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Maneuvers: operational performance of sugarcane harvesters

Welligton Morais Gallo[1], Jenyffer da Silva Gomes Santos[1], Hernani Mazier Júnior[2], Angel Pontin Garcia[1], Daniel Albiero[1]

[1] Universidade Estadual de Campinas, Campinas, São Paulo, Brasil. E-mail: welligton.feagri@gmail.com, jnfgomes@gmail.com, angelpg@unicamp.br, daniel.albiero@gmail.com

[2] Usina Alta Mogiana, São Joaquim da Barra, São Paulo, Brasil. E-mail: hernani-junior@altamogiana.com.br

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ABSTRACT

Sugarcane is among the main crops that compose Brazilian's agribusiness. Therefore, cropping has a significant economic and social role, as production increases yearly. Currently, in Brazil, the mechanized harvest of sugarcane is growing fast in most of the country. The improvement in the harvester's performance allows for fewer expenses and a higher operating yield. This study aimed to analyze the correlation between fuel consumption and maneuvering time of sugarcane harvesters in three different areas (W1 > 20 ha, 10 ha < W2< 20 ha, and W3 < 10 ha). Were calculated fuel consumption per maneuver in each area and analyzed how this value can change due to the tracks' spatial variability combined with the machine's hourly consumption. Based on the variable maneuvering time results and consumption per maneuver, the treatment W3 was the one that obtained the lowest fuel consumption with the T maneuver, due to the shorter mean maneuvering time, besides the more significant available track space to perform them. So that is the best configuration that aims at more significant savings in production cost.

Keywords: Fuel consumption, Maneuvering time, Agricultural machinery, Mechanized harvest.

Manobras: desempenho operacional de colhedoras de cana-de-açúcar

RESUMO

A cana-de-açúcar está entre as principais culturas que compõem o agronegócio brasileiro. A cultura tem um papel econômico e social significativo, uma vez que a produção aumenta a cada ano. Atualmente, no Brasil, a colheita mecanizada de cana de açúcar está crescendo rapidamente na maior parte do país. A melhoria no desempenho da colhedora permite menos despesas e um maior rendimento operacional. Este estudo teve como objetivo analisar a correlação entre o consumo de combustível e o tempo de manobra das colhedoras de cana em três áreas diferentes (W1 > 20 ha, 10 ha < W2 < 20 ha, e W3 < 10 ha). Foi calculado o consumo de combustível por manobra em cada área e analisado como este valor pode mudar devido à variabilidade espacial das pistas combinadas com o consumo horário da máquina. Com base nos resultados da variável tempo de manobra e consumo por manobra, o tratamento W3 foi o que obteve o menor consumo de combustível com a manobra T, devido ao menor tempo médio de manobra, além do maior espaço disponível nas pistas para realizá-las. Portanto, esta é a melhor configuração que visa uma maior economia no custo de produção.

Palavras-chave: Consumo de combustível, Tempo de manobra, Máquinas agrícolas, Colheita mecanizada.

1. Introduction

Sugarcane production in Brazil began in the first years after the discovery of the country, and since the beginning of colonization, its production has increased with each crop. Sugarcane is one of the primary sources in the production of sugar, ethanol, and bioelectricity in Brazil, establishing the development of the sugar-energy sector, thus ensuring the economic relevance of the cropping (Alves et al., 2021; Pereira and Barreto, 2020).

Besides its economic importance, Brazil's high sugarcane production makes it a significant ethanol and sugar exporter (Solomon, 2016). In the 2020/2021 crop, Brazil exported about 32.2 million tons of sugar, resulting in a 69.8% increase compared to the previous cycle. It contributed to the country reaching the highest sugar export in its history. In the same period, ethanol increased by 55.1% (CONAB, 2022). Due to the high production of sugarcane, it is necessary to create a system that can efficiently remove the product from the field and make it available at the right time for the mills to conduct chemical and physical processes to obtain the by-products that will be marketed on a national and international scale.

Since the Green Revolution, Brazil's agricultural technological development has intensified (Defante et al., 2020). Currently, the mechanized system is employed on a large scale in many commercial sugarcane fields in Brazil (Silva et al., 2021). According to the Brazilian National Supply Company (CONAB), in the last ten years, sugar cane increased from 55.1 %—in the 2010/2011 crop— to 89.1% in the last crop. This show that mechanized harvest is growing fast in the sugarcane crop.

