ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.29, n.4, e281575, 2025
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v29n4e281575

Original Article

# Energy performance of sugarcane harvesters equipped with knives and saws for basal cutting[1]

## Desempenho energético de colhedora de cana-de-açúcar equipada com facas e serras para corte basal

Aldir C. Marques Filho[2*], João V. P. Testa[3], Murilo B. Martins[4], Fernanda P. de A. P. Bortolheiro[4], Pablo L. de Almeida[4] & Kléber P. Lanças[5]

[1] Research developed at Universidade Estadual Paulista, Botucatu, SP, Brazil
[2] Universidade Federal de Lavras/Departamento de Engenharia Agrícola, Lavras, MG, Brazil
[3] CNH Industrial, Global Product Specialist Sugar Cane and Coffee, Piracicaba, SP, Brazil
[4] Universidade Estadual de Mato Grosso do Sul/Departamento de Agronomia, Cassilândia, MS, Brazil
[5] Universidade Estadual Paulista/Departamento de Engenharia Rural, Botucatu, SP, Brazil

*HIGHLIGHTS:*

*Sugarcane yield impacts the fuel consumption of sugarcane harvesters.*
*The type of cutting system does not influence the performance of sugarcane harvester.*
*Cutting tools such as knives and saws perform similarly in energy demand, but saws consume slightly more fuel.*

**ABSTRACT:** The mechanized cutting of sugarcane requires improvements, as cutting tools can affect the longevity of sugarcane fields and increase production costs. Furthermore, these tools can increase the energy demand of machines in the field. This study evaluated the sugarcane harvester performance equipped with different basal cutting devices: impact cutting (blades) and continuous cutting (saws) in three commercial sugarcane production areas. The experimental design was completely randomized in a 3 × 2 factorial scheme with six repetitions. Effective fuel consumption and harvesting capacity were evaluated. The saws increased fuel consumption per area by 3.9 and 8.9% per Mg harvested. The crop's yield characteristics determine harvesting systems' energy demand. For yields above 90 Mg ha$^{-1}$, energy demand has stabilized up to 120 Mg ha$^{-1}$. The fuel demand for harvesting ranged between 1.0 and 1.2 L Mg$^{-1}$ of harvested material. Regardless of the cutting system, each Mg requires 37.3 kJ of energy to be removed from the field.

**Key words:** *Saccharum officinarum*, sustainability, mechanization, energy demand, operational efficiency

**RESUMO:** O corte mecanizado da cana-de-açúcar necessita de aprimoramentos, visto que as ferramentas de corte podem afetar a longevidade dos canaviais e aumentar os custos de produção. Além disso, essas ferramentas podem aumentar a demanda energética das máquinas no campo. Este estudo avaliou o desempenho de colhedoras de cana-de-açúcar equipadas com distintos mecanismos de corte basal: corte por impacto (lâminas) e corte contínuo (serras) em três áreas comerciais de produção de cana-de-açúcar. O consumo efetivo de combustível e a capacidade efetiva de colheita das máquinas foram avaliados em cada tratamento. O delineamento experimental adotado foi inteiramente casualizado em esquema fatorial 3 × 2 com seis repetições. As serras aumentaram o consumo de combustível por área em 3,9 e 8,9% por Mg colhido. As características produtivas da cultura determinam a demanda energética dos sistemas de colheita. Para produtividades acima de 90 Mg ha$^{-1}$, a demanda energética estabilizou-se até 120 Mg ha$^{-1}$. A demanda de combustível para a colheita variou entre 1,0 e 1,2 L Mg$^{-1}$ de material colhido. Os resultados mostram que independente do sistema de corte, cada Mg de cana colhida necessita em média de 37,3 kJ de energia para ser retirado do campo.

**Palavras-chave:** *Saccharum officinarum*, sustentabilidade, mecanização, demanda energética, eficiência operacional

• Ref. 281575 – Received 18 Dec, 2023
* Corresponding author - E-mail: aldir@ufla.br
• Accepted 04 Oct, 2024 • Published 29 Oct, 2024
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

## Introduction

Sugarcane mechanization harvesting brought several environmental benefits (Silva et al., 2021) and reduced the need for labor. However, some issues related to the base cut quality still need to be overcome. New cutting tools, such as serrated blades (Marques Filho et al., 2022), were developed to improve the cutting process quality and reduce losses.

