

Spatial variability characterization of acoustic discomfort and zone of admissible noise caused by micro-tractor

Caracterización de la variabilidad espacial del malestar acústico y zona de ruido admisible por microtractor

<https://doi.org/10.15446/rfnam.v75n2.96242>

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ABSTRACT

Keywords:

Acoustic comfort
Occupational health
Spatial variability

Agricultural development requires greater adoption of machinery by producers to avoid damage to the worker's health due to excessive noise. In this scenario, this study aimed to analyze the noise magnitude emitted by a micro-tractor using geostatistics and Statistical Process Control (SPC) in mapping spatial variability to identify healthy zones for workers. The study was carried out at the Federal University of Lavras (UFLA), where noise levels were collected at points distributed in a regular 2.0×2.0 m sample grid around the machine. The spatial dependence of noise was analyzed by adjusting the wave-type semivariogram and interpolating by ordinary kriging and the SPC through individual control charts. It was possible to observe alarming noise values above 85 dB(A) in a radius of up to 6 m around the tractor in operation. The maximum value of 91 dB(A) was obtained from the operator's seat, thus allowing maximum daily exposure of 3.5 h. In addition, it was observed that people located at distances greater than 4 m from the micro-tractor do not need to wear personal protective equipment for an exposure of 8 h of work.




RESUMEN

Palabras clave:


Comodidad acústica
Salud ocupacional
Variabilidad espacial

El desarrollo agrícola exige una mayor adopción de maquinaria por parte de los productores para evitar el daño a la salud de los trabajadores por el exceso de ruido. En este escenario, este estudio presenta análisis utilizando geoestadística y Control Estadístico de Procesos (SPC) en el mapeo de la variabilidad espacial de la magnitud del ruido emitido por un microtractor para identificar zonas saludables para los trabajadores. El estudio se llevó a cabo en la Universidad Federal de Lavras (UFLA), donde los niveles de ruido se recolectaron en puntos distribuidos en una cuadrícula de muestra regular de 2,0×2,0 m alrededor de la máquina. La dependencia espacial del ruido se analizó ajustando el semivariograma de tipo onda e interpolando por kriging ordinario y el SPC a través de cartas de control individuales. Fue posible observar valores de ruido superiores a 85 dB(A) en un radio de hasta 6 m alrededor del tractor en funcionamiento. El valor máximo de 91 dB(A) se obtuvo desde el asiento del operador, permitiendo así una exposición diaria máxima de 3,5 h. Además, se observó que las personas ubicadas a distancias mayores a 4 m del microtractor no necesitan usar equipo de protección personal para una exposición de 8 h de trabajo.

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Studies on the spatial distribution of acoustic discomfort are essential for improving the work environment, especially in evaluating the salubrity which operators and helpers will be subjected to the operation of a micro-tractor whose work rotation is 2400 rpm. Fernandes and Morata (2002) cite that physical agents such as noise, heat, vibration, pressure, radiation, and chemical agents such as smoke, dust, gases, and vapors, are some of the environmental stressors which are found in several workplaces.

Arcoverde *et al.* (2011) emphasize the importance of studies about noise levels in agricultural operations for the real need of adopting prevention to minimize noise effects and improve comfort and safety.

Bistafa (2018) conceptualizes noise as a sound without harmony, in general of a negative connotation, in other words, in most cases it can be classified as an undesirable way sonorously, standing out as one of the occupational risk agents.

Previous studies have evaluated the noise emitted by agricultural machines through geostatistics, but for the adjustment of the semivariogram, these studies used the spherical model (Ferraz *et al.*, 2013; Júnior *et al.*, 2014) and the Gaussian model (Missio *et al.*, 2015; Pimenta *et al.*, 2012; Spadim *et al.*, 2015). However, these mentioned models may not represent the noise behavior correctly, being necessary to adjust these models as a periodic function or sinusoidal function, as the Wave model used by Gonçalves *et al.* (2019).