When the harvester reaches the end of the row during sugarcane harvesting, it is necessary to realign the harvester to the next row. The time interval spent to perform movements at the headland of the plot in order to position the machine for the harvesting process in the next row is called maneuvering time (Ramos et. al., 2016a). The geometry of these maneuvers directly affects the time spent realigning the machine. According to Spekken et al. (2015), the harvester can be maneuvered in four ways: U, Ω, P, and T.

The U-shaped maneuver (Figure 1A) is performed with only one movement and requires a smaller space to realign. Therefore, it is more indicated when the plot has large rows, allowing the machinery to maneuver. The type Ω (Figure 1B) is performed continuously and with a low time to realign the harvester. However, the headland size is an issue, as this maneuver requires a larger space. The T maneuver (Figure 1C) is the most common at harvest fronts. It is performed in three movements and requires a smaller space at the headland of the plot.

For the P-shaped maneuver (Figure 1D), it is necessary to space perform the maneuver in which the harvester travels a distance to this location and, after performing the maneuver, returns to the row that needs to be harvested. The time in this maneuver is an issue because the total time to perform the maneuver will be the sum of the back-and-forth trip distance plus the time interval spent in the maneuvering space.

Due to the high spatial variability of the plots found in a comparable property, a standard way of maneuvering is commonly used in the industry, and operators receive training on how to perform them correctly.

Some factors can directly influence the harvester's performance, either at harvesting the product from the field or at the headland maneuvers. To find the right point for the maneuvering of the harvester, machine working speed, engine rotation, and hourly fuel consumption are essential factors that must be analyzed, the latter being a direct variable of the other factors besides being one of the main bottlenecks of mechanized harvesting since it influences the total costs of mechanical activities (Ripoli and Ripoli, 2009; Ramos et al. 2016a; Martins et al., 2017; Drudi et al., 2019).

This study aims to correlate the harvester maneuvering time at the headland of the plots, from the layout of the planting in the area (>20 ha, 10< >20 ha<10) to fuel consumption, thus determining the best configuration that aims at more significant savings in production cost.

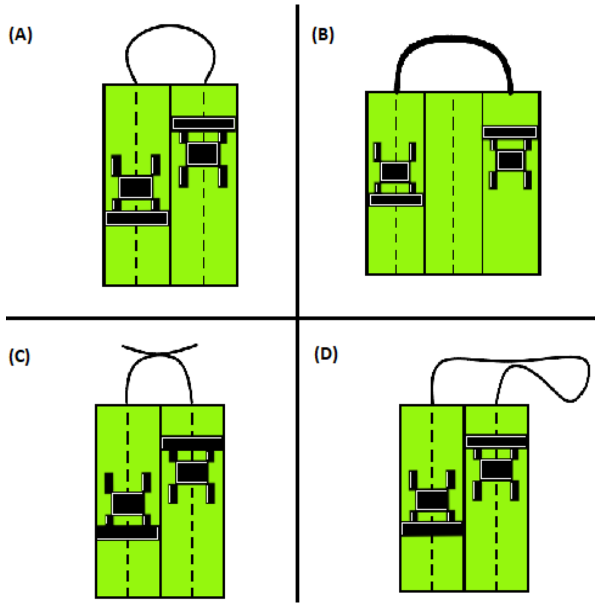

Figure. 1 - Representation of the four types of maneuvers for realigning the harvester, namely: U (a), Ω (b), P(c), and T(d). Source: elaborated by the authors

2. Material and Methods

The data used in this study belong to a sugar-alcohol mill located in the inner land of São Paulo. However, due to the General Data Protection Law, the location and name of the mill were omitted. In order to study the correlation between fuel consumption and maneuvering time in different plots, three treatments were determined: W1, W2, and W3. Three harvesters of the same model were used for each of the three treatments: John Deere CH570. This model harvests one row at a time with a John Deere 6090T PowerTechTM (Marl) engine, which has a power of 342 hp. The transmission system has two hydrostatic pumps that provide variable speeds with a capacity of 605 liters.

