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Economic analysis of different sugarcane (*Saccharum* spp.) transport equipment

Análise econômica de diferentes equipamentos do transporte de cana-de-açúcar (*Saccharum* spp.)

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Resumo

O Brasil é o maior produtor mundial de cana-de-açúcar. O transporte de cana das usinas é realizado por caminhões com reboques e cavalos mecânicos com semirreboques. O sistema modal rodoviário do transporte de cana faz uso desses equipamentos, a fim de atender a demanda contínua da matéria-prima colhida, visando alcançar um mínimo custo. O objetivo deste trabalho foi de analisar as variáveis do desempenho operacional e econômico de diferentes equipamentos do transporte de cana-de-açúcar. Devido à dificuldade em atender o objetivo nas condições a campo, optou-se em desenvolver um modelo computacional denominado *"TransporteCana"*, em planilha eletrônica. O modelo foi verificado quanto a possíveis erros de rotina, validado, utilizado na análise das variáveis e na geração de resultados. Os resultados evidenciaram que a carga das carrocerias, raio médio da distância e preço do combustível são as variáveis que mais impactam no custo dos equipamentos do sistema de transporte.

Palavras-chave adicionais: mecanização agrícola; modelo computacional; planejamento e gerenciamento; rodotrem; treminhão

Abstract

Brazil is the world's largest producer of sugarcane. Sugarcane transportation from mills is carried out by trucks with trailers and mechanical horses with semi-trailers. The modal road system for sugarcane transport uses this equipment to meet the continuous demand for the harvested raw material, aiming to achieve a minimum cost. The objective of this study is to analyze the operational and economic performance variables of different sugarcane transport equipment. Due to the difficulty in meeting this objective under field conditions, this study develops a computational model called *"TransporteCana"* in an electronic spreadsheet. The model was verified for possible routine errors, validated, and used in the analysis of variables and in generating results. The results show that the load of truck bodies, average radius of distance, and fuel price are the variables that most affect the cost of transport system equipment.

Additional keywords: agricultural mechanization; computational model; planning and management; road train; large trucks

Introduction

In Brazil, the estimated area cultivated with sugarcane for the 2019/2020 harvest was 8.44 million hectares and the estimated total production in that harvest was 642.70 million tons (CONAB, 2020).

To meet the demand for raw materials harvested in the field, a road transport system is essential to deliver sugarcane to mills. According to Iannoni and Morabito (2002), the system uses trucks and mechanical horses with trailers and semi-trailers to meet the continuous demand for the harvested raw material. It is influenced by factors such as climate and distance between the plant and the field. In addition to these factors, according to Carreira (2010), the technical characteristics of the equipment, of a managerial and economic nature, also affect the system. The economic factor is the cost of transportation, which is directly related to the distance traveled by the equipment between the plant and the field (Françoso et al., 2017). In this sense, Margarido & Santos (2016) argue that if the average distance between the plant and sugarcane harvest fronts is less than 20 km, it could cause a waiting line for trucks to unload the raw material at the plant's reception.

The planning and management of the transport system must be carried out in advance, as according to Higgins (2006), they contribute to reducing the waiting line for transport equipment on the plant's scale, the downtime of the mill, and the number of equipment needed, so that there are fewer operating costs and higher plant competitiveness compared to other plants. According to Hansen et al. (2002), the absence of a good planning method in the sugarcane transport system may cause delays in operational times and, mainly, damage to the quality of the raw material harvested. The authors developed a computational model to identify the factors that contribute to the long delays between harvesting and crushing sugarcane. Delays during a 20-week simulated harvest period were approximately 35.1 hours, shorter than the actual weekly average, also evaluated over a 20-week period, which varied between 48 and 72 hours.

In the management of agricultural mechanized systems, according to Santos (2018), the operational performance of the equipment affects directly economic performance. According to Santos (2019), this is because operational and economic performance variables are interrelated in a systemic way. However, under field conditions, it is difficult to study the sugarcane transport system due to the number of variables involved. Computer modeling makes this analysis possible. According to Santos et al. (2015) citing Williams (2008), computational modeling is a tool that simplifies the development of the proposed idea aiming to represent structures and generate scenarios. According to Santos et al. (2015) citing Oksanen (2007), modeling provides acceptable solutions to solve a problem. Thus, the aim of this research is to analyze the operational and economic performance variables of different sugarcane transport equipment using an electronic spreadsheet for data modeling and simulation.

Materials and methods

This study involves the creation of a hypothetical facility known as the "Hypothetical Plant," including its sugarcane transport system. The equipment considered comprises bitruck trucks with trailers (long trucks) and mechanical horses with semi-trailers (road trains). The transport system's operation adheres to a standard Brazilian plant, encompassing the equipment's round trip from the field to the plant, covering the entire loading and unloading cycle without imposing restrictions on equipment coupling and uncoupling during the process.

