



Article

Noise Level of an Agricultural Tractor in Natural Rubber Harvesting

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Abstract

The rubber tree is the world's main source of natural latex. However, the latex extraction and harvesting system requires a high level of human labor with agricultural tractors, which can expose workers to adverse conditions, such as noise. This study focused on evaluating the noise level emitted by an agricultural tractor during rubber harvesting at different operating points and working speeds. The experimental design adopted was completely randomized in a two-factor factorial arrangement with six replications. The treatments consisted of two tractor engine speeds (900 and 1500 rpm) and two workstation positions (worker inside the tractor and inside the transport trailer) during the latex coagulate collection. For the harvesting operations, a Massey Ferguson model 265 tractor coupled with a transport trailer noise exposure were used during the following operations: 1—distribution of boxes between the rows of rubber trees; 2—loading of the boxes with the collected coagulate; 3—transport of the boxes with latex coagulate to the storage location for commercialization; 4—unloading of the boxes at the storage location for commercialization. Noise assessments were performed at the workers' ear level using a decibel meter according to technical standards. The workers' positions and the tractor's engine speed influenced the noise level during latex coagulate harvesting. The highest noise levels were observed when the agricultural tractor operated at a higher engine speed (1500 rpm), compared to 900 rpm engine speed. Regarding the workstation position, it was found that the noise level at the tractor operator's station was higher than the noise level at the trailer workers' station in all harvesting operations.



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1. Introduction

Two types of rubber are used worldwide: natural rubber, produced by plants, and synthetic rubber, synthesized through chemical processes [1]. Both rubbers can be used together, as in the manufacture of radial truck tires, which require 50% natural rubber; and off-road (OTR) tires, which need to be made with 90% natural rubber. Aircraft tires need to be made with 100% natural rubber. In addition, according to statistics, there are more

than 70,000 types of products worldwide made from natural rubber [2]. The rubber tree (*Hevea brasiliensis*) is the main natural rubber source, and is widely cultivated in tropical and subtropical places of Asia and South America. Natural rubber is applied in strategic areas, such as medical devices, transportation, and industrial production [3], due to its high yield and superior latex quality [4].

With the increasing demand for natural rubber, Brazil has sought to expand production, encouraging cultivation in new areas and increasing export capacity [5]. In this country, rubber tree cultivation has grown in recent years, primarily in tropical areas in the central-west region, due to market share and favorable climatic conditions. Natural rubber production begins with the extraction of latex, a fluid cellular complex with 30% to 50% natural rubber in its composition. This liquid is obtained by making shallow cuts in the tree trunks and collecting the sap, in a repetitive and sustainable process [6,7].

However, harvesting rubber trees presents a particular challenge, as the latex extraction process, known as tapping, is a manual activity requiring specialized labor and demanding high precision and care [8]. This process, carried out over several months, requires appropriate practices to avoid damage to the plant and maximize production, demonstrating the need for in-depth studies on the techniques and challenges faced by rubber tappers [9]. Process improvements in the rubber cycle include the evaluation and development of machinery for mechanizing the harvest and the removal of raw material from the field.

Despite considerable recent progress in crop-specific rubber machinery [10], some challenges remain to be addressed in order to improve human working conditions in the fields. In the rubber tree harvesting process, after latex extraction, clots form in collecting cups. These are subsequently collected and packed in boxes, loaded onto trailers pulled by agricultural tractors and transported to industry or sale. Therefore, it is considered a specialized job and is entirely dependent on manual labor [11]. These manual activities allow for close contact between workers and machines, presenting risks that range from accidents to long-term exposure hazards.

Tractors are the primary agricultural machines, as they are involved in most field operations [12], including rubber tree tapping management. Mechanized operations using agricultural tractors can have a positive effect on increasing the efficiency of various crops, as the tractor plays a fundamental role in many operations during the crop cycle [13,14].

Despite the advantages tractors offer in work productivity, the health implications of their use require attention; improper adjustments can lead to issues ranging from impacts on soil structure [15] to risks associated with exposure to noise, vibration, smoke, and toxic gases, as well as failures in machine safety signals [16]. Therefore, the safety and agricultural machinery efficiency operators have become increasingly important global concerns [17].

