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Viabilidade econômica do sistema de colheita mecanizado por enfardamento de palhiço de cana-de-açúcar (*Saccharum* spp.) em caixa financeiro de uma usina

Economic viability of the mechanized harvesting system by baling sugarcane straw (*Saccharum* spp.) in a mill's cash flow

[1] Autor para correspondência, Doutor em Engenharia Agrícola, Universidade Federal do Piauí, Campus Ministro Petrônio Portella, Departamento de Engenharia Agrícola e Solos, Teresina, PI; neisvaldo@gmail.com

Neisvaldo Barbosa dos SANTOS[1]

[1] "Autor para correspondência", Doutor em Engenharia Agrícola, Universidade Federal do Piauí, Campus Ministro Petrônio Portella, Departamento de Engenharia Agrícola e Solos, Teresina, PI. e-mail: neisvaldo@gmail.com

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Resumo

O Brasil é o maior produtor mundial de cana-de-açúcar para as usinas produtoras de açúcar, álcool e bioenergia. As usinas têm levado em consideração os custos de produção para facilitar o controle financeiro, a fim de auxiliar em tomadas de decisões para rentabilizar a atividade agrícola e deixá-las cada vez mais fortes e competitivas no mercado. As usinas investem na aquisição de tratores agrícolas, ancinhos enleiradores, enfardadoras, recolhedoras, carregadoras e caminhões para a colheita mecanizada por enfardamento de palhiço de cana, com o propósito de obter ganhos econômicos com a comercialização de energia elétrica e de etanol de segunda geração. Entretanto, a aquisição dessas máquinas agrícolas, requer alto investimento sobre o fluxo de caixa projetado da usina. Devido a isso, este trabalho teve como objetivo identificar a viabilidade econômica do sistema de colheita mecanizado por enfardamento de palhiço de cana-de-açúcar para o caixa financeiro da usina. A metodologia empregada considera os custos de implantação e cultivo da lavoura de safras futuras projetadas, a metodologia de análise de custo e os mecanismos referenciadores, sendo nela utilizados dados secundários. Para a geração de dados do sistema de colheita mecanizado de cana-de-açúcar foi adotado, como sendo uma plataforma gerencial, o modelo computacional "*ColhePalhiçodeCana*". Os resultados evidenciaram que, o sistema de colheita mecanizado alcançou o ponto de equilíbrio na quarta colheita/ano de safra.

Palavras-chave adicionais: administração financeira; cogeração; mecanização agrícola; ponto de equilíbrio; planejamento e gerenciamento.

Abstract

Brazil is the world's largest producer of sugarcane for sugar, ethanol, and bioenergy production. Processing mills have increasingly analyzed production costs to improve financial control and support decision-making aimed at enhancing profitability and market competitiveness. To capture additional economic returns from electricity sales and second-generation ethanol production, mills invest in agricultural tractors, rakes, balers, harvesters, loaders, and transport trucks for mechanized collection and baling of sugarcane straw. However, acquisition of this machinery requires substantial capital allocation within projected cash flow structures. This study aimed to evaluate economic viability of a mechanized sugarcane straw baling harvesting system in relation to mill cash flow performance. Methodological procedures included estimation of crop establishment and cultivation costs for projected harvest cycles, application of cost-analysis frameworks, and use of secondary data sources. Operational data for mechanized sugarcane harvesting were generated using the "*ColhePalhiçodeCana*" computational model as a management support platform. Results indicated that the mechanized harvesting system reached the break-even point in the fourth harvest.

Additional keywords: financial management; cogeneration; agricultural mechanization; break-even analysis; planning and management.

Introduction

In Brazil, the estimated area cultivated with sugarcane in the 2024/2025 crop season is 8.63 million hectares, with projected production of 689.80 million tons (CONAB, 2024). Brazil remains the world's largest producer of sugarcane, supplying raw material for sugar, ethanol, and electricity cogeneration. Production of these outputs involves substantial operational expenditures. Consequently, processing mills have increasingly incorporated production cost analysis into financial control practices to support decision-making and improve profitability and market competitiveness (Santos and Nascimento, 2021).

Production costs generally comprise fixed and variable components associated with land use, agricultural operations, and input acquisition, as well as operational expenses related to asset depreciation, infrastructure improvements, and labor requirements (Pereira et al., 2015). In sugar-energy production systems, cultivation costs include expenditures on agrochemicals, soil amendments, fertilizers, agricultural machinery and implements, and contracted services for soil preparation, planting, crop management, and harvesting operations (Oliveira and Nachiluk, 2011). Within this cost structure, agricultural mechanization represents a major economic constraint, accounting for a significant share of total production costs, particularly during harvesting stages (Pecege, 2012).

Mechanized collection and baling of sugarcane straw has emerged as a sustainable biomass management strategy and an economically attractive alternative for processing mills. Sugarcane straw constitutes an important feedstock for electricity generation and second-generation ethanol production, thereby contributing to expansion and technological modernization of sugar-energy facilities in Brazil (Piracicaba Engenharia, 2020). Accordingly, mills have increased investment in mechanized straw harvesting systems to enhance revenue from electricity sales to energy distribution networks and from advanced biofuel markets.

However, acquisition of specialized machinery for mechanized sugarcane straw baling systems requires substantial capital investment. Even when financed, such investments impose long-term financial commitments that directly affect projected cash flow performance. Previous studies have emphasized importance of evaluating economic feasibility of agricultural production systems through cost-analysis indicators, including internal rate of return and net present value, as well as reference metrics such as benefit-cost ratio and discounted payback period (Fernandes et al., 2016; Ávila et al., 2017; Araújo et al., 2018; Pereira et al., 2018; Konopatzki et al., 2022). Using these analytical approaches, Santos and Nascimento (2021) demonstrated greater economic feasibility of mechanized harvesting systems equipped with two-row harvesters compared with single-row configurations.

Despite potential economic benefits, high capital requirements associated with mechanized sugarcane straw baling systems highlight need for robust financial feasibility assessments. Therefore, this study aimed to evaluate economic viability of a mechanized sugarcane straw baling harvesting system in relation to projected mill cash flow.

Materials and Methods

This study adopted a case study approach based on secondary data obtained from published sources on sugarcane production costs in the state of São Paulo. These data refer to crop management practices and estimated production expenditures reported by CONAB (2023).

The analysis considered a representative processing unit, here defined as the Brazilian Standard Mill, operating an owned cultivated area of 22,000 ha dedicated to sugarcane production, harvesting operations, industrial processing, and electricity cogeneration. For analytical purposes, six harvests of sugarcane straw recovery were evaluated, with biomass allocated exclusively to electricity cogeneration. Average straw yield was assumed to be 15 t ha^{-1}, with a windrow width of 7.6 m, an effective windrow pickup width of 1.4 m, and a total straw recovery rate of 40%.

For the projected 2024 harvest, the electricity sale price received by the mill was assumed to be US$ 67.24 MWh^{-1}, based on market information reported by CANALENERGIA (2022). For the projected 2025 cycle, the electricity price was estimated using a relative increase of 30.13%, calculated from the difference between the reference price of US$ 67.24 MWh^{-1} for 2024 and the previously observed market price of US$ 51.67 MWh^{-1} (FORBES, 2021).

