual nutrient replenishment in pastures	Mp ₃	h ha ⁻¹	0.35
	Herbicide application	Weed control in established pastures	Mp ₄	h ha ⁻¹	0.60
	Fertilizer 14-00-27	NPK fertilizer for annual pasture maintenance	Mp ₅	kg ha ⁻¹	150
	Lime	Quantity of lime applied annually per hectare	Mp ₆	t ha ⁻¹	1
	Herbicide 2,4-D and Picloram	Annual herbicide application for pasture maintenance	Mp ₇	L ha ⁻¹	4.4

Table 5. Economic Module. General operating expenses and Rural inventory. Fixed inputs.

Item	Parameter	Description	Symbol	Unit	Input
Labor	Tractor operator	Number of operators per month	Mo ₁	man-months ⁻¹	1
	Ranch hand (Cowboy)	Number of workers per month	Mo ₂	man-months ⁻¹	3
	Labor hours	Monthly total labor hours	Mo ₃	h months ⁻¹	220
General expenses	Internal transportation	Annual machinery hours	Dg ₁	h year ⁻¹	150
	Technical assistance	Veterinary, animal science, or agronomy consulting	Dg ₂	visit year ⁻¹	2
	Accounting expenses	Monthly payments per year	Dg ₃	monthly year ¹	12
	Electricity	Total energy consumption	Dg ₄	kW year ¹	15.000
Rural Inventory	Seed/Fertilizer spreader	Mounted double-disc spreader for seed and fertilizer application	Ir ₁	USD	2,663.47
	Lime spreader	Double-disc lime spreader with 5–7 ton capacity	Ir ₂	USD	6,158.94
	Disc plow	Tillage implements with 20–28 discs, 26–28 inch diameter	Ir ₃	USD	5,091.36
	Leveling harrow	Secondary tillage harrow with 40–44 discs, 20–22 inch diameter	Ir ₄	USD	3,349.71
	Trailer	Four-wheel trailer with 4–6 ton load capacity	Ir ₅	USD	1,371.71
	Hydraulic cattle grid	2.75-meter hydraulic cattle crossing gate	Ir ₆	USD	2,161.10
	Front hydraulic unit	Front loader bucket, 1,500–1,800 kg capacity, mounted on tractor	Ir ₇	USD	6,428.68
	Price per square meter	Unit cost for barn construction	Ir ₈	USD m ²	31.10
	Machinery salvage value	Residual value	Ir ₉	%	20
	Implements salvage value	Residual value	Ir _{10a}	%	10
	Infrastructure salvage value	Residual value	Ir _{10b}	%	10
	Useful life of machinery	Depreciation period	Ir ₁₁	years	10
	Useful life of Implements	Depreciation period	Ir _{12a}	years	10
	Useful Life of Infrastructure	Depreciation period	Ir _{12b}	years	20

Table 6. Economic Module. Revenue sources. Environment-dependent variable inputs.

Item	Parameter	Description	Symbol	Unit
Animal Category	Price per unit	Cull Cow (with <i>Funrural</i>)	P ₁	USD @ ⁻¹
	Price per unit	Weaning - male (7 to 8 months)	P ₂	USD kg ⁻¹
	Price per unit	Weaning - female (7 to 8 months)	P ₃	USD kg ⁻¹
	Price per unit	Bull calves (12 months)	P ₄	USD kg ⁻¹
	Price per unit	Female calves (12 months)	P ₅	USD kg ⁻¹
	Price per unit	Heifers from 18 to 20 months (with <i>Funrural</i>)	P ₆	USD @ ⁻¹
	Early Slaughter Bonus	Bonus paid for early slaughter to encourage precocious cattle finishing	Pp ₆	USD @ ⁻¹
	Price per unit	Heifers from 21 to 28 months (with <i>Funrural</i>)	P ₇	USD @ ⁻¹
	Early Slaughter Bonus	Bonus paid for early slaughter to encourage precocious cattle finishing	Pp ₇	USD @ ⁻¹
	Price per unit	Heifers from 29 to 36 months	P ₈	USD @ ⁻¹
	Early Slaughter Bonus	Bonus paid for early slaughter to encourage precocious cattle finishing	Pp ₈	USD @ ⁻¹
	Price per unit	18-month old bull	P ₉	USD @ ⁻¹
	Price per unit	Lean bull (12 to 13 arrobas)	P ₁₀	USD @ ⁻¹
	Price per unit	Fat bull 18 to 20 months (MT, with <i>Funrural</i>)	P ₁₁	USD @ ⁻¹
	Early Slaughter Bonus	Bonus paid for early slaughter to encourage precocious cattle finishing	Pp ₁₁	USD @ ⁻¹
	Price per unit	Fat bull 21 to 28 months (up to 2 permanent teeth, with <i>Funrural</i>)	P ₁₂	USD @ ⁻¹
	Early Slaughter Bonus	Bonus paid for early slaughter to encourage precocious cattle finishing.	Pp ₁₂	USD @ ⁻¹
	Price per unit	Fat bull 29 to 36 months (up to 4 permanent teeth, with <i>Funrural</i>)	P ₁₃	USD @ ⁻¹
	Early Slaughter Bonus	Bonus paid for early slaughter to encourage precocious cattle finishing	Pp ₁₃	USD @ ⁻¹
	Price per unit	Fat bull (37 to 48 months, adult, with <i>Funrural</i>)	P ₁₄	USD @ ⁻¹
	Price per unit	Older fat bull "toruno" (60 months, with <i>Funrural</i>)	P ₁₅	USD @ ⁻¹

Table 7. Economic Module. Production costs. Environment-dependent variable inputs.

