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Noise levels emitted by agricultural tractors with and without implements activation

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ABSTRACT: The noise levels emitted by agricultural machines can be harmful to the worker's health, and it is sometimes neglected in rural areas. This work aimed to measure the noise level emitted by three agricultural tractors of different power activating two types of implements to assess whether there were risks to operators' health and the supporter workers around the tractor. The noise level data were collected using a decibel meter in ten points on each machine side (forward, rear, left, and right) for a total of 40 points around each tractor. Three different tractors were evaluated in different scenarios: without any implement, coupling and activating a spreader, and coupling and activating a rotary hoe. The tractor was parked at the centre of the mash with an engine speed that ensured 540 rotation per minute (RPM). to the power take-off (PTO) during the entire data collection. The data were analyzed by charts, linear regression, and hierarchical clustering analysis. The results indicated that the sound pressure levels in all of the studied situation exceed the standard's limits regulatory standard 15, making hearing protectors essential during the working day.

Keywords: ergonomics; acoustic comfort; agricultural mechanization; sound pressure level.

Níveis de ruído emitidos por tratores agrícolas com e sem acionamento de implementos

RESUMO: Os níveis de ruído emitidos pelas máquinas agrícolas podem ser prejudiciais à saúde do trabalhador e, por vezes, negligenciados no meio rural. Este trabalho teve como objetivo mensurar os níveis de ruído emitidos por três tratores agrícolas de diferentes potências acionando dois tipos de implementos para avaliar se havia riscos à saúde dos operadores e trabalhadores de apoio ao redor da operação. Os dados de ruído foram coletados por decibelímetro em dez pontos de cada lado da máquina (frente, trás, esquerda e direita) para um total de 40 pontos ao redor de cada trator. Três tratores diferentes foram avaliados em diferentes cenários: sem implemento, acoplando e acionando uma esparramadora de corretivo e acoplando e acionando uma enxada giratória. O trator foi estacionado no centro da mistura com uma rotação do motor que garantiu 540 rotações por minuto (RPM). para a tomada de potência (TDP) durante toda a coleta de dados. Os dados foram analisados por meio de gráficos, regressão linear e análise de agrupamento hierárquico. Os resultados indicaram que os níveis de pressão sonora em todas as situações estudadas ultrapassam os limites da norma regulamentadora (NR) 15, tornando os protetores auditivos indispensáveis durante a jornada de trabalho.

Palavras-chave: ergonomia; conforto acústico; mecanização agrícola; nível de pressão sonora.

1. INTRODUCTION

Rural areas are facing significant social, economic, demographic, and environmental challenges (BAMBI et al., 2019). One of these challenges could be highlighted is the mechanization of the rural operations. The technological development of the agricultural machinery not only promotes the increase of agricultural production but also seeks improvements in the development of activities and the reduction of time losses during the operations (VIAN et al., 2013). Parallel to the development of technology, the use of mechanization processes of agricultural production has brought about the factors such as noise, vibration, exhaust, etc., which affect the working environment of users of those machines (AYBEK et al., 2010).

Agriculture is among the risky industries accompanied by different process and tasks where each task has the capability for any kind of risks and harmful effects on farmers (GHOTBI et al., 2013). Extreme temperature, noise, mechanical vibration injuries, dust, ultraviolet, and pesticides are among the harmful effects that farmers are faced with (KUMAR et al., 2005). Currently, attention has been focused on the workers' well-being during the labor activities, focusing mainly on their safety and comfort (YANAGI JUNIOR et al., 2012). Workers' comfort is directly related to their performance and efficiency in performing their activities (BRAVALHERI et al., 2010).

According to the Brazilian regulatory NR-15 (Occupational Safety and Health Regulatory Standard, 1990) the noise levels should not exceed 85 dB (A), during the eight hours workday, to ensure healthy conditions for workers. This standard also states that levels above 115 dB (A) without proper protection expose a severe risk to human health.

The study of noise emission by agricultural machines, as well as its effects, mitigation ways, and prevention, are very relevant, as they can contribute to the comfort and well-being of rural workers, and consequently to their health and better performance. Hence, it is essential to know the conformity to the level noise of tractors and agricultural implements. Compare the noise emitted by tractors that are activating different implements is significant to understand. Thus, this work aimed to measure the noise levels emitted by three agricultural tractors with different power and activate different agricultural implements to assess the operator's health risk and the supporter workers around the tractor.