The Hypothetical Plant incorporates plots with variable distances, spanning average radii ranging from 10 to 50 km. This encompasses the distances the equipment will traverse during the loading and unloading cycle. To derive the outcomes, a predefined scenario was crafted, encompassing descriptions of the equipment's economic, technical, managerial, and operational attributes (Table 1).

Table 1 - Economic, technical, managerial, and operational variables of equipment for the prepared scenario.

Variable	Abbreviation	Unit	Bitruck Truck	Trailer	Mechanical Horse	Semi-trailer
Initial value	IV	US$	143,000	17,000	119,000	38,000
Nominal Engine Power	NEP	kW/cv	368/500	-	368/500	-
Body Load	BL	t	20	18	-	35
Number of Bodies	NB	Number	-	3	-	2
Number of Tires	NT	Number	12	24	10	24
Working Hours	WH	h	24			
Availability Efficiency	Ave	Decimal	0.70			
Average Working Speed	AWS	km h^{-1}	40		40	
New Tire Service Life	NTSL	km	80,000		80,000	
Retreaded Tire Service Life	RTSL	km	75,000		75,000	
Number of Tire Retreads	NTR	km	2		2	
Average Distance Radius	ADR	km	30		30	
Loading Time	LT	min	55		50	
Unloading Time	UT	min	55		50	

The (Ave) variable aligns with Banchi & Lopes (2007) and is defined by the equipment's service life in kilometers. Loading and unloading times were predicated on data extracted from Carreira's study (2010).

The computational model developed is termed *"Transportecana"* and simulates the fundamental characteristics of sugarcane transport systems within Brazilian mills. The model adheres to the flowchart outlined in Figure 1 and aligns with Oakland's (2007) proposed framework.

The *"TransporteCana"* has been implemented in an Excel® spreadsheet. The model's operation commences (1) with the input of crop-related data (2), such as sugarcane production quantities earmarked for transport and the price of a delivered ton of sugarcane to the plant. The weather data (3) encompasses the number of days required for transport, counting Sundays and holidays, as well as the number of workdays unsuitable for transport. These factors define the available time in days.