Treatment W1 (Figure 2A) is located at Sítio Olhos D'Água III, in the municipality of Ipuã - SP. The treatment corresponds to Plot 4 and has an area of 23.29 hectares with a track area of 2.5 ha (3.34%). Treatment W2 (2B) is located at Sítio Boa Sorte II, in the municipality of Ipuã - SP. The treatment corresponds to Plot 2 and has an area of 17.22 hectares with a track area of 3.49 ha (3.52%). Treatment W3 (2C) is located at Sítio Laranjal, in the municipality of Ipuã - SP. The treatment corresponds to Plot 1 and has an area of 8.58 hectares with a track area of 1.87 ha (5.94%) and an unplanted area (4.94 ha).

Two parameters were used: plot area and speed level as a function of the time variation. For treatment W1, the research area is above 20 hectares. The area analyzed for the second treatment (W2) is between 10 and 20 hectares. Moreover, finally, in treatment W3, the research area is below 10 hectares. The harvester setup provided information regarding the speed variation as a function of time. For example, the mill's sugarcane harvesting speed was 5.0 km.h-1.

According to the area and speed variation as a function of time, the three treatments were characterized for the analysis of the data obtained at harvesting: Treatment (W1) - It corresponds to the large plot in which the area is above 20 hectares. Also, the speed level of around 5 km.h-1 is maintained for a longer interval, showing a greater harvest distance; Treatment (W2) - It corresponds to the average plot ranging from 10 to 20 hectares. The speed variation in this treatment shows a slightly lower level when compared to treatment W1; Treatment (W3) - It corresponds to the small plot, smaller than 10 hectares. Notably, in this scenario, the speed level remains for less time compared to treatments W1 and W2 which shows that the harvest distance is shorter. Moreover, it will be necessary to perform more maneuvers.

The data were obtained with the support of the mill intelligence center by the JDLink system integrated into the machine that provides the data, such as maps, alerts, operating hours, and maintenance. With the help of this telemetry system, it was possible to obtain the data used in each treatment. Thus, for the three treatments above, the analyzed period was 24 hours for each treatment, while the following activities were still conducted: maneuvering, harvesting, engaging, and transporting, among others.

Throughout the period, the machine information collection system records the time spent on each activity, the average consumption, and the start and the end time of each activity. When the operator reaches the end of the row, the maneuvering mode is activated, decreasing the harvester engine rotation to 1500 RPM. As tracked in site, three movements are performed for each maneuver, as highlighted in the characteristic T curve. A 5% significance level was used. It was possible to obtain the minimum number for each treatment.

Table 1 shows that the kurtosis values for maneuvering time and consumption per maneuver of treatment W1, maneuvering time, and consumption per maneuver in the symmetry of treatment W2 and all variables for treatment W3 for kurtosis were abnormal. Thus, it was necessary to use a nonparametric analysis.

In treatment W3, the harvester does not have the JDlink system to report fuel consumption in the maneuver. Because it is an older machine with less mechanical availability, it is relocated to plots with worse harvesting possibilities to maximize the yield of the newer harvesters. In order to determine the hourly consumption of the harvester of treatment W3, as the three machines studied have the same model, the variation in hourly consumption is negligible. With the information of the harvesters used in treatments W1 and W2, it was considered the consumption of the machine that showed the lowest coefficient of variation, obtained from equation 1.

$$\text{Coefficient of variation} = \frac{\sigma}{\chi} \qquad (1)$$

Where:

σ – standard sample deviation

χ – sample's mean

Based on the information generated by each machine, the mean consumption was found (L.h-1), varying according to the employed activity to obtain fuel consumption per maneuver. The mean hourly consumption for the maneuvers was used to calculate the fuel used in realigning the harvester. For the calculation of consumption in each maneuver, the same time interval was used for both pieces of information. For example, for the hourly consumption observed between 00:00 a.m. and 01:00 a.m., the maneuvers performed in this period were selected, and so on for the other periods within 24 hours.