The sugarcane harvesting system is considered the most important production stage due to its operating costs and influence on harvested material quality (Martins et al., 2023). Sugarcane harvests suffer several factors directly influencing fuel consumption, such as failures in the sugarcane field, topography, plant bedding, operator experience, crop yield, and environmental factors (Martins et al., 2017).

The crop yield can influence operational harvesting capacity (Banchi et al., 2020). In addition to yield, wear on mechanical components in this context can affect harvesting operational capacity (Hong et al., 2018) and fuel consumption (Fiorese et al., 2012; Shin et al., 2012), so measuring the types of consumption helps in decision-making (Queiroz et al., 2017).

Only some studies evaluate the sugarcane harvesters' performance when equipped with saws for basal cutting, as these tools are new to the production sector and applied experimentally. Cutting tools can affect the energy performance of sugarcane harvesters. Replacing smooth, straight blades with serrated, inclined ones can positively affect the basal cut quality (Marques Filho et al., 2022) but may require more energy from the machine. This study evaluated the sugarcane harvester performance equipped with different basal cutting devices: impact cutting (blades) and continuous cutting (saws) in three commercial sugarcane production areas.

## Material and Methods

The experiment was conducted in São Paulo, Brazil, during two crop cycles in three different areas in Borborema and Lençóis Paulista municipalities, in areas without irrigation and with the same cultural treatments for weed control, fertilization, and pesticide application. In all areas, the harvest was conducted without prior sugarcane burning. The specific characteristics of each experimental area are described in Table 1.

Two cutting tools were assessed: a proposed new continuous cutting system (saws) composed of saws and an impact cutting system composed of carbon steel knives (blades) conventionally used in sugarcane harvesters. Each cutting device was considered a treatment, and six repetitions were conducted for each treatment, with two crop rows used in each repetition to evaluate all proposed variables. The treatments conducted in the field trial were: Cutting system with saws (Figure 1A) and blades (Figure 1B) evaluated individually in areas 1, 2 and 3.

Two models of sugarcane harvester were used: in area 1, a John Deere™ harvester, model 3520, 2015, with 3.749 engine hours and 2.232 elevator hours; and in areas 2 and 3, a CASE™ IH harvester, model A8800 SR, 2015, with 3.555 engine hours and 1.840 elevator hours. The machines had the same engine power range and a single harvest row.

All machines in this study were set to work at an average speed of 4.5 km h$^{-1}$, with variable engine speed according to the field cruise and smart cruise systems, respectively. The base cutting mechanism had its angular speed set to 480 rpm on each rotating tray, regardless of the cutting tool (knives or saws). These configurations were adopted because they are sugarcane harvesting operations' recurring average operating conditions. Keeping the working rotation and speed constant in real field parameters ensured that these conditions were treated as experimental covariates.

The harvesting operation included position and speed control through the monitor integrated into the harvester with

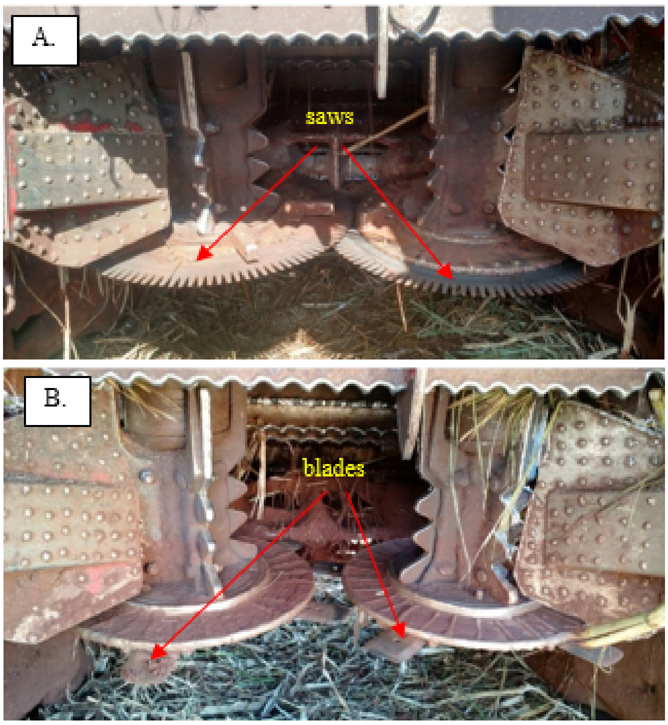



**Figure 1.** Sugarcane harvest cutting systems. A. The continuous cutting system (saws) comprises overlapping steel saws; B. Conventional impact cutting system (blades), with carbon steel cutting knives

