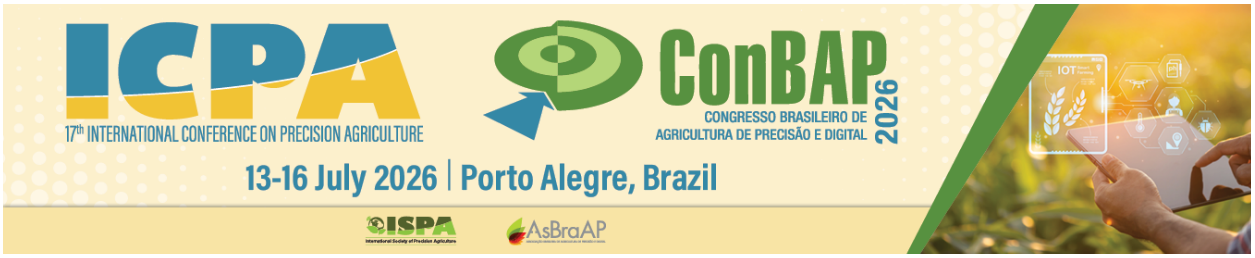

PROFITABILITY MAPPING IN PRECISION AGRICULTURE: AN ECONOMIC-SPATIAL MODEL APPLIED TO SOYBEAN FARMING IN NORTHWESTERN MATO GROSSO

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Abstract. *Precision agriculture generates large volumes of spatial data; however, their integration into economic decision models and financial planning still presents a significant gap. This paper presents and validates a parameterized economic simulation tool built in an Excel spreadsheet to support decision-making by rural producers in Precision Agriculture (PA) systems. The tool integrates historical production cost data from IMEA/Senar-MT (crop years 2021/22 to 2025/26) with parameters from productive stability zones (ZAE, ZME, ZBE, and Variable/Unstable), calculating Gross Margin, Break-Even Point, and Safety Margin by zone and by crop year, under both Fixed Rate (FR) and Variable Rate (VR) management. The difference between margins constitutes the Spatial Information Value (SIV), an economic indicator of the return from site-specific management. The structure comprises seven interdependent analytical modules: IMEA historical series, zone analysis under FR, zone analysis under VR, weighted FR vs. VR comparison, simulation of eight risk scenarios per zone, scenario summary matrix, and two-dimensional price-productivity sensitivity analysis. Results show that total operating cost (COT) grew 38.3% over the period, the Safety Margin declined from 30.71 sc/ha to 8.07 sc/ha, and the average SIV was R$ 75.07/ha (R$ 325,313.65/crop year on the farm). The tool constitutes a practical, renewable, and low-cost instrument to support decision-making on farms adopting PA.*

Keywords. *precision agriculture; profitability mapping; stability zones; soybean; IMEA; scenario analysis.*

Introduction

Soybean farming represents the primary economic asset of Brazilian agribusiness. In the 2023/24 crop year, national production reached approximately 153.0 million tonnes (CONAB, 2024), with Mato Grosso accounting for approximately 30% of this volume. The macroeconomic relevance of the crop contrasts with growing pressure on profitability margins, a phenomenon explained by rising production costs, exchange rate volatility, and international commodity price fluctuations.

Precision Agriculture (PA) emerged in the second half of the 1980s with the objective of improving fertilizer application by varying doses and compositions within fields (Robert, 2002). In Brazil, Amado et al. (2007), in a commercial 57-ha farm in Rio Grande do Sul managed for more than ten years under no-till, demonstrated that productivity exhibits spatial continuity correlated over years, evidencing that harvest history is the primary source of information for site-specific management. Brusco et al. (2005) constructed soybean profitability maps under a PA cropping system in Cascavel, PR, showing that the economic analysis methodology based on georeferenced productivity data allows observing large result variations relative to the area average.

Despite the technical soundness of these approaches, the transformation of PA spatial data into structured economic information for producer decision-making remains a practical challenge. Gabbi (2013), in a dissertation developed at PPGAP/UFSM, demonstrated that PA as a support tool for fertilizer acquisition cost management generates savings of R$ 134.14/ha, making the investment viable in the first year of implementation. This result, however, lacks a systematic tool allowing the producer to calculate, each crop year, the economic return of differentiated management based on real cost and price parameters.