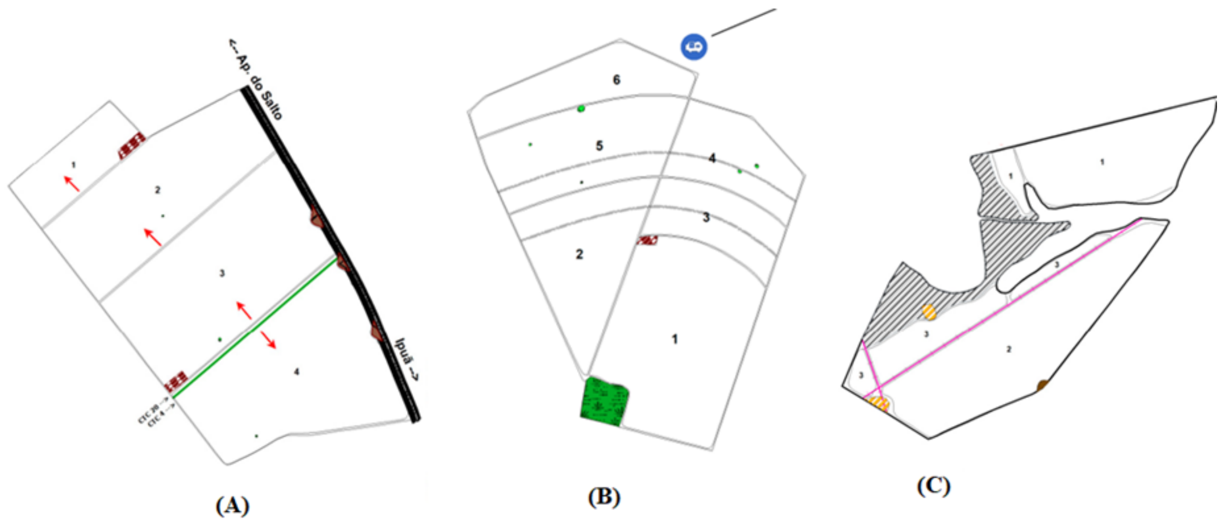

Figure 2. (A) Area of 23.39 ha corresponding to treatment W1 (plot 4); **(B)** Area of 17.22 ha corresponding to treatment W2 (Plot 2); **(C)** Area of 8.58 ha corresponding to treatment W3 (plot 1).

Table 1. Symmetry and kurtosis normality tests for fuel consumption data, maneuvering time and consumption per maneuver of treatments W1, W2 and W3.

Norm. test/ Characteristic	Fuel Consumption			Maneuvering Time			Consumption per maneuver		
	W1	W2	W3	W1	W2	W3	W1	W2	W3
Kurtosis	2.59	−0.11	5.18	4.84	2.10	10.64	6.27	1.95	8.65
Symmetry	−0.56	2.67	1.76	1.49	8.13	2.52	1.94	7.17	2.22

Kruskall-Wallis nonparametric test was performed at 5% significance level to evaluate if there was a difference between the treatments.

In order to obtain the number of liters used in each treatment, the equations below were used.

$$\text{ConsF} = \frac{\text{ConsH}}{3600} \quad (2)$$

Where:

ConsF: Fuel Consumption (l/s)

ConsH: Consumption (L/h)

3600: factor of conversion for consumption (l/s)

$$\text{ConsM}=\text{ConsL}*\Delta t \quad (3)$$

Where:

ConsM: Consumption per Maneuver (l)

Δt: time used in each maneuver (s)

$$\text{ConsTotal}=\sum \text{ConsM} \quad (4)$$

Where:

ConsTotal: Total Consumption per Maneuver (l)

To analyze the normality of data, the symmetry and kurtosis test was performed for each of the analyzed variables since these tests are the ones that best represent the variability found in the field. The symmetry and kurtosis value must be between −2 and 2 (Cramer 2019) for all variables, attesting to data normality.

3. Results and Discussion

Figure 3 shows how the second factor can be analyzed to characterize each treatment according to greater or lesser speed variations during a time interval Δt. It is verified that, among the three studied areas, treatment W1 (Figure 3A) is the one with the lowest speed variation, followed by W2 (Figure 3B) and W3 (Figure 3C), with higher variations. Thus, the larger the size of the plot, the greater the harvest distance, so the machine will maintain the speed for a more extended period since the number of maneuvers will be smaller.

Table 2 shows the p-values. Considering that all values were inferior to 0.05, it is understood that there is a significant difference between treatments for all analyzed variables. Thus, our null hypothesis was rejected. Then, the Nemenyi test was performed to compare the means. Figure 4 shows the results obtained from the hourly consumption of each harvester. The coefficients of variation obtained for the 4798 (W2) and 4797 (W1) harvesters correspond to 6.5% and 11.5%. Machine 4797 shows the highest consumption because it was used in plots with better harvesting conditions than treatment W2.