Currently, many strategies have been developed to improve workers' quality of life and reduce impacts on human health, particularly regarding noise and hearing damage among workers [18,19]. Although modern agricultural tractors have exhibited significant advances in ergonomic design, the use of older models remains widespread.

According to Butkus et al. [20], noise levels are correlated with the year of manufacture, indicating that older tractors generally generate higher noise exposure. Their findings suggest an increase of approximately 1 dB in noise level for each additional year of tractor age. Furthermore, measurements conducted on agricultural tractors manufactured between 1981 and 2015 revealed substantial variability in cabin noise levels across different models. This occurs because there is a variety of different tractor models and designs, particularly regarding the engine type and the engineering systems used to attenuate noise and vibration.

Furthermore, Singh et al. [21] emphasized that, despite the ergonomic benefits provided by modern tractor fleets, the high cost of acquisition limits their adoption, particularly in developing countries. As a result, many farmers continue to rely on older tractor models. This highlights the need for studies focused on assessing existing tractors and identifying feasible engineering solutions to improve operator comfort, safety, and ergonomic conditions.

However, protective measures are typically implemented for the machine operator inside the cab and do not take into account the noise or gases emitted by the engines into the surrounding environment, where other workers are present. Engine speed, indicating the number of revolutions directly on the crankshaft, directly affects emissions [22] and noise levels depending on the selected gear and operating speed. Gear selection, on the other hand, indicates the tractor's travel speed. The combination of engine speed and gear selection influences the tractor performance, fuel consumption and operational costs [23].

Noise and associated risks can reduce operational efficiency. The negative impact of noise on the operator manifests itself in reduced concentration and increased irritability, in addition to potentially leading to failures during work and faster onset of fatigue, thus affecting labor performance and productivity [24]. Prolonged exposure to noise levels can aggravate hearing loss [25]. In addition, workplace noise exposure, combined with genetic factors, leads to the manifestation of complex occupational disorders [26].

Despite recent advancements in tractors and cabs, the noise emitted by machinery can affect outdoor workers and necessitate improved personal protection systems. This highlights the need for further acoustic studies to determine safe working levels for tractors without cabs [27].

Based on the foregoing, it is expected that operations involving higher engine speeds will result in higher noise levels and that operators working closer to the agricultural tractor's engine will be exposed to higher noise levels than workers positioned further away. Thus, this study aimed to evaluate the noise generated by an agricultural tractor during natural rubber (*Hevea brasiliensis*) harvesting, considering different positions and operational configurations.

2. Materials and Methods

2.1. Site of Study

The experiment was conducted in a commercial latex extraction area located in the Paranaíba municipality, eastern region of Mato Grosso do Sul, Brazil (coordinates 19°41'42" S, 51°12'06" W and altitude 416 m above sea level). The area consisted of rubber tree plants of the clone RRIM 600.

According to the Köppen classification, the region's climate is tropical rainy (Aw), with a rainy summer and a dry winter (winter precipitation less than 60 mm), with average annual precipitation and temperature of 1520 mm and 24.1 °C, respectively.

2.2. Experimental Design and Field Operations

The completely randomized experimental design (CRD) was used, with two-factors arranged in factorial design, with six replications. The treatments consisted of two engine speeds (900 and 1500 rpm) and two worker positions (embedded on the tractor; outside the tractor—transport trailer or near of the tractor). Noise levels were collected for external operators—with three replicates taken at the trailer and three at the ground worker position—and these data were aggregated to calculate the average external noise level. On average, external workers remain approximately 3 m away from the noise source, whereas the tractor operator (onboard driver) remains at an average distance of 1 m from the engine.

Noise measurements were conducted during the distribution and collection of natural rubber harvesting boxes, considering the positions on the tractor operator (driver), ground-based workers (external worker loader), and the worker stationed on the trailer (external worker on the trailer) during operations with the tractor stationary or movement at 900 and 1500 rpm.

Data was collected at six successive noise measurements, serving as the replications during the collection of latex coagulate, with the following operations: 1—distribution of boxes between the rows of rubber trees; 2—loading of the boxes with the collected coagulate; 3—transport of the boxes with latex coagulate to the storage location for commercialization; 4—unloading of the boxes at the storage location for commercialization (Figure 1).