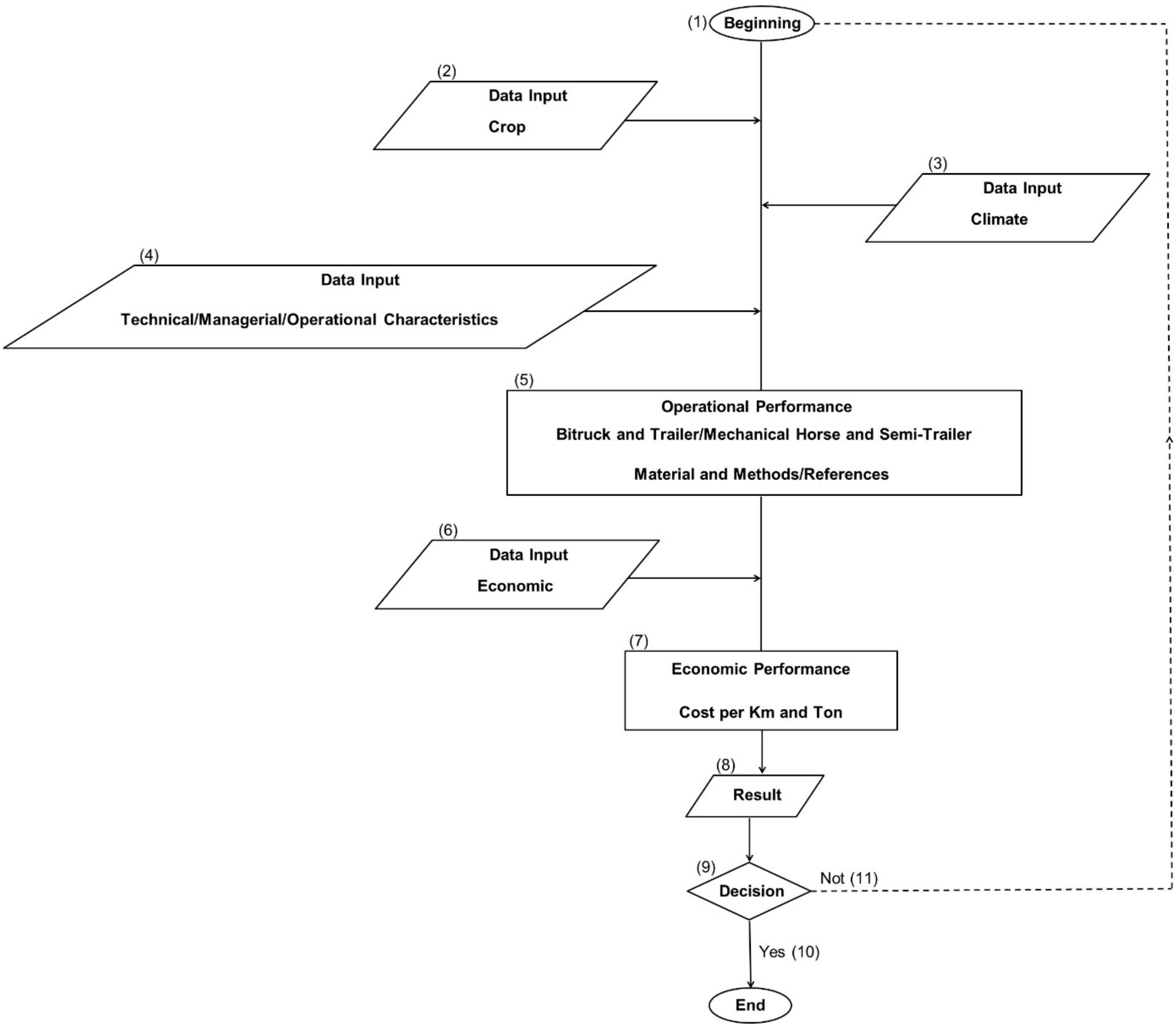

Figure 1 - General flowchart of the computational model.

Data input (4) encompasses the technical, managerial, and operational characteristics of the transport equipment, including nominal engine power, body loads, the number of bodies, tire quantities, average working speeds, working hours, new tire service life, retreaded tire service life, the count of tire retreads, average distance radii, loading and unloading durations.

The interaction between the components (2), (3), and (4) dictates the operational performance of bitruck truck and trailer sets and mechanical horses with semi-trailers (5). This entails the total time needed for loading and unloading cycles, the frequency of loading and unloading within a day, month, and harvest, the aggregate load of the set, the total production capacity of the set, daily, monthly, and harvest-based transported production, daily, monthly, and harvest-based travel distances, fuel consumption during the harvest, production rates, and the requisite number of sets.

The operational performance results, coupled with the input of economic machinery-related data (6), comprising initial and final values, service life in years and hours, yearly interest rates, accommodation, insurance and fees (AIF), licensing, fuel consumption, and repair and maintenance, culminate in the computation of economic performance (7). This aspect pertains to the fuel cost, repair and maintenance costs, costs associated with new tire repair and maintenance, costs of retreaded tire repair and maintenance, on a per-kilometer and per-ton basis, as well as the plant's gross and net gains attributed to transported production.

The model's outcomes (8) empower the user to evaluate the operational and economic performance of the transport system and decide (9) whether it is a viable option (10). In instances where transport with the equipment isn't deemed viable by the user (11) or the user intends to explore alternative scenarios, fresh data must be input into the model.

Climate

Local climate plays a pivotal role in determining the available time during harvest days (AVd) for the transportation of harvested raw material, following the adjusted framework of Mialhe (1974). The calculation of available time during harvest days (AVd) considers the number of days (Nd), the number of Sundays and holidays (Nsh), and the number of working days unsuitable for transportation (Nwdu) (equation 1).

$$\mathrm{AVd} = [\mathrm{Nd} - (\mathrm{Nsh} + \mathrm{Nwdu})] \quad (1)$$

Where: AVd represents the available time in days, Nd signifies the number of days, Nsh denotes the number of Sundays and holidays, and Nwdu designates the number of working days unsuitable for transport.

Operational performance

Several operational performance parameters were derived based on the proposal by Carreira (2010, equation 2). These parameters include the total time required for loading and unloading cycles (TTLUC), the number of loading and unloading operations in a day (NLUD), daily and harvest-based transported production quantities (PTD and PTH), as well as the daily and harvest-based travel distances (DTD and DTH).

The total loading and unloading cycle time (TTLUC) was computed by considering the average radius of distance (ADR), average working speed (AWS), loading time (LT), and unloading time (UT), as defined by Carreira (2010).

$$\mathrm{TTLUC} = \left[\left(\frac{\mathrm{ADR} * 2}{\mathrm{AWS}}\right) + \left(\frac{\mathrm{LT} + \mathrm{UT}}{60}\right)\right] \quad (2)$$

Where: TTLUC signifies the total loading and unloading cycle time (in hours), ADR represents the average distance radius (in kilometers), 2 is a constant, AWS is the average working speed (in kilometers per hour), LT represents the loading time (in minutes), UT designates the unloading time (in minutes), and 60 is a constant.