Electricity price projections for subsequent harvests (2026-2029) were determined by applying the same relative increase of 30.13% to the price estimated for the immediately preceding cycle. This procedure enabled construction of a forward price trajectory for electricity cogeneration revenues within the financial feasibility analysis.

Initially, a baseline scenario was defined through tabulation of secondary data in spreadsheet format and application of the "*ColhePalhiçodeCana*" computational model. This model was selected because it incorporates the fundamental operational characteristics of mechanized sugarcane straw harvesting by baling. The platform was developed using Excel® spreadsheets integrated with routines programmed in the Visual Basic® language.

The "*ColhePalhiçodeCana*" model was structured to include modules for climatic planning, operational performance, economic performance, and electricity cogeneration analysis, as well as estimation of gross and net revenues associated with bioenergy production. Climatic planning followed the methodological framework proposed by Mialhe (1974) to estimate effective field time available for straw harvesting operations. Operational performance parameters were based on approaches described by Mialhe (1974), Ripoli and Ripoli (2009), Carreira (2010), and Santos et al. (2022; 2023), enabling determination of required mechanized sets, including tractor-rake, tractor-baler, tractor-trailer collector, loader, and transport truck configurations.

Economic performance assessment was conducted according to cost-engineering procedures outlined by Mialhe (1974), Balastreire (1990), Banchi et al. (2008), Carreira (2010), ASABE (2011), Goodyear (2017), and Rosa (2017). These procedures supported estimation of hourly fixed costs, fuel consumption costs, repair and maintenance expenditures, hourly variable costs, total operational costs, and unit production costs associated with machinery use. Electricity cogeneration estimates during harvest seasons were derived from the adjusted methodology proposed by Ripoli and Ripoli (2009), while revenue projections from electricity generation during the harvest seasons were based on analytical approaches reported by Santos et al. (2015; 2017), Santos (2018; 2019), and Santos et al. (2022; 2023).

The "*ColhePalhiçodeCana*" platform was applied as a decision-support tool to generate operational and financial data related to machinery sizing, equipment production costs, electricity generation during the harvest season, and projected gross and net revenues from cogeneration activities. Initial capital values for the mechanized harvesting system were estimated based on price quotations obtained from national dealerships representing major agricultural machinery manufacturers.

Secondary cost data were organized to construct production projections for harvest cycles from 2024 to 2029. For each projected cycle of the Brazilian Standard Mill, owned cultivated land and outsourced mechanized services for periodic soil preparation, planting, and crop management were considered, following cost estimates reported by CONAB (2023). Labor and agricultural inputs were assumed to be supplied internally by the mill and were incorporated into total production cost structures for each projected cycle, as per estimates.

Regarding sugarcane straw harvesting operations, the mill was assumed to acquire mechanized baling system equipment at the beginning of the analysis period, including rakes, balers, collector trailers, loaders, and transport trucks. Capital investment was structured with 80% financed through internal cash flow resources and the remaining 20% obtained via agricultural machinery credit lines.

Costs of crop establishment and cultivation for projected harvests

Estimates of crop establishment and cultivation costs were based on secondary data derived from harvests between 2018 and 2023, as reported by CONAB (2023). Secondary data refer to previously published cost information available in scientific and technical literature. These data were used to project establishment and cultivation expenditures for the Brazilian Standard Mill across six future harvests, covering the period from 2024 to 2029 (Table 1). Projected cost structures included expenditures related to machinery and service leasing, labor, farm management personnel, planting material (seed-cane), fertilizers, agrochemicals, administrative overheads, and other operational inputs.

Table 1 *- Planting and cultivation costs for projected harvests from 2024 to 2029*.

Tabela 1 - Custos de implantação e cultivo da lavoura para as safras futuras projetadas de 2024 a 2029.

-	Harvest 2024	Harvest 2025	Harvest 2026	Harvest 2027	Harvest 2028	Harvest 2029
Crop Production Cost (US\$ ha^{-1})	473.71	464.19	472.76	478.86	887.43	735.24

Source: CONAB (2023)

Cost analysis methodology

Application of cost-accounting procedures in agricultural production systems depends on decision needs of the economic agents involved. Information derived from cost estimation supports short-term managerial decision-making, long-term business sustainability assessments, evaluation of financing capacity, verification of project feasibility or potential discontinuation of production activities, and identification of profitability drivers within production systems (PEREIRA *et al.,* 2015). Pereira *et al.* (2015) also highlighted that long-term financial performance is closely associated with relationships between cash flow generation and profit formation. Discounted cash flow techniques can therefore be applied to estimate economic performance of sugarcane production systems. In this study, the analysis incorporated both crop production costs and capital expenditures associated with mechanized sugarcane straw harvesting by baling. Financial feasibility was assessed using net present value (NPV) and internal rate of return (IRR) indicators. These metrics account for the time value of money and enable comparison between initial capital investment and periodic net cash inflows generated by the project (SENAR, 2016).

The IRR represents expected annualized return of the investment over the defined analytical horizon. It is determined by the discount rate that equalizes present value of projected net cash flows with initial capital outlay, as described by Assaf Neto (2010), Gitman (2010), and SENAR (2016) (Equation 1).

$$\mathrm{IRR} = \sum_{t=1}^{n} \frac{\mathrm{CF_t}}{(1 + \mathrm{IRR})^t} = 0 \qquad (1)$$

Wherein: IRR is the internal rate of return (%), CF_t represents the initial investment (negative cash flow) and the projected revenues of the plant’s cash flow over time (US\$), 0 is the result of the equation (US\$), and t denotes the time horizon (in months).

The NPV indicates whether a project generates positive or negative economic returns over a defined analytical horizon, considering the capital invested in its implementation (SENAR, 2016). According to

Sandroni et al. (1999), NPV corresponds to the present value of expected future cash inflows discounted at an appropriate interest rate, minus the present value of total investment costs.

NPV was calculated as the discounted sum of projected net cash flows generated by the processing mill over the analysis period, using a discount rate that reflects the opportunity cost of capital, following the methodological approaches proposed by Assaf Neto (2010), Gitman (2010), and SENAR (2016) (Equation 2).

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1 + i)^t} \quad (2)$$

Wherein: NPV is the net present value (US$); CF_t is the present value of the plant's projected cash flow (US$); i represents the initial investment (initial capital outlay) (US$); and t is the time horizon (in months).

Reference mechanisms

The benefit-cost (B/C) ratio is used to indicate, over the defined analytical horizon of the investment project, the economic return generated per monetary unit invested. This indicator expresses how much value is created in monetary terms for each US$ 1.00 allocated to the project, following the conceptual approach described by Assaf Neto (2010) and SENAR (2016).

The B/C ratio was calculated as the relationship between the NPV of the project and the value of the initial investment, according to the methodological framework proposed by Assaf Neto (2010) and SENAR (2016) (Equation 3).

$$B/C = \frac{NPV}{P0} + 1 \quad (3)$$

Wherein: B/C is the benefit-cost ratio (US$), NPV is the net present value (US$), and P0 is the initial investment value (US$).