Item	Parameter	Description	Symbol	Unit
Labor	Hourly wage	Tractor operator	Mo ₁	USD h ⁻¹
	Hourly wage	Ranch hand (Cowboy)	Mo ₂	USD h ⁻¹
General Expenses	Cost per hour	Internal transportation	Dg _{1.1}	USD h ⁻¹
	Cost per visit	Technical assistance (veterinary, animal science, or agronomy)	Dg _{2.1}	USD visit ⁻¹
	Cost per month	Accounting expenses	Dg _{3.1}	USD month ⁻¹
	Cost per kilowatt	Electricity	Dg _{4.1}	USD kW ⁻¹
Soil preparation	Cost per hour	Stump removal	Ps _{1.1}	USD h ⁻¹
	Cost per hour	Topography	Ps _{2.1}	USD h ⁻¹
	Cost per hour	Terracing	Ps _{3.1}	USD h ⁻¹
	Cost per hour	Road adaptation	Ps _{4.1}	USD h ⁻¹
	Cost per hour	Chemical destruction	Ps _{5.1}	USD h ⁻¹
	Cost per hour	Lime spreading	Ps _{6.1}	USD h ⁻¹
	Cost per hour	Lime loading	Ps _{7.1}	USD h ⁻¹
Pasture Establishment	Cost per hour	Disking	Fp _{2.1}	USD h ⁻¹
	Cost per hour	Plowing	Fp _{3.1}	USD h ⁻¹
	Cost per hour	Leveling	Fp _{4.1}	USD h ⁻¹
	Cost per hour	Seeding/fertilizing	Fp _{5.1}	USD h ⁻¹
	Cost per hour	Herbicide application	Fp _{6.1}	USD h ⁻¹
	Cost per kg	Seed	Fp _{7.1}	USD kg ⁻¹
	Cost per metric ton	Dolomitic limestone	Fp _{8.1}	USD t ⁻¹
	Cost per kg	Fertilizer 04-14-08	Fp _{9.1}	USD kg ⁻¹
	Cost per liter	Herbicide 2,4-D and Picloram	Fp _{10.1}	USD L ⁻¹
Annual Pasture Maintenance	Cost per hour	Lime spreading	Mp _{1.1}	USD h ⁻¹
	Cost per hour	Disking	Mp _{2.1}	USD h ⁻¹
	Cost per hour	Fertilizer spreading	Mp _{3.1}	USD h ⁻¹
	Cost per hour	Herbicide application	Mp _{4.1}	USD h ⁻¹
	Cost per kg	Fertilizer 14-00-27	Mp _{5.1}	USD kg ⁻¹
	Cost per metric ton	Lime	Mp _{6.1}	USD t ⁻¹
	Cost per liter	Herbicide 2,4-D and Picloram	Mp _{7.1}	USD L ⁻¹
Nutrition	Cost per kg	Mineral salt	C _{p1}	USD kg ⁻¹
	Cost per kg	Reproduction of cow mineral salt	C _{p2}	USD kg ⁻¹
	Cost per kg	Mineral protein supplement	C _{p3}	USD kg ⁻¹
	Cost per kg	Mineral energy supplement	C _{p4}	USD kg ⁻¹
	Cost per kg	Creep-feeding	C _{p5}	USD kg ⁻¹
	Cost per kg	Corn grain	C _{p6}	USD kg ⁻¹
	Cost per kg	Mineral nucleus for 85:15 semi-confinement diet	C _{p7}	USD kg ⁻¹
Animal Health	Cost per dose	FMD Vaccine	V _{p1}	USD dose ⁻¹
	Cost per dose	Blackleg Vaccine	V _{p2}	USD dose ⁻¹
	Cost per dose	Brucellosis Vaccine	V _{p3}	USD dose ⁻¹
	Cost per dose	Dewormer	V _{p4}	USD dose ⁻¹

Table 8. Simulation Panel for the Minimum Module.