2. MATERIAL AND METHODS

The experiment was carried out in Lavras, Minas Gerais State, Brazil, in an open area of the Engineering Department (DEG) of the Federal University of Lavras (UFLA). The area consists of asphalt pavement without the presence of surrounding buildings, measuring 50 x 60 m. It is located between the coordinates 21°13'50.74” S and 44°58'30.86” W of Greenwich.

Three tractors were tested in this experiment. They have no cabin protection and had different levels of nominal powers. They were tested in three scenarios: (1) without the coupling of implements; (2) coupling and activating a spreader; and (3) coupling and activating a rotary hoe. Table 1 presents the tractors and the implements used in this experiment, as well as their main features.

Tabel 1. Technical specifications of agricultural machines and implements used in the experiment.
Tabela 1. Especificações técnicas das máquinas e implementos agrícolas utilizados no experimento.

	Nominal power (kW)	Rated engine speed (rpm)*	Manufacture year
Tractor A	80.90	1920	2007
Tractor B	69.87	1890	1996
Tractor C	60.31	1700	1986
Implements	Brand and Model		
Rotary Hoe (R)	Lavrale RSFE 50, with a working width of 1.6m e working depth of 0.25m		
Spreader (S)	Maschietto CA 2600 27011		

*to ensure 540 rpm at PTO

Noise levels were determined using the sound level meter, Instruterm DEC – 480, in the slow response circuit and "A" equalization, expressed in dB. The windshield of this meter was used for all measurements. The noise level evaluations were performed according to the methodology described in NBR 9999 (ABNT, 1987), in which the ambient temperature should be between -5 and 30 ºC, and the air velocity should be less than 5.0 m s-1. So, the trials were performed in the early morning (07:00 a.m) and late afternoon (04:00 p.m), at a temperature of approximately 25 °C, according to the Lavras meteorological station.

The data collection was performed at the average height of the operator's ear. According to Kroemer and Grandjean (2005), the average height of a standing man is 1.70 m, from the floor. At the operator's seat, it was collecting the noise at 0.9 m from the tractor floor, which corresponds to a seated operator's height in the working position on the tractor (KROEMER; GRANDJEAN, 2005).

The data were collected at points placed every two meters on the right, left, forward, and rear sides and at the operator seat (41 sampling points) (Figure 1) from the agricultural machine. The center point (0, 0) corresponded to the place where the tractor remained parked and in rated engine speed that ensures 540 RPM. to the power take-off (PTO) during the entire collection. Also, the point (0,0) corresponds to the operator seat.

The values described by the Brazilian standard NR-15 of the Ministry of Labor and Employment (Table 2) were used to identify the worker discomfort according to the noise level.

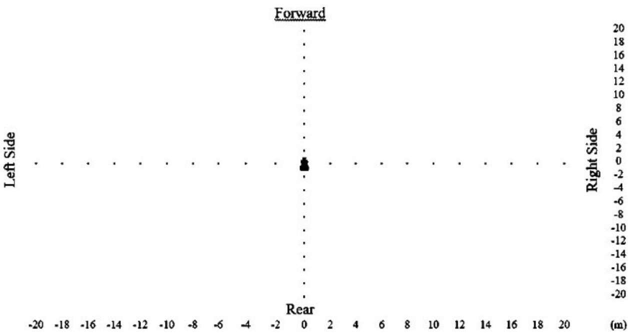

Figure 1. Diagram of noise level sampling points.
Figura 1. Diagrama de pontos de amostragem do nível de ruído.

Table 2. Tolerance limits for continuous or intermittent noise (NR-15).
Tabela 2. Limites de tolerância para ruído contínuo ou intermitente (NR-15).

Noise level dB (A)	Maximum allowable daily exposure
85	8 hours
86	7 hours
87	6 hours
88	5 hours
90	4 hours
95	2 hours
100	1 hour
105	30 minutes
110	15 minutes
115	7 minutes

A descriptive analysis was used to describe the noise level emitted by the tractor in three scenarios and on each side of the machine. In addition to this, the hierarchical clustering analysis has been made using the R statistical software was proceeded to identify similarity among the three tractors' situations, and the side of the noise level sampling.