The discounted payback is a parameter used to determine the time required to recover the capital applied (Assaf Neto, 2010; Ramos, 2016). It is calculated based on the initial investment (capital contribution) and NPV from annual net cash flows, considering the time, expressed in months, required for the processing mill to recover the capital invested in acquisition of the mechanized sugarcane straw baling harvesting system, according to the methodological approach proposed by SENAR (2016).

The discounted payback period is determined by cumulative comparison between the initial investment and the discounted NPV values generated over the defined analytical horizon, following the procedures described by Assaf Neto (2010), Gitman (2010), and SENAR (2016) (Equation 4).

$$\textit{Discounted payback} = \frac{P0}{(NPV + P0) \div t} + 1 \qquad (4)$$

Wherein: *Discounted payback* is the time required to recover the investment made (in months), P0 is the initial amount invested (US$), NPV is the net present value (US$), and t is the analytical time horizon (months).

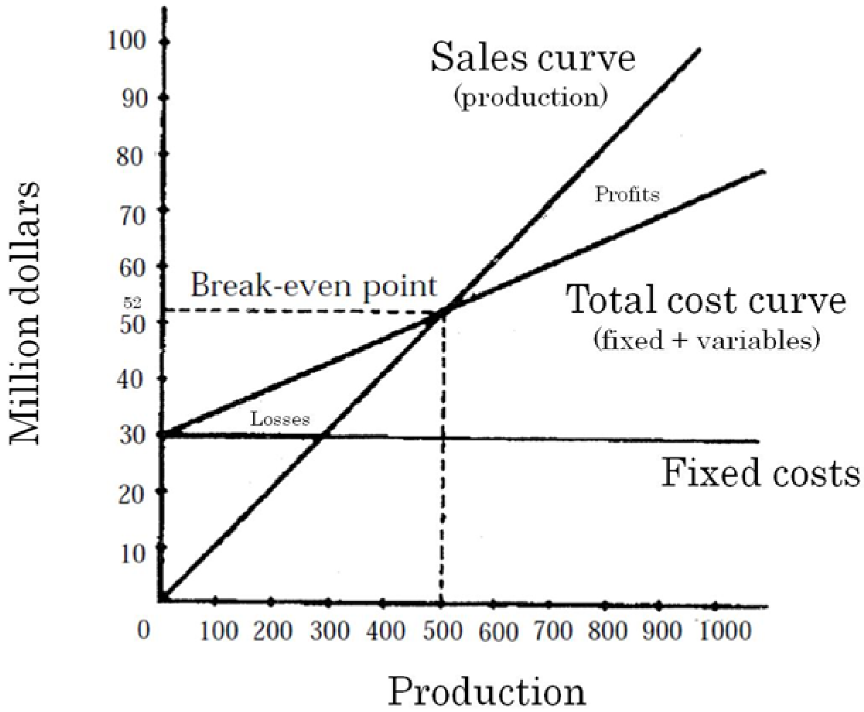
The break-even point indicates the quantity of product units (expressed as gross revenue from electricity cogeneration during the harvest period) that must be generated to cover the processing mill's operating costs. In other words, it represents the level at which total revenues are equal to total costs. It is calculated as the ratio between total costs per period and the unit price of the product, defined as the electricity tariff paid to the mill per megawatt-hour generated, following the methodological approach proposed by SENAR (2016) (Equation 5).

$$\textit{Break-even point} = \frac{TC}{UP} \qquad (5)$$

Wherein: *Break-even point* represents the quantity of electricity generated during the harvest period (MWh $year^{-1}$), TC is the total cost per period (US$ $year^{-1}$), and UP is the unit price of electricity received by the processing mill, expressed as the tariff paid by the electricity distributor (US$ MWh^{-1}).

For determination of the break-even point, the unit price (UP) was considered, defined as the average electricity tariff paid to the processing mill by the power distribution company, amounting to US$ 143.41 MWh^{-1}.

According to Sandroni et al. (1999), the break-even point represents the production level at which a company neither generates profit nor incurs loss. Above this threshold, operating revenues exceed total costs and the enterprise begins to generate profits, whereas production levels below this point result in financial losses. In addition, break-even analysis can be used to estimate approximate profit or loss outcomes associated with different production levels (Figure 1).



Source: Adapted from Sandroni *et al.* (1999)

Figure 1 *- Break-even point illustration*.

Figura 1 - Demonstração do ponto de equilíbrio.

Results and Discussion

For analysis of the Brazilian Standard Mill, a baseline scenario was adopted, considering implementation of the mechanized sugarcane straw harvesting system based on baling operations.

Under this baseline scenario, agronomic, operational, and electricity cogeneration variables associated with projected harvests are presented (Table 2). Equipment sizing results indicated the operational requirement of one rake, two balers, four collector trailers, two loaders, and two transport trucks for execution of straw recovery activities.

Table 2 *- Input and output data for agronomic, operational, and electricity cogeneration variables across projected harvests*.

Tabela 2 - Dados de entrada e saída das variáveis agronômica, agrícola e de cogeração das safras futuras projetadas.

Agronomic	Harvest 2024	Harvest 2025	Harvest 2026	Harvest 2027	Harvest 2028	Harvest 2029
Harvested area (ha)	22,000	22,000	22,000	22,000	22,000	22,000
Windrow width (m)	7.6	7.6	7.6	7.6	7.6	7.6
Effective windrow pickup width (m)	1.4	1.4	1.4	1.4	1.4	1.4
Average straw yield (t ha^{-1})	15	15	15	15	15	15
Total straw recovery rate (%)	40	40	40	40	40	40
Straw production (t)	132,000	132,000	132,000	132,000	132,000	132,000
Operational	**Harvest 2024**	**Harvest 2025**	**Harvest 2026**	**Harvest 2027**	**Harvest 2028**	**Harvest 2029**
Initial tractor cost (US$)	35,619					
Initial rake cost (US$)	81,905					
Initial tractor cost (US$)	127,331					
Initial baler cost (US$)	228,571					
Initial tractor cost (US$)	127,331					
Initial straw collector cost (US$)	171,429					
Initial loader cost (US$)	95,238					
Initial truck tractor (prime mover) cost (US$)	113,333					
Initial semi-trailer cost (US$)	36,190					
Number of windrow rakes	1	1	1	1	1	1
Number of balers	2	2	2	2	2	2
Number of straw collectors	4	4	4	4	4	4
Number of loaders	2	2	2	2	2	2
Number of transport trucks	2	2	2	2	2	2
Operational production cost of rake (US$ t^{-1})	0.32	0.32	0.32	0.32	0.32	0.32
Operational production cost of baler (US$ t^{-1})	1.96	1.96	1.96	1.96	1.96	1.96
Operational production cost of straw collector (US$ t^{-1})	3.46	3.46	3.46	3.46	3.46	3.46
Operational production cost of loader (US$ t^{-1})	1.24	1.24	1.24	1.24	1.24	1.24
Operational production cost of truck (US$ t^{-1})	2.68	2.68	2.68	2.68	2.68	2.68
Total investment in mechanized harvesting system (US$)	2,586,274					
Total operational cost of mechanized harvesting system (US$)	1,274,344	1,274,344	1,274,344	1,274,344	1,274,344	1,274,344
Electricity cogeneration	**Harvest 2024**	**Harvest 2025**	**Harvest 2026**	**Harvest 2027**	**Harvest 2028**	**Harvest 2029**
Total electricity generated during harvest season (MWh)	176,000	176,000	176,000	176,000	176,000	176,000
Electricity tariff paid to the mill by the utility company (US$ MWh^{-1})	67.24	87.50	113.86	148.16	192.80	250.90

Source: The Author

The operational production costs associated with the rake, baler, straw collector, loader, and transport truck were US$ 0.32, 1.96, 3.46, 1.24, and 2.68 t^{-1}, respectively. The total cost of the mechanized harvesting system required to perform straw recovery operations was US$ 1,274,344.