**Table 1.** Characteristics of the experimental areas for evaluating sugarcane basal cutting mechanisms

| Data | Area 1 | Area 2 | Area 3 |
|---|---|---|---|
| Local – SP State | Borborema | Lençóis Paulista | Lençóis Paulista |
| Coordinates | 21° 37' 10.41" S - 49° 00' 17.92" W | 22° 35' 26.77" S - 48° 43' 56.06" W | 22° 37' 02.96" S - 48° 44' 01.73" W |
| Average altitude | 429 m | 540 m | 540 m |
| Sugarcane variety | SP813250 | RB855156 | RB966928 |
| Harvest date | November/2016 | April/2017 | April/2017 |
| Soil texture | Sandy | Clayey | Clayey |
| Planting/ratoon | 2010 - 6º Cut | 2016 - 1º Cut | 2014 - 3º Cut |
| Yield (Mg ha$^{-1}$) | 61.4 | 114.8 | 93.4 |
| Spacing | Simple space | Simple space | Alternating Double |
| Row spacing (m) | 1.5 | 1.5 | 1.5 – 0.9 |

the Global Navigation Satellite System (GNSS) locator. The operational speed was adjusted on an onboard computer and varied depending on the sugarcane size and biomass in the field and the machine's bushings at the harvest. The average speed measurement during the tests used data from the harvester's onboard monitor and was compared using a Garmin model 60x handheld GNSS navigator.

During the fuel consumption data acquisition, two liquid flow sensors from the Oval brand, model LSF45, with a maximum reading capacity of 500 L $h^{-1}$, were installed in each of the harvesters evaluated; one sensor was installed in the fuel supply system (inlet), between the fuel reservoir (tank) and the engine injection pump. The second fuel sensor was installed on the tank's injection system return (outlet). The harvester performance evaluation methodology was based on Drudi et al. (2019) and Martins et al. (2021).

The flowmeters sent data at a rate of one pulse for every 10 mL of fuel, with these pulses transmitted to a data acquisition system consisting of two pulse counters and a digital timer activated in each experimental range. Consumption data were measured based on the difference between the flowmeters' inlet and outlet pulses and converted by the data collection system into liters per work hour (L $h^{-1}$) according to Eq. 1.

$$HFC = \frac{\sum(IP - OP) \times 3.6}{\Delta T} \quad (1)$$

where:

HFC - hourly fuel consumption (L $h^{-1}$);

$\Sigma$(IP – OP) - the difference between pulses from the inlet and outlet flowmeters, equivalent to the amount of fuel consumed by the harvester in the period,

$\Delta$T - time taken (s); and,

3.6 - conversion factor.

Fuel consumption per harvested area was calculated using Eq. 2.

$$FCA = ET \times HFC \quad (2)$$

where:

FCA - fuel consumption per area in L $ha^{-1}$;

ET - effective time required in h $ha^{-1}$; and,

HFC - hourly fuel consumption in L $h^{-1}$.

The amount of raw material harvested was calculated based on the yield plot (Mg $ha^{-1}$) for the useful area of the plot (ha). Fuel consumption per Mg of sugarcane harvested was obtained using Eq. 3.

$$FC = \frac{FCA}{Yd} \quad (3)$$

where:

FC - fuel consumption per Mg of sugarcane harvested (L $Mg^{-1}$);

FCA - fuel consumption per area (L $ha^{-1}$); and,

Yd - sugarcane yield (Mg $ha^{-1}$).

The effective field capacity in ha $h^{-1}$ was determined by the relationship between the useful area of the worked plot and the time spent traveling through the plot, using Eq. 4.

$$Efc = \frac{UAP}{\Delta T} \times 0.36 \quad (4)$$

where:

Efc - effective field capacity (ha $h^{-1}$);

UAP - useful area of the worked plot ($m^2$);

$\Delta$T - time spent traveling the experimental plot (s); and,

0.36 - conversion factor.

The effective harvesting capacity in Mg $h^{-1}$ was determined by multiplying the field yield Mg $ha^{-1}$ by the effective field capacity obtained in ha $h^{-1}$, according to Eq. 5.

$$Ehc = Efc \times yield \quad (5)$$

where:

Ehc - effective harvesting capacity (ha $h^{-1}$);

Efc - effective field capacity (ha $h^{-1}$); and,

Yield - sugarcane yield per plot (Mg $ha^{-1}$).