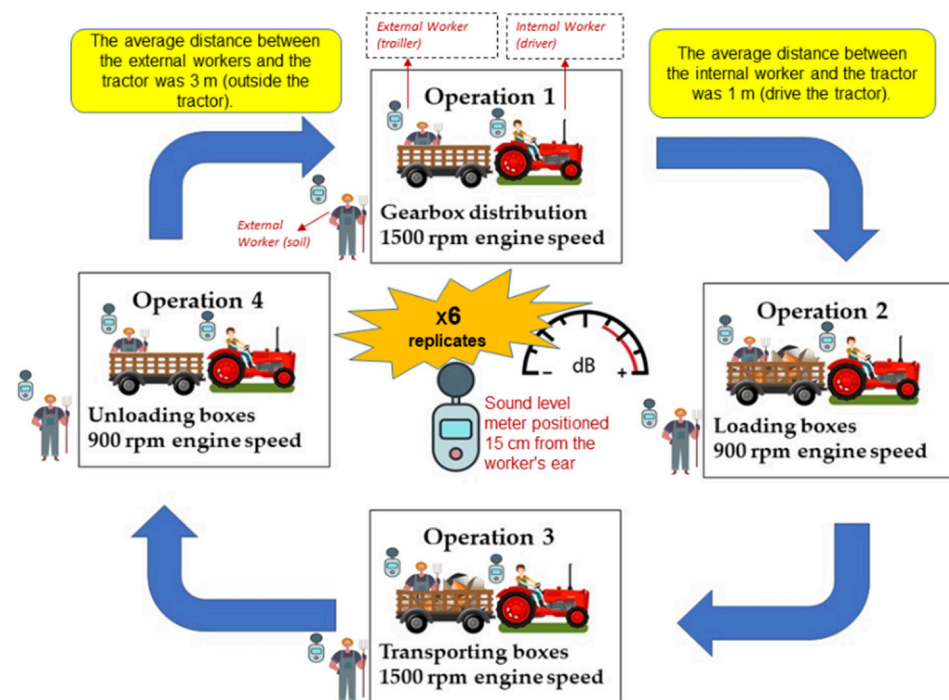


Figure 1. Evaluation of noise levels in four rubber tree harvesting operations. Field boxes distribution operation (1) and transport of full crates (3) at an engine speed of 1500 rpm; crate loading (2) and unloading (4) operations at a 900 rpm reduced speed.

To conduct field tests, a Massey Ferguson, São Paulo, Brazil, model 265 open cab tractor, 4 × 2 model, year 1985, 47.8 kW engine power, was used in all harvesting operations. The model has a transmission with 8 forward gears and 2 reverse gears, equipped with 18.4/15–28 in rear axle and 750/16 in front axle. In all operations, the tractor operated in the second reduced gear, resulting in an average travel speed of 3.0 km h^{−1} at 900 rpm and 3.5 km h^{−1} at 1500 rpm; noise data was collected for both the operator on the agricultural tractor and the rubber tappers positioned on the trailer.

During harvesting operations, data noise emitted by the agricultural tractor was collected throughout the monitoring of harvesting operations and the collection of extracted latex clots. After the clots were stored in the boxes, an agricultural tractor was used to carry the boxes from the field to the storage location for commercialization. This entire logistics process is described as four operations.

In operation 1, plastic boxes were distributed along the rubber tree plantation to hold the extracted coagulated latex. Then, latex was collected along a route pre-established by the rubber tappers and the agricultural tractor operator. This distribution was carried out with the aid of an agricultural tractor, where the tractor operator, with the rubber tappers

positioned in the trailer attached to the tractor, organize the boxes along the route. For this operation, the agricultural tractor operated at 1500 rpm engine speed.

In operation 2, after distribution, the rubber tappers begin collecting the coagulated latex, which is deposited in boxes. The same tractor is used to collect the boxes containing the coagulated latex within the plots, where the tractor operates at 900 rpm engine speed.

In operation 3, the rubber tappers load the boxes containing coagulated latex onto the agricultural trailer for transport to the storage location. At this stage, the tractor operates again at 1500 rpm engine speed.

The final step of the harvest consists of unloading the boxes at the storage location for sale (operation 4). During this stage, the tractor is stationary and maintained the 900 rpm engine speed. The distance range maintained by workers during rubber harvesting can vary between 3 and 7 m outside the tractor.