In addition, the Statistical Process Control (SPC) was another tool used to analyze these data. SPC is a simple tool, and its effectiveness is witnessed by a repetition physically established in industries around the world. Therefore, it is possible to control significant characteristics of the product and the process in real-time, guaranteeing quality levels at a cost supported by the market (Nomelini *et al.*, 2009).

Among the main tools of the SPC, the control graphs stand out. They are among the most used when it comes to monitoring processes. According to Werkema (1995), the interpretation of control graphs is made through non-random patterns. Therefore, this work aimed to illustrate

and discuss such patterns based on statistical and probabilistic concepts.

According to Nomelini *et al.* (2009), SPC is a robust methodology developed to effectively control product quality and production processes, using statistics to analyze the process's limitations. SPC application in noise emitted analysis by agricultural machinery is hardly found in scientific research, highlighting the importance of this study.

It is also noted that the mitigation of the noise problem is linked to reducing the intensity of the same source, reducing the exposure time, or using individual protective equipment. Thus, it is essential to know the reality of the machine under study in terms of noise to plan the best strategy to combat the problem.

Given the exposure, the aim of this study was to use geostatistics and Statistical Process Control (SPC) from individual charts to map and characterize the magnitude of the spatial variability of noise emitted by a micro-tractor, to identify healthy zones for workers.

MATERIALS AND METHODS

The experiment was developed at the Federal University of Lavras (UFLA), Lavras, Minas Gerais, Brazil. In this study, a micro-tractor with a nominal power of 11 kW (15 hp) was evaluated, whose year of manufacture was 2007. Its working rotation is 2400 rpm. The tractor had a coupled trailer, which did not have any driver.

The noise level rating of this agricultural machine was carried out in which the ambient temperature was between -5 and 30 °C and the air velocity was less than 5.0 m s⁻¹. For the measurement of noise propagated by the tractor, a digital decibel meter model dec 460 was used to measure the noise level emission, the description of which is based on a sound pressure level measuring instrument with instantaneous reading and peak reading, automatic scale, and frequency weighting in A and C. There is a measurement of 35 to 130 dB (A) and internal calibrator in terms of the measurement scale.

Readings were taken at an average height of the operator's ear, at points distributed in a regular 2x2 m

sampling grid. Totalling 441 sampling points around the agricultural machine in stationary operation (Figure 1). These samples were later used in descriptive statistics. A spatial coordinate was arbitrated in meters where the

central point (0, 0) corresponded to the point where the agricultural machine remained in operation during all collection. The central point (0, 0) corresponded to the operator's seat (Figure 1).

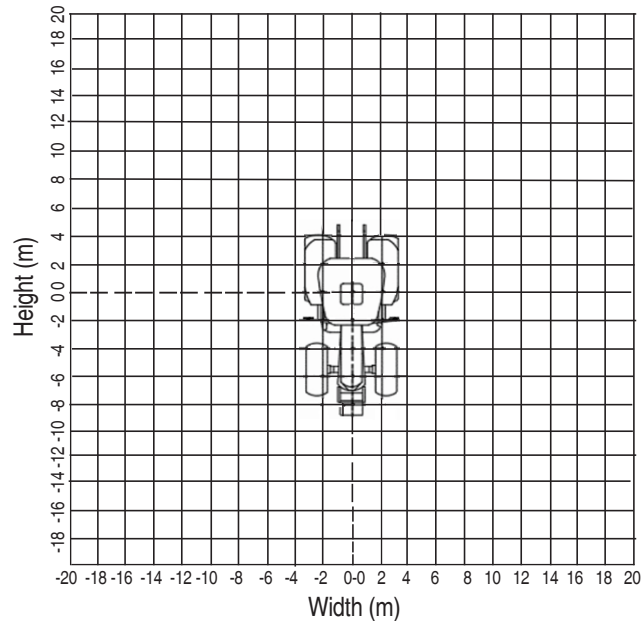


Figure 1. Sampling area of the noise levels emitted by the micro-tractor under study.