Item	Parameter	Description	Symbol	Unit	Input
Administration assumptions	Producer profile	The simulation assumes a beef cattle rancher operating as an individual (non-corporate farming unit)	Up ₁	–	Individual (Sole Proprietor)
	Land ownership status	Production occurs on owned land (not leased)	Up ₂	–	Owned property
Economic target	Minimum required remuneration by the rancher	Annual income target to ensure economic sustainability	Rr ₁	USD y ⁻¹	70,725.93
Economic performance	Animal category price	Average price for each animal category (cull cows, weaned calves, etc.) for each year simulated (2017–2020)	P _i	USD y ⁻¹	2017; 2018; 2019; 2020
Total costs	Production costs	Average price for each component of the costs (labor, nutrition, etc.) for each year simulated (2017–2020)	C _i	USD y ⁻¹	2017; 2018; 2019; 2020
Grazing conditions	Pasture carrying capacity	Stocking rate based on pasture potential (Low, Medium, or High)	Sr ₂	AU ha ⁻¹	0.5; 1.0; or 1.5
Land constraints	Legal reserve area	Legally protected area (20%) required by Brazilian Forest Code	Ar ₁	%	20
	Environmental preservation area	Additional environmental reserve area (10%) assumed for the MM model	Ar ₂	%	10
Production settings	Location of simulation	Geographic focus of the study	Sim ₁	–	Campo Grande Microregion, Midwest Brazil
	Year of simulation	Years evaluated by the Minimum Module (MM) model	Sim ₂	–	2017; 2018; 2019; 2020
	Production system intensification level	Management intensity level (Low, Medium, or High)	Ni ₃	–	3; 2; or 1
	Number of breeding cows	Initial number of cows in the herd	N _c	Head	< 1

Footnote: Administrative assumptions, economic targets, grazing conditions, and general settings are defined in Section 2.3.

Table 9. Assumptions for animal production in the Animal Production Module of the MM simulation model. Brazil

Item	Parameter	Description	Input
Animal Production Module	Animal breed	Nelore beef cattle breed	Nelore
	Infrastructure	Housing for labor (common workers and tractor operators)	1 complete setup
	Livestock handling facilities	Facilities for cattle management	1 complete setup
	Fencing	Boundary and pasture subdivision fences	1 set of fencing
	Water access and feed trough	Access to water and covered feed trough for supplementation	1 complete setup
	Natural breeding system	Natural breeding station	1 station
	Mating season	Breeding season (November to January)	November to January
	First exposure conception rate	Pregnancy rate after first bull exposure (50-85%)	50-85%
	Bull replacement	Bull replacement system for breeding	1 system
	Annual conception rate	Pregnancy rate after second bull exposure (75-92%)	75-92%
	Pregnancy diagnosis and weaning	Diagnosis and weaning (March to May)	March to May
	Pregnancy loss	2-5% loss of pregnancies	2-5%
	Birth period	Calving season (August to October)	August to October
	Open herd	Open herd system, including purchase of animals from previous phases	1 system
	Slaughter sales	Includes slaughter and replacement sales	1 system

Table 10. Economic Module. Financial assumptions and Macroeconomic parameters. Fixed Inputs. Brazil.

Item	Parameter	Description	Symbol	Unit	Input
Economic Module	Income tax	Federal income tax rate	Ef ₁	(% yr ¹)	27.50
	Funrural (Rural Social Security Tax)	Contribution levied on gross revenue from cattle sales for slaughter	Ef ₂	(%)	1.50
	MARR	Minimum acceptable rate of return	Ef ₄	(% yr ¹)	6.00
	Real discount rate	Discount rate for present value calculation	Ef ₅	(% yr ¹)	6.00
	Inflation rate	Annual inflation rate	Ef ₇	(% yr ¹)	4.50
	Equity investment	Proportion of capital from own equity	Ef ₈	(%)	40.00
	Third-party capital on herd value	Share of herd value financed with third-party capital	Ef ₉	(%)	60.00
	Total number of installments	Repayment period for third-party financing	Ef ₁₀	(Years)	10
	Grace period	Years before liability repayment begins	Ef ₁₁	(Years)	2
	Annual interest rate	Nominal annual interest rate	Ef ₁₂	(% yr ¹)	7.00
	Bare land value	Average municipal value of unimproved pastureland	Ef ₁₃	(USD ha ¹)	1,500.00

Table 11. Fixed Intensification Parameters for the Minimum Module Pasture Systems: LL (low level), ML (medium level), and HL (high level), 2017-2020.

Parameter	Unit	LL	ML	HL
Pasture ¹	(Cg-Rg)	(Cg)	(Cg-Rg)	(Rg)
Stocking rate ²	(AU ha ⁻¹)	0.5	1	1.5
Pasture fertilization	(kg ha ⁻¹)	40	120	180
Reproductive mineral salt	(g hc ⁻¹ d ⁻¹)	25	25	25
Mineral supplement	(g hc ⁻¹ d ⁻¹)	100	100	100
Protein supplement (7/8 months)	(g hc ⁻¹ d ⁻¹)		200	200
Energy supplement (12 months)	(g hc ⁻¹ d ⁻¹)		130	130
Creep feeding ³	(kg hc ⁻¹ d ⁻¹)			1.120
Diet ⁴ (85:15)	(%)			1.2
Pasture formation ⁵	(%)	1	1	5
Pasture maintenance ⁵	(%)	2	10	10
Lease rate ⁶	(%)	10	12	15
Calving rate	(%)	70	82	90
Tractor	(Hp)	120	140	180
Hydraulic terracing plow with 16 discs	(Units)		1	1
6m Mounted Boom Sprayer – 600L	(Units)		1	1
Barn	(m ²)	50	220	600

Footnotes: ¹ C_g: continuous grazing. R_g: rotated grazing. ² Animal unit [450 kg of body weight]. ³ Private supplementations. ⁴ Semi-confined diet composed of 85% corn grain and 15% mineral core (% of live weight). ⁵ Pasture formation and maintenance percentages refer to the share of available grazing area (AgA%) that undergoes formation and annual upkeep, respectively. ⁶ Calculated based on the lease rate, which is a percentage of the “arropa – value per @ is 15 kg” price of fat cattle (L_a: leased area).

