

Spatial variability of the noise level of a hedge trimmer and backpack blower

Mariana de O. e Silva¹, Tadayuki Yanagi Junior¹, Leonardo Schiassi¹,
Diogo F. Rossoni², Jackson A. Barbosa¹, Sílvia de N. M. Yanagi¹

¹ Universidade Federal de Lavras, Departamento de Engenharia, Campus Universitário, CEP 37200-000, Lavras-MG, Brasil. Caixa Postal 3037. E-mail: marianaoesilva@gmail.com; yanagi@deg.ufla.br; leonardo.schiassi@deg.ufla.br; jackson_barbosa@deg.ufla.br; snmonteiro@yahoo.com.br

² Universidade Estadual de Maringá, Campus Universitário, Departamento de Estatística, Avenida Colombo, 5790, CEP 87020-900, Maringá – PR. E-mail: dfrossoni@uem.br

ABSTRACT

Despite the advantages associated to mechanization, the noise generated by machines and equipment may cause discomfort to workers, possibly even jeopardizing their health. Thus, this paper is aimed at assessing the noise level of two agricultural machines (hedge trimmer and backpack blower) and to characterize them spatially by means of geostatistics. Data collection was performed at the average height of the worker's ear and within an equidistant circumference of 1 m up to the limit of a sample area with a radius of 22 m. The data fitted models of gaussian and spherical semivariograms for the evaluated equipment, a hedge trimmer and backpack blower, respectively. The spatial noise analysis allows for the definition of a work regime and the need for the use of personal protection equipment.

Key words: acoustic comfort, geostatistics, human wellbeing

Variabilidade espacial do nível de ruído de uma motopoda e um soprador costal

RESUMO

Apesar das vantagens associadas à mecanização, o ruído gerado pelas máquinas e equipamentos pode favorecer o desconforto aos trabalhadores, inclusive prejudiciais à saúde. Desta forma objetivou-se, com o presente trabalho, avaliar os níveis de ruído de duas máquinas agrícolas (motopoda e soprador costal) e caracterizá-los espacialmente por meio da geoestatística. As coletas de dados foram realizadas na altura média do ouvido do trabalhador e em circunferências equidistantes 1 m, até o limite da área amostral, com raio de 22 m. Os dados se ajustaram aos modelos de semivariogramas gaussiano e esférico para os equipamentos avaliados, motopoda e soprador costal, respectivamente. A análise espacial do ruído permite a definição do regime de trabalho e a necessidade de uso de equipamentos de proteção individual.

Palavras-chave: conforto acústico, geoestatística, bem-estar humano

Introduction

The wellbeing of rural workers has been gaining much deserved attention thanks to regulatory measures by the Ministry of Labor, through the regulatory standard NR-15 (BRASIL, 1990). Within this context, the evaluation and analysis of noises that surround workers has been an object of study (Damasceno et al., 2008; Bravalheri et al., 2010; Yanagi Junior et al., 2011).

Sound pollution is a physical agent commonly found in work environments; however, little attention is currently paid to the prevention of the effects of noise. It is known that sound pollution contributes to increase in stress and discomfort in field operations, causing emotional and cardiovascular disorders, fatigue, as well as problems with alertness and tiredness. Noise at elevated levels are responsible for temporary and permanent hearing disorders, as reported by Miranda et al. (1998) and Yanagi Junior et al. (2012).

The noise evaluation must be conducted based on the regulations established by the Associação Brasileira de Normas Técnicas – ABNT (Brazilian Association of Technical Regulations) by NBR-9999 (ABNT, 1987a) which regulates noise measurements in agricultural machines and NBR-10152 (ABNT, 1987b), which establishes acoustically comfortable noise levels. The Ministry of Labor and Employment's NR-15 (BRASIL, 1990), refers to harmful activities and operations, also considering limits relative to exposure to noise.

Thus, this paper seeks to assess the level of noise generated in a backpack blower and a hedge trimmer, by means of geostatistics.

Material and Methods

The noise level of two machines was evaluated, using one Stihl BR 420 backpack blower, with a maximum motor power of 3.5 kW rotating at 3,100 rpm and a 56.5 cm³ cylinder and; a Stihl ht131 hedge trimmer, with a maximum motor power of 1.4 kW rotating at 10,500 rpm and a 36.3 cm³ cylinder.

