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Geostatistics applied to evaluation of thermal conditions and noise in compost dairy barns with different ventilation systems

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Abstract. The objective of this work was to evaluate the spatial distribution of thermal conditions and bed variables in compost dairy barns with different ventilation systems, through the technique of geostatistics. The experiment was conducted in April 2017, in farms located in Madre de Deus, Minas Gerais, Brazil. Three facilities were evaluated with different ventilation systems: natural (NV); mechanical of low volume and high speed (LVHS); and mechanical of high volume and low speed (HVLS). The interior of the premises was divided into 40 meshes equidistant points, in which air temperature, relative humidity and air speed were manually collected. Geostatistics technique was used to assess the spatial dependence of the variables. The results showed the occurrence of dependence and spatial variability of the variables evaluated. Based on thermal comfort indexes, it was concluded that dairy cows were under stress conditions during the hottest hours of the day in the three animal facilities evaluated. The results obtained allow us to understand that the thermal environment is more influenced by the ventilation system adopted.

Key words: animal welfare, dairy cattle, compost barns, geostatistics.

INTRODUCTION

The dairy industry is one of the most important for Brazilian agribusiness, especially for the importance of milk and its derivatives in the composition of the human diet (Sabbag & Costa, 2015). In 2017, the national production increased +4.02%, with a total of 24.07 million tons of milk (Carvalho et al., 2018).

Thus, in order to achieve satisfactory results in their activity, more dedication and investments are demanded by the milk producers. Every day, they face several challenges, since factors such as building structure, thermal cow environment, management, among others, have direct implications on the productivity of the herd. Especially the building structure is of great importance for the success of the activity, since well-sized facilities provide better comfort