This paper aims to develop and validate a parameterized economic simulation tool capable of calculating Gross Margin, Break-Even Point, and Spatial Information Value by stability zone and risk scenario, for a 5,839.2-ha farm (4,333.21 ha planted) in Mato Grosso, over five crop years. The analysis integrates fundamentals of farm management (Kay, Edwards, and Duffy, 2016), rural accounting (Marion, 2012; Crepaldi, 2019), and agribusiness economics (Mankiw, 2021; Corbari, Garcias, and Soares, 2007), with empirical anchoring in the IMEA/Senar-MT historical series (2024).

Theoretical Framework

Structure of Rural Production Costs

Cost analysis is the foundation of economic management in any productive activity. In the context of soybean farming, the cost structure adopted by IMEA/Senar-MT and CONAB is organized into three hierarchical levels (CONAB, 2024; IMEA, 2024). The Effective Operating Cost (COE) represents the sum of direct cash disbursements incurred in the production cycle. The Total Operating Cost (COT) adds to the COE the depreciation of machinery and infrastructure and the family owner's compensation, and is the indicator adopted for break-even point calculation in this study, as recommended by Crepaldi (2019) and Marion (2012). The Total Cost (CT) further incorporates the Opportunity Cost of production factors (Pindyck and Rubinfeld, 2013; Iunes, n.d.).

Corbari, Garcias, and Soares (2007), when analyzing soybean and corn production costs in Paraná, demonstrated that opportunity cost measurement is an essential approach for producer decision-making regarding which crop to plant each season, a reference adopted in calculating CT in this tool. Farago et al. (2016) identified a moderate correlation between agricultural production costs and the Selic interest rate (40.07%), showing that monetary policy structurally affects agribusiness costs through financial expenses, a component explicitly disaggregated in the IMEA series used.

Result Indicators, Risk, and Information Value

Gross Margin (GM) is calculated as the difference between Net Revenue (after deductions of 1.7% for Funrural, Senar, and FETHAB) and the reference cost. The Break-Even Point (BEP) is the minimum productivity to equate revenue and cost, calculated on the COT according to Equation 1:

$$BEP\ (sc/ha) = COT\ (R\$/ha) \div [Price\ (R\$/sc) \times (1 - Deduction)]$$

Equação (1)

The Safety Margin (SM), defined as the difference between realized productivity and the BEP, quantifies the productive buffer before results turn negative (Callado, 2011). The Spatial Information Value (SIV) quantifies the net economic return of variable rate management, measured as the Gross Margin differential between VR and FR, net of incremental PA costs, according to Equation 2:

$$SIV\ (R\$/ha) = GM(VR) - GM(FR) = [NetRev(VR) - COT(VR)] - [NetRev(FR) - COT(FR)]$$

Equação (2)

Blackmore (2000) was the pioneer in calculating the economic significance of stability zones by producing gross margin maps, finding returns of £741, £691, and £644/ha for high, low, and unstable zones, respectively. Maestrini and Basso (2021), analyzing 5,520 harvest maps from 768 American fields, confirmed that the productivity difference between high and low stable zones for soybean is 0.34 Mg/ha, reinforcing the empirical basis for differentiated management. In the Brazilian context, Matoso and Garcia (n.d.) concluded that PA will yield greater economic returns when inputs have higher unit costs and fields present greater spatial heterogeneity — conditions fully present in Mato Grosso soybean farming over the analyzed period.

Scenario Simulation and Risk Analysis

Scenario analysis is an essential planning instrument under uncertainty (Mankiw, 2021). Lee, Swinton, and Basso (2025) demonstrated that the return on variable rate prescriptions varies substantially with seasonal climate and market conditions, finding profitability ranging from -US$ 410/ha to +US$ 350/ha depending on the year, reinforcing the need to evaluate multiple scenarios before strategic management decisions.

Methodology

Research Classification

The research is classified as applied, with a qualitative-quantitative approach (Gil, 2019; Marconi and Lakatos, 2017) and exploratory-descriptive design. The qualitative component lies in the analytical structuring of the tool and the interpretation of risk scenarios for managerial decision support. The quantitative component manifests in the systematic calculation of economic indicators from secondary historical data.