The two pieces of equipment were evaluated in an area free of obstacles, measuring 45.0 x 90.0 m, with the entire surrounding area enclosed by bamboo (*Bambusa vulgaris*) with the objective of isolating the collection area of external noise influence, and the ground covered with batatais grass (*Paspalum notatum*). The geographical coordinates of the experiment area are 21°14'S latitude, 45°00'W longitude and an altitude of 918.8 m.

The evaluation followed the methodology described in NBR-9999 (ABNT, 1987a). According to this regulation, the temperature should be between -5 and 30°C with a wind speed below 5.0 m.s⁻¹. Instrutherm DEC - 480 sound pressure gauges, with an accuracy of ± 1.5 dB(A) and a precision of 3% in the slow response circuit and equalization "A", expressed in dB(A), and the draft shield of decibelimeters was used in all measurements, thus avoiding possible influences on measurements derived from wind or reflection noise.

Similar to the methods employed by a number of authors (Baesso et al., 2008; Mion et al., 2009; Yanagi Junior et al., 2012), the noise sensors were positioned at the operator's

average ear height and at an equidistant circumference of 1 meter to the limit of the 22-meter radius sample area. Within each circumference 12 recording sensors were distributed at equal intervals, with the collection time in each circumference set at 1 minute with an interval of 1 second between recordings, thereby totaling sixty repetitions per recording point in each circumference (Figure 1).

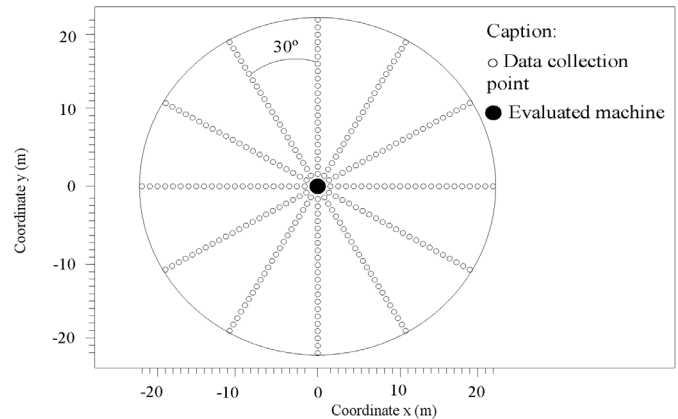


Figure 1. Sketch of the experiment area. Croqui da área experimental

The spatial noise dependences of the evaluated machines were characterized by means of semivariogram adjustments, this is a tool that allows quantitatively represent the variation of a regionalized phenomenon in space (Journel; Huijbregts, 1978), and interpolation by ordinary kriging. Semivariance was estimated through equation 1 (Cressie, 1993).

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

with, $\hat{\gamma}(h)$: estimated semivariance between pairs of points $Z(x_i)$ and $Z(x_i + h)$, noted in x_i e $x_i + h$, and $N(h)$: number of observation experiment pairs $Z(x_i)$ e $Z(x_i + h)$, separated by distance h .

As described by Cressie (1993), using the experiment semivariogram resulted in the adjustment of a theoretical model to the calculated values of $\hat{\gamma}(h)$, followed by an estimation of theoretical model parameters for the semivariogram, called the Nugget Effect, C_0 ; level, C ; and reach, a .

The index of spatial dependence calculated through the division of C_0/C multiplied by 100 was used to assess the degree of spatial dependence for the attributes under study. According to Cambardella et al. (1994), values of $(C_0/C) < 25\%$ characterized strong dependence, $25\% \leq (C_0/C) \leq 75\%$ indicated moderate spatial dependence and $(C_0/C) > 75\%$ weak spatial dependence.

