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Occupational Noise and Vibration Assessments in Forest Harvesting Equipment in North-eastern Brazil

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Authors' contributions

This work was carried out in collaboration among all authors. Authors CFL, APS, LJM and SS designed the study. Authors GSPN, RCAL and MPLV managed the analysis and wrote the draft protocol of the manuscript. All authors performed the corrections and revised the drafts of the manuscript, as well as approved the final manuscript.

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ABSTRACT

Occupational hazards arising from physical agents present in wood harvesting equipment may cause irreversible damage to the health of exposed operators. Thus, the objective of this study was to quantify the noise and vibration levels emitted by three types of wood harvesting equipment (Feller-buncher, Harvester and Forwarder) in a forestry company in north-eastern Brazil during a workday. Noise measurements were performed with an equivalent noise level meter (audiodosimeter) at the workstation and compared with the limits set in NR-15. To evaluate the vibration was used a full cup gauge, which has a sensor called triaxial accelerometer (directions X, Y and Z), installed on the operator's seat. As a result, the average noise dose of all activities in the operation studied did not exceed the maximum allowable limit of 85 dB (A) for 8 hours of continuous

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work. The whole body vibration in all equipment was below the exposure level, however, some equipment obtained indexes slightly higher than the alert level, a fact that shows a higher accuracy in the equipment.

Keywords: Health; physical agents; operators; forestry.

1. INTRODUCTION

The Brazilian forest sector occupies the sixth place among the forest producing countries with an estimated area of about 7.78 million hectares representing 6.2% of the GDP of the Brazilian industrial production [1]. This sector is a wood producer to manufacture a huge list of products needed by the population. However, there is a need to seek technological and operational advances in this field, with the objective of increasing productivity and global competitiveness, based on a model of environmental and social sustainability, since wood production is, in its essence, a costly and impactful activity [2].

One of the most important stages of the production chain is the harvesting of wood, which can represent up to 60% of the final product cost. The harvest has undergone major advances in recent years by the introduction of new equipment. These forestry equipment consist of a set consisting of a tire or track tractor and a coupled front implement (head), which is responsible for cutting trees [3].

The equipment used for harvesting wood can be Harvester, Forwarder and Feller-buncher, among others. These equipments are, in general, imported from European countries, having their design characteristics different from the Brazilian reality [4].

In this sense, there is a concern in investigating aspects related to workers' safety, since their activities are carried out inside the cabins with equipment in forest areas subject to sloping and eroded reliefs. In addition, forestry operators are known to be exposed to a variety of fatigue-causing factors such as cab vibration, shrill movement due to uneven terrain, uncomfortable working positions and the constant twisting and turning of the head, neck and cervical regions [5]. In this context it is necessary to assess the environmental risks present in the workplace [6], given that many forestry companies are more concerned with production than with ergonomics and work organization [7].

Environmental hazards are characterized as existing elements in the workplace that, in relation to their concentration, intensity, nature and exposure time can cause damage to workers' health. The risks may come from chemical, physical, biological, ergonomic and accident agents, depending on the type of activity [8].

It is noted, therefore, that forest harvesting requires special attention from companies due to the high representativeness in production costs, high risk and high demand for skilled labor, often even outsourced [9]. The elements that require this attention in the analysis are variations in risk agents, where we highlight the physical agent. This agent is characterized as the various forms of energy to which the worker may be exposed, examples are noise; the vibrations; abnormal pressures; extreme temperatures; ionizing radiation; non-ionizing radiation, among others [10].

Thus, it must be ensured that the concentration and the exposure time of the worker to the risk agent are in accordance with Brazilian law. Therefore, this determines that the ideal conditions for the development of activities compatible with the occupational health of the operators are assured [11].

Given this scenario, the objective of this study is to evaluate the occupational hazards arising from physical agents noise and vibration in equipment used for harvesting wood in north-eastern Brazil.

2. MATERIALS AND METHODS

2.1 Study Area and Work System

The research was carried out in a forest company located in the northeast region of Brazil from May 2017 to July 2018. In an area of *Eucalyptus* spp. approximately six years old, in a region of low slope and good drainage, already in the wood harvesting phase.

The evaluations were performed in the two harvesting systems employed by the company. System 1 consists of: Feller-buncher slaughter + Harvester processing +

Forwarder extraction. System 2 consists of: Harvester slaughter and processing + Forwarder extraction. Both systems used are considered Cut-to-length.