2.3. Noise Level Measurement

Noise data collection was carried out during rubber harvesting operations, following the stages described in the previous sections. All measurements were taken on the same day, with repetitions performed at 15 s intervals and a data acquisition frequency of 2 Hz (two readings per second), resulting in 30 data points per repetition. These data were interpolated, and the mean noise value (in decibels) was used for the statistical analysis of each treatment.

No wind gusts or external noises affecting the measurements occurred during data collection. The testing environment was controlled, and any extraneous noise unrelated to the experiment was disregarded, in accordance with the standards of the Organisation for Economic Co-operation and Development (OECD) Code 5.

The Sound Level meter used for data collection, as Akron, Rio Grande do Sul, Brazil, model KR923 digital with a standard windshield (foam) microphone for wind protection was used. It was programmed for noise capture in slow response mode (SLOW) and with an "A" weighting circuit, as recommended by Code 5 (OECD). The device has a sound measurement range, from 30 dB to 130 dB. When acquiring data with the decibel meter, the measured values were allowed to stabilize before data collection began with a 15 s interval between readings (with 2 records per second). The decibel meter was positioned 15 cm from the operator's ear, and the same reading parameters were used for external workers and driver tractor.

2.4. Statistical Analysis

The assessment results were first categorized by rotational speed, regardless of the operating location. Subsequently, we evaluated the effect of noise at different positions (on the tractor and off the tractor). Finally, we assessed the differences in noise emissions across various harvesting operations and worker positions. Normality tests and analysis of variance were performed on the entire noise dataset; where differences were found (significant F-value), the Tukey test was applied at a 95% confidence level. The Minitab v.16 software was used for data analysis.

3. Results and Discussion

Noise emission is highly dependent on the engine's operating regime, with higher rotational speeds resulting in greater noise emission. The highest noise levels were obtained in operations 1 and 3, differing statistically from operations 2 and 4 (Figure 2).

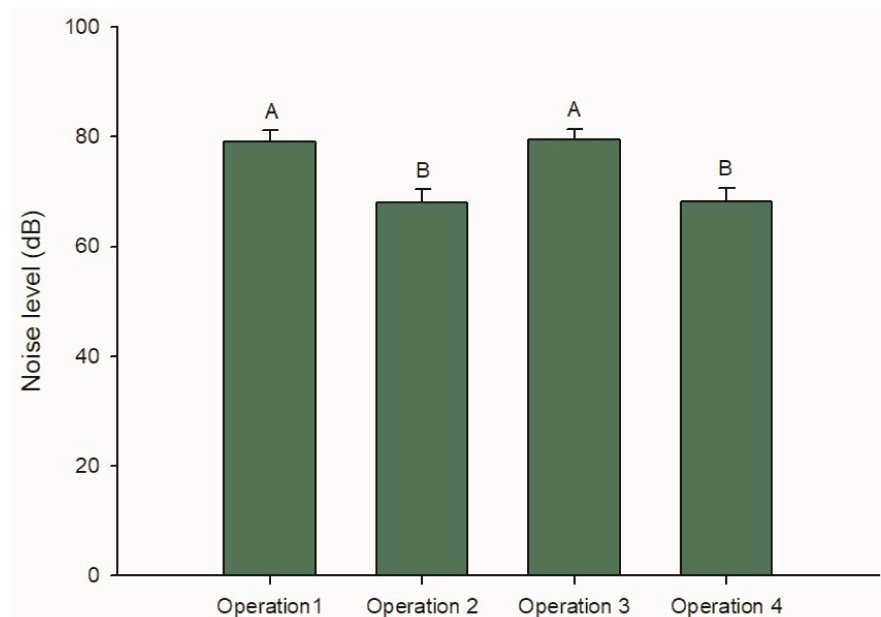


Figure 2. Noise Level in harvesting operations. Means followed by the same letter do not differ, according to Tukey's test ($p < 0.05$). Standard error.

The higher noise in operations 1 and 3 related to the higher tractor engine speed. In the distribution boxes between the rows of rubber trees and in the transport boxes, the tractor's engine speed was 1500 rpm, while for operations 2 and 4, loading and unloading the boxes, respectively, the tractor operated at a lower engine speed of 900 rpm. Thus, with a lower engine speed, the operating demands are lower, resulting in less noise.