The hierarchical agglomerative clustering analyses (HCA) was used to separate objects into groups based on characteristics of the objects. The basic idea is to put in the same group objects that are similar according to some predetermined criterion (LINDEN, 2009). The HCA was proceeded according to Lau et al. (2009) and Ferraz et al. (2014). The cluster heat map described the results of this analysis.

According to Wilkinson; Friendly (2009), the cluster heatmaps visualize a hierarchically clustered data matrix using a reordered heatmap with dendrograms in the margin. According to Yu et al. (2020) the heatmap, a graphical representation of data with the individual values contained in a matrix, was represented as grids of colors plus clustering on both rows and columns. So, these analyses make it possible to compare the noise level emitted by the rural machinery tested by this study in different situations.

3. RESULTS AND DISCUSSION

According to NR15, the sound level 85 dB(A) is the maximum allowed for a daily exposure of eight hours, which corresponds to the daily working hours of a tractor operator, without the obligation to use the ear protector device. However, the maximum values observed during the experiment points to a maximum daily exposure of approximately two hours. So, it requires the use of the ear protector device to protect the operator during the operation.

It is possible to observe in Figure 2 that the highest noise level measured at the tractor forward was at two meters from the worker seat for all of the studied scenarios. It was expected since it is closer to the tractor engine. Noise levels decreased as the distance between the engine and the measured point increased. Tractor C presented the minor critical distance for the workers' health at the tractors forward. This distance was 3 m without implement and also when it was activating the rotary hoe, and approximately 5m when it was activating the spreader. Tractor B presented a critical distance higher than Tractor C. It is possible to observe that this critical distance can be 6 m.

Furthermore, it was possible to observe that the noise level emitted at the front of Tractor B had similar values to all investigated scenarios. The tractor C, coupled with a rotary hoe, emitted higher levels at the front than the spreader. Analyzing Tractor A, even with the activation of implements, the noise levels did not present significant variations.

The small noise levels variation measured at the tractor forward among the scenarios of activated implements or without implement occurred because the implements were coupled at the backside of the tractor. Therefore, the noise emitted was directed towards the tractor rear (Fig. 3), and it did not affect the forward measurements.

All of the investigated tractors presented higher levels of noise at the rear in all scenarios, which caused an increase of the critical distance to the worker's presence. Thus, the implement contributed to the increase of noise levels at the rear. Even with tractors operating with the spreader and rotary hoe, the highest noise levels were found at the front of the tractor, because the engine operation makes a high noise level, but the coupling of the implements increased the noise level emitted by the set at the rear.

The safe distance without ear protection observed at the rear of the tractor was 4 m for Tractor A, 6 m for Tractor B, and 4 m for Tractor C, all of them occurred when they were activating the spreader.

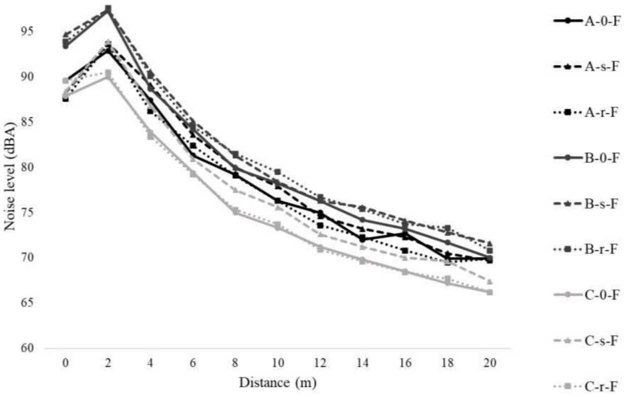

Figure 2. Values of the noise levels measured at the tractor A, B, and C forward (F) at the three studied situations: without implement (0), with spreader (S) and with a rotary hoe (R).
Figura 2. Valores dos níveis de ruído medidos na frente dos tratores A, B e C nas três situações estudadas: sem implemento (0), com esparramadora (S) e com uma enxada rotativa (R).