2.2 Rated Equipment

The following are the crawler Feller-buncher equipment without leveling device - FB1; crawler Feller-buncher with leveling device - FB2 (Fig. 1). This equipment is used to cut down and accumulate trees in rows.

Forwarder-type equipment has a load capacity of 1400 kg, cab suspension system and 6 × 6 - FW1 and 8 × 8 - FW2 and FW3 traction tire wheels (Fig. 2). This equipment is used for logging and its main function is to take the wood to the edge of the area.

And finally Harvester-type equipment, with crawler and appropriate head - HV1 and HV2; Harvester with tires and appropriate head - HV3 and adapted tire agricultural machinery with Harvester head - HV4 (Fig. 3). This equipment simultaneously performs felling, delimbing, tracing, and wood stacking operations.

The engine characteristics of the evaluated equipment are described in Table 1 and were described based on the manufacturer's catalog.

2.3 Occupational Noise Assessment

The assessment was performed using an equivalent noise level meter called the audiometer. The instrument is of the brand INSTRUTHERM and model DOS-500, with precision ± 1.5 dB. The instrument's microphone was installed clipped to the shirt collar near the operator's ear. The microphone is connected via a wire to the meter that has been attached to the waist of the pants.

Measurements were made during the operator's normal working day with equipment in normal operation, enclosed cab and operators wearing personal protective equipment.

The values obtained were compared with the maximum exposure limits determined by Regulatory Standard NR-15, which deals with unhealthy activities and operations, of the former Ministry of Labor [12]. When the equipment was not in operation, the measuring instrument was switched off in order to disregard: a) noise interference in the conversation and hearing of acoustic warning signals; b) presence of undesirable noises due to lack of equipment maintenance.

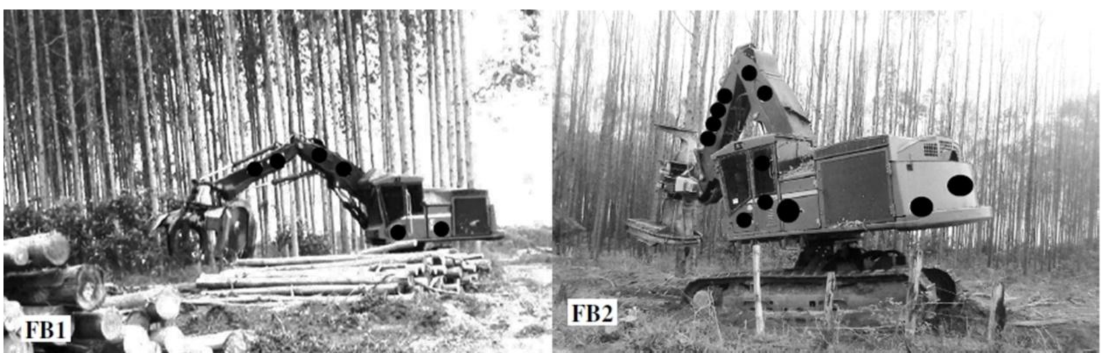

Fig. 1. Crawler feller-buncher without leveling device – FB1; Crawler feller-buncher with leveling device – FB2

Fig. 2. Tire forwarder with 6x6 cab suspension system – FW1; Tire forwarder with 8x8 cab suspension system – FW2 and FW3

Fig. 3. Crawler harvester– HV1 and HV2; Tire havester – HV3; Adapted tire agricultural machinery with Harvester head – HV4

Table 1. Characteristics of rated equipments

Equipment	Peak power	Displacement	Maximum power at 1900 rpm	Net torque
FB1	224 kW	9.0 L	300 HP	1270 Nm at 1500 rpm
FB2	246 kW	9.0 L	300 HP	1392 Nm at 1500 rpm
FW1	115.5 kW	4.5 L	155 HP	645 Nm at 1400 rpm
FW2	145 kW	6.8 L	195 HP	800 Nm at 1400 rpm
FW3	145 kW	6.8 L	195 HP	800 Nm at 1400 rpm
HV1	224 kW	9.0 L	300 HP	1270 Nm at 1500 rpm
HV2	224 kW	9.0 L	300 HP	1270 Nm at 1500 rpm
HV3	170 kW	6.8 L	228 HP	1250 Nm at 1400 rpm
HV4	220 kW	9.0 L	300 HP	1200 Nm at 1500 rpm

Where: kW: Kilowatt; L: liters; rpm: rotation per minute; HP: horse power; Nm: nweton meter