The spatial dependence of the noise emitted by the micro-tractor placed in the operation regime was analyzed through adjustment of classic semivariogram by the Ordinary Least Squares (OLS) method and the Wave model. The classic semivariogram was estimated by Equation 1:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

Where $N(h)$ is the number of experimental pairs of observations, $Z(x_i)$ and $Z(x_i+h)$ and separated by a distance h , the semivariogram is represented by the graph $\gamma(h)$ estimated semivariance for distance h . From the adjustment of a mathematical model to the calculated values of $\gamma(h)$, the coefficients of the theoretical model are estimated for the semivariogram called the nugget effect, C_0 ; threshold, $C_0 + C_1$ and the reach, a , as described by Vieira *et al.* (1983).

In Equation 2, the theoretical model adjusted to the experimental semivariogram utilized for the research is

the Wave model (Mota, 2008; Gonçalves *et al.*, 2019).

$$\gamma(h) = C_1^2 + \frac{a}{h} \sin\left(\frac{h}{a}\right) \quad (2)$$

Where C_1^2 is the contribution, a is the range, and h is the distance between the points observed.

Equation 2 represents periodic variations, which indicate non-monotonic growth of the semivariance with distance, presenting models with and without threshold (Andriotti, 2004). These non-monotonic structures can have reduced wave amplitudes, be isotropic, and be anisotropic (Carvalho *et al.*, 2004). Another analysis that must be carried out is based on the relationship between theoretical and practical scope. According to Chilès and Delfiner (2012), the practical range of the Wave model is reached when the h is approximately equal to $4.5a$.

For the geostatistical analysis, R was used as a statistical computer system with GeoR package (Ribeiro Júnior and Diggle, 2001). SURFER 15.2 software was used to plot the maps. The values recommended by

ABNT (2021) were used for the evaluation of admissible levels. NR 15 norm defines a time limit for workers to be exposed to continuous or intermittent noise that will not harm their health.

In addition to the geostatistical analysis, the noise data emitted by this micro-tractor was evaluated through process control charts (SPC). Control charts also present complementary criteria for quality analysis. Including a sequence of points occurrence, upward downward trends, shifting in the process cyclic patterns, points plotted close to the control limits and clustering around the mainline (Szekut *et al.*, 2018). Civardi (2017) suggested a sequence of steps to analyze the control charts: build experimental control limits after data collection according to the sampling plan; verify that all points are within the control limits and no random configuration is being performed. If these two conditions are met, it can be said that the process is under statistical control, and the next step is to assess the capacity of the process; if there are points outside the control limits and/or some non-random configuration, it may conclude that the process is out of the state of statistical control. In this

case, special reasons that caused each point should be identified.

For the composition of individual letters in the SPC, the Minitab 19 software was used. Because of this, it was separated into five stages consecutively. Such stages were formed to facilitate the analysis of the data obtained in the sample grid. From these data, stage 1 was developed from radius 0 to 4 m; stage 2 was created from radius 4 to 8 m, stage 3 was set from radius 8 to 12 m, stage 4 was made from radius 12 to 16 m and the stage 5 consisted of a radius of 16 to 20 m.

RESULTS AND DISCUSSION

The descriptive statistics of the noise emitted by the studied tractor are shown in Table 1. Analyzing the minimum and maximum limits, the coefficient of variation, and the average noise, it was possible to observe a variation in the data. However, this analysis does not demonstrate the spacial position of the lowest and highest values of noise emitted by the tractor, therefore geostatistical studies are required.

The geostatistical analysis of the noise levels emitted by

Table 1. Descriptive statistics of noise (dB) emitted by the studied tractor.

Min	Max	X	Md	SD	Var	CV	K	Asymmetry
59.0	91.20	70.50	69.50	5.418	29.357	0.0770	1.522	1.038

Min – Minimum value of the variable; Max – Maximum value of the variable; X- Average; Md – Median; SD – Standard deviation; Var – Variance; CV – Coefficient of variation; K – Coefficient of kurtosis

the micro-tractor in the operating regime can be noted in Table 2. Thus, it is observed that the semivariogram (Table 2; Figure 2) and its parameters (nugget effect, “ C_0 ”; contribution, “ C_1 ”; sill, “ $C_0 + C_1$ ”; and range, “ a ”)

were obtained by the Ordinary Least Squares method (OLS - ordinary least square) and by the Wave model (Figure 2).