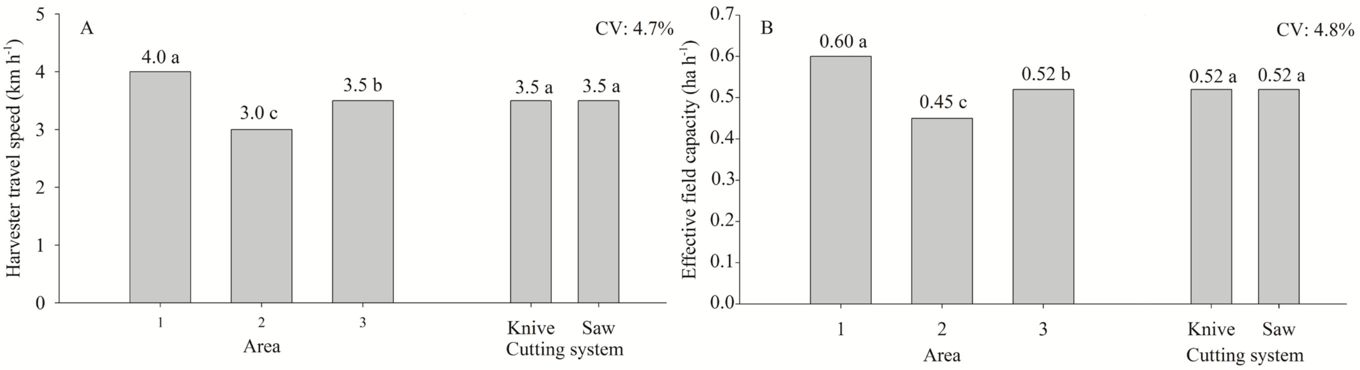
The experimental design was completely randomized and consisted of three areas (areas 1, 2, and 3), two cutting devices (saws and knives), and six replications in a 3 × 2 factorial scheme. The data underwent a normality test, analysis of variance, and the Tukey test at $p \leq 0.05$. The software used in the statistical analysis was Minitab v.16.

## Results and Discussion

After establishing the standard harvesting speed on the harvesters' onboard monitor, we verified that the average speed reached the pre-established standard of 4.5 km $h^{-1}$ in all experimental areas. This occurred due to small reductions in the machine's rotation or due to kickback when it became overloaded with material in the cutting system. No interaction effects were verified between the factors; therefore, the results are presented independently for the cutting mechanisms and different areas. Additionally, differences were found between the average speeds of the harvesters in each area (Figure 2A), indicating that the size of the sugarcane field and the crop characteristics affect the speed and, consequently, the operational harvest yield.

The highest travel speed (4.0 km $h^{-1}$) during mechanized sugarcane harvesting was achieved in area 1 for both cutting systems. For this area, it was possible to use a higher harvesting speed due to its characteristics, planting spacing, and lower yield (61.4 Mg $ha^{-1}$) concerning the other study areas, as the amount of material processed by the harvester was lower, reducing bushing and stops during harvest. The variation in travel speed during sugarcane harvesting can occur due to the topography of the area, plant bedding, operator experience, and crop yield, among others (Martins et al., 2017).

The analyses carried out in area 2 demonstrate results with the lowest average harvest speed (3.0 km $h^{-1}$), proving that the higher yield (114.8 Mg $ha^{-1}$) affects the machine's




Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$)

**Figure 2.** Travel harvester speeds according to the study area and cutting systems (A) and effective field capacity according to the study area and cutting systems (B)

performance in the operation, thus, to avoid losses and not overload the machine, the speed may have been reduced at specific points in the crop with high yield due to the amount of material entering the harvester's industrial system. This was proven by Maldaner et al. (2021), where mass flow affected the harvester's travel speed.

Silva et al. (2021), in a comparative study between green sugarcane harvesting and burning, stated that the operational speed in burned areas is higher than in green sugarcane areas; this increases operational efficiency and can encourage resilience to use fire in crops. Higher operational speeds can increase harvesting efficiency, as they allow the operation to be conducted in less time; however, negative effects of speed can occur in areas of high yield, mainly the increase in losses and damage to ratoons.