Total electricity generation during the harvest season was estimated at 176,000 MWh. The electricity tariffs received by the processing mill in the projected harvests of 2024, 2025, 2026, 2027, 2028, and 2029 were estimated at US$ 67.24, US$ 87.50, US$ 113.86, US$ 148.16, US$ 192.80, and US$ 250.90 MWh^{-1}, respectively.

Figure 2 presents the data structure generated by the *"ColhePalhiçodeCana"* computational model.

Dados de Entrada-Cenário Modelo

Item	Variável	Sigla	Unidade	SCMPC								
				Trator	Ancinho	Trator	Enfardadora	Trator	Recolhedora	Carregadora	Cavalo Mecânico	Semirreboque
PLANEJAMENTO – Clima	Tempo Disponível (Inserir os Dados dos Meses de Safra da Colheita do Palhiço)	TD	h	4.680								
Cultura	Área a ser Colhida	AC	ha	22.000								
	Produtividade Média do Canavial	PMC	$t\ ha^{-1}$	100								
	Produtividade Média do Palhiço	PMP	$t\ ha^{-1}$	15								
Econômico	Valor Inicial	VI	R$	187.000	430.000	668.490	1.200.000	668.490	900.000	500.000	595.000	190.000
	Valor Final	VF	Decimal	0,30	0,20	0,30	0,30	0,30	0,25	0,30	0,50	0,50
	Vida Útil em Anos	VUA	Ano	10	10	10	10	10	10	10	8	8
	Vida Útil em Horas/Quilômetro	VUH/VUQ	h/km	12.000	2.500	12.000	3.000	12.000	3.000	12.000	500.000	250.000
	Juro ao Ano	i	Decimal	0,1350	0,1350	0,1350	0,1350	0,1350	0,1350	0,1350	0,1500	0,1500
	Alojamento, Seguro e Taxas	AST	Decimal	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,04	0,03
	IPVA e Licenciamento	LIC	R$	-	-	-	-	-	-	-	2.756	756
	Fator de Reparo e Manutenção	FRM	Decimal	1,00	0,60	1,00	0,75	1,00	0,80	1,00	1,00	1,00
	Preço do Pneu Novo	PPN	R$	-	-	-	-	-	-	-	1.920	1.400
	Preço do Pneu Recapado	PPR	R$	-	-	-	-	-	-	-	620	520
	Preço do Combustível	PL	$R\$\ L^{-1}$	5,68								
	Fator de Consumo (Consumo Médio / Cons. Estimado (L h))	FC	$L\ h^{-1}/km\ L^{-1}$	4,0		5,0		5,0		6,0	1,0	
Características Técnicas/Operacionais/Energética	Velocidade de Operação	VEL	$km\ h^{-1}$	10,0		5,0		6,0		-	40,0	
	Largura Efetiva de Trabalho	LET	m	9,0		-		-		-	-	
	Largura de Faixa do Enleiramento/Largura Efetiva do Enleiramento	LFE/LEE	m	-		7,6	1,4	-		-	-	
	Eficiência de Campo/Eficiência de Disponibilidade	EFC/EFD	Decimal	0,8		0,8		0,8		0,8	0,7	
	Capacidade Total de Carga	CTCr/CTCc	t	-		-		7,0		-	33	
	Jornada de Trabalho	JT	h	-		-		-		-	24	
	Potência no Motor do Trator Agrícola/Carregadora/Caminhão	POT	cv	76		220		223		90	420	
	Massa Média do Fardo	MMF	kg	-		475		-		-	-	
	Tempo de Espera para Recolher o Fardo no Talhão	TEr	s	-		-		33		-	-	
	Tempo de Descarregamento	TDr/TDc	min	-		-		1,5		-	40	
	Distância Média entre o Talhão e o Carreador	DMTC	m	-		-		100		-	-	
	Tempo Médio para Carregar o Fardo de Palhiço no Caminhão	TMCFPC	min	-		-		-		1,5	-	
	Tempo de Carregamento	TC	min	-		-		-		-	40	
	Raio Médio da Distância	RMD	km	-		-		-		-	20	
	Vida Útil do Pneu Novo	VUPN	km	-		-		-		-	80.000	80.000
	Vida Útil do Pneu Recapado	VUPR	km	-		-		-		-	75.000	75.000
	Número de Pneus	NP	Número	-		-		-		-	10	32
	Número de Recapagens do Pneu	NRP	Número	-		-		-		-	2	2
	Taxa de Recolhimento Total de Palhiço	TRTP	Decimal	0,4								
	Poder Calorífico do Palhiço	PCP	$MJs\ t^{-1}$	12.000								
	Rendimento do Conjunto Caldeira e Turbina da Usina na Cogeração de Energia Elétrica	RCCTUCEE	Decimal	0,4								
	Preço do Megawatt Pago a Usina pela Empresa de Energia Elétrica	PMPUEEE	$R\$\ MWh^{-1}$	271,26								