By analyzing Figure 2 and also observing Table 2, the practical

Table 2. Methods, models, and parameters estimated the experimental semivariogram to the noise level emitted by a tractor.

C_0	C_1	C_0+C_1	a	a'	ME	SD _{ME}	RE	SD _{RE}
0.0000	29.53210	29.53210	4.6606	13.94206	-0.03177	1.92932	-0.009346	1.2986

C_0 – Nugget effect; C_1 – Contribution; C_0+C_1 – sill; a – Range; a' – Practical range; ME – Mean error; SD_{ME} – Stand deviation of mean error; RE – Reduced mean error; SD_{RE} – Standard deviation of reduced mean errors

range of the spatial distribution of the noise emitted by this machine was 13.94 m, which implies that to this distance, the variable under study is influenced through space. It is observed in Figure 3 that the alarming values of

the noise emitted by the micro-tractor, above 85 dB (A), for daily exposure of 8 h (ABNT, 2021) are seen, in general, up to 6 m of distance around the tractor in operation regime. Note that in the center of the map

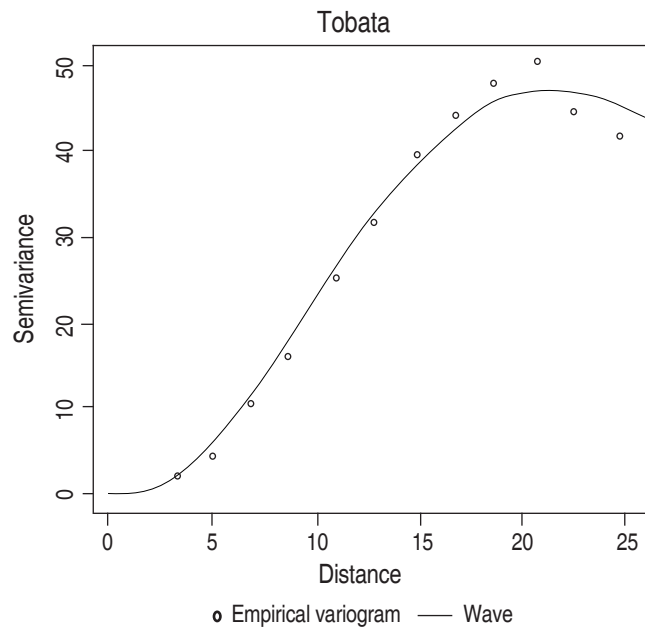


Figure 2. Semivariogram of the noise emitted by the micro-tractor under study.

(0,0), where the operator is positioned, the measured noise level was 91.20 dB (A), represented by the red color. This value can be considered high for daily exposure. The regulatory standard (NR 15) Ordinance 3,214/78 Ministry of Labor and Employment (MTbE) establishes that the maximum noise level allowed for 8 h of daily exposure is 85 dB(A). Above this limit, noise and disturbing human activities can cause serious

damage to health (Silva *et al.*, 2004).

The approximate value of the maximum noise 91.0 dB (A), was observed at point (0, -2), which was measured near the micro-tractor (noise emitting source), represented by the red color in the map. According to ABNT (2020), the permitted limit was exceeded for a daily exposure of 8 h in all cases evaluated. In this way, it was noted that both