The adjusted semivariogram models were spherical (Equation 2), exponential (Equation 3) and the gaussian (Equation 4). The selection of the best models was based on the cross validation of data, which consists of a technique to assess estimative errors, allowing for a comparison between simulated and gauged values (Isaaks & Srivastava, 1989). Thus, the reduced mean error (RME) and the standard deviation of the reduced error (SD_{RME}) are calculated (Cressie, 1993; Isaaks

& Srivastava, 1989), which should be close to zero and one, respectively.

$$\gamma(h) = \begin{cases} 0 & , |h| = 0 \\ C_0 + C_1 \left[1,5 \left(\frac{|h|}{a} \right) - 0,5 \left(\frac{|h|}{a} \right)^3 \right] & , 0 < |h| \leq a \\ C_0 + C_1 & , |h| > a \end{cases} \quad (2)$$

$$\gamma(h) = \begin{cases} 0 & , |h| = 0 \\ C_0 + C_1 \left[1 - \exp\left(-\frac{|h|}{a}\right) \right] & , |h| \neq 0 \end{cases} \quad (3)$$

$$\gamma(h) = \begin{cases} 0 & , |h| = 0 \\ C_0 + C_1 \left[1 - \exp\left(-\frac{|h|^2}{a}\right) \right] & , |h| \neq 0 \end{cases} \quad (4)$$

After choosing the best models for each assessed machine, the data were interpolated by means of ordinary kriging, mapping the noise level around the evaluated machines.

Area referencing was achieved based on the coordinates obtained in marking the sample point (meter) (Figure 1). For the geostatistic analysis and to obtain the kriging maps the R statistics computer system was used (R Development Core Team, 2010), by means of the geoR package (Ribeiro Júnior & Diggle, 2001).

Results and Discussion

The variability of noise data for the evaluated equipment (Table 1 and Figure 2) shows that the use of the average or even median may result in classification errors for harmfulness, due to the spatial dependence of the data. In this sense, geostatistics provides information for the satisfactory management of interventions necessary to attaining safe conditions for workers, thereby increasing productivity and also preserving their health.

Upon analyzing the reduced mean error (RME) and the standard deviation of the reduced error (SD_{RME}) (Table 2), it is noted that the theoretical models of the semivariograms that

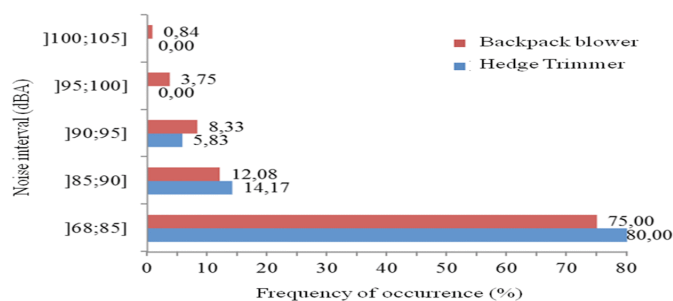


Figure 2. Frequency of occurrence of noise levels for the equipment: hedge trimmer and backpack blower

presented the best adjustments were the gaussian and spherical types for the hedge trimmer and backpack blower, respectively. According to Cressie (1993), a model is considered well-adjusted if the RME is close to zero and the SD_{RME} is close to one.

The selected models are considered transitive (Faria et al., 2008), as they have a level, that is, starting from a specific value of the distance between samples, there is no longer spatial dependence, that is, the variance of the difference between the sample pairs becomes invariant with the distance. Similar results were found by Yanagi Junior et al. (2012).

In spite of showing inexplicable variability due to the distance of the sample used, the nugget effect (C_0) can be expressed as a percentage of the level, thereby facilitating the comparison of the degree of spatial dependence for the variables under study (Trangmar, 1985). Through the C_0/C ratio calculated for the adjusted gaussian and spherical models for the hedge trimmer and backpack blower, respectively, strong spatial dependence is presented, as $C_0/C < 25\%$ (Cambardella et al., 1994), which are expressed in the semivariograms illustrated in Figure 3.

At a later date, estimates were made of the noise values using kriging, based on the spatial dependence of the semivariogram models (Faraco et al., 2008; Souza et al., 2010). These estimates allowed for the preparation of maps showing the spatial distribution of noises (Figure 4), which, according to Ferraz et al. (2012), allows for the adoption of more precise interventions.