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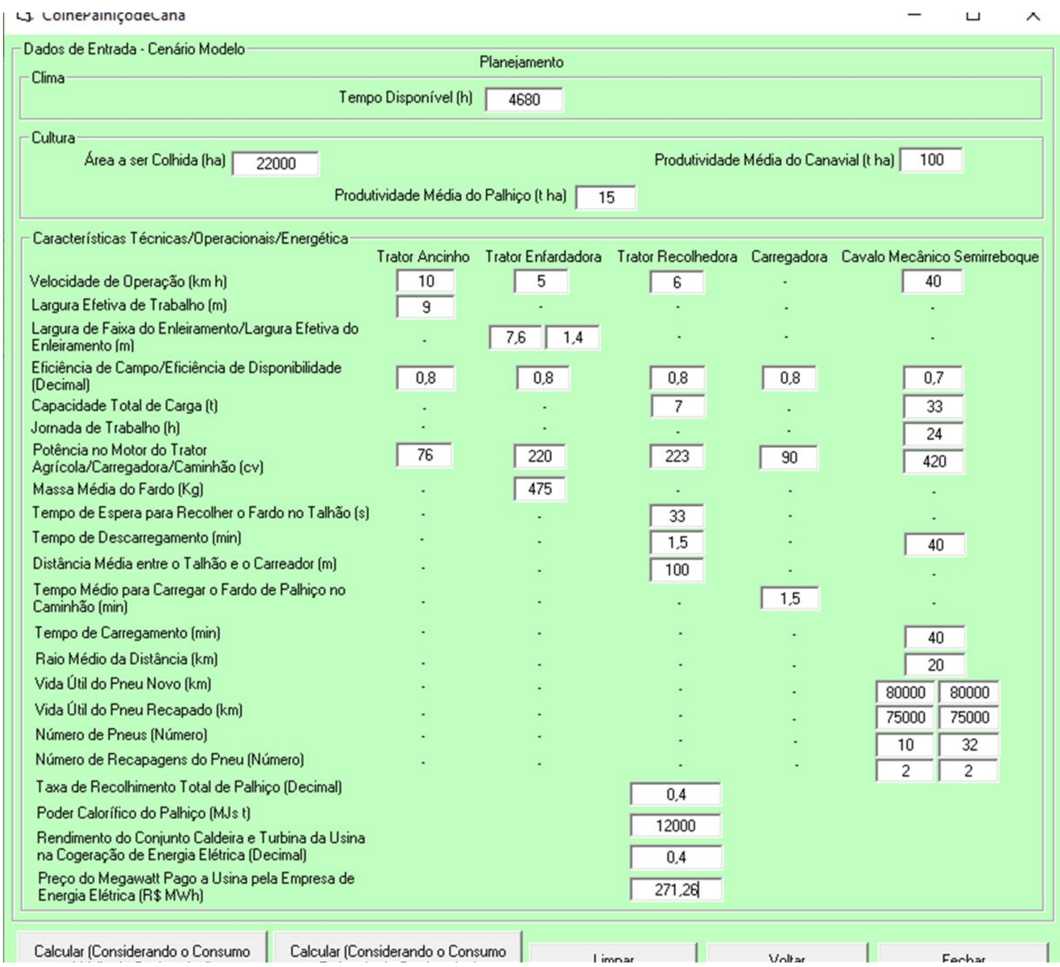
Source: The Author

Item	Variável	Sigla	Unidade	SCMPC Trator	Ancinho	Trator	Enfardadora	Trator	Recolhedora	Carregadora	Cavalo Mecânico	Semirreboque
	Dados de Saída-Cenário Modelo											
RESULTADOS – Agronomia	Tempo Disponível	TD	Dia						195			
	Ritmo Operacional	RO	ha h^{-1}						4,70			
	Ritmo de Produção de Palhiço	RPP	t h^{-1}						28			
	Produção de Cana	PC	t						2.200.000			
	Produção de Palhiço	PP	t						132.000			
Desempenho Operacional	Capacidade de Campo Efetiva	CCE	ha h^{-1}	9,00		4,50		-		-	-	
	Capacidade de Campo Operacional	CCO	ha h^{-1}	7,20		3,60		-		-	-	
	Capacidade de Enleiramento Operacional	CEO	t h^{-1}	108,00		-		-		-	-	
	Número de Cargas e Descargas	NCD	Número/Número Dia^{-1}	-		-		47.143		-	7	
	Tempo de Carregamento	TCr	min	-		-		7,78		-	-	
	Tempo Total do Ciclo de Carregamento e Descarregamento	TTCCD	min/h	-		-		11,83		-	2,33	
	Cap. de Prod. Operacional/Oper. de Recol./Oper. de Carreg./Oper. de Transp.	CPOe/COr/COc/COt	t h^{-1}	-		54,00		28,41		15,20	9,90	
	Horas Trabalhadas	HT	h	3.056		6.111		8.861		8.684	-	
	Horas Máquina	HM	h Ano^{-1}	3.056		3.056		2.215		4.342	-	
	Número de Máquinas	NM	Número	1		2		4		2	2	
	Dist. Total Trafegada no Talhão/na Safra	DTTT/DTTS	km/km Ano^{-1}	24.444		24.444		33.873		-	56.160	
Desempenho Econômico	Custo Fixo Anual	CFA	R$ Ano^{-1}	33.239	77.830	118.824	213.300	118.824	161.438	88.875	130.681	39.706
	Custo Fixo Horário/Custo Fixo	CFH/CF	R$ h^{-1}/R$ km^{-1}	10,88	25,47	38,89	69,81	53,64	72,87	20,47	2,33	0,71
	Depreciação	DPA	R$ Ano^{-1}	13.090	34.400	46.794	84.000	46.794	67.500	35.000	37.188	11.875
			R$ h^{-1}/R$ km^{-1}	4,28	11,26	15,31	27,49	21,12	30,47	8,06	0,66	0,21
	Juros Anual	JRA	R$ Ano^{-1}	16.409	34.830	58.660	105.300	58.660	75.938	43.875	66.938	21.375
			R$ h^{-1}/R$ km^{-1}	5,37	11,40	19,20	34,46	26,48	34,28	10,10	1,19	0,38
	Alojamento, Seguro e Taxas	AST	R$ Ano^{-1}	3.740	8.600	13.370	24.000	13.370	18.000	10.000	23.800	5.700
			R$ h^{-1}/R$ km^{-1}	1,22	2,81	4,38	7,85	6,04	8,13	2,30	0,42	0,10
	IPVA e Licenciamento	LIC	R$ Ano^{-1}	-	-	-	-	-	-	-	2.756	756
			R$ km^{-1}	-	-	-	-	-	-	-	0,05	0,01
	Consumo de Combustível	CB	L t^{-1}	0,04		0,30		0,58		0,42	1,11	
			L h^{-1}/km L^{-1}	4,28		16,26		16,48		6,43	1,09	
	Custo com Combustível	CCB	R$ h^{-1}/R$ km^{-1}	24,30		92,35		93,60		36,50	5,21	
	Custo com Reparo e Manutenção por Hora/por Quilômetro	CRMH/CRMQ	R$ h^{-1}/R$ km^{-1}	15,58	103,20	55,71	300,00	55,71	240,00	41,67	1,19	0,76
	Custo com Reparo e Manutenção por Ano	CRMA	R$ Ano^{-1}	47.616	315.333	170.217	916.667	123.408	531.667	180.921	66.830	42.682
	Custo com Reparo e Manutenção do Pneu Novo	CRMPN	R$ km^{-1}	-	-	-	-	-	-	-	0,24	0,56
	Custo com Reparo e Manutenção do Pneu Recapado	CRMPR	R$ km^{-1}	-	-	-	-	-	-	-	0,17	0,44
	Custo Horário/por Quilômetro	CH/CQ	R$ h^{-1}/R$ km^{-1}	50,77	128,67	186,94	369,81	202,95	312,87	98,63	9,13	2,47
	Custo Operacional	CO	R$ ha^{-1}/R$ km^{-1}	24,92		154,65		143,28		-	11,60	
	Custo Operacional de Produção	COP	R$ t^{-1}	1,66		10,31		18,16		6,49	14,07	
Cogeração	Energia Total Gerada na Safra	ETGS	MWh						176.000			
	Custo com os Equipamentos	CE	R$	219.312		1.360.940		2.396.848		856.563	1.856.645	
	Custo Total com os Equipamentos	CTE	R$						6.690.307			
	Renda Bruta da Usina com a Cogeração	RBUCG	R$						47.741.760			
	Renda Líquida da Usina com a Cogeração	RLUCG	R$						41.051.453			