Data Sources

The primary database is the historical production cost series for conventional soybean in Mato Grosso, published by IMEA in partnership with Senar-MT (IMEA, 2024), covering crop years 2021/22 to 2025/26. The series disaggregates costs into eleven COE components (seeds; fertilizers and amendments; agrochemicals; mechanized operations; labor; maintenance; taxes and fees; financial expenses; post-harvest; other costs; land leasing), plus depreciation, owner compensation, and opportunity cost, totaling 14 components per crop year.

Soybean spot prices (R$/sc) were obtained from CEPEA/Esalq-USP and exchange rates (R$/USD) from the Central Bank of Brazil. Modal productivity per crop year was extracted from the same IMEA series. The reference price in dollars (USD 10.50/sc) adopted for the exchange rate parity scenario (C6) corresponds to the average international commercialization price of conventional soybean in Mato Grosso over the period. The incremental PA cost (R$ 120.00/ha), covering mapping, agronomic prescription, and GPS automation, was fixed based on market references mercado levantadas pelo IMEA (2024) e confirmado pela estimativa de Gabbi (2013) de R$ 135,00/ha para implantação de AP em propriedade do Rio Grande do Sul.

Stability Zone Parameterization

The model farm has 5,839.2 ha total area and 4,333.21 ha planted, subdivided into four Stability Zones. The stability zone concept adopted is based on Blackmore's (2000) farming-by-yield approach, which classifies fields into high and low stable productivity zones and unstable areas based on multi-year harvest map history. Maestrini and Basso (2021) confirmed that additional years of maps increase classification certainty, and that unstable zones are more frequent in years with high rainfall heterogeneity, a pattern observed over the 2021–2026 period.

Each zone is characterized by three operational parameters entered in the tool's Parameters tab: (i) the Yield Potential Index (YPI), a multiplier that scales the IMEA modal productivity to reflect each zone's relative performance; (ii) the percentage fertilizer dose adjustment (ΔDose), defining the input variation applied under variable rate relative to the average uniform dose; and (iii) the production elasticity coefficient, quantifying yield sensitivity to fertilizer increase or reduction. Table 1 presents the parameters for the four zones.

Table 1. Stability zone parameters entered in the simulation tool.

Zona	% Área	Área (ha)	IPN	ΔFert. Dose	Elasticity	Strategic Class
ZAE: High Stable	28,4%	1.658,3	1,25	+15%	0,60	Priority Investment
ZME: Medium Stable	31,2%	1.821,8	1,00	0%	0,40	Standard Management
ZBE: Low Stable	19,7%	1.150,3	0,75	–20%	0,20	Correction/Divestment
Variável/Instável	20,7%	1.208,7	0,92	–8%	0,35	Case-by-Case Assessment

Source: Model parameterized with IMEA/Senar-MT (2024) data. Authors' elaboration.

The weighted average of YPIs by area reproduces the IMEA modal productivity (average field = YPI 1.00), guaranteeing internal model consistency. ΔDose and elasticity parameters were calibrated based on Santi et al. (2012), who identified in a 54-ha area in Rio Grande do Sul that high-productivity zones respond more strongly to nutritional adjustments (K, Ca:K), while low-productivity zones are limited by physical soil attributes (compaction, infiltration), resulting in low fertilizer elasticity. Ramos et al. (2017), in Red Dystrophic Latosol in Mato Grosso, confirmed that P and Mn contents in grains explain productivity variation in management zones delimited by ordinary kriging, reinforcing elasticity differentiation between zones.

Simulation Tool Structure

The tool is structured in an Excel spreadsheet with seven interdependent analytical modules, all fed by a central Parameters tab that consolidates IMEA historical data and zone and scenario configurations. This architecture ensures that updating a single parameter set propagates automatically across all modules, guaranteeing consistency and traceability of calculations. Fig. 1 illustrates the logical structure of the tool's analytical flow, which is planned for future development into a system of precision a gricultureecisão e validado junto a empresa SPD Soil Diagnostic.