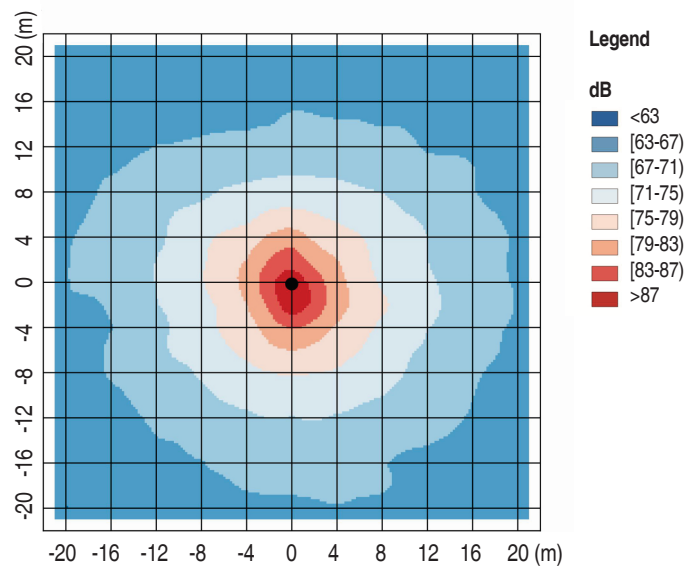


Figure 3. Spatial distribution map of the noise emitted by the studied micro-tractor.

the operator of the evaluated tractor and the helper for the agricultural operation would be subjected to the harmful effects of the noise emitted by this machine.

It was found that operators need to wear hearing protection, that is, personal protective equipment (PPE). Therefore, the farther from the tractor, the more the color of the spots becomes bluish, which indicates the decrease in the noise level, thus becoming more appropriate for workers and not requiring the use of PPE. However, it is noted that even so, all workers involved in the operation of this machine use PPE. The minimum noise value produced by this tractor was about 59.0 dB (A) observed at point (-12, -20), that is, the furthest from the emitting source point.

Furthermore, observing the ABNT (2020) it is noted that the rural or similar employer must adopt ergonomic principles that aim at adapting working conditions to the psychophysiological characteristics of workers, to provide improvements in comfort conditions and safety at work, and also provides for the use of hearing protection, in this case, hearing protectors for activities with noise levels harmful to health.

Although the agricultural activity in Brazil is the most important since the colonial period until the middle of the 20th century, it had a significant advance for employees only from the Federal Constitution of 1988 in the seventh's article, where it guarantees rights to rural workers as well as

urban workers and include unemployment insurance, the minimum wage, the severance pay for the length of service, the extra salary and the 8 h working day. Recently, ABNT (2020) presented progress for rural workers. It came to make the planning and development of agriculture, livestock, forestry, and aquaculture activities compatible with the safety and health of workers. With regard to ergonomics and safety in the use of agricultural machinery, this standard states that "all machines, equipment, implements, furniture, and tools must provide the worker with conditions of good posture, visualization, movement, and operation".

The majority of motocultivators use air-cooled single-cylinder engines. They are typically powered by diesel, with a four-stroke thermodynamic cycle and power ranging between 7,457 and 14,914 W. The total displacement varies between 250 and 500 (cm³) with a maximum operating regime between 3000 and 3800 rpm (Márquez, 2012). In addition, when Gomes *et al.* (2013) evaluated the increase of motor rotation, they observed that this operation could cause an increase in the sound power level, but only at extreme speeds (2,200 rpm).

The values of the noise emitted by the studied machinery above 85 dB (A), for daily exposure of 8 h NR 15 (ABNT, 2021), are visualized in the operation regime, in general, up to 2 m on the right side and the front and 4 m at the rear and 2 m at the left side of the machine (Figure 4). The maximum noise emission value found in the tractor