The number of loading and unloading operations per day (NLUD) was determined based on the working hours (WH), total loading and unloading cycle time (TTLUC), and availability efficiency (Ave), all following Carreira's (2010) proposal.

The number of loading and unloading operations per month (NLUM) was established by combining the number of daily loading and unloading operations (NLUD) and the total number of days in a month (TDM).

The number of loading and unloading operations during a harvest (NLUH) was computed by linking the number of daily loading and unloading operations (NLUD) with the available time during harvest days (AVd).

The total load of the set (TLS) was determined by the combination of the load of the bodies (LB) and the number of bodies (NB).

The total production capacity of the set (TSPC) was defined as the ratio between the total load of the set (TLS) and the total loading and unloading cycle time (TTLUC).

Daily transported production (PTD) was calculated by associating the number of daily loading and unloading operations (NLUD) with the total load of the set (TLS), as per Carreira (2010).

Monthly transported production (PTM) was established by connecting daily transported production (PTD) with the total number of days in a month (TDM).

Harvest-based transported production (PTH) was determined by relating daily transported production (PTD) to the available time during harvest days (AVd), adhering to Carreira's (2010) guidelines.

The total distance traveled during the loading and unloading cycle (DTLUC) was calculated by considering the average distance radius (ADR), as depicted in equation 3.

$$\mathrm{DTLUC} = \mathrm{ADR} * 2 \quad (3)$$

Where: DTLUC stands for the total distance traveled during the loading and unloading cycle (in kilometers).

The daily distance traveled (DTD) was derived based on the total distance traveled during the loading and unloading cycles (DTLUC) and the number of daily loading and unloading operations (NLUD), conforming to Carreira's (2010) rationale (equation 4).

$$\mathrm{DTD} = \mathrm{DTLUC} * \mathrm{NLUD} \quad (4)$$

Where: DTD denotes the distance traveled per day (in kilometers per day).

Monthly distance traveled (DTM) was determined by relating the daily distance traveled (DTD) to the total number of days in a month (TDM).

Harvest-based distance traveled (DTH) was calculated by connecting daily distance traveled (DTD) with the available time during harvest days (AVd), as stipulated in Carreira's (2010) framework.

Operational fuel consumption during the harvest (OFCH) for bitruck trucks with trailers and mechanical horses with semi-trailers was established based on the distance traveled during the harvest (DTH), fuel consumption (FC), and harvest-based transported production (PTH).

The production rate (PR) was defined as the ratio between the plant's production in the harvest (PPH) and the available time during harvest days (AVd).

The number of sets required (NSR) was calculated by ratio between the production rate (PR) and daily transported production (PTD).

Economic performance

The fixed cost of the equipment (FCE) was determined using the adjusted methodology from Asabe (2011). It is calculated as the ratio between annual depreciation (AD), annual interest (AI), accommodation, insurance and taxes (AIF), licensing (LIC), and distance traveled during harvest (DTH) (Equation 5).

$$\mathrm{FCE} = \left| \frac{\langle \left\{ \mathrm{Iv} * \left[\left(\frac{1\text{ - Fv}}{\mathrm{SLE}} \right) + \left(\frac{1 + \mathrm{Fv}}{2} \right) * \mathrm{i} + \mathrm{AIF} \right] \right\} + \mathrm{LIC} \rangle}{\mathrm{DTH}} \right| \quad (5)$$

Where: FCE represents the fixed cost of the equipment (in US$ per kilometer), Iv is the initial value of the equipment (in US$), Fv is the final value of the equipment (in decimal), SLE is the service life in years of the equipment (in years), i is the annual interest rate (in decimal), AIF is the accommodation, insurance, and fees per year (in decimal), LIC is the licensing cost (in US$ per year), and DTH is the distance traveled during the harvest (in kilometers per year).

The variable equipment cost (VEC) is the summation of the fuel cost (FC), repair and maintenance cost (RMC), repair and maintenance cost for new tires (RMCNT), and repair and maintenance cost for retread tires (RMCRT), derived from the adjusted principles of Mialhe (1974) and Balastreire (1990).

The fuel consumption (FC) for the bitruck truck and mechanical horse can be estimated or averaged. When selecting the estimated consumption, the estimated value must be specified. The average consumption option aligns with the proposal of Banchi et al. (2008), providing average fuel consumption values for sugarcane trucks according to the nominal engine power range of the equipment.

The fuel cost (FCO) is calculated as the ratio between the price per liter of fuel (PPL) and fuel consumption (FC). The price of a liter of fuel (PPL) is 0.94 US$ L^{-1}.

The cost of repair and maintenance for the bitruck truck and mechanical horse (RMCBTMH) is defined based on the adjusted proposal of Asabe (2011).