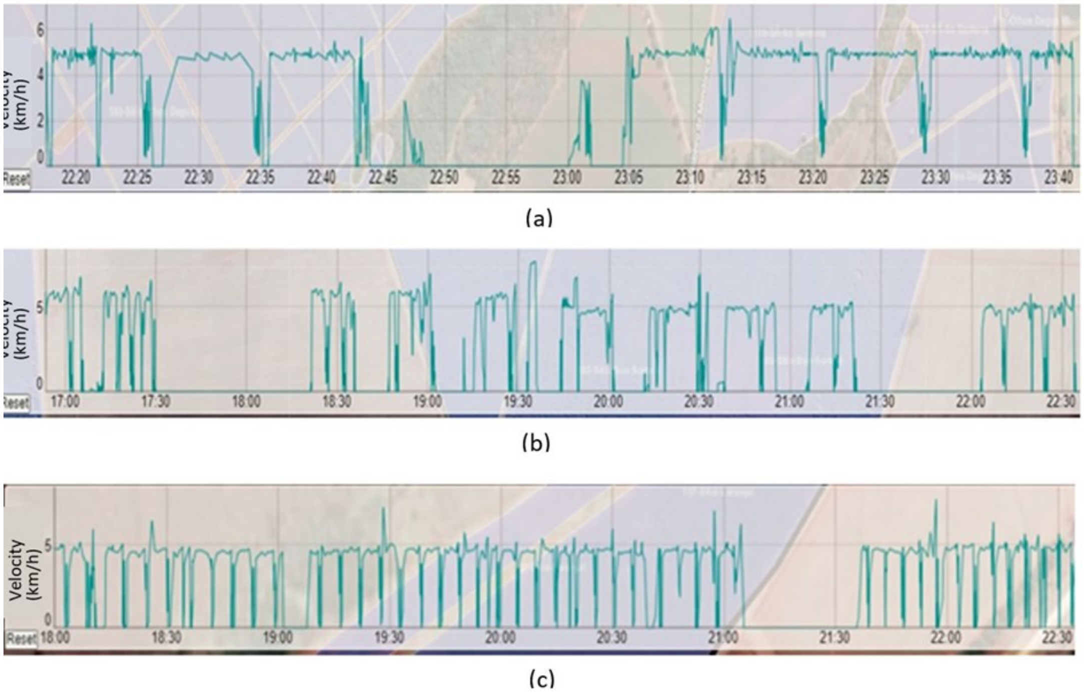

Figure 3. Speed variations as a function of the time for treatments W1 (a), W2 (b), and W3 (c).

As the harvester used in treatment W3 has no information on the hourly fuel consumption, the hourly consumption of the machine used in treatment W1 was considered. The Nemenyi test identified which treatments have differences between them. The first comparison between treatments W1 and W2 showed no significant differences (Figure 5). Note that in figure 2, the track area in the two properties is similar. The first treatment had 3.34% of the contract track area, and the second had 3.52%. This way, the available space to perform the maneuver influenced the amount of time used by the operator to realign the harvester.

It is also possible to observe that treatment W3 only shows a significant difference concerning the other two treatments. However, as this is the treatment with the most significant area available for maneuvering, with 5.94% of the runway area (figure 2), this reduces the maneuvering time. According to the results of the Nemenyi test at a 5% significance level, we noticed a difference in fuel consumption per maneuver between treatments (Figure 6). Between treatments W1 and W2, there was no significant difference in fuel consumption, although the first treatment showed higher mean consumption because of maneuvering time and mean consumption per hour.

The first factor, according to the results presented above, treatment W1 shows the longest mean time to maneuver the harvester, mainly influenced by the availability of space in the tracks, which is the lowest proportion in the contract area of the three treatments. The mean consumption of the harvester in treatment W1 was higher than that observed in the harvester used in treatment W2, which influences fuel consumption per maneuver.

Table 2. P-values for nonparametric Kruskal-Wallis analysis for the variables of fuel consumption, maneuvering time and consumption per maneuver of treatments W1, W2, and W3.