Still in reference to Figure 4, one notes the directional effect of noise distribution due to the position of the operator and the motor, generating a unique spatial distribution pattern,

Table 1. Minimum, maximum, average, standard deviation and standard error for the noise values [dB(A)] in the evaluated equipment

Equipment	Noise level (dB(A))				
	Minimum	Average	Maximum	Median	Standard error
Hedge Trimmer	68.97	79.31	93.00	78.02	5.74
Backpack Blower	69.95	81.60	103.05	80.64	6.65

Table 2. Estimates for the parameters of the experimental semivariogram for the variable noise level of evaluated equipment and cross validation

Equipment	Model	Parameters				Cross validation	
		Nugget effect (C_0)	Reach (a)	Level (C)	C_0/C	RME	SD_{RME}
Hedge trimmer	Spherical	0.00	51.30	20.79	0.0000	0.00264	1.92
	Gaussian	2.38	49.68	17.17	0.1386	0.00019	1.67
	Exponential	0.00	83.24	58.65	0.0000	0.00151	2.05
Backpack blower	Spherical	0.00	68.90	21.43	0.0000	0.00520	2.19
	Gaussian	9.04	62.62	19.30	0.4684	0.00110	3.19
	Exponential	0.00	113.91	20.58	0.0000	0.00430	2.35

C_0/C : Degree of spatial dependence, RME: reduced mean error and SD_{RME} : standard deviation of reduced mean error

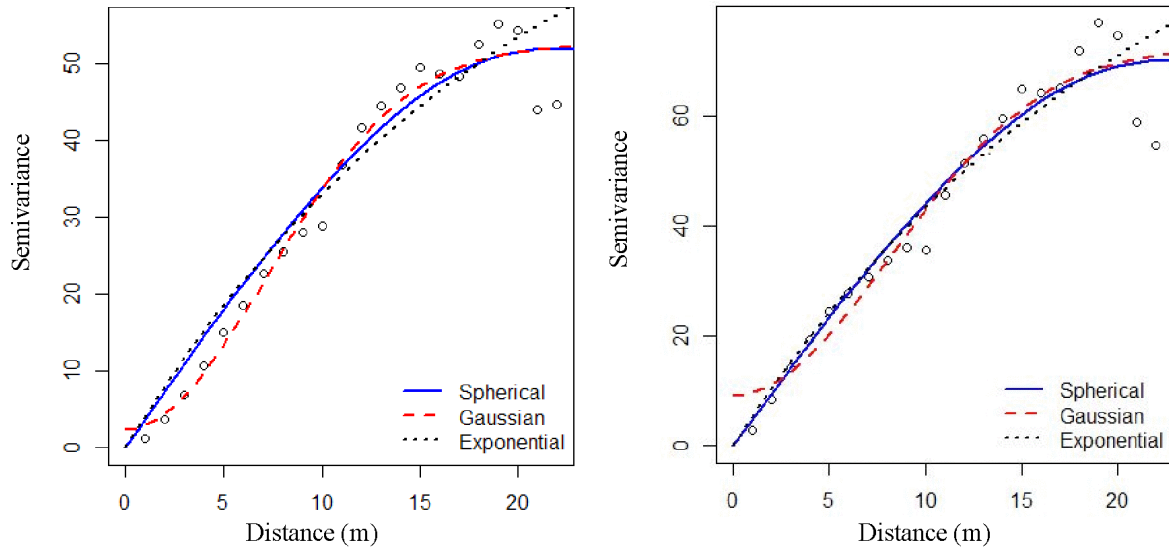


Figure 3. Semivariograms for the gaussian and spherical function of the noise data for the following equipment: (a) hedge trimmer and (b) backpack blower