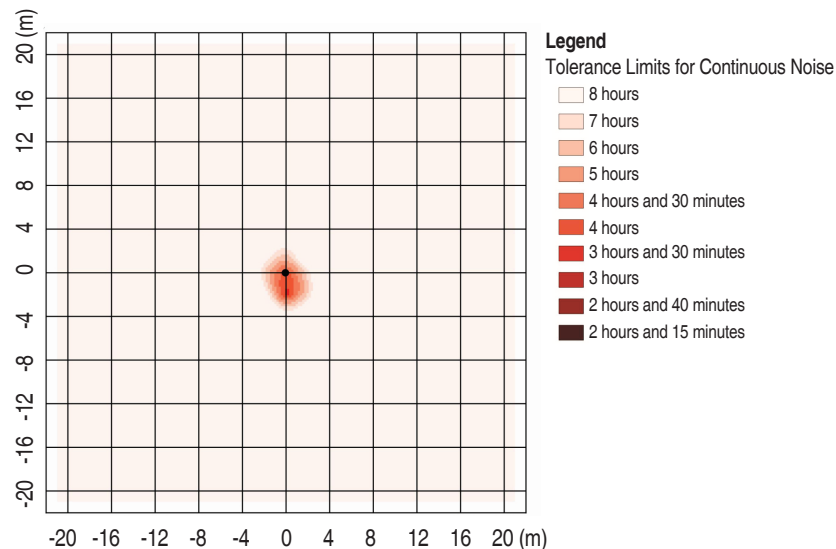


Figure 4. Map of the spatial distribution of the time of exposure to noise emitted by the tractor studied.

understudy was 91.20 dB(A), in the operator's seat (Figure 4). Thus, according to NR 15 (ABNT, 2021), the maximum exposure allowable daily is 3 h and 30 min. Thus, it is always recommended to use ear protectors when operating this tractor.

In Figure 5, the values related to noise levels obtained

near the operator's ear are presented. At the front of the tractor, there was a similarity in the values of noise emitted by the tractor, indicating the noise emitted predominantly by the engine; however, only people located at distances greater than 4 m do not need to use PPE for shifts of 8 h.

Figure 6 shows the control chart of the averages of noise

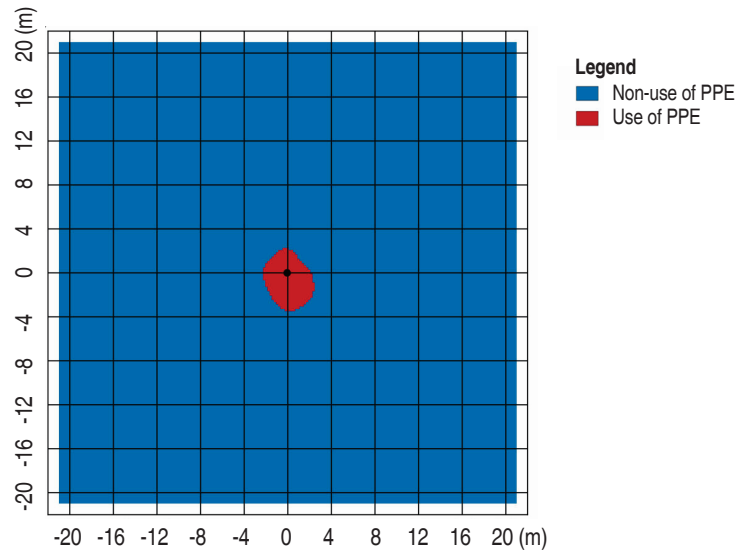


Figure 5. Map of necessity to use or not a Personal Protective Equipment (PPE).

level variable. It may be that the process is controlled, it means that the points at the upper and lower control limits (UCL and LCL) show that the process suffered variations from common causes. Furthermore, there

are probably more points below the control limits for the micro-tractor studied, which show that the operation of this machinery was closer to the control. When the points outside these limits are observed, it is