Table 2. Criteria for noise analysis by normalized exposure level (NEL)

NEL dB(A)	Daily dose %	Technical consideration	Recommendation
Up to 82	0 to 50	Acceptable	At a minimum maintaining existing condition
82 to 84	50 to 80	Above action level	Adopt preventive measures
84 to 85	80 to 100	Region of uncertainty	Adopt preventive and corrective measures to reduce daily dose
Over 85	Over 100	Over exposure limit	Immediate adoption of corrective measures

Fundacentro (2001)

Noise was individually assessed for the analyzed machines, following Occupational Hygiene Standard NHO-01 which establishes the Normalized Exposure Level (NEL), ie the noise exposure level converted to an 8-hour workday [13].

The criteria adopted for decision making on forest machinery were those present in NHO-01, described in Table 2.

2.4 Occupational Vibration Assessment

In the vibration evaluation, a 01dB Triaxial Seat Accelerometer was used to measure the full body vibration. The instrument has a sensor that measures levels of vibration on the X, Y and Z axes with 99% accuracy that has been installed in the operator's seat, recording acceleration values in $m.s^{-2}$.

The measurement results were compared to the values recommended by Occupational Hygiene Standard NHO-09 [14], expressed as Accelerated Resulting from Normalized Exposure (AREN) obtained using equation 1 below:

$$AREN = \mathrm{ARE}\sqrt{\frac{T}{To}} \quad (1)$$

where:

ARE= acceleration resulting from exposure;
T= time of daily workday expressed in hours or minutes;
To= 8 hours or 480 minutes.

The standard reference values are: threshold for action level, AREN = 0.5 $m \cdot s^{-2}$ and daily occupational exposure limit (8 hours), AREN = 1.1 $m \cdot s^{-2}$.

2.5 Statistical Analysis

The number of sample units to estimate the parameters of an infinite population to a desired precision level, based on the standard error of the mean [14], was given by using equation below:

$$\mathrm{n} = \frac{\mathrm{t}^2.\mathrm{s}^\mathrm{s}}{\mathrm{d}^2.\mathrm{m}^2} \quad (2)$$

where:

n = estimated sample size;
t = value of Student's t distribution, at 5% probability;
s^2 = variance;
d = error in the average estimate, in percentage;
m = sample mean.

Considering a 95% confidence level, equivalent to two deviations, and an estimation error of 5%, the minimum sample size was obtained, consisting of 36 measurements for machine FB1, 39 for FB2, 35 for FW1, 33 for FW2, 38 for FW3, 42 for HV1, 44 for HV2, 39 for HV3 and 47 for HV4. However, 60 measurements for each machine were performed, for analyzed factors, noise and vibration. Each measurement had duration of four minutes, a time interval capable of absorbing the entire operational cycle of the machine for the slaughter and processing of 10 trees [15].

Descriptive statistics with mean and standard deviation was used to characterize the data. The results were submitted to analysis of variance and means test, using Tukey test at 5% of probability. Statistical analysis was performed using SAS Software version 9.1 [16].

3. RESULTS AND DISCUSSION

The parameters set for adopting the noise compliance level for an 8-hour work shift per day was the Action Limit of 80 dB(A) and Maximum Permitted Exposure Limit of 85 dB(A). For whole body vibration, the parameters established for adopting the compliance level are as follows: below alert level (0.5 $m \cdot s^{-2}$) and below exposure level (1.1 $m \cdot s^{-2}$). Table 3 presents the average values of the forest equipment evaluation with the corresponding noise and vibration levels.

3.1 Occupational Noise Assessment

Noise analysis has shown the need for all operators to wear the recommended hearing protector since, on average, all forestry equipment is close to the 80 dB(A) action limit set by NR-15 [17]. The source of the intense noise may be in the field, as there are several plots and forestry machines working in an integrated manner, so, at times, the noise of one can interfere with the other [18]. Allied to this, the results indicate some insulation failure of the machine cabs, which is a relevant problem. Since, one of the main functions and safety differential of other methods is the presence of cabs on tractors to protect operators from adverse environmental influences [19].

The discomfort generated by loud noise tends to impair mental concentration when performing certain tasks that require attention, speed or precision of movement [20].