Table 12. Minimum and maximum values of input variables. Animal Module.

Parameter	Unit	Amplitudes
Stocking rate	UA ha ⁻¹	0.3 - 2.0
Birth rate	%	50 - 90
Slaughter age for bulls	months	12 - 44
Average herd mortality rate	%	2 - 5
Annual culling rate for cows	% v ⁻¹	15 - 20
Annual culling rate for bulls	% v ⁻¹	15 - 25
Selection pressure for sale (females)	% v ⁻¹	15 - 70
Selection pressure for sale (males)	% v ⁻¹	15 - 100
Slaughter weight for culling cows	kg hc ⁻¹	380 - 500
Slaughter weight for bulls	kg hc ⁻¹	750 - 800
Slaughter weight for steers	kg hc ⁻¹	380 - 480
Slaughter weight for heifers	kg hc ⁻¹	360 - 420
Weight for weaned males (7-8 months)	kg hc ⁻¹	170 - 300
Weight for 18-20 month steers (DL)	kg hc ⁻¹	320 - 480
Weight for 21-28 month steers (up to 2 permanent teeth)	kg hc ⁻¹	380 - 540
Weight for 29-36 month steers (up to 4 permanent teeth)	kg hc ⁻¹	400 - 570
Weight for 37-48 month steers (adult)	kg hc ⁻¹	405 - 650
Carcass yield (males)	%	52 - 58
Average daily gain (ADG) (male calf)	kg d ⁻¹	0.150 - 0.950
ADG (male rearing)	kg d ⁻¹	0.199 - 1.100
ADG (male finishing)	kg d ⁻¹	0.350 - 1.500
Weight for weaned females (7-8 months)	kg hc ⁻¹	120 - 180
Weight for 18-20 month heifers (DL)	kg hc ⁻¹	160 - 360
Weight for 21-28 month heifers (up to 2 permanent teeth)	kg hc ⁻¹	199 - 380
Weight for 29-36 month heifers (up to 4 permanent teeth)	kg hc ⁻¹	260 - 395
Weight for 37-48 month cows (adult)	kg hc ⁻¹	300 - 500
Carcass yield (females)	%	50 - 52
ADG (female calf)	kg d ⁻¹	0.164 - 0.784
ADG (female rearing)	kg d ⁻¹	0.164 - 0.950
ADG (female finishing)	kg d ⁻¹	0.300 - 1.200
ADG (cow finishing)	kg d ⁻¹	0.750 - 1.100
ADG (pasture without mineral supplementation)	kg d ⁻¹	0.150 - 0.550
ADG (pasture with mineral supplementation)	kg d ⁻¹	0.250 - 1.900
Carcass yield (cow)	%	48 - 50
Bull-to-cow ratio	AU	15 - 25
Cow coefficient	AU	0.92 - 1.08
Culling cow coefficient	AU	0.74 - 0.92
18-20 month heifer (DL) coefficient	AU	0.35 - 0.8
21-28 month heifer (2 permanent teeth) coefficient	AU	0.40 - 0.8
29-36 month heifer (4 permanent teeth) coefficient	AU	0.56 - 0.87
37-48 month cow (adult) coefficient	AU	0.66 - 1.11
18-20 month steer (DL) coefficient	AU	0.71 - 1.06
21-28 month steer (2 permanent teeth) coefficient	AU	0.84 - 1.20
29-36 month steer (4 permanent teeth) coefficient	AU	0.88 - 1.26
37-48 month steer (adult) coefficient	AU	0.90 - 1.33
Bull coefficient	AU	1.44 - 1.88
Short-cycle diet consumption coefficient (kg per 100 kg body weight)	%	0.75 - 2
Grazing efficiency coefficient (dry and rainy season)	%	20 - 80
Daily forage dry matter consumption	kg AU ⁻¹	7.5 - 12.5
Forage coefficient (kg crude protein per 100 kg dry matter)	%	4.2 - 13.4
Mineral salt consumption	kg hc ⁻¹	0.050 - 0.150
Mineral salt consumption for reproduction cows (kg per 100 kg body weight)	kg hc ⁻¹	0.015 - 0.035
Mineral protein supplement consumption (kg per 100 kg body weight)	kg hc ⁻¹	0.100 - 0.250
Mineral energy supplement consumption (kg per 100 kg body weight)	kg hc ⁻¹	0.120 - 0.300
Creep feeding consumption	kg hc ⁻¹	0.328 - 1.400

Table 13. Economic Module. Components of the Discounted Cash Flow (DCF).