a

Source: The Author



b

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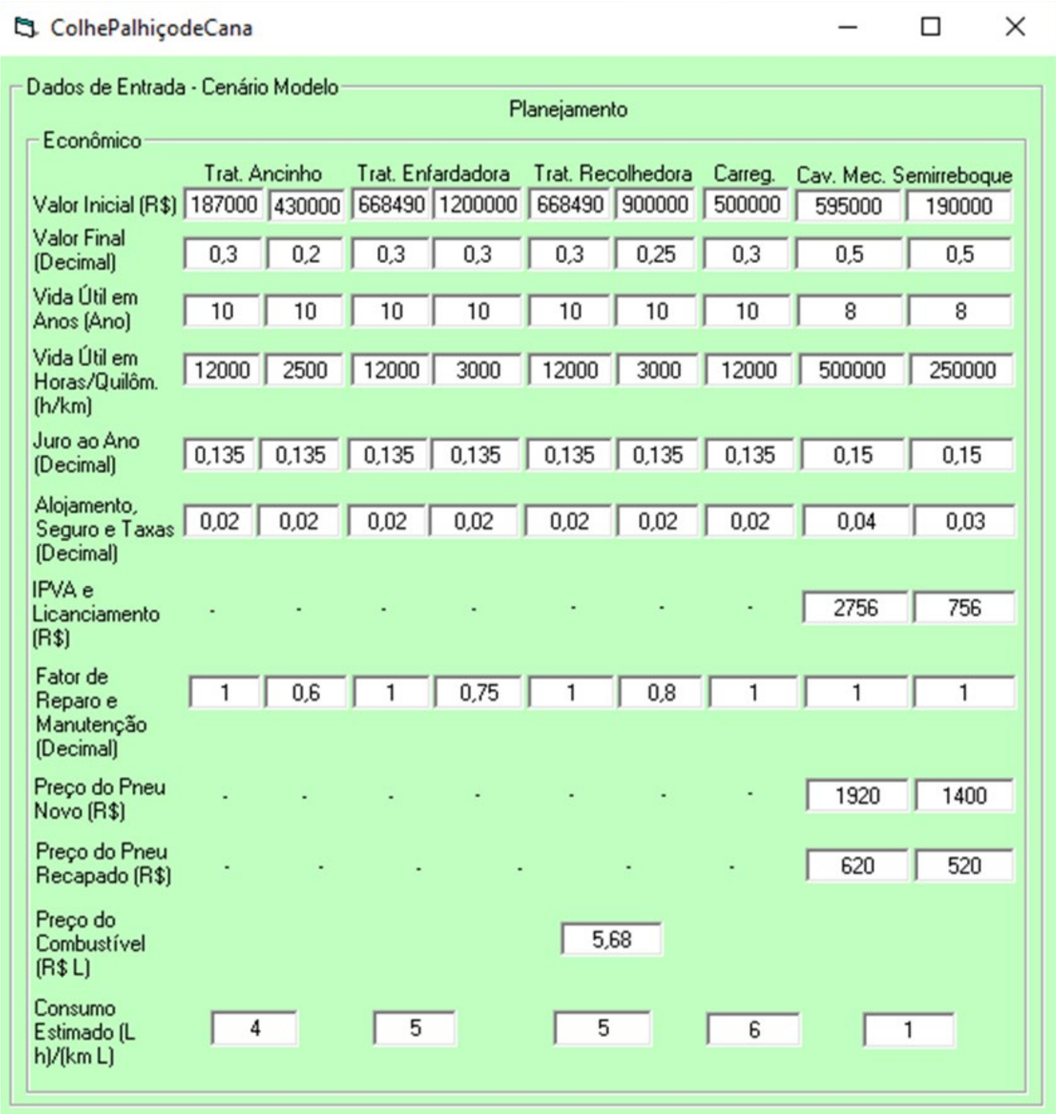

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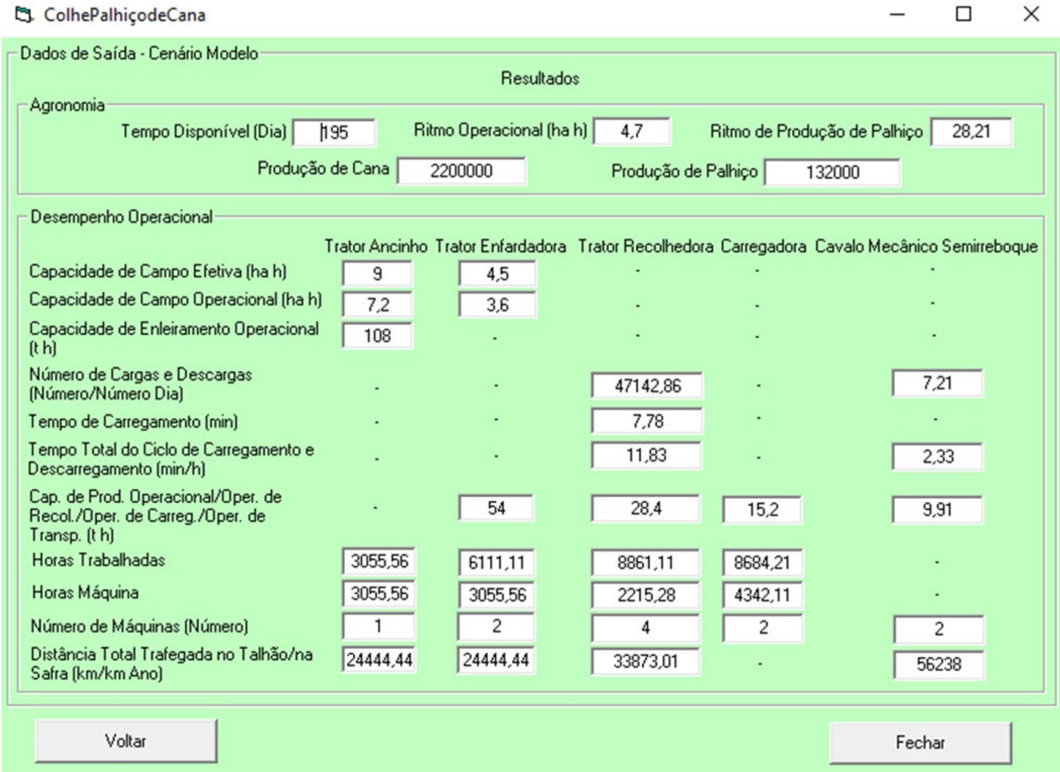


CollhePalhiçodeCana

Dados de Saída - Cenário Modelo

Resultados

Agronomia

Tempo Disponível (Dia)	195
Ritmo Operacional (ha h)	4,7
Ritmo de Produção de Palhiço	28,21
Produção de Cana	2200000
Produção de Palhiço	132000