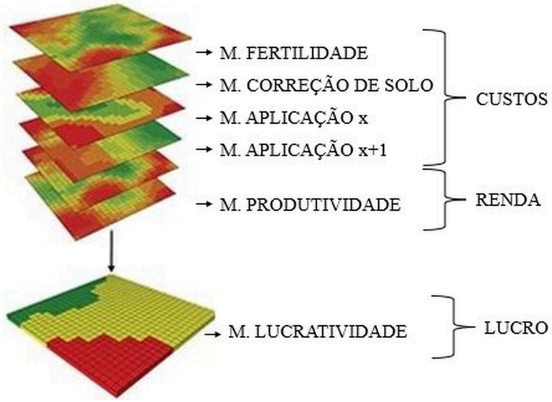

Fig. 1. Analytical flow of the simulation tool: relationship between cost layers (fertility, amendment, applications) and income (productivity) layers underpinning the spreadsheet modules, from the profitability map to risk scenarios. Authors' elaboration.

Module 1 — IMEA Historical Series

Records the 14 cost components per crop year, calculating COE, COT, and CT for each year in the series. Displays the percentage variation of each component between 2021/22 and 2025/26, enabling identification of which items most pressured total cost over the period. This is the data entry module and the anchor for all subsequent calculations.

Module 2 — Zone Analysis under Fixed Rate

Applies the YPI of each zone to the COT and modal productivity of each crop year, calculating for each zone-crop year combination: expected productivity (sc/ha), gross and net revenue (R$/ha), COE and COT by zone, Gross Margin (R$/ha and R$ total in zone), Break-Even Point on COT (sc/ha), and Safety Margin (sc/ha). Simulates uniform management as a comparison baseline, corresponding to conventional operation without differentiation by productive potential.

Module 3 — Zone Analysis under Variable Rate

Incorporates ΔDose adjustment and elasticity coefficient to recalculate productivity and COT for each zone under site-specific management. Productivity under variable rate is calculated as:

$$Yield(VR) = Yield(FR) \times [1 + (\Delta Dose \times Elasticity)]$$

Equação (3)

Fertilizer cost is adjusted proportionally to ΔDose, recalculating the zone's COT. The Gain vs. FR (R$/ha) is the GM differential between VR and FR before deducting PA cost, indicating the gross advantage of differentiated management by zone.

Module 4 — Weighted FR vs. VR Comparison

Aggregates zone results by area weighting (%), calculating the weighted average field for both FR and VR. Presents, per crop year and as period average: weighted average GM (R$/ha), total farm GM (R$, multiplied by the 4,333.21 ha), Break-Even Point on COT (sc/ha), Safety Margin (sc/ha), COT per bushel (R$/sc), and Spatial Information Value (SIV = net VR vs. FR gain after deducting the R$ 120.00/ha PA cost). This module is the analytical comparison core of the paper.

Module 5 — Scenario Simulation by Zone

Applies eight parameterized risk scenarios to each zone-crop year combination, in both FR and VR. The eight scenarios are: C1 (IMEA historical baseline, actual parameters per crop year); C2 (Input shock, +30% in fertilizers, proxy for the Russia-Ukraine 2022 impact); C3 (Price drop, fixed price of R$ 95/sc, floor observed in the region in 2023/24); C4 (Adverse climate La Niña, −25% in productivity, proxy for a severe event in Northwestern Mato Grosso); C5 (Price rally, +20%, commodity appreciation cycle); C6 (Exchange rate parity, price calculated as USD 10.50 × crop year exchange rate); C7 (Combined adverse, −20% price, +15% fertilizer, and −15% productivity simultaneously); and C8 (Favorable cycle, +10% price and +10% productivity). Multipliers for C1–

C8 are editable in the Parameters tab, allowing calibration of new shocks as markets evolve.

Module 6 — Scenario Summary Matrix

Consolidates Module 5 results into a presentation matrix with eight scenario rows and six crop year columns (plus average, minimum, and maximum), for both FR and VR. Applies automatic conditional formatting gradient: green cells indicate positive margins and red cells indicate losses, allowing the producer and technical advisor to visually identify which zone-crop year-scenario combinations are economically viable. This module constitutes the tool's main decision dashboard.