The cost of repair and maintenance (CRM) for the trailer and semi-trailer (CRMTST) is calculated according to the proposal of Banchi et al. (2009).

The cost of repair and maintenance for new tires (RMCNT) and retread tires (CRMRT) of the equipment is based on the proposals of Goodyear (2017) and Rosa (2017). The cost of repair and maintenance for new tires (RMCNT) is determined by the price of new tires (NTPR), the number of tires (NT), and the service life of new tires (NTSL), according to Goodyear (2017) and Rosa (2017) (Equation 6).

$$\mathrm{RMCNT} = \left(\frac{\mathrm{NTPR} * \mathrm{NT}}{\mathrm{NTSL}} \right) \quad (6)$$

Where: RMCNT represents the cost of repair and maintenance for new tires (in US$ per kilometer), NTPR is the price of new tires (in US$), NT is the number of tires, and NTSL is the service life of new tires (in kilometers).

The cost of repair and maintenance for retread tires (RMCRT) is determined based on the price of retread tires (RTP), the number of tire retreads (NTR), the number of tires (NT), and the service life of retread tires (RTSL), following the proposals from Goodyear (2017) and Rosa (2017) (Equation 7).

$$\mathrm{RMCRT} = \left(\frac{\mathrm{RTP} * \mathrm{NTR} * \mathrm{NT}}{\mathrm{RTSL}} \right) \quad (7)$$

Where: RMCRT signifies the cost of repair and maintenance for retreaded tires (in US$ per kilometer), RTP represents the price of retreaded tires (in US$), NTR is the number of tire retreads, and RTSL is the useful life of retreaded tires (in kilometers).

The equipment operating cost (EOC) is calculated as the sum of the fixed cost (FCE) and variable cost (VC), adhering to the adjusted principles of Mialhe (1974) and Balastreire (1990).

The operating cost of the bitruck truck and trailer (OPBTT) is determined as the sum of the truck's operating cost (TOC) and the trailer's operating cost (TOP).

The operating cost of the mechanical horse and semi-trailer set (OCMHSTS) is derived from the summation of the operating cost of the mechanical horse (OCMH) and the operating cost of the semi-trailer (OCST).

The operational cost of production for the bitruck truck and mechanical horse (OCPBTMH) is calculated based on the equipment's operational cost (EOC), the distance traveled during harvest (DTH), and the production transported during harvest (PTH), following Carreira's adjusted proposal (2010) and Rosa (2017) (Equation 8).

$$\text{OCPBTMH} = \left[\text{EOC} * \left(\frac{\text{DTH}}{\text{PTH}}\right)\right] \quad (8)$$

Where: OCPBTMH denotes the operational cost of producing the equipment (in US$ per ton), EOC stands for the equipment's operational cost (in US$ per kilometer), DTH signifies the distance traveled during harvest (in kilometers per year), and PTH represents the production transported during the harvest (in tons per year).

The operating cost of production for the trailer and semi-trailer (OCPTST) is determined in a manner like the operating cost of production (OCPBTMH) for the bitruck truck and mechanical horse, based on Carreira's (2010) and Rosa's (2017) adjusted proposal.

The operational cost of producing the bitruck truck and trailer set (OCPBTTS) is defined as the summation of the operating cost of producing the bitruck truck (OCPBT) and the operating cost of producing the trailer (OCPT).

The operational cost of producing the mechanical horse and semi-trailer set (OCPMHSTS) is calculated as the summation of the operational cost of producing the mechanical horse (OCPMH) and the operational cost of producing the semi-trailer (OCPST).

The total cost of the set (TCS) is determined through the association of the operating cost of production of the set (OCPS) with the production transported during harvest (PTH).

Economic gains by the plant

The plant's gross (PGGTP) and net (PNGTP) gains from the transported production were calculated based on the modified proposals of Santos et al. (2014), Santos et al. (2015), and Santos et al. (2017).

In this context, the plant's gross profit from the production transported during the harvest (PGGTP) is determined through the association of the estimated price of a ton of sugarcane delivered to the plant (EPTSDP) with the production transported during harvest (PTH). The plant's net gain from production transported during the harvest (PNGTP) is derived from the difference between the plant's gross profit from production transported during the harvest (PGGTP) and the total cost of the set (TCS). The estimated price of a ton of sugarcane delivered to the plant is 14.98 US$ per ton, as per Udop (2019).

Validation

The *“TransporteCana”* model was validated through a comparative analysis of simulation results with bibliographic data (secondary data). Validation, sensitivity, and consistency analyses of the computational model were performed using the operational production cost.