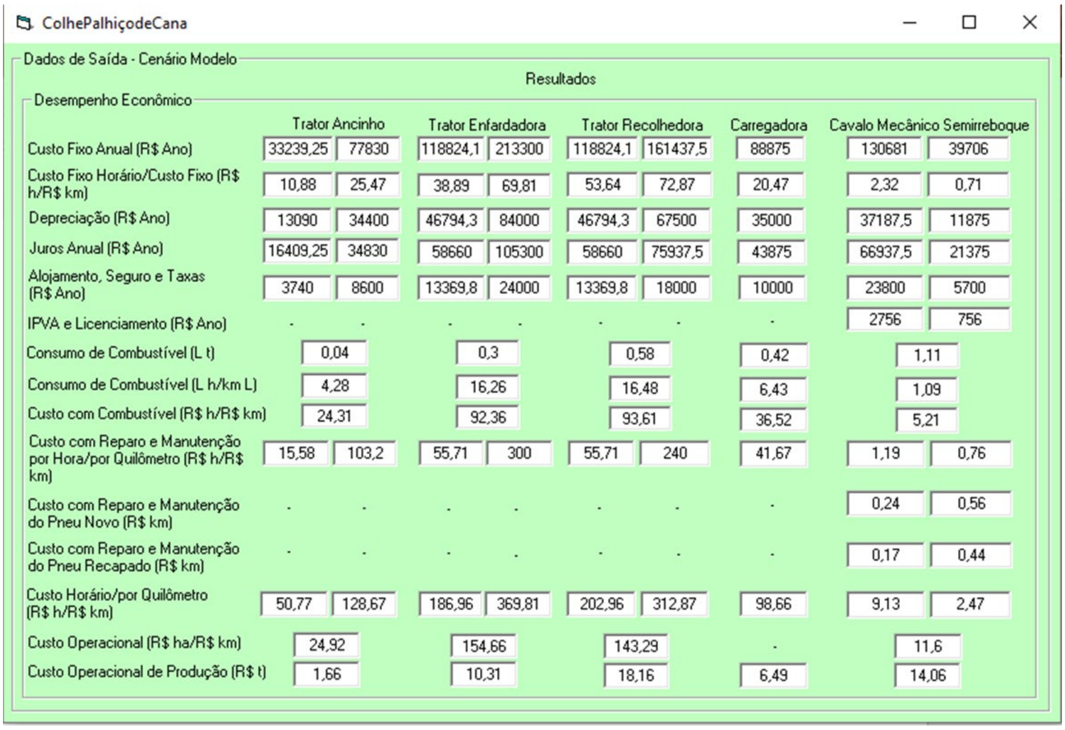
Desempenho Operacional

	Trator Ancinho	Trator Enfardadora	Trator Recolhedora	Carregadora	Cavalo Mecânico Semirreboque
Capacidade de Campo Efetiva (ha h)	9	4,5	-	-	-
Capacidade de Campo Operacional (ha h)	7,2	3,6	-	-	-
Capacidade de Enleiramento Operacional (t h)	108	-	-	-	-
Número de Cargas e Descargas (Número/Número Dia)	-	-	47142,86	-	7,21
Tempo de Carregamento (min)	-	-	7,78	-	-
Tempo Total do Ciclo de Carregamento e Descarregamento (min/h)	-	-	11,83	-	2,33
Cap. de Prod. Operacional/Oper. de Recol./Oper. de Carreg./Oper. de Transp. (t h)	-	54	28,4	15,2	9,91
Horas Trabalhadas	3055,56	6111,11	8861,11	8684,21	-
Horas Máquina	3055,56	3055,56	2215,28	4342,11	-
Número de Máquinas (Número)	1	2	4	2	2
Distância Total Trafegada no Talhão/na Safra (km/km Ano)	24444,44	24444,44	33873,01	-	56238

Voltar | Fechar

b

Source: The Author



CollhePalhiçodeCana

Dados de Saída - Cenário Modelo

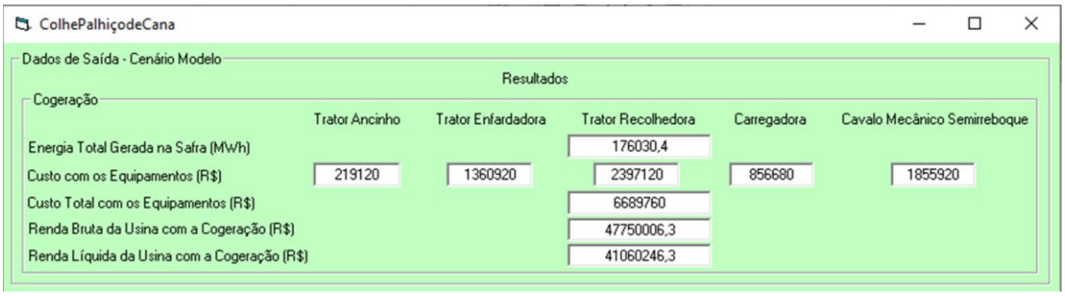
Resultados

Desempenho Econômico

	Trator Ancinho		Trator Enfardadora		Trator Recolhedora		Carregadora	Cavalo Mecânico Semirreboque	
Custo Fixo Anual (R$ Ano)	33239,25	77830	118824,1	213300	118824,1	161437,5	88875	130681	39706
Custo Fixo Horário/Custo Fixo (R$ h/R$ km)	10,88	25,47	38,89	69,81	53,64	72,87	20,47	2,32	0,71
Depreciação (R$ Ano)	13090	34400	46794,3	84000	46794,3	67500	35000	37187,5	11875
Juros Anual (R$ Ano)	16409,25	34830	58660	105300	58660	75937,5	43875	66937,5	21375
Alojamento, Seguro e Taxas (R$ Ano)	3740	8600	13369,8	24000	13369,8	18000	10000	23800	5700
IPVA e Licenciamento (R$ Ano)	-	-	-	-	-	-	-	2756	756
Consumo de Combustível (L t)	0,04		0,3		0,58		0,42	1,11	
Consumo de Combustível (L h/km L)	4,28		16,26		16,48		6,43	1,09	
Custo com Combustível (R$ h/R$ km)	24,31		92,36		93,61		36,52	5,21	
Custo com Reparo e Manutenção por Hora/por Quilômetro (R$ h/R$ km)	15,58	103,2	55,71	300	55,71	240	41,67	1,19	0,76
Custo com Reparo e Manutenção do Pneu Novo (R$ km)	-	-	-	-	-	-	-	0,24	0,56
Custo com Reparo e Manutenção do Pneu Recapado (R$ km)	-	-	-	-	-	-	-	0,17	0,44
Custo Horário/por Quilômetro (R$ h/R$ km)	50,77	128,67	186,96	369,81	202,96	312,87	98,66	9,13	2,47
Custo Operacional (R$ ha/R$ km)	24,92		154,66		143,29		-	11,6	
Custo Operacional de Produção (R$ t)	1,66		10,31		18,16		6,49	14,06	

b

Source: The Author



b

Source: The Author

Figure 2 *- Data layout generated by the "ColhePalhiçodeCana" computational model: (a) spreadsheet interface; (b) programmed interface*.