Component	Equation	Description of the Equation	References
Total Revenue	$TR_{annual} = \sum_{i=1}^n Q_i \times (W_i \times R_i \times P_{si}) \times P_i$	Calculated as the sum of the products of quantity sold (Q_i), average live weight (W_i), carcass yield (R_i), market selection pressure (P_{si}), and price per kilogram of carcass (P_i) across all animal categories (i).	Jorge (2019, p. 124; 2024, p. 127)
Net Income	$Ni_{annual} = TR \times (1 - \alpha)$	Net income after deduction of the <i>Funrural</i> tax rate α .	Damodaran (2010; 2020)
Total Operating Cost	$TOC_{annual} = FOC_1 + FOC_2 + FOC_n + ... + VOC_1 + VOC_2 + VOC_n$	Sum of fixed operating costs (FOC) and variable operating costs (VOC).	Matsunaga et al. (1976); Jorge (2019, p. 124)
Opportunity Cost	$OC_p = Z \times P_a \times AgA \times 12$	Calculated as a percentage (Z) on the potential beef production value, using the market price per arroba (P_a) and the minimum grazing area AgA , adjusted to an annual basis.	Ross et al. (2013, p.172); Jorge (2019, p. 124; 2024, p. 127)
Total Cost	$TC_{annual} = FOC + VOC + OC_p$	Sum of fixed, variable, and opportunity costs.	Matsunaga et al. (1976)
EBITDA	$EBITDA_{annual} = Ni - TC$	Earnings before interest, taxes, depreciation, and amortization.	Damodaran (2010; 2020)
Depreciation	$Dep_{annual} = \left(\sum_{i=1}^n \frac{0.80 \times M_i}{10} \right) + \left(\sum_{j=1}^m \frac{0.8}{j} \right) + \left(\sum_{k=1}^o \frac{0.9}{k} \right)$	Annual depreciation calculated separately for machinery, equipment, and infrastructure, considering salvage value.	Damodaran (2000; 2010); Kay et al. (2023, p. 75); Jorge (2019, p. 124; 2024, p. 127)
EBIT	$EBIT_{annual} = EBITDA - Dep$	Earnings before interest and taxes.	Damodaran (2000; 2010)
Rural Land Tax	$RLT_{annual} = VTN \times GU$	Annual land tax calculated as the product of the average bare land value for pasture areas (VTN) and the land use coefficient (GU), set at 80% in this study.	Jorge (2019; 2024)
Income Tax	$Itax_{annual} = \sum_{i=1}^n [(EBIT_i - L_{min,i}) \times T_i]$	Income tax calculated by applying progressive rates (T_i , 0%-27.5%) to each income segment ($EBIT_i - L_{min,i}$) across n tax brackets.	Brazilian Federal Revenue Service (2019); Jorge (2019, p. 139)
Re-investment	$R_{annual} = \sum_{i=1}^n R_i$	Total annual reinvestment, including livestock replacement, machinery, equipment, and infrastructure improvements.	Damodaran (2000; 2010; 2020)
Free Cash Flow to Equity	$FCFE_{annual} = EBIT - RLT - R - (K_p \times i)$	Cash flow available to shareholders after taxes, reinvestments, and debt service (principal(k) and interest (i)).	Damodaran (2000; 2010); Ross et al. (2013, p.29)
Accumulated Free Cash Flow to Equity	$FCFE_a = -I_0 + \sum_{i=1}^T FCFE_i$	Accumulated free cash flow to equity ($FCFE_a$), calculated as the sum of annual free cash flows to equity ($FCFE_i$) over the 20-year horizon, including the initial investment (I_0) as an outflow.	Jensen (1986); Damodaran (2000; 2010; 2020)

Economic Result	$Er_{\text{annual}} = \frac{FCFE_i}{AgA}$	Economic results per hectare of grazing area (AgA).	Jorge (2019, p. 124; 2024 p. 129)
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Table 14. Financial Indicators – Final Outputs of the Minimum Module.

Indicator	Equation	Description of the Equation	References
Net Present Value (NPV)	$NPV = \sum_{i=1}^T \frac{CF_i}{(1+i)^t} - K_0$	Present value of net cash flows (CFT) over the investment horizon (T=20 years), discounted at rate (<i>i</i>), minus the initial investment (<i>K</i> ₀). NPV ≥ 0 defines the minimum economic scale, where the removal of a single breeding cow results in a negative NPV, indicating the viability threshold.	Damodaran (2000;2010; 2020); Ross et al., 2013, p. 101); Jorge (2019, p. 140; 2024, p. 129)
MIRR	$MIRR = \left(\frac{\sum_{t=1}^n CF_t^+ + (1+i_b)^{n-t}}{\sum_{t=1}^n \frac{CF_t^-}{(1+i_d)^t}} \right)^{\frac{1}{n}} - 1$	MIRR represents the return rate that equates the future value of positive cash flows (reinvested at <i>i</i> _b) with the present value of negative cash flows (discounted at <i>i</i> _d) over <i>n</i> periods. The Minimum Module (MM) is economically viable if MIRR>MARR; unviable if MIRR<MARR; and indifferent if MIRR=MARR.	Damodaran (2000;2010; 2020); Ross et al., 2013, p. 141); Jorge (2019, p. 141; 2024, p. 130)
Discounted Payback Period	$\sum_{t=0}^{DP} \left(\frac{CF_t}{(1+i)^t} \right) \geq K_0$	Time (in years) required for the cumulative discounted cash flows to equal or exceed the initial investment (<i>K</i> ₀). Reflects the time to recover the invested capital considering the time value of money.	Ross et al., 2013, p. 141)

Table 15. Economic Performance and Herd Value Indicators – Final Outputs of the Minimum Module.