Module 7 — Sensitivity Analysis

Generates two-dimensional Gross Margin tables for each zone, crossing price ranges (R$ 95/sc to R$ 185/sc in R$ 10/sc intervals) with productivity ranges (48 sc/ha to 76 sc/ha in 4 sc/ha intervals), fixing the reference COT at 2024/25 (R$ 6,493.70/ha, the worst cost scenario in the series). This module allows the producer to immediately identify the minimum price-productivity pair for zone viability, anticipating decision-making on input scaling based on market expectations. Basso et al. (2001) propose a similar approach of spatial validation of economic results through the integration of simulation models with field data, of which this module is an operational adaptation for managerial use.

Calculation and Validation Procedure

All tool calculations are performed by native Excel formulas, without macros or external code, ensuring that any user with basic spreadsheet knowledge can audit, replicate, and update results. Model validation was conducted in three steps: (i) comparison of COE and COT calculated by the tool with values published directly in the IMEA/Senar-MT series (2024), verifying 100% adherence for all five years; (ii) verification that the weighted average of zone productivities by YPI and percentage area share reproduces the IMEA modal productivity for each crop year; and (iii) confirmation that the sum of zone GMs weighted by area reproduces the average field GM calculated in Module 4. The model is structured for annual updating with new IMEA data, maintaining the historical series as a permanent cumulative baseline.

Model Limitations

The tool operates with zone-average parameters, not capturing intrazone variability. YPI, ΔDose, and elasticity coefficients are parameterized based on bibliographic references (Blackmore, 2000; Maestrini and Basso, 2021; Santi et al., 2012; Ramos et al., 2017) and calibrated to reproduce IMEA modal productivity, but do not derive from field data collected at the study farm. Future studies should replace these parameters with coefficients estimated from multi-year productivity maps and georeferenced soil analyses of the real farm, following the methodology developed by Amado et al. (2007) and Santi et al. (2012) for farms in Rio Grande do Sul, and adapted by Ramos et al. (2017) for the Mato Grosso context. Integration of the tool with geoprocessing platforms (QGIS) for automatic extraction of zone parameters from productivity maps constitutes the next planned development step in the PPGAP/UFSM dissertation project (Macedo, 2026).

Results and Discussion

Evolution of Production Costs (2021/22 to 2025/26)

Table 2 presents the disaggregated historical cost series calculated by Module 1 of the tool for the five crop years analyzed.

Table 2. Historical soybean production cost series in Mato Grosso, generated by Module 1 of the tool (R$/ha).

Cost Component	2021/22	2022/23	2023/24	2024/25	2025/26	Var. (%)
Seeds	456,26	888,06	675,09	508,16	317,84	–30,3%
Fertilizers and Amendments	1.104,96	2.318,92	1.585,17	1.807,75	1.727,43	+56,3%
Agrochemicals	1.294,64	1.569,24	1.545,61	1.553,98	1.651,79	+27,6%
Mechanized Operations	155,29	223,91	175,73	188,58	207,44	+33,6%
Labor	100,78	107,78	138,81	190,17	269,16	+167,1%
Maintenance	138,16	134,12	209,96	318,93	352,63	+155,2%
Taxes and Fees	157,85	181,80	209,68	242,00	272,00	+72,3%
Financial Expenses	303,95	466,71	412,59	451,04	345,36	+13,6%
Post-Harvest	198,24	193,04	147,15	175,53	173,09	–12,7%
Other Costs	105,38	121,72	145,10	144,91	157,20	+49,2%
Land Leasing	256,45	288,92	326,83	260,52	279,67	+9,1%
TOTAL COE (R$/ha)	4.271,96	6.494,22	5.571,72	5.841,57	5.753,61	+34,7%
Depreciation	210,92	208,04	406,97	535,85	425,51	+101,7%
Family Owner Compensation	66,85	72,78	99,22	116,28	114,98	+72,0%
TOTAL COT (R$/ha)	4.549,73	6.775,04	6.077,91	6.493,70	6.294,10	+38,3%
Opportunity Cost	808,26	1.001,02	1.121,92	1.035,82	1.567,41	+93,9%
TOTAL COST CT (R$/ha)	5.357,99	7.776,06	7.199,83	7.529,52	7.861,51	+46,7%

Source: IMEA/Senar-MT (2024). Processed by the tool (Module 1). Authors' elaboration.