Although operations 1 and 3 resulted in higher noise levels of 79 dB, these values were below the limit established by the NR-15 standard of 85 dB (A) for noise levels, as were operations 2 and 4, which resulted in 68 dB (A). Noise levels are commonly expressed in decibels (dB). However, because the human auditory system does not exhibit equal sensitivity across all frequencies, sound measurements are often reported using the A-weighting filter, expressed as dB (A). This weighting system adjusts sound pressure levels to approximate the frequency response of human hearing, placing greater emphasis on frequencies to which the ear is more sensitive and reducing the influence of frequencies that are perceived less effectively. Consequently, dB (A) provides a more representative measure of the perceived loudness of environmental and occupational noise [19].

The results obtained for operations 2 and 4 are similar to those observed by [28] during noise evaluation at the operator's station at different engine speeds of the agricultural tractor, with values close to 60 dB (A) at 800 rpm, thus remaining within the limits established by the NR-15 standard.

Poje [29] analyzed the noise emitted by tractors used in forestry under different loads and found that the noise level measured under light load did not exceed the permitted noise level, while under heavy load it reached more than 88 dB (A). This was due to the higher power demand and consequently the engine speed required for higher loads.

Engine speed is a key factor influencing noise emission in agricultural tractors. In a study evaluating noise reduction in the cab of an MF399 tractor during sugar transport operations, Mofrad et al. [30] assessed noise levels in a Massey Ferguson 399 tractor equipped with and without a cab at engine speeds of 1500, 1750, and 2000 rpm. The results showed that noise levels increased with increasing engine speed under both operating conditions. In rubber tree cultivation, older, open-cab tractors—such as the type used in this study—are common; consequently, noise levels experienced by operators can be intensified by engine operating speeds and, at times, may exceed standard measurements

taken at the operator's position due to the short distance between the workers and the noise source (engine).

For the tractor without a cab, the maximum noise level recorded was 88 dB (A) at 2000 rpm. In contrast, the tractor equipped with a cab exhibited a maximum noise level of 72 dB (A) at the same engine speed, demonstrating the effectiveness of the cab in attenuating operator noise exposure. These findings indicate that while cab insulation can substantially reduce noise levels, engine speed remains a major determinant of noise generation in agricultural tractors. The presence of a cab can offer greater protection to the operator; however, external workers remain subject to exposure. For the model evaluated in our study, simple personal protective equipment—such as ear protection—would be sufficient to protect the work crew across all harvesting positions and operations.

According to Di Stefano et al. [31], noise emission is influenced by operating speed and terrain characteristics, machine maintenance conditions, and the presence of worn or deteriorated components. Furthermore, engine speed is determined by the power requirements of the specific agricultural operation being performed, as sufficient engine output is needed to provide traction and power to attached implements, thereby affecting the resulting noise levels.

Mushtaq et al. [32] evaluated the noise emissions of a 55 kW agricultural tractor coupled to a disc plow, rotary tiller, and cultivator. The authors observed a progressive increase in noise levels, with values exceeding the occupational exposure limit of 85 dB (A) under certain operating conditions. These findings demonstrate that noise generation in agricultural tractors is a multifactorial phenomenon influenced by operational, mechanical, and environmental factors, all of which may contribute to increased worker exposure to potentially harmful noise levels.

Therefore, the choice of rotational speed can affect working speed, which in turn impacts operational performance and operating costs. Our results suggest that when working at higher speeds—where feasible—reducing the rotational speed can save fuel and energy without sacrificing operational output. In addition to these benefits, lower noise emissions can contribute to safeguarding workers' health.

Figure 3 shows the average noise level during rubber tree harvesting. It can be observed that the tractor driver's station had the highest result, 80 dB (A), statistically different from the external workers, at 66 dB (A). The higher noise level for the tractor driver was due to the greater proximity to the noise source; that is, the engine and exhaust were 1 m away, while the workers in the trailer were positioned at a greater distance from the noise source, at 3–7 m, resulting in lower sound intensity.