Table 3. Average noise levels by standard exposure level (NEL) and acceleration vibration resulting from standard exposure (AREN) for each equipment

Forestry Equipment	NEL dB(A)		AREN $m \cdot s^{-2}$	
FB1	84.5	a	0.45	c
FB2	84.5	a	0.60	b
FW1	82.6	a	0.38	d
FW2	75.0	b	0.70	a
FW3	75.0	b	0.70	a
HV1	78.9	b	0.27	f
HV2	76.2	b	0.37	d
HV3	77.4	b	0.33	e
HV4	78.6	b	0.37	d
Average	79.2		0.46	
p	0.012*		0.061*	

** Significant at 5.0% probability, by t-test with n-2 degrees of freedom.*
Note: Means followed by the same letter in each column do not differ from each other by Tukey test at 5% probability

For the work on Feller-bunchers (FB1 and FB2), the level of attention should be increased, as they presented very high noise levels and very close to exceeding the maximum allowable exposure limit of 85 dB (A). If exposure above the limit may occur, a new adjustment should be proposed. In this case, for every 5 dB(A) above the limit, the operator will have a 50% reduction in their working hours [21]. However, there are no productivity targets to be adjusted in any of the evaluated equipment due to noise.

3.2 Occupational Vibration Assessment

Whole body vibration in all equipment was below 1.1 $m \cdot s^{-2}$ exposure level. However, the overall average remained close to the 0.5 $m \cdot s^{-2}$ alert level. The FB2, FW2 and FW3 equipment had indices slightly higher than the alert level, a fact that needs greater accuracy in machinery, although it remains in a normalized classification, against Annex VIII of NR-15 [10]. In this case, there are no productivity targets to adjust for vibration.

Other authors have found similar results for vibration indices [22], however, even though Brazilian standards are acceptable, they are considered to be in disagreement with Directive 2002/44/CE of the European Parliament and the Council of the European Union.

Exposure to vibration is determined by the intensity and time of exposure of the operator, as well as the body parts used to perform such activities [23]. Due to the fact that it is considered harmful and represents a major risk to the health, comfort and safety of people involved in activities with high motion emission equipment, it is important to have readjusted goals when the vibration exceeds the proposed tolerable limit.

It is noteworthy that, in addition to the type of activity performed, machinery speed, tire calibration, terrain type, among other variables considerably interfere with the vibration and noise indices transmitted to the operator [24,25].

As a contribution of this study, it is worth noting the great statistical difference presented between the evaluated machines with regard to whole body vibration, a factor that should be taken into account when purchasing new machines to protect operators against the development of possible work-related musculoskeletal disorders.

3.3 Overall Result

For the forestry equipment studied, the results, even with some warning, none are exceeding the compliance limit, which shows promising improvements in the forest machinery and working environment. Since, in this scenario, the noise and vibration levels of the forest machines were commonly above the safety limits established by the NR-15 standard, to which workers were exposed during their working hours.

The results of this study corroborate those of other authors [26], who highlight the technological advances and improvements in the workplace of high performance forestry equipment in recent years, but point out that the equipment still exposes the operator to some degree of risk and mainly influences your occupational health. From this comes the importance of studies on the ergonomic quality of forest harvesting machinery in order to improve the working conditions of national operators. Several authors [27,28,29] performed evaluations on different types of forest harvesting machines on various ergonomic aspects of the machines, mainly addressing anthropometric issues, work area visibility and operator exposure to physical agents.

Disregarding noise exposure below the limits allowed by Brazilian law, forestry machine operators are often exposed to high levels of whole-body vibrations during the development of their activities and are therefore affected by spinal disorders and various other types of diseases. The origin of these problems can hardly be eliminated, due to the well-known dynamics of the soil-machine-operator interaction. Machine designers have been adopting many different techniques in order to minimize the vibrations that, from the soil, appear until the human body. However, field activities can take place in very different scenarios: roughness and slope of the soil, machine speed, presence of tires or tracks, maintenance of machines, devices for specific tasks (e.g. harvester head), etc. In addition, the influence of such factors on human health is still not well understood and, therefore, it is not easy to limit the amount of vibrations acting on the design variables [30].

4. CONCLUSIONS

The results of the present study demonstrate a new behavior of the forestry machinery and equipment industries, which have been intensifying the development and application of new technologies, in order to provide greater comfort and safety to their operators.

Despite all the technology involved in each machine evaluated, the results of the occupational exposure of the operators to mechanical vibration and noise were at levels that suggest more effective actions, including the reduction of working hours.

Immediate interventions on the machines and the processes are necessary in order to reduce the exposure of the operators to vibration, as well as their deleterious effects on their health.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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