Figura 2 - *Layout* dos dados gerados pelo *"ColhePalhiçodeCana"*: a - Em planilha eletrônica; b - Em linguagem de programação.

Table 3 presents the projected cash flow, including inflows and outflows. Cash inflows correspond to the total projected revenue per harvest cycle of the processing mill, whereas capital outflows refer to the investment required for acquiring machinery used in the mechanized sugarcane straw baling harvesting system. In this case, capital investment accounted for 80% of the total machinery acquisition cost (US$ 2,069,019), financed with the company's own funds. The remaining 20% (US$ 517,255) was financed through an agricultural machinery credit line.

Table 3 - Projected cash flow with inflows and outflows.

Tabela 3 - Fluxo de caixa com as entradas e saídas.

Cash inflows and outflows	Harvest 2024	Harvest 2025	Harvest 2026	Harvest 2027	Harvest 2028	Harvest 2029
Inflows			-			
Gross revenue from power cogeneration (US$)	11,833,905	15,399,162	20,038,857	26,076,495	33,933,135	44,157,562
Capital contribution (US$)	2,069,019			-		
Total Inflows (US$)	13,902,924	15,399,162	20,038,857	26,076,495	33,933,135	44,157,562
Outflows			-			
Investments (US$)			2,586,274			
Mechanized Harvesting System Cost (US$)	1,274,344	1,274,344	1,274,344	1,274,344	1,274,344	1,274,344
Crop Production Cost (US$)	9,996,277	10,214,103	10,402,300	10,536,590	19,522,838	16,176,157
Total Outflows (Total Costs) (US$)	13,856,895	11,488,447	11,676,644	11,810,935	20,797,182	17,450,501
Operating balance (US$)	46,029	3,910,715	8,362,213	14,265,560	13,135,953	26,707,061
Profit (Mill Revenue) (US$)	**46,029**	**3,910,715**	**8,362,213**	**14,265,560**	**13,135,953**	**26,707,061**

Source: The Author

Cash outflows correspond to capital investment in machinery acquisition for the mechanized sugarcane straw baling harvesting system, operational costs associated with the harvesting system, crop production costs, total cash outflows, and the operating balance for each projected harvest. Based on the comparison between cash inflows and outflows, net profit was estimated for each projected harvest of the processing mill. Table 4 presents the financial analysis over a six-year time horizon.

***Table 4** - Financial analysis over a six-year time horizon.*

Tabela 4 - Análise para o horizonte de seis anos.

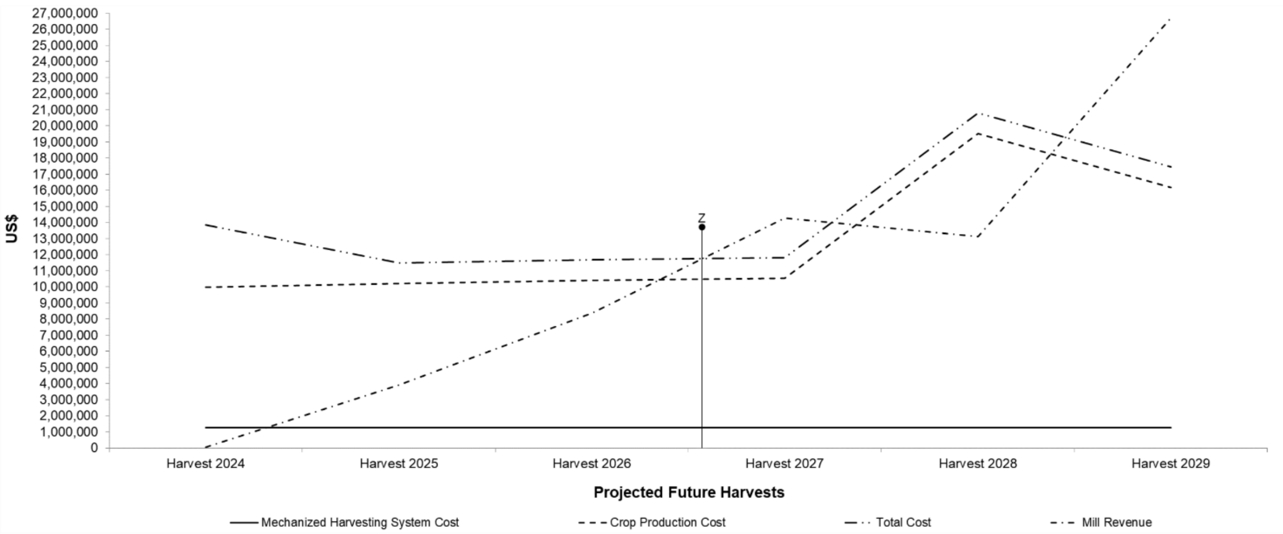
IRR	1.39%
NPV	US$ 33,117,925
B/C	US$ 1.00 : US$ 3.24
Discounted payback	4 Months
Break-even point	89,312 MWh Year^{-1}

Source: The Author

According to the cost analysis methodology, the maximum interest rate indicated by the internal rate of return (IRR) that the investment could support was 1.39%. In this analysis, the IRR was relatively high because the project did not consider capital tied up in fixed assets, such as land, industrial infrastructure of the processing mill, sugarcane processing operations (sugar and ethanol production), agricultural machinery, logistics systems, irrigation facilities, and related components. If these elements had been included, a substantially larger volume of capital would have been committed, and the recovery of invested resources would likely require several decades.

The net present value (NPV) indicated a positive economic return of US$ 33,117,925. The benefit–cost (B/C) ratio showed that each US$ 1.00 invested generated an economic return of US$ 3.24. Based on the discounted payback period, capital recovery was estimated at four months. The break-even point indicated that mill revenues and operating costs become equivalent when annual electricity generation reaches 89,312 MWh Year^{-1}.

Figure 3 illustrates the costs and revenue as a function of projected future harvests.



Source: The Author

Figure 3 *- Costs and revenue as a function of projected future harvest cycles*.
Figura 3 - Custeios e receita em função das safras futuras projetadas.

According to the Basic Scenario (Figure 3), total costs exceeded mill revenues during the first three harvest cycles. From the 2027 harvest cycle (fourth production year) onward, the intersection between total cost and revenue occurred, defining the break-even point (Z).

In the 2028 harvest cycle (fifth production year), total cost again exceeded revenue due to a substantial increase in crop production costs, mainly associated with higher fertilizer prices. This behaviour is consistent with the projected production cost data adopted for this cycle, which were based on sugarcane production cost estimates for the 2022 harvest season reported by CONAB (2023).

In the 2029 harvest cycle (sixth production year), mill revenue once again exceeded total cost. Therefore, the break-even point (Z) indicates that, from the 2027 harvest cycle onward, the mechanized sugarcane straw baling harvesting system becomes economically viable for the processing mill. These results also indicate that, in the harvest cycles preceding the break-even point, revenues were primarily used to recover the capital invested in the acquisition of mechanized straw harvesting equipment.

Conclusions

The mechanized sugarcane straw baling harvesting system becomes financially viable for the processing mill from the break-even point (Z), which occurs in the fourth harvest cycle of the production period.

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