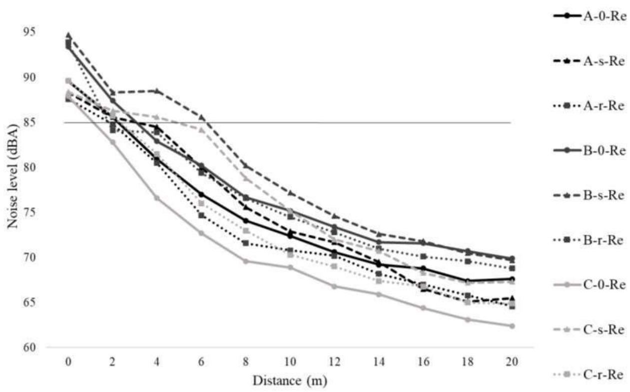

Figure 3. Values of the noise levels measured at the rear (Re) A, B, and C of the tractors at the three studied situations: without implement (0), with spreader (S) and with a rotary hoe (R).
Figure 2. Valores dos níveis de ruído medidos na traseira (Re) A, B e C dos tratores nas três situações estudadas: sem implemento (0), com esparramadora (S) e com uma enxada rotativa (R).

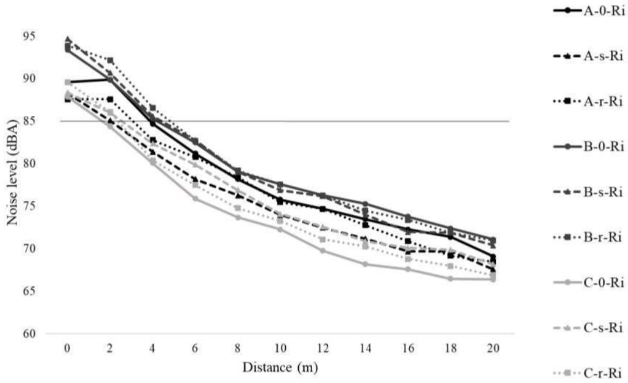

Figure 4. Values of noise levels measured on the right side (Ri) of tractors A, B and C in the three situations studied: without implement (0), with spreader (S) and with a rotary hoe (R).
Figure 2. Valores dos níveis de ruído medidos no lado direito (Ri) dos tratores A, B e C nas três situações estudadas: sem implemento (0), com esparramadora (S) e com uma enxada rotativa (R).

Through the analysis of Fig. 4 and Fig. 5, it is possible to observe how the noise levels behave on the left and right sides, respectively, for tractors A, B, and C with and without the activation of implements.

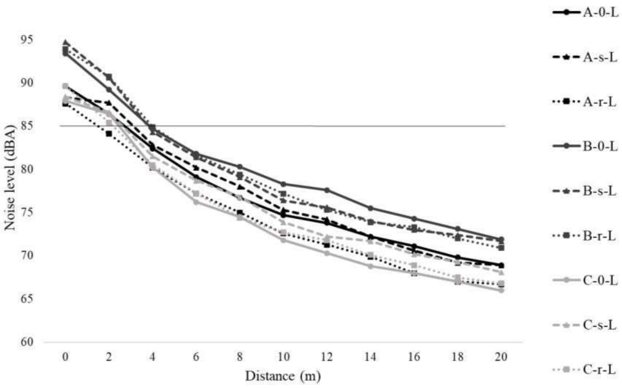

Figure 5. Values of the noise levels measured at the tractor A, B, and C left (L) side at the three studied situations: without implement (0), with spreader (S) and with a rotary hoe (R).

Figure 2. Valores dos níveis de ruído medidos no lado esquerdo (L) dos tratores A, B e C nas três situações estudadas: sem implemento (0), com esparramadora (S) e com uma enxada rotativa (R).

4. DISCUSSION

The observed critical distance to avoid the use of hearing protection devices at the right side was 4 m for Tractor A, 5 m for Tractor B, and 2 m for Tractor C. For the left side of the tractors the critical distance was observed at 4 m and 3 m, respectively, for A, B, and C.

Although the noise levels observed on both sides seem similar, the right side showed slightly higher levels than the left side, which were caused by some engine components located on the right side of the tractor's front. Baesso et al. (2017), studying noise levels observed in several distance points from comparable tractors of those investigated, found similar values in the right and left sides, which corroborates to the results found by this work.