Characteristic	p-value
Fuel consumption	0.04242
Maneuvering Time	$6.83 * 10^{-9}$
Consumption per maneuver	$9.38 * 10^{-9}$

Treatments W2 and W3 showed significant differences between them. Although the mean hourly fuel consumption is 7% higher in treatment W3 compared to the second treatment, we noted that the consumption per maneuver is below the second treatment because the mean maneuvering time is shorter and has greater availability of space to perform the maneuvers in the third treatment.

Comparatively, treatments W1 and W3 show the most distant values for significant minimum difference, either for maneuvering time or fuel consumption. As the mean consumption used for treatment W3 was the same as for W1, the difference between the mean maneuvering time in each treatment influences the higher fuel consumption. As the harvester is configured to maneuver at maneuvering time, with rotation of 1500 RPM and three movements to realign the harvester, the availability of space in the tracks is an essential factor, interfering in the time to perform the maneuver and consequently in the amount of fuel consumed by the machine.

Ramos et al. 2016b and Martins et al. (2021), studying the mechanized sugarcane harvest with different work speeds, concluded that the forward speed influences harvesting capacity and fuel consumption. Figure 7 shows the fuel consumption in liters for each treatment. Treatment W1, despite showing the most significant area and the most extended harvest distances, the time and mean fuel consumption influenced the amount of fuel consumed by the harvester since the proportion of area available for maneuvers is the lowest observed in all treatments.

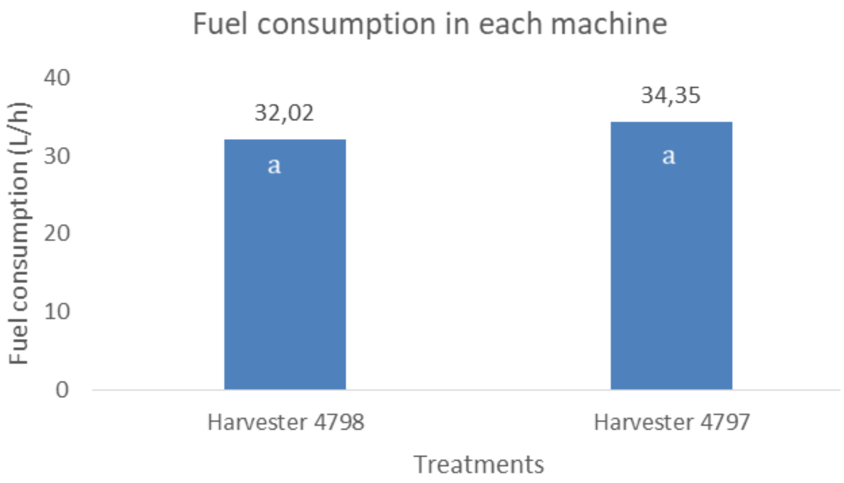

Figure 4. Comparison between mean fuel consumption in the 4798 (W2) and 4797 (W1) harvesters.

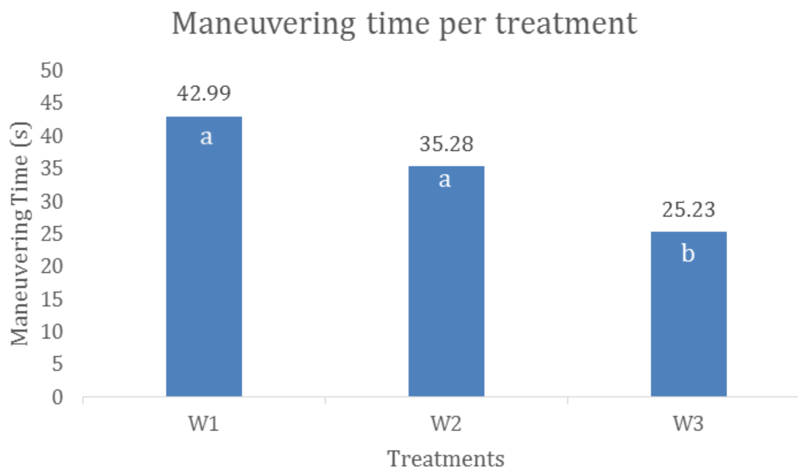

Figure 5. Comparison between means for the variable maneuvering time for treatments W1, W2, and W3.