Noise is any unwanted and unpleasant sound that poses risks to human health and hearing in various ways and to which the human body cannot adapt. It is defined as any undesirable sound in the environment where people live and work, which causes discomfort and can affect health [33]. Our results showed that operator exposure limits are high but within the limits permitted by the safety standard. According to Barač [19] the worker's proximity to the noise source intensifies the effects of the noise on their health, placing them at greater risk than other workers in the same environment. Furthermore, the combination of the distance from the source and the machine's operating regime influences the intensity of the occupational risk involved [34,35].

Silva et al. [36] evaluated the spatial distribution of noise generated by a 63 kW backhoe loader and found that sound pressure levels reached up to 85 dB (A) within a 6 m radius of the machine. These results highlight the value of spatial noise assessment as a tool for establishing effective worker protection and operational management strategies.



Figure 3. Noise level in different positions during harvesting. Means followed by the same letter do not differ, according to Tukey's test ($p < 0.05$). Standard error.

To ensure the safety of tractor operators and workers exposed to agricultural machinery, the use of tools such as noise interpolation maps can support the identification of safe working distances and the development of operational strategies, including recommendations for the use of personal protective equipment [27].

For the results of interactions between operations and workers positions, the lowest noise level was for the external workers compared to the tractor driver, since they are further away from the noise source (Figure 4). In operations 1 and 3, the use of ear protection is indicated because the value exceeds the 85 dB recommended by the NR15, since prolonged exposure to noise levels above the permitted limit is one of the aggravating factors for permanent or temporary hearing loss [25].

Furthermore, noise exposure can adversely affect machine operators by impairing concentration, increasing irritability, and contributing to a greater occurrence of operational errors. Continuous exposure to elevated noise levels may accelerate fatigue development, resulting in decreased work performance and reduced productivity [24]. Addressing occupational health concerns in rubber harvesting can mitigate accidents and boost worker productivity, as it ensures greater attentiveness and reduces risks—especially when the team uses personal protective equipment.

In operations 1 and 3, at 1500 rpm, the operator would be required, according to NR 15, to use ear protection, since the noise exceeds the 85 dB established by the standard. Although the tractor evaluated in this study was an open-cab model, the elevated noise levels recorded at 1500 rpm attributed to manufacturing year. Butkus et al. [20] assessed noise emissions from 50 agricultural tractor models manufactured between 1981 and 2015 and demonstrated that older tractors generally produce higher noise levels than newer models. The reported values ranged from 67 to 94 dB (A), with an estimated average increase of 1 dB (A) in noise level for each additional year of tractor age. This reinforces the idea that newer machines can contribute to reducing workplace risks and increasing operational efficiency.

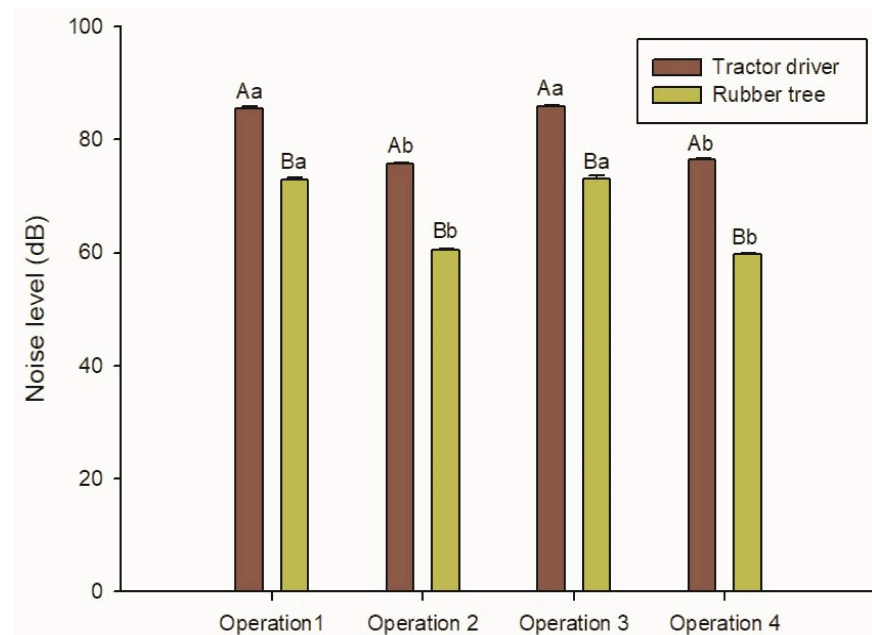


Figure 4. Noise level during harvesting operations and working position. Means followed by the same uppercase letters do not differ for job position, and the same lowercase letters do not differ for operation, according to Tukey's test ($p < 0.05$). Standard error.