The COT rose from R$ 4,549.73/ha in 2021/22 to R$ 6,775.04/ha in 2022/23, an increase of 48.9% in a single crop year, driven by fertilizers and amendments (+110%), reflecting the Russia-Ukraine conflict and the disruption of international supply chains (CONAB, 2024). Farago et al. (2016) identified that agricultural production costs show moderate correlation with the Selic interest rate (40.07%), but the fertilizer shock in the 2021–2023 cycle was predominantly driven by exogenous geopolitical factors.

Economic Indicators by Crop Year — Module 4

Table 3 consolidates economic indicators by crop year for the weighted average field, generated by Module 4 of the tool.

Table 3. Economic indicators by crop year: weighted average field, generated by Module 4 of the tool (R$/ha).

Indicator	2021/22	2022/23	2023/24	2024/25	2025/26
Modal Productivity (sc/ha)	56,86	57,21	61,34	61,34	64,60
Spot Price (R$/sc)	177,00	163,00	118,00	124,00	125,00
Exchange Rate (R$/USD)	5,144	5,231	5,074	5,160	5,688
Gross Revenue (R$/ha)	10.064,22	9.325,23	7.238,12	7.606,16	8.075,00
GM Average Field — FR (R$/ha)	5.394,74	2.439,24	1.074,09	1.021,96	1.684,82
GM Average Field — VR (R$/ha)	5.494,41	2.540,04	1.122,60	1.080,94	1.752,27
Net SIV VR–FR (R$/ha)	99,63	100,80	48,51	58,98	67,45
BEP on COT (sc/ha)	26,15	42,28	52,40	53,27	51,22

Indicator	2021/22	2022/23	2023/24	2024/25	2025/26
Safety Margin (sc/ha)	30,71	14,93	8,94	8,07	13,38
COT per Bushel (R$/sc)	80,02	118,42	99,09	105,86	97,43

Source: IMEA/Senar-MT (2024); CEPEA/Esalq-USP. Processed by the tool (Module 4). Authors' elaboration.

The Safety Margin on COT declined from 30.71 sc/ha in 2021/22 to a minimum of 8.07 sc/ha in 2024/25, signaling growing vulnerability to exogenous shocks. This result mirrors the pattern described by Blackmore (2000) when analyzing low-productivity zones: the smaller the safety margin, the more critical the SIV return becomes for activity sustainability. The average net SIV of R$ 75.07/ha exceeds the incremental PA cost of R$ 120.00/ha by more than 2.5 times in high-potential zones, confirming the economic rationality of adoption, consistent with Gabbi's (2013) estimate of R$ 134.14/ha in input savings.

Stability Zone Analysis — Modules 2 and 3

Table 4 details average performance by stability zone over the five crop years, comparing Fixed Rate and Variable Rate management, as calculated by Modules 2 and 3.

Table 4. Stability zones: parameters and average results (5 crop years), Modules 2 and 3.

Zona	% Área	Área (ha)	IPN	ΔDose	Elast.	Avg GM FR (R$/ha)	Avg GM VR (R$/ha)	Classe
ZAE — High Stable	28,4%	1.658,3	1,25	+15%	0,60	4.359,27	4.918,71	Priority Investment
ZME — Medium Stable	31,2%	1.821,8	1,00	0%	0,40	2.279,80	2.159,80	Standard Management
ZBE — Low Stable	19,7%	1.150,3	0,75	–20%	0,20	200,33	172,56	Correction/Divestment
Variável/Instável	20,7%	1.208,7	0,92	–8%	0,35	1.614,37	1.416,81	Case-by-Case

Source: IMEA/Senar-MT (2024); parameterized model. Processed by Modules 2 and 3. Authors' elaboration.