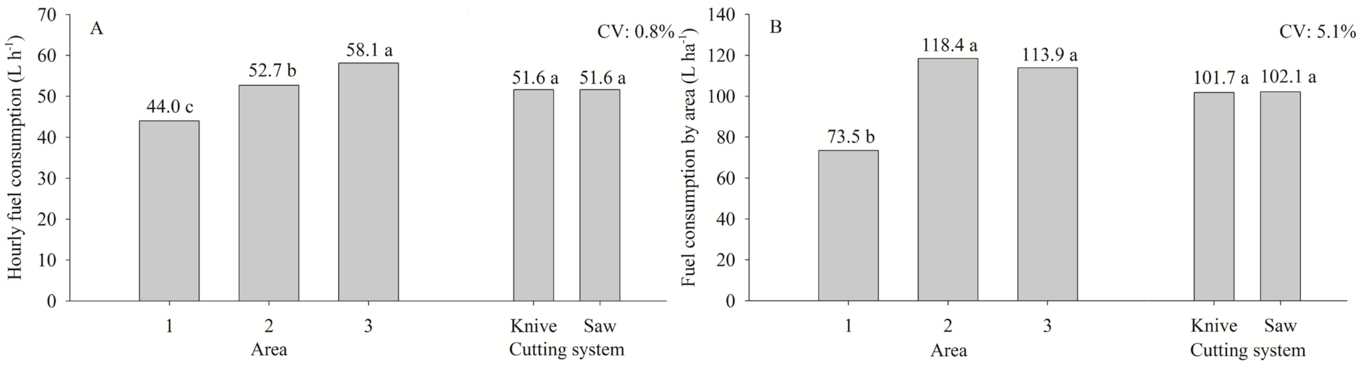
In this research, sugarcane was not burned before harvesting. However, Silva et al. (2021) found that green sugarcane biomass can hinder the harvester's progress and operational speed. This effect was observed in the areas with the highest sugarcane yields. The large amount of biomass that must be processed during harvesting in areas with higher yields overloads the harvesters' internal mechanisms, requiring the operation to be conducted at lower speeds.

No significant statistical differences were found for the average effective field capacities during harvesting between the cutting systems; this indicates that the knife and saw systems had similar performance during the harvesting operation. Thus, the application of knives or saws does not reduce the sugarcane harvesting capacity; however, the crop size impacts the operation's efficiency as we had differences between the field capacities in areas 1, 2, and 3 (Figure 2B).

The greatest effective field capacity found (0.60 ha $h^{-1}$) occurred in Area 1; this can be explained by the lower yield of this area and the higher operational speed of the harvester. This increase in speed must be cautious, as when the speed is too high, the base cut device may not have time to cut the stem, and the stem may be broken instead of cut (Li et al., 2023), resulting in a low-quality operation.

According to González-Cueto et al. (2021), the increase in crop yield changes the efficiency of the field, as this variable is decisive in the speed of the harvester to be adopted during the harvesting process. The values in this research follow the averages found by Drudi et al. (2019), who, when analyzing several tests with one- and two-row sugarcane harvesters, found similar results for both types of harvest, being 0.6 to 1.1 ha $h^{-1}$, respectively.

It was observed that the lowest value of effective harvesting capacity in Mg $h^{-1}$ occurred in Area 1 (36.8 Mg $h^{-1}$), demonstrating that even with a higher speed of movement in this area, the low yield (61.4 Mg $ha^{-1}$) had a decisive influence in crop yield (Figure 3A). The greatest effective harvesting capacity occurred in Area 2 (114.8 Mg $h^{-1}$), demonstrating the combination effect of the area of greatest yield and effective harvesting capacity. Therefore, area 2 presented the highest effective harvesting capacity even with the lowest operational speed.




Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$)

**Figure 3.** Effective harvesting capacity according to the study area and cutting systems (A) and hourly fuel consumption and fuel consumption according to the harvested area (B)

The operational harvesting capacity can be influenced by crop yield, as depending on the productive characteristics, the harvester may be limited during the process (Banchi et al., 2020). Our results highlight the more important relationship between yield and harvest performance for area 2, even with the lowest effective field capacity.

Testa et al. (2016) found similar results in studies with a harvester with two simultaneous sugarcane rows, which obtained harvesting capacities between 68.7 and 87.7 Mg $h^{-1}$. Ramos et al. (2016), using harvesting speeds close to 4 km $h^{-1}$, obtained harvesting capacities between 40 and 59 Mg $h^{-1}$ with a single-row sugarcane harvester, similar to those used in our study.

The average effective fuel consumption during harvest did not show statistical differences between the cutting systems; the differences were significant only between areas 1, 2, and 3 (Figure 3B). According to Fiorese et al. (2012), fuel consumption must be measured and evaluated during effective operation, contributing to the procedure adopted in this research.