Results and Discussion

For the climatic planning of the Hypothetical Plant scenario, we considered the rainfall data from the Minas Gerais triangle region in the State of Minas Gerais, spanning from 1980 to 2010. This data, as reported by Roldão & Assunção (2012) with a citation from Ana (2012), was coupled with information on the clay soil prevalent in the region. As a result of this climatic planning, the calculated available time in harvest days (AVd) amounted to 235.

The results obtained for the prepared scenario (depicted in Figure 2) illustrate that the cost of the bitruck truck and trailer is primarily influenced by the fuel cost (FCO), which accounts for 45.72% of the total cost. It is followed by the repair and maintenance cost (RMC) at 19.05% and annual interest (AI) at 11.71% (as indicated in Figure 2a). The variable costs sum up to 76.58% (represented by dashed lines), with the remaining 23.42% comprising fixed costs (represented by solid lines).

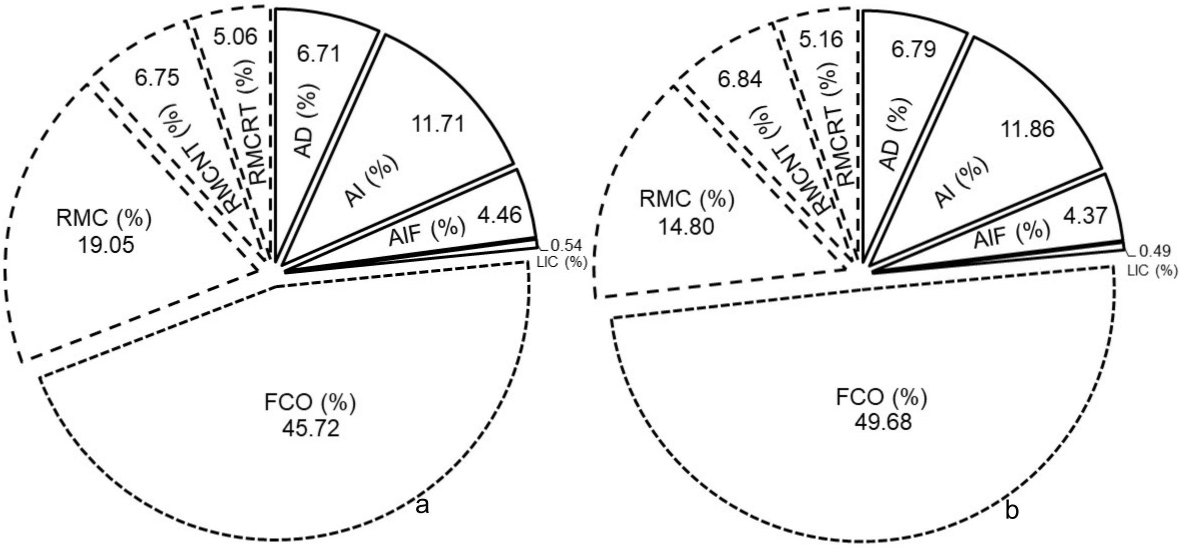

Figure 2 - Distribution of costs (%) for the prepared scenario: a - Bitruck Truck and Trailer Set; b - Mechanical Horse and Semi-trailer Set. AD - Annual depreciation, AI - Annual interest, AIF - Accommodation, insurance, and taxes, LIC - Licensing, FCO - Fuel cost, RMC - Repair and maintenance cost, RMCNT - New tire repair and maintenance cost, and RMCRT - Cost of repair and maintenance of the retread tire.

Similarly, for the mechanical horse and semi-trailer set, the most substantial cost contributor is the fuel cost (FCO), making up 49.68% of the total cost, followed by the repair and maintenance cost (RMC) at 14.80% and annual interest (AI) at 11.86%. Variable costs account for 76.48% (indicated by dashed lines), with fixed costs making up the remaining 23.51% (indicated by solid lines) (Figure 2b). Figure 3 demonstrates the operational cost of producing these sets in two operating conditions: at an average working speed of 30 km h^{-1} and 40 km h^{-1} (prepared scenario), as it relates to the average distance radius between the plant and the field. A linear increase in cost is observed with an increase in the average radius of distance, while elevating the work speed is correlated with a reduction in set costs. For example, within a radius of 10 km, at speeds of 30 km h^{-1} and 40 km h^{-1}, the cost for the bitruck truck and trailer set was 0.73 US$ t^{-1} and 0.71 US$ t^{-1}, respectively. In comparison, the mechanical horse and semi-trailer set cost 0.71 US$ t^{-1} and 0.69 US$ t^{-1}, respectively.