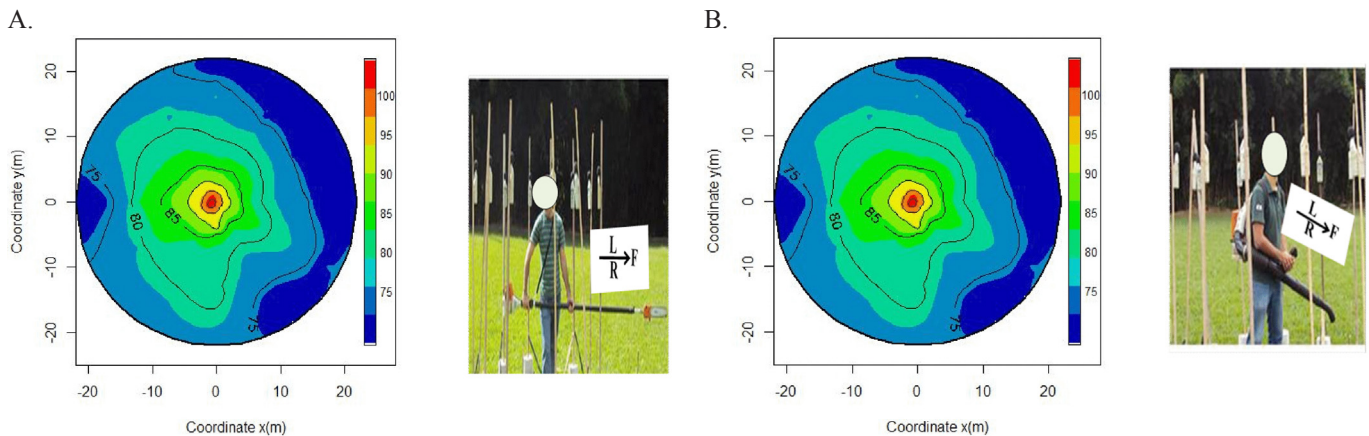


Figure 4. Spatial distribution of noise levels (dB(A)) for the following equipment: (a) hedge trimmer and (b) backpack blower

similar to the results found by other authors (Silveira et al., 2007; Yanagi Junior et al., 2012).

The high concentration of noise levels higher than 85 dB(A) is noted close to the evaluated machines, indicating the need for Personal Protection Equipment (PPE) for operators and others working in areas around the equipment, implementing maintenance services or even overseeing activities, similar to that noted by Yanagi Junior et al. (2012).

Conclusions

Characterization of the magnitude of spatial variability for noise data was possible thanks to semivariogram adjustments, allowing for the generation of contour maps using the kriging method.

The spatial analyzes of noise data, using geostatistics, allows for the determination of the level of harm that operators are subject to, fostering the definition of a work regime and the need of personal protection equipment.

Acknowledgments

The authors thank CAPES, CNPq and FAPEMIG for the financial support granted in favor of this research.

Literature Cited

- Associação Brasileira de Normas Técnicas. Norma NBR 10.152: níveis de ruído para conforto acústico. Rio de Janeiro: ABNT, 1987b. 21p.
- Associação Brasileira de Normas Técnicas. Norma NBR 9999: Medição do nível de ruído no posto de operação de tratores e máquinas agrícolas. Rio de Janeiro: ABNT, 1987a. 21p.
- Baesso, M. M.; Teixeira, M. M.; Junior, F. A. R.; Junior, R. G. M.; Fernandes, H. C. Avaliação do nível de ruído emitido por um conjunto trator-pulverizador com e sem assistência de ar. *Revista Engenharia na Agricultura*, v.16, n.4, p. 400-407, 2008. <<http://www.seer.ufv.br/seer/index.php/reveng/article/view/56>>. 18 Out. 2011.
- Brasil. Norma Regulamentadora de segurança e saúde no trabalho (NR-15): atividades e operações insalubres. Brasília: Ministério do Trabalho e Emprego, 1990. <<http://www.mte.gov.br/temas/segau/legislacao/normas/conteudo/nr15>>. 10 Set. 2011.
- Bravalheri, A. C.; Bernardo, L. A.; Miranda, M. A.; Angelo, T. N.; Parahyba, V. E. S. Poluição sonora em ambientes da Unicamp. *Revista Ciências do Ambiente On-Line*, v.6, n.1, p.1-7, 2010. <<http://sistemas.ib.unicamp.br/be310/index.php/be310/article/viewFile/217/163>>. 20 Dez. 2010.