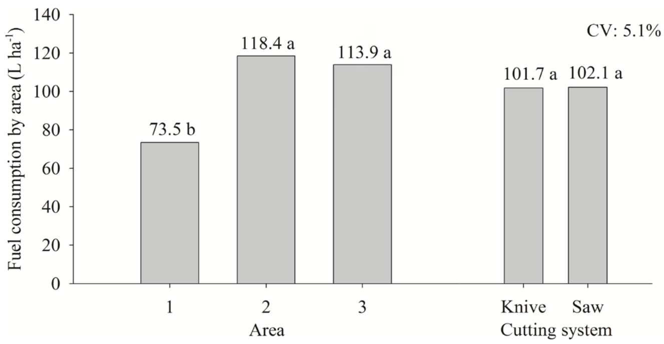
The highest effective hourly fuel consumption was observed in area 3 (58.1 L $h^{-1}$); the cultivation system used was the alternating double row. This requires greater power from the harvester engine, which needs to process a large quantity of plant material, as also observed by Testa et al. (2016) evaluating the operational and energy performance of sugarcane harvesters (*Saccharum* spp.) for one and two-crop rows, with greater engine power demand when harvesting two crop rows.

The results of this research differ from Martins et al. (2021), where the increase in travel speed increased fuel consumption and the cost of the operation, as in area 1 during mechanized harvesting, a higher travel speed was used (4 km $h^{-1}$) concerning the other areas and lowest fuel consumption was observed.

In addition to the harvester's operational speed, the engine's rotation at harvest impacts its energy consumption; thus, even using a higher speed in area 1 due to low yield (61.4 Mg $ha^{-1}$) required lower engine rotations, resulting in lower effective consumption. Ramos et al. (2016) explain that engine speed variations significantly influence harvesters' fuel consumption, regardless of the operational configurations in sugarcane fields.

The results obtained in this study follow the findings of Drudi et al. (2019), where the evaluation of average hourly consumption in different sugarcane field conditions, adopting single-row harvesters with a speed of 3 km $h^{-1}$, found average consumption between 47 and 57 L $h^{-1}$.

The effective fuel consumption during harvest did not show a statistically significant difference between the cutting systems; however, the differences were significant only between the assessed areas (Figure 4). The results followed the patterns verified in the assessment of hourly fuel consumption, indicating that the cutting devices impose similar resistance to the harvester's processing systems so that fuel consumption is not affected regardless of saws or blades. In percentual terms, fuel consumption per area in harvesters equipped with saws increased by 3.9% compared to the knife system, even without the difference in the statistical analysis.




Means followed by the same letters do not differ by the Tukey test ($p < 0.05$)

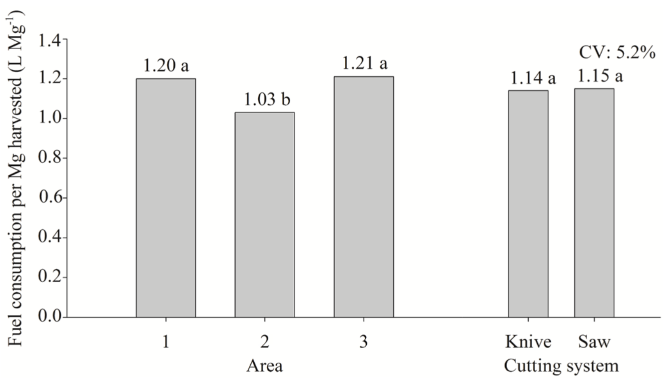
**Figure 4.** Fuel consumption according to the harvested area and cutting systems

The highest average fuel consumption per harvested area was found in area 2, with a consumption of 118.4 L $ha^{-1}$; this result is related to the high yield of the area (114.8 Mg $ha^{-1}$) in addition to the lower harvesting speed due to the high-power requirements of mechanized systems since to process more plant material per unit of time, the fuel flow and greater engine speed requirements increase (Ramos et al., 2016; Martins et al., 2021). In addition, according to Queiroz et al. (2017), operating time in the same area at low speeds provides greater fuel consumption per area worked.

The results show that between areas 2 and 3, there were no significant differences in fuel consumption. The highest absolute values indicate that, for the difference in sugarcane yield of the areas (21.4 Mg), consumption did not vary significantly, showing that the harvester's power demand, based on the sugarcane yield, may not present a difference in the energy demand of cut. Thus, harvesting a sugarcane field with a yield of 90 Mg ha may require a similar amount of energy to harvesting a sugarcane field of 120 Mg ha.