Picu [37] assessed the health risks associated with noise and vibration exposure among agricultural machinery operators in Romania by comparing noise emissions from two tractor models manufactured in 1993 and 2013. The results showed that the older tractor produced noise levels of 95 dB (A), while the newer model presented substantially reduced noise emissions of 65 dB (A).

Even at a engine speed of 1500 rpm, noise levels remained below 85 dB for the rubber tapper. At 900 rpm, the levels also remained below the level established by NR 15 regarding the mandatory use of ear protectors. Gonçalves [5] stated that there is spatial dependence in the distribution of noise in the agricultural environment and indicated that up to 6 m away from a pigtail tractor professionals should use ear protectors.

De Souza et al. [34] reported that the noise reduction coefficient was satisfactory for evaluating the acoustic performance of tractor cabs. Furthermore, the noise reduction coefficient of the tractor cab remained stable with variations in crankshaft angular velocity. These findings highlight that cab design and insulation characteristics play a critical role in controlling operator noise exposure, particularly under different engine operating conditions. In contrast, open-cab tractors expose operators directly to external noise sources, resulting in a noisier working environment due to the absence of acoustic insulation provided by the cab [31].

Given the importance of the topic, constant evaluation of noise levels in tractors and agricultural machinery is essential to minimize the effects of noise on workers, and the adoption of tools to optimize the collection of this information is crucial, such as machine learning technologies to predict noise levels [38]. Barač et al. [19] evaluated and predicted noise levels based on operational parameters of an agricultural tractor using a machine learning approach. The authors demonstrated that machine learning methods provided accurate predictions of noise levels inside the tractor cab.

The findings demonstrate that, although protective measures such as sound-insulated cabs and personal protective equipment (PPE) have been implemented, occupational noise exposure continues to represent a major challenge in agricultural environments. Therefore, integrated approaches involving operator training, modernization of agricultural machinery fleets, continuous improvement of prevention and protection practices, proper

use of PPE, and periodic maintenance of machinery are essential to minimize health risks and promote safer working conditions for agricultural operators [31].

The implementation of preventive strategies is essential, with particular emphasis on operator training and instruction regarding the proper use of personal protective equipment (PPE), especially in work environments where noise exposure exceeds recommended safety limits. Additionally, periodic maintenance of agricultural machinery represents an effective approach for reducing noise emissions, particularly in older equipment. The gradual replacement of obsolete machines with modern, low-noise models equipped with sound-insulated cabs may further contribute to minimizing occupational noise exposure and enhancing operator health and safety [24].

Research conducted on noise levels generated by agricultural tractors during the harvesting of natural rubber from *Hevea brasiliensis* demonstrated the importance of considering the impacts of the work environment on workers' health. The data obtained indicated that operations performed with tractors, especially at speeds of 1500 rpm, resulted in noise levels that can exceed the limits established by Regulatory Standard NR-15, highlighting a significant risk to the hearing health of operators.

4. Conclusions

Noise emissions during natural rubber harvesting are affected by the operator's position and the tractor's operating speed. The main findings of this research can be summarized as follows:

- (1) The highest operating speeds (1500 rpm) exhibited the highest noise levels, regardless of the worker's position.
- (2) The distance from the noise source has a direct impact on noise level for workers, where the tractor operator—the person closest to the noise source—is exposed to levels above 85 dB during operations at 1500 rpm.
- (3) The results highlight the need to implement control measures, such as adoption of ergonomic practices, permanent use of personal protective equipment to mitigate the harmful effects of noise and promote a safer work environment.

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Institutional Review Board Statement: This manuscript is justified under Resolution No. 510 of 7 April 2016, which indicates that research aimed at the theoretical exploration of situations arising spontaneously and contingently within professional practice—provided it does not reveal data that could identify the subjects—does not require registration with an ethics committee. Accordingly, the research in question makes no mention of any characteristics of the individuals involved during data collection that could lead to their identification.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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