Indicator	Equation	Description of the Equation	References
Gross Margin	$GM = TR - VOC$	Revenue minus variable operating costs (VOC); reflects gross profitability before fixed costs.	Damodaran (2000); Kay et al. (2023, p. 193)
Total Profit	$TP = Ni - TC$	Net income (after taxes) minus total cost, including fixed, variable, and opportunity costs.	Damodaran (2000;2010); Kay et al. (2023, p. 80)
Profitability Operational	$Pr_{op} = \frac{TP}{AgA}$	Profit per hectare per year, calculated as total profit divided by the available grazing area (AgA).	Kay et al. (2023, p. 83); Jorge (2019, p. 140; 2024, p. 129)
Final Stock Head	$SH_i = N_{i, \text{initial}} + B_i + Pu_i - Mt_i - S_i$	Final number of heads in each animal category (<i>i</i>) calculated by summing the initial stock and herd additions (births <i>B</i> _{<i>i</i>}), purchases (<i>Pu</i> _{<i>i</i>}) and subtracting mortalities (<i>Mt</i> _{<i>i</i>}) and sales (<i>S</i> _{<i>i</i>}).	Jorge (2019, p. 128; 2024, p. 349)
Total Herd Value	$HV = \sum_{i=1}^n (SH_i + W_i + P_i)$	Total market value of the herd at year-end, calculated as the product of final stock heads (<i>SH</i> _{<i>i</i>}), average live weight (<i>W</i> _{<i>i</i>}), and market price per kg (<i>P</i> _{<i>i</i>}).	Jorge (2019, p. 140)

Table 16. Production Indicators – Final Outputs of the Minimum Module.

Indicator	Equation	Description of the Equation	References
Productivity	$Prod = \frac{\sum_{i=1}^n (Q_i x @_i)}{AgA}$	Total production of beef in arrobas (@), calculated as the sum of animals sold (Q_i) times the weight in arrobas ($@_i$), divided by the available grazing area (AgA).	Jorge (2019, p. 140; 2024, p. 349)
Total Animal Units	$TAU = \sum_{i=1}^n \frac{LW_i}{450}$	Sum of live weights of all animal categories (LW_i , in kg), divided by the standard live weight equivalent of 450 kg per animal unit.	Jorge (2019, p. 134)

Table 17. Sustainability Indicators – Final Outputs of the Minimum Module.

Indicator	Equation	Description of the Equation	References
Available Grazing Area	$AgA_i = \frac{Hq_i}{Sr_i}$	Minimum pasture area required to sustain the herd size (Hq_i) under the stocking rate (Sr_i) for each production intensification level (i). The herd size Hq_i is simulated based on the producer's required annual income (Rr_i), which is defined externally by the user and considered a fixed cost. The model computes the minimum viable configuration that satisfies the economic viability condition $NPV \geq 0$, making AgA_i , an endogenous outcome driven by user-defined income expectations and system intensification.	Jorge (2019, p. 134)
Total Area	$TA_i = \frac{AgA_i}{1 - \frac{LR_i}{100} - \frac{PP_i}{100}}$	Total land area required to implement the Minimum Module (MM) under each production intensification level (i). It includes the minimum grazing area (AgA_i) plus the proportions of land allocated to the Legal Reserve (LR_i) and the Permanent Preservation Area (PP_i), both defined according to Brazilian environmental regulations. Since AgA_i is derived from the simulated herd size required to meet the producer's target income (Rr_i), the total area TA_i reflects both economic viability and land use compliance.	Jorge (2019, p. 135; 2024, p. 108); Brazilian Forest Code (Law No. 12,651 of May 25, 2012)

Table 18. Cost, Revenue, and Profitability Components for Monte Carlo Risk Analysis in the MM Model.

Identification	Item	Data classification
<i>A</i>	Opportunity cost (land lease)	Input
<i>B</i>	Facilities and improvements	Input
<i>C</i>	Depreciation	Input
<i>D</i>	Machines and equipment	Input
<i>E</i>	Depreciation	Input
<i>F</i>	Producer's management fees	Input
$G = \sum (A \text{ to } F)$	Fixed Cost (FC)	Output
<i>H</i>	Pasture formation	Input
<i>I</i>	Pasture maintenance	Input
<i>J</i>	Maintenance of facilities and improvements	Input
<i>K</i>	Maintenance of machinery and equipment	Input
<i>L</i>	Mineral supplement	Input
<i>M</i>	Protein/energy-raising/fattening supplement	Input
<i>N</i>	Creep-feeding weaning supplement	Input
<i>O</i>	Vaccines	Input
<i>P</i>	Dewormers	Input
<i>Q</i>	Other medicines	Input
<i>R</i>	Fuel and lubricants	Input
<i>S</i>	Salaries + employee charges	Input
<i>T</i>	General services and accountant	Input
<i>U</i>	Technical assistance	Input
<i>V</i>	Electricity, telephone, and transportation	Input
$W = \sum (H \text{ to } V)$	Variable Cost (VC)	Output
$X = \sum (G \text{ and } W)$	Total cost (TC)	Output
<i>Y</i>	Average price	Input
<i>Z</i>	Productivity	Input
$\alpha = (Y \cdot Z)$	Gross revenue	Input
$\beta = (\alpha \cdot i)$	Tax and/or fee (<i>Funrural</i> ¹)	Output
$\delta = (\alpha - \beta)$	Net income	Output
$\mu = (\alpha - W)$	Gross margin	Output
$\lambda = (\alpha - G)$	Operating profit - net margin	Output
$\Omega = (\delta - X)$	Total profit	Output
$\Psi = (\Omega / AgA)^2$	Operating profitability ^b (USD ha ⁻¹ year ⁻¹)	Output