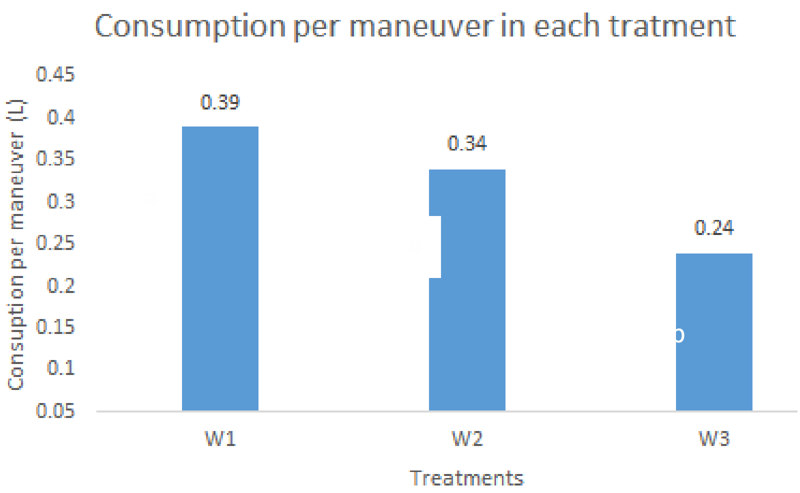

Figure 6. Comparison of means for the variable maneuvering time for treatments W1, W2, and W3

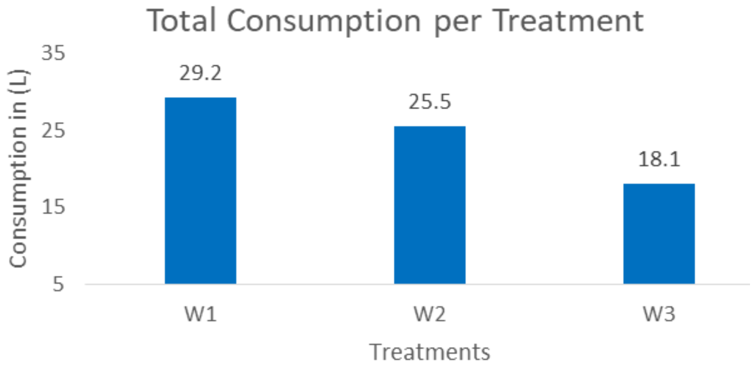

Figure 7. Total fuel consumption for treatments W1, W2, and W3

For treatment W2, we observed that the consumption was below treatment W1 due to the mean consumption being lower than the one observed in the first treatment, besides the relatively higher availability of the track area compared to W1. Finally, treatment W3 showed the lowest consumption compared to the other two treatments. Silva et al. (2018), analyzing the correlation of the operational capacity of sugarcane harvesters with property size, concluded that Property size is the variable that better represent the operational capacity of harvesters. According to Santos et al. 2018, decreased time lost increases machine productive time and time worked.

Thus, the amount of fuel used in each treatment varies because of the hourly consumption of the machine, the area available to perform the maneuver, and the time spent to realign the harvester. Parameters such as rotation and amount of movements do not vary because of the scene since the harvester has a specific drive system for the moment of maneuvers.

4. Conclusions

Treatment W3 was the one that obtained the lowest fuel consumption with the T maneuver, due to the shorter mean maneuvering time, besides the more significant available track space to perform them. So that is the best configuration that aims at more significant savings in production cost.

A Suggestion for future work is must be studied the track area available in each property because, according to this parameter, one can obtain the minimum distance necessary to perform the maneuvers in the shortest time combined with the hourly consumption. Thus, achieving significant differences in the total consumption of liters used at the harvest fronts.

Authors' Contribution

All authors contributed to the study's conception and design. Wellington Morais Gallo e Daniel Albiero performed material preparation, data collection, and analysis. The first draft of the manuscript was written by Wellington Morais Gallo, Jenyffer da Silva Gomes Santos, and Daniel Albiero, and all authors commented on previous versions of the manuscript.

All authors read and approved the final manuscript. In this review the authors Daniel Albiero and Wellington Morais Gallo had the idea for the article, Jenyffer da Silva Gomes Santos and Wellington Morais Gallo performed the literature search and data analysis, and Daniel Albiero, Angel Pontin Garcia, and Hernani Mazier Júnior, drafted and critically revised the work.

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