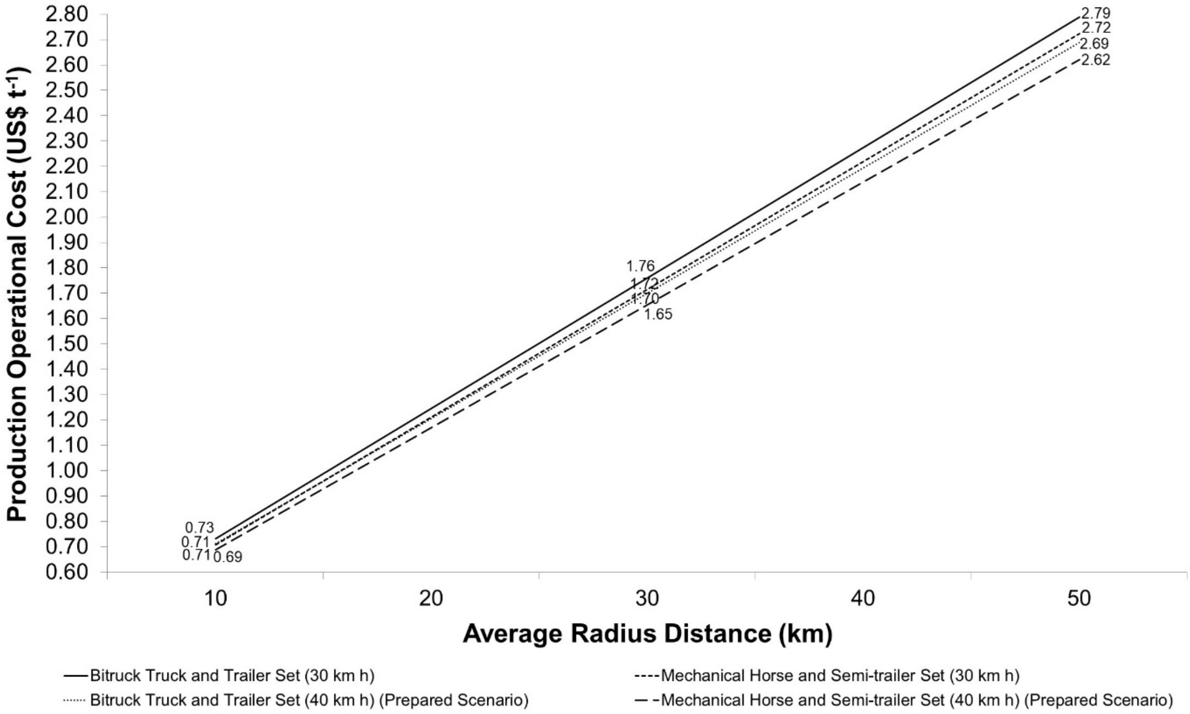

Figure 3 - Production operational cost and average working speed as a function of the average radius distance.

This aligns with Carreira's (2010) study on sugarcane transport with a mechanical horse and semi-trailer over a 10 km radius, considering working speeds of 11 km h^{-1}, 42.4 km h^{-1}, and 71 km h^{-1}, which resulted in costs of 0.58 US$ t^{-1}, 0.47 US$ t^{-1}, and 0.45 US$ t^{-1}, respectively.

The cost differences become more pronounced when considering larger radii. For instance, within a radius of 30 km (as in the prepared scenario), costs for the bitruck truck and trailer set are 1.76 US$ t^{-1} at 30 km h^{-1} and 1.70 US$ t^{-1} at 40 km h^{-1}. On the other hand, the mechanical horse and semi-trailer set costs 1.72 US$ t^{-1} at 30 km h^{-1} and 1.65 US$ t^{-1} at 40 km h^{-1}. Within a 50 km radius, costs rise further, with the bitruck truck and trailer set reaching 2.79 US$ t^{-1} at 30 km h^{-1} and 2.69 US$ t^{-1} at 40 km h^{-1}, while the mechanical horse and semi-trailer set costs 2.72 US$ t^{-1} at 30 km h^{-1} and 2.62 US$ t^{-1} at 40 km h^{-1}.

Carreira's (2010) study, which considers a mechanical horse and semi-trailer set in a 50 km radius, with working speeds of 11 km h^{-1}, 42.4 km h^{-1}, and 71 km h^{-1}, led to costs of 2.35 US$ t^{-1}, 1.79 US$ t^{-1}, and 1.71 US$ t^{-1}, respectively.

The cost disparities are significant. For instance, compared to a radius of 10 km and a speed of 30 km h^{-1}, costs for the bitruck truck and trailer set increase by 1.03 US$ t^{-1} (140.22%) and 2.06 US$ t^{-1} (280.45%) for radii of 30 km and 50 km, respectively. When the speed is increased to 40 km h^{-1}, costs rise by 0.99 US$ t^{-1} (138.55%) and 1.98 US$ t^{-1} (277.11%) for the same radii. For the mechanical horse and semi-trailer set, cost increases concerning a 10 km radius at 30 km h^{-1} amount to 1.01 US$ t^{-1} (142.19%) and 2.02 US$ t^{-1} (284.38%) for radii of 30 km and 50 km, respectively. At a speed of 40 km h^{-1}, cost increases by 0.97 US$ t^{-1} (140.47%) and 1.93 US$ t^{-1} (280.94%) for the same radii.