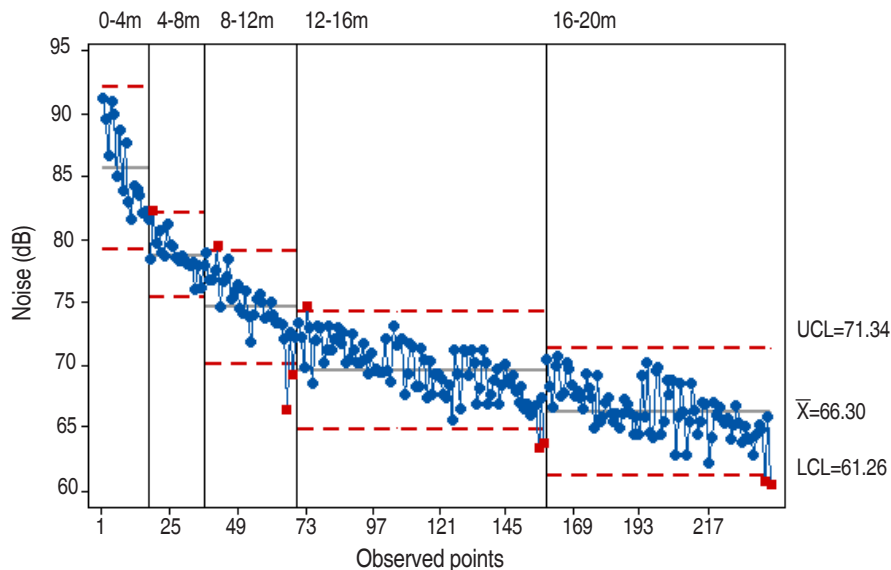


Figure 6. Control of noise levels of the studied tractor.

noted that these data were generated by incorrect data collection procedures or manufacturing years (Civardi, 2017). In contrast, when it comes to the sequences found, the main sequence pattern is when 7 (seven) or more consecutive points appear on just one side, below or above the midline (gray line). These sequences are more difficult to detect since it is necessary to analyze if the special causes will improve or harm the process (Nomelini *et al.*, 2009).

In Figure 6, this phenomenon did not occur in the analysis of the individual control chart of the machinery under study. It is considering that the periodicity is a detectable configuration in the long term. The points are distributed as a curve that has an alternating up and downtrend. This variation can be associated, for example, with interference variability.

An individual control chart was chosen to be used as an evaluation parameter along with geostatistical data. The individual control chart (Figure 6) shows that across all single value/observation relationships, evaluated across 441 collected points, some points are outside the control limit. It can be seen that through the points collected, the value of the highest noise peak in the experiment was 91.2 dB (A), as shown in Table 1.

Still, analyzing the control chart present in Figure 6, it is possible to observe the convergence of the distribution values around the average and note that most of these values are close to their respective stages during the process. The points distribution is explained according to the coefficients of asymmetry and kurtosis with positive values, in which the distribution of values tended to be more to the left and more flattened. Therefore, in a positively asymmetric distribution, the tendency is for positive deviations to be much more significant than the negative ones. Concerning the behavior of the tail being more flattened, it is linked to the kurtosis value of the distribution, which is greater than 0.263 (Table 1), the distribution is flatter than the normal curve of the same area, and it is said to be a platycurtic curve. (Sindelar *et al.*, 2014).

The individual control chart confirms that there were outliers in this case, as there were peaks in values within the subgroup and it was affecting the sample amplitude.

Statistically, outliers are considered data outside the standard of the studied population; in this case, these data are considered interference peaks, which occur due to the influence of some external factor (Silva, 2019).

To sum up, Figures 3, 4, 5, and 6 illustrate the spatial distribution of noise that this machine may generate. These maps, based on the values recommended by NR 15 (ABNT, 2021) have fundamental importance for the management of acoustic health during the use of the agricultural machine, as they facilitate the understanding of the risks caused by noise exposure.

CONCLUSIONS

It was possible to characterize the structure and magnitude of spatial dependence of noise level emitted by the micro-tractor using the Wave model and its spatial distribution map through kriging.

The process has been studied in detail by the process control charts (SPC). It allowed identifying special causes according to variations in the process. Thus, it was possible to develop maps of the noise level emitted by the studied micro-tractor such as Spatial distribution map, Map of the spatial distribution of the time of noise exposure, and Map of necessity to use or not a Personal Protective Equipment (PPE), contributing to the management of acoustic health during the operation of the studied tractor.

For further studies, it is recommended to use a decibel meter and a dosimeter to improve the analyses. Also, it is useful to do this kind of study in other agricultural tractors, machines, and implements.

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