Similar to the hourly fuel consumption and by area, the tested cutting systems did not show significant differences in fuel consumption per mass (Mg); the significant differences occurred only for the tested areas (Figure 5).

Area 3 (1.21 L $Mg^{-1}$) had the highest fuel consumption, depending on the amount of plant material harvested, followed by area 1 (1.20 L $Mg^{-1}$). These results were above the averages of Drudi et al. (2019), who used speeds close to 3.5 km $h^{-1}$ and found values of 0.85 to 0.96 L $Mg^{-1}$. It is worth noting that the average fuel consumption in harvesters equipped with saws




Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$)

**Figure 5.** Fuel consumption per mass harvested according to the area and cutting systems

increased by 8.7% compared to the knife system, even without the difference in the statistical analysis.

The lowest fuel consumption value found was 1.03 L $Mg^{-1}$ in area 2; this indicates that the high yield in this area attenuated the highest volumetric fuel consumption averages. Our results approach the findings of Testa et al. (2016), who, using speeds close to 3.5 km $h^{-1}$, found a consumption of 0.76 L $Mg^{-1}$. However, the machine model and the environmental conditions found in crops can alter the machines' energy performance.

Converting the calorific value of the fuel, we find that each Mg of sugarcane harvested, regardless of the cutting system, requires an average of 37.3 kJ of energy during harvest. This energy demand is further increased by the demand from the tractor and cargo vehicle and road transport to the processing mill. According to Powar et al. (2020), the energy balance of sugarcane yield has a positive balance in energy terms; this occurs due to the energetic power of by-products from the industrial process, such as sugar and ethanol, in addition to the energy contained in the crop's biomass.

Martins et al. (2023) state that new techniques to promote harvesting efficiency have emerged in recent years, including precision agriculture and digital systems. In this way, new telemetry and control systems integrated into sugarcane harvesters can adjust operational speed and crop conditions, optimizing energy demand and improving general process conditions.

## Conclusions

1. Saws or cutting blades do not affect harvesters' operational performance, regardless of crop yield. However, saws increased fuel consumption per area by 3.9% and 8.9% per Mg harvested.

2. Sugarcane yield significantly affected the operational speed and fuel consumption of sugarcane harvesters; therefore, sugarcane fields with higher yields require higher fuel and energy. For sugarcane yields above 90 Mg $ha^{-1}$, the effect of increased energy demand stabilizes up to 120 Mg $ha^{-1}$.

3. The fuel demand ranged between 1.0 and 1.2 L $Mg^{-1}$ harvested, excluding the energy for loading or transport. Thus, 37.3 kJ of energy is required for each Mg harvested from the harvester.

**Contribution of authors:** Design research: João V. P. Testa, Aldir C. Marques Filho, Kléber P. Lanças; Collection, analysis and interpretation of data, and preparation of the manuscript: João V. P. Testa, Murilo B. Martins, Aldir C. Marques Filho; Writing and literature review: Aldir C. Marques Filho, João V. P. Testa, Murilo B. Martins, Fernanda P. de A. P. Bortolheiro, Pablo L. de Almeida; Administration: Kléber P. Lanças; Acquisition financing: Murilo B. Martins.

**Supplementary documents**: There are no supplementary sources.

**Conflict of interest:** The authors declare no conflict of interest.

**Financing statement:** There was no source of funding for the research.

## Literature Cited

Banchi, A. D.; Garcia, A. P.; Albiero, D.; Galvão, C. B.; Favarin, L. G. A. Importance of crop productivity and equipment lifetime in the strategic and tactical management of sugarcane harvesters. Engenharia Agrícola, v.40, p.601–608, 2020. http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v40n5p601-608/2020

Drudi, F. S.; Martins, M. B.; Testa, J. V. P.; Ramos, C. R. G.; Lanças, K. P. Desempenho energético de colhedoras de cana-de-açúcar em diferentes produtividades agrícolas e velocidades de trabalho. Energia na Agricultura, v.34, p.180-186, 2019. http://dx.doi.org/10.17224/EnergAgric.2019v34n2p180-186

Fiorese, D. A.; Lanças, K. P.; Guerra, S. P. S.; Marasca, I.; Aleixo, E. V.; Maciel, A. J. da S. Características energéticas dos tratores agrícolas. Agriworld, v.04, p.38–46, 2012.