On the right and left sides, it was highlighted that the critical distance becomes smaller than the front and rear of the tractor. It was also possible to notice that in the operator's seat, the noise levels found for the three tractors, with and without the activation of implements, was higher than 85dB (A), which makes it obligatory the use of hearing protector for both operator and assistants which were working within 6 m or less of the tractors tested.

Hierarchical clustering analysis was developed to make a comparison of all studied scenarios, using average values (Figure 6). This analysis is used to separate objects into groups based on the characteristics of the objects (Ferraz et al., 2014). According to Linden (2009), the basic idea is to put in the same group objects that are similar according to some predetermined criterion. So, Figure 6 represents the cluster heatmap with HCA related to the similarity noise values of the tractors in the forward, rear, right, and left side, with and without the activation of implements.

The result showed that tractor C with spreader (C-s) was grouped with A – 0 and A- s. They ware similar to all studied side (Figure 6). Similar behaviour was found by Bilski (2013). Thus, it was noteworthy that newer tractors have a lower noise emission due to studies and advances in the field of ergonomics (BILSKI, 2013; LJUNGBERG; NEELY, 2007; LJUNGBERG et al., 2004).

Tractor B, even without the activation of implements, has registered the highest noise levels as it is possible to observe by the red colours in Figure 6. Also, it has been clustered separately from other tractors. These results reinforced that technology development was carried about the noise emissions and consequently about the workers' health. Tractor A was manufactured 11 years after the tractor B and presented 11 kW more power than tractor B, and Tractor B presented the highest level of noise values.

According to Cunha et al. (2012), tractors with higher horsepower emit higher noise levels. However, technological advancement allows for better machine quality in terms of ergonomics, improving operator health, comfort, and efficiency (Cunha et al., 2012). Tractor A is 11 years newer than tractor B. This fact may explain why tractor B presented a higher noise level than A, even it is of lower power than tractor A.

Between the studied implements, the spreader presented higher noise levels than the rotary hoe, which means that this implement requires more caution when related to noise emissions. Regarding to the machine side, the left and right were grouped (Figure 6), while the front side and rear were group into two other different groups.

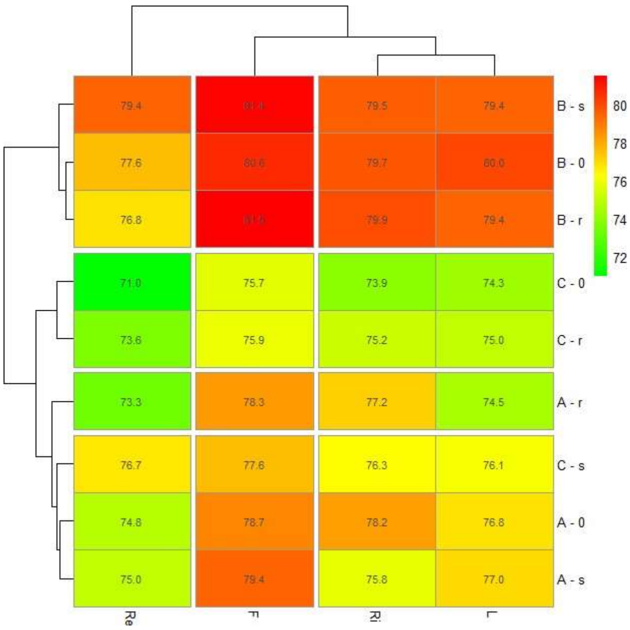

Figure 6. Dendrogram of the noise levels observed at the forward, rear, right and left side of tractors A, B, and C to the three studied situations.

Figure 2. Dendrograma dos níveis de ruído observados à frente, atrás, lado direito e esquerdo dos tratores A, B e C para as três situações estudadas.

5. CONCLUSION

The activation of a rotary hoe and also the spreader activation increase the noise emitted by the studied tractors. The tractor C presented similar noise emission values to Tractor A. Tractor B presented the highest noise emissions values for all studied situations.

It was observed that in all studied scenarios, the operator was subjected to high noise levels, above the 85 dB (A) limit for 8 hours of daily exposure, without an ear protector. It was also highlighted that the activation of the rotary hoe and the spreader contributed to the increase of noise levels observed, especially at the tractor rear. The safer distance from the tractor in all studied scenarios was 5 m for tractor A and C and 6 m for Tractor B.

6. ACKNOWLEDGEMENTS

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