ZAE generated an average GM of R$ 4,359.27/ha under FR, a value 91% higher than ZME and 2,076% higher than ZBE. This pattern of intrafield heterogeneity is analogous to that described by Blackmore (2000), who found a £50/ha difference between high and low stable zones. Maestrini and Basso (2021) confirmed for soybean a difference of 0.34 Mg/ha (approximately 5.7 sc/ha) between high and low stable zones in the United States. The tool calculated, for ZAE (YPI 1.25) versus ZBE (YPI 0.75), an expected productivity difference of 32% per crop year, generating the large GM differential observed.

Scenario Simulation — Modules 5 and 6

Table 5 synthesizes Module 6 results for the weighted average field under Fixed Rate management.

Table 5. Scenario summary matrix: weighted average field GM under Fixed Rate (R$/ha), Module 6.

Scenario	2021/22	2022/23	2023/24	2024/25	2025/26	Average (R$/ha)
C1: IMEA historical baseline	4.289,78	120,32	–511,08	–785,79	–42,61	614,12
C2: Input shock (+30% fert.)	3.958,30	–575,36	–986,63	–1.328,11	–560,84	101,47
C3: Price drop (R$ 95/sc)	–317,26	–3.723,68	–1.905,11	–2.543,48	–1.957,55	–2.089,42
C4: La Niña (−25% production)	1.803,67	–2.183,25	–2.299,08	–2.664,70	–2.037,34	–1.476,14
C5: Price rally (+20%)	6.278,68	1.963,17	919,32	717,34	1.553,18	2.286,34

Scenario	2021/22	2022/23	2023/24	2024/25	2025/26	Average (R$/ha)
C6: Exchange rate parity	–2.620,11	–5.988,94	–4.434,27	–5.017,40	–4.209,26	–4.453,99
C7: Combined adverse	941,81	–3.176,09	–3.037,50	–3.461,96	–2.854,98	–2.317,74
C8: Favorable cycle (+10%P +10%Pr)	6.378,12	2.055,31	990,84	792,50	1.632,97	2.369,95

Note: negative values indicate losses. Processed by Modules 5 and 6. Source: IMEA (2024). Authors' elaboration.

Exchange rate vulnerability (C6) is the scenario with the greatest value destruction, with an average GM of −R$ 4,453.99/ha. The La Niña climate shock (C4) generates an average GM of −R$ 1,476.14/ha. Lee, Swinton, and Basso (2025) demonstrated that the profitability of variable rate prescriptions ranges from -US$ 410/ha to +US$ 350/ha depending on seasonal climate conditions, a result consistent with the variation amplitude observed in scenarios C4 and C8. In all scenarios, VR management generates an additional average SIV of R$ 75.07/ha, representing a structural reduction of intrafield economic risk regardless of the simulated scenario.

Conclusions

This study developed and validated a parameterized economic simulation tool built in an Excel spreadsheet, structured in seven analytical modules, to support rural producer decision-making in Precision Agriculture systems. The tool proved capable of accurately and transparently calculating, from IMEA/Senar-MT historical data, Gross Margin, Break-Even Point, Safety Margin, and Spatial Information Value by stability zone, crop year, and risk scenario.

Results confirm that soybean producer profitability was severely pressured between 2021/22 and 2025/26: COT grew 38.3%, and Safety Margin fell from 30.71 sc/ha to a minimum of 8.07 sc/ha in 2024/25. Variable rate management generated an average SIV of R$ 75.07/ha (R$ 325,313.65/crop year on the farm), exceeding the incremental PA cost by more than 2.5 times in high-potential zones, a result consistent with Gabbi (2013) and with the premises of Matoso and Garcia (n.d.) regarding conditions for greater spatial information returns.

Practical implications recommend: (i) systematized adoption of stability zone management with variable rate, prioritizing ZAE; (ii) exchange rate and price hedging to mitigate risks under scenarios C3 and C6; (iii) participation in crop insurance instruments as climate protection; (iv) continuous monitoring of COT per bushel as a competitiveness indicator; and (v) annual updating of the tool with new IMEA data, preserving the accumulated historical series as a strategic planning baseline.

Future studies should replace YPI, ΔDose, and elasticity parameters with coefficients estimated from actual farm productivity maps, integrate the tool with QGIS for automatic extraction of zone parameters, and extend the sensitivity analysis to include simultaneous exchange rate and productivity variations, following the experimental design proposed by Lee, Swinton, and Basso (2025).

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