The total cost significantly influences the plant's economic gains, as depicted in Figure 4. In the prepared scenario, the bitruck truck and trailer set transported 87,646 t of production in a single harvest (PTH), resulting in a gross gain of US$ 1,312,931 from the production transported during the harvest (PGGTP). In this scenario, the bitruck truck and trailer set incurs a total cost (TCS) of 11.36%, translating to a net gain (PNGTP) of 88.64%, equivalent to US$ 1,163,845 (Figure 4a).

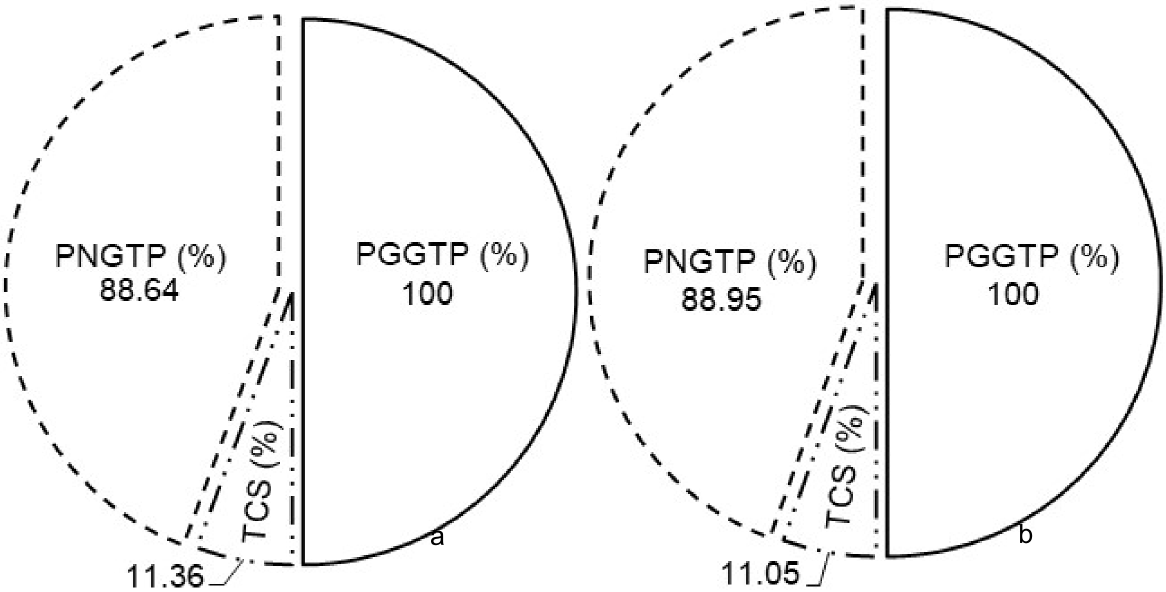

Figure 4 - Distribution (%) of the plant's gross gain resulting from the production transported in a harvest (PNGTP), the plant's net gain from the production transported in the harvest (PGGTP) and total cost (TCS) of the sets (a) Truck Set Bitruck and Trailer and (b) Mechanical Horse and Semi-trailer Set.

For the mechanical horse and semi-trailer set, the PTH is 87,272 t, leading to a gross gain from the production transported during a harvest (PGGTP) amounting to US$ 1,307,328. In this case, the mechanical horse and semi-trailer set's total cost (TCS) is 11.05%, resulting in a net gain (PNGTP) of 88.95%, equivalent to US$ 1,162,910 (Figure 4b). This translates to a difference in total cost (TCS) of 0.31% and a net gain (PNGTP) of US$ 935 when compared to the bitruck truck and trailer set.

Conclusions

Fuel costs emerge as the most significant among both fixed and variable expenses for these sets.

Enhancing the average operational speed has a beneficial impact on the performance, both operationally and economically, of these sets.

On the contrary, an increase in the average distance radius exerts a substantial detrimental influence on the operational costs of set production.

Within the transport system, the bitruck truck and trailer combination exhibits a higher operational production cost, consequently leaving a more substantial imprint on the plant's overall earnings.

To optimize profits, plants should prioritize cultivating areas near the industrial site, aiming to curtail equipment expenses. However, an emphasis on areas extremely close to the plant, particularly within a 20 km radius, may lead to queuing of trucks at the reception, which could, regrettably, entail a reduction in the quality of the raw material.

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