González-Cueto, O.; Castillo-Rodríguez, J. A.; Ávalos-Clavelo, J. L.; López-Bravo, E.; Herrera-Suárez, M.; Salcerio, S. Analysis of the field efficiency of sugarcane harvesters. INMATEH - Agricultural Engineering, v.63, p.301-308, 2021. https://doi.org/10.35633/inmateh-63-30

Hong, W.; Cai, W.; Wang, S.; Tomovic, M. M. Mechanical wear debris feature, detection, and diagnosis: A review. Chinese Journal of Aeronautics, v.31, p.867-882, 2018. https://doi.org/10.1016/j.cja.2017.11.016

Li, Z.; Lin, Z.; Li, S.; Zhang, H. Optimization research on the working parameters of sugarcane harvester on the cutting time of stalks using virtual prototype technology. Sugar Tech, v.25, p.41-56, 2023. https://doi.org/10.1007/s12355-022-01195-3

Maldaner, L. F.; Corrêdo, L. de P.; Canata, T. F.; Molin, J. P. Predicting the sugarcane yield in real-time by harvester engine parameters and machine learning approaches. Computers and Electronics in Agriculture, v.181, e105945, 2021. https://doi.org/10.1016/j.compag.2020.105945

Marques Filho, A. C.; Testa, J. V.; Moura, M. S.; Martins, M. B.; Lanças, K. P. Continuous and impact cutting systems for sugarcane harvester. Engenharia Agrícola, v.42, e20210167, 2022. https://doi.org/10.1590/1809-4430-Eng.Agric.v42n2e20210167/2022

Martins, M. B.; Marques Filho, A. C.; Drudi, F. S.; Bortolheiro, F. P. de A. P.; Vendruscolo, E. P.; Esperancini, M. S. T. Economic efficiency of mechanized harvesting of sugarcane at different operating speeds. Sugar Tech, v.23, p.428-432, 2021. https://doi.org/10.1007/s12355-020-00910-2

Martins, M. B.; Marques Filho, A. C.; Santana, L. S.; Bortolheiro, F. P. de A. P.; Silva, K. G. P. da. Sugarcane harvester: a bibliometric review. Sugar Tech, v.25, p.1316-1327, 2023. https://doi.org/10.1007/s12355-023-01286-9

Martins, M. B.; Ramos, C. R. G.; Souza, F. L. de; Sartori, M. M. P.; Lanças, K. P. Relação entre velocidade de deslocamento, rendimento da cana-de-açúcar e o consumo de combustível da colhedora. Revista de Agricultura Neotropical, v.4, p.88–91, 2017. https://doi.org/10.32404/rean.v4i1.1264

Powar, R. V.; Mehetre, S. A.; Patil, P. R.; Patil, R. V.; Wagavekar, V. A.; Turkewadkar, S. G.; Patil, S. B. Study on energy use efficiency for sugarcane crop production using the data envelopment analysis (DEA) technique. Journal of Biosystems Engineering, v.45, p.291-309, 2020. https://doi.org/10.1007/s42853-020-00070-x

Queiroz, R. F.; Mota, W. A. da; Macedo, D. X. S.; Costa, E.; Chioderoli, C. A. Loads in the fertiliser tank of a seeder and operating performance. Revista Ciência Agronômica, v.48, p.271-277, 2017. https://doi.org/10.5935/1806-6690.20170031

Ramos, C. R. G.; Lanças, K. P.; Lyra, G. A. de; Sandi, J. Fuel consumption of a sugarcane harvester in different operational settings. Revista Brasileira de Engenharia Agrícola e Ambiental, v.20, p.588–592, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n6p588-592

Silva, M. J. da; Neves, L. de O.; Correa, M. H. F.; Souza, C. H. W. de. Quality indexes and performance in mechanized harvesting of sugarcane at a burnt cane and green cane. Sugar Tech, v.23, p.499–507, 2021. https://doi.org/10.1007/s12355-021-00957-9

Shin, C. S.; Kim, K. U.; Kim, K. W. Energy efficiency classification of agricultural tractors in Korea. Journal of Biosystems Engineering, v.37, p.215-224, 2012. http://dx.doi.org/10.5307/JBE.2012.37.4.215

Testa, J. V. P.; Lanças, K. P.; Martins, M. B.; Sandi, J.; Drudi, F. S. Desempenho operacional e energético de colhedoras de cana-de-açúcar (*Saccharum* spp.) para uma e duas linhas da cultura. Energia na Agricultura, v.31, p.253-258, 2016. https://doi.org/10.17224/EnergAgric.2016v31n3p253-258