Footnotes: ¹ *i*: Funrural rate of 1.5%. ² *AgA* = available grazing area

Table 19. Minimum Module Outputs by Intensification Level (LL, ML, HL) for 2017–2020.

Intensification level	L _L				M _L				H _L			
P _Y	2017	2018	2019	2020	2017	2018	2019	2020	2017	2018	2019	2020
Prod	3.38	3.38	3.35	3.30	6.69	6.69	6.63	6.55	10.00	10.00	9.94	9.83
Nc	1,011	1,010	675	406	1,131	1,160	731	444	1,727	1,799	1,046	566
AgA	5,424	5,419	3,831	2,556	3,248	3,323	2,211	1,467	3,367	3,498	2,122	1,245
TA	7,748	7,741	5,473	3,651	4,640	4,748	3,159	2,095	4,810	4,998	3,032	1,778

Footnotes: productivity (Prod, @ ha⁻¹ year⁻¹), Number of breeding cows (Nc, animal), available grazing area (AgA, ha) and total area (TA, ha); AU = animal unit (450 kg live weight); Low-level (LL, 0.5 AU ha⁻¹), Medium-level (ML, 1.0 AU ha⁻¹) and High-level (HL, 1.5 AU ha⁻¹) production systems for the productive years (PY).

Table 20. Annual Herd Evolution for the Minimum Module by Intensification Level (LL, ML, HL) for 2017–2020.

Intensification level	L _L				M _L				H _L			
Evolution of the herd (Quantity)	2017	2018	2019	2020	2017	2018	2019	2020	2017	2018	2019	2020
	Animals	Period change ⁹	Animals	Period change	Animals	Period change	Animals	Period change	Animals	Period change	Animals	Period change
Cows (37 to 48 months)	1,111	1,012	935	682	1,131	1,027	1,049	724	1,727	1,479	1,534	963
Heifers 29 to 36 months	15	15	14	10	17	17	18	12	27	27	28	17
Heifers 21 to 28 months	149	149	138	101	173	173	177	121	271	271	282	175
Heifers 18 to 20 months	250	250	232	170	290	290	296	203	455	455	472	294
Female calves 12 months	281	281	260	190	325	325	332	228	511	511	530	329
Weaning females ¹	474	474	439	321	549	549	561	385	862	862	895	556
Weaning males ²	474	474	439	321	549	549	561	385	862	862	895	556
Male calves (12 months)	281	281	260	190	325	325	332	228	511	511	530	329
Young bulls (18 months)	236	236	219	160	274	274	280	192	430	430	446	277
Lean bull ³	200	200	185	135	231	231	236	162	363	363	377	234
Fat bull 18 to 20 months ⁴	169	169	156	114	195	195	199	137	307	307	318	198
Fat bull 21 to 28 months ⁵	100	100	93	68	116	116	119	82	183	183	190	118
Fat bull 29 to 36 months ⁶	50	50	46	34	58	58	59	40	90	90	94	58
Fat bull (37 to 48 months) ⁷	25	25	23	17	29	29	29	20	45	45	47	29
Older fat bull ⁸	44	42	38	28	45	42	43	29	69	61	64	40

Footnotes: AU = animal unit (450 kg live weight); Low-level (LL, 0.5 AU ha⁻¹), Medium-level (ML, 1.0 AU ha⁻¹) and High-level (HL, 1.5 AU ha⁻¹).¹ 7 to 8 months of age. ² 7 to 8 months of age. ³ between 12 and 13 arrobas of live weight. ⁴ Milk-tooth animal category (MT). ⁵ Up to 2 permanent teeth animal category. ⁶ Up to 4 permanent teeth animal category. ⁷ adult. ⁸ Over 60 months of age. ⁹ Animal age change.

Table 21. Annual Cost Structure for the Minimum Module by Intensification Level (LL, ML, HL) for 2017–2020.