- Cambardella, C. A.; Moorman, T. B.; Parkin, T. B.; Karlen, D. L.; Novak, J. M.; Turco, R. F.; Konopka, A. E. Field scale variability of soil properties in Central Iowa soils. *Soil Science Society of America Journal*, v.58, n.5, p.1501-1511, 1994. <<http://dx.doi.org/10.2136/sssaj1994.03615995005800050033x>>.
- Cressie, N. *Statistics for spatial data*. New York: J. Wiley, 1993. 900p.
- Damasceno, F. A.; Yanagi Junior, T.; Gomes, R. C. C.; Lima, R. R. de; Schiassi, L.; Moraes, R. P. de. Avaliação do nível de ruído produzido por caminhões de ração no município de Itaberaí (GO). *Revista Ciências do Ambiente On-Line*, v.4, n.1, p.44-48, 2008. <<http://sistemas.ib.unicamp.br/be310/index.php/be310/article/viewFile/126/91>>. 20 Feb. 2010.
- Faraco, M. A.; Uribe-Opazo, M. A.; Silva, E. A. A. da; Johann, J. A. Seleção de modelos de variabilidade espacial para elaboração de mapas temáticos de atributos físicos do solo e produtividade da soja. *Revista Brasileira de Ciência do Solo*, v.32, n.2, p.463-476, 2008. <<http://dx.doi.org/S0100-06832008000200001>>.
- Faria, F. F.; Moura, D. J.; Souza, Z. M.; Matarazzo, S. V. Variabilidade espacial do microclima de um galpão utilizado para confinamento de bovinos de leite. *Ciência Rural*, v.38, n.9, p.2498-2505, 2008. <<http://dx.doi.org/10.1590/S0103-84782008000900013>>.
- Ferraz, G. A. S.; Silva, F. M. da; Alves, M. C.; Lima Bueno, R. de; Costa, P. A. N. Geostatistical analysis of fruit yield and detachment force in coffee. *Precision Agriculture*, v. 13, n. 1, p.76-89, 2012. <<http://dx.doi.org/10.1007/s11119-011-9223-8>>.
- Isaaks, E. H.; Srivastava, R. M. *An introduction to applied geostatistics*. New York: Oxford University, 1989. 561p.
- Journel, A. G.; Huijbregts, C. J. *Mining geostatistics*. San Diego: Academic, 1978. 600p.
- Mion, R. L.; Viliotti, C. A.; Dantas, M. J. F.; Nascimento, E. Avaliação dos níveis de ruído de um conjunto mecanizado trator e semeadora adubadora pneumática. *Revista Engenharia na Agricultura*, v.17, n.2, p.87-92, 2009. <<http://www.seer.ufv.br/seer/index.php/reveng/article/viewFile/48/50>>. 14 Set. 2011.
- Miranda, C. R.; Dias, C. R.; Pena, P. G. L.; Nobre, L. C. C.; Aquino, R. Perda auditiva induzida pelo ruído em trabalhadores industriais da região metropolitana de Salvador, Bahia. *Revista Informe Epidemiológico do SUS*, v.7, n.1, 1998. <<http://dx.doi.org/10.5123/S0104-16731998000100005>>.
- R Development Core Team. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna: R Development Core Team, 2010. <<http://www.r-project.org>>. 12 Feb. 2011.
- Ribeiro Júnior, P. J.; Diggle, P. J. GeoR: a package for geostatistical analysis. *R-News*, v.1, n.2, p.14-18, 2001. <https://geodacenter.asu.edu/system/files/rnews1.2.15-18_0.pdf>. 12 Feb. 2011.
- Silveira, J. C. M. da; Fernandes, H. C.; Rinaldi, P. C. N.; Modolo, A. J. Níveis de ruído em função do reio de afastamento emitido por diferentes equipamentos em uma oficina agrícola. *Engenharia na Agricultura*, v. 15, n.1, p.66-74, 2007. <<http://www.higieneocupacional.com.br/download/ruído-oficina.pdf>>. 24 Mar. 2012.
- Souza, G. S.; Lima, J. S. S.; Xavier, A. C.; Rocha, W. S. D. Krigagem ordinária e inverso do quadrado da distância aplicados na espacialização de atributos químicos de um argissolo. *Scientia Agraria*, v.11, n.1, p.73-81, 2010. <<http://ojs.c3sl.ufpr.br/ojs-2.2.4/index.php/agraria/article/viewArticle/15939>>. 24 Mar. 2012.
- Trangmar, B. B. Applications of geostatistics to spatial studies of soil properties. *Advances in Agronomy*, v.38, n.1, p.45-94, 1985.
- Yanagi Junior, T.; Amaral, A. G.; Teixeira, V. H.; Lima, R. R. D. Caracterização espacial do ambiente termoacústico e de iluminância em galpão comercial para criação de frangos de corte. *Engenharia Agrícola*, v.31, n.1, p.1-12, 2011. <<http://dx.doi.org/10.1590/S0100-69162011000100001>>.
- Yanagi Junior, T.; Schiassi, L.; Rossoni, D. F.; Ponciano, P. F.; Lima, R. R. D. Spatial variability of noise level in agricultural machines. *Engenharia Agrícola*, v.32, n.2, p.217-225, 2012. <<http://dx.doi.org/10.1590/S0100-69162012000200002>>.