Intensification level		L _L				M _L				H _L			
Year		2017	2018	2019	2020	2017	2018	2019	2020	2017	2018	2019	2020
Id	Description	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹
	A–Fixed cost	253,536	252,991	227,535	211,501	257,623	267,546	234,880	223,757	258,772	271,755	236,325	218,285
1	Opportunity cost ^a	83,635	86,098	71,599	63,095	50,812	52,802	41,323	36,213	51,960	55,581	39,661	30,732
2	Facilities and improvements	6,825	6,916	6,962	6,543	18,614	18,862	18,987	17,844	18,614	18,862	18,987	17,844
3	Depreciation	341	346	348	327	931	943	949	892	931	943	949	892
4	Machines and equipment	66,390	68,050	62,434	64,424	88,692	100,147	85,156	89,217	88,692	101,447	87,981	89,225
5	Depreciation	6,639	6,805	6,243	6,442	8,869	10,015	8,516	8,922	8,869	10,145	8,798	8,922
6	Producer's management fees	89,706	84,776	79,949	70,670	89,706	84,776	79,949	70,670	89,706	84,776	79,949	70,670
	B– Variable cost	100,006	102,904	93,350	72,776	189,453	188,895	145,745	108,693	515,604	535,393	370,978	239,454
1	Pasture formation	16,533	17,323	11,894	6,962	11,554	12,126	7,905	4,996	64,865	69,754	42,096	23,666
2	Pasture maintenance	8,218	8,393	5,450	3,960	47,606	48,275	31,341	22,076	60,259	62,678	37,574	23,279
3	Maintenance of facilities and improvements	4,330	4,380	4,493	4,000	4,330	4,380	4,493	4,002	4,579	4,559	4,720	4,395
4	Maintenance of machines and equipment	4,209	4,629	4,552	4,214	4,209	4,629	4,552	4,234	4,956	4,794	5,441	4,823
5	Mineral supplement	39,137	39,232	30,746	18,801	17,027	16,819	12,009	6,461	25,625	26,095	17,186	8,236
6	Protein/energy-raising/fattening supplement	-	-	-	-	75,724	72,264	48,110	30,869	193,536	202,779	132,023	77,037
7	Creep-feeding weaning supplement ^b	-	-	-	-	-	-	-	-	126,322	128,821	82,931	48,173
8	Vaccines	3,200	3,104	2,157	1,516	3,983	3,898	2,543	1,766	6,150	6,193	3,669	2,247
9	Deworming	2,704	2,643	2,366	1,432	3,346	3,301	2,777	1,662	5,159	5,236	4,003	2,115
10	Other medicines	92	131	125	129	92	131	125	131	142	236	193	171
11	Fuel and lubricants	4,452	4,418	4,471	6,308	4,452	4,418	4,471	6,313	4,950	4,651	4,696	6,470
12	Salaries + employee charges	13,654	14,836	22,425	20,309	13,654	14,836	22,425	20,497	13,654	15,295	30,019	30,850
13	General services and accountant	1,459	1,574	1,439	1,885	1,459	1,574	1,439	1,885	2,243	1,574	1,439	1,885
14	Technical services	343	377	533	785	343	377	533	785	1,030	377	1,599	2,748
15	Electricity, telephone, and transportation	1,675	1,865	2,698	2,473	1,675	1,865	3,021	3,016	2,133	2,352	3,390	3,359
	C–Total costs (A+B)	353,542	355,895	320,885	284,278	447,077	456,440	380,625	332,451	774,376	807,148	607,303	457,739

Footnotes: AU = animal unit (450 kg live weight); Low-level (LL, 0.5 AU ha⁻¹), Medium-level (ML, 1.0 AU ha⁻¹) and High-level (HL, 1.5 AU ha⁻¹).¹Land lease. ² private feeding trough - creep-feeding.

Table 22. Annual Profitability Metrics for the Minimum Module by Intensification Level (LL, ML, HL) for 2017–2020.

Intensification level	L _L				M _L				H _L			
Year	2017	2018	2019	2020	2017	2018	2019	2020	2017	2018	2019	2020
Description	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹	USD year ⁻¹
Total revenue	568,461	566,594	512,939	456,601	688,693	692,789	589,693	522,369	1,055,519	1,092,971	848,644	665,021
Tax (<i>Funrural</i>) ¹	6,595	6,574	5,883	5,111	7,882	7,932	6,677	5,791	12,034	12,469	9,598	7,375
Net Revenue	561,866	560,019	507,056	451,491	680,812	684,858	583,015	516,578	1,043,485	1,080,502	839,046	657,646
Fixed cost	253,536	252,991	227,535	211,501	257,623	267,546	234,880	223,757	258,772	271,755	236,325	218,285
Variable cost	100,006	102,904	93,350	72,777	189,453	188,894	145,745	108,693	515,604	535,393	370,978	239,454
Gross margin	468,455	463,690	419,589	383,825	499,240	503,895	443,948	413,676	539,915	557,578	477,666	425,567
Total cost	353,542	355,895	320,885	284,278	447,077	456,440	380,625	332,451	774,376	807,147	607,303	457,739
Net margin	314,925	313,603	285,404	245,100	431,070	425,243	354,813	298,612	796,748	821,217	612,318	446,736
Total profit	208,324	204,124	186,171	167,213	233,735	228,417	202,390	184,127	269,110	273,355	231,743	199,907
Profitability	38	38	49	65	71	69	91	125	80	78	109	161
NPV	1,659	1,141	3,276	779	102	2,507	296	1,013	1,077	453	1,874	1,089

Footnotes: AU = animal unit (450 kg live weight); Low-level (LL, 0.5 AU ha⁻¹), Medium-level (ML, 1.0 AU ha⁻¹) and High-level (HL, 1.5 AU ha⁻¹).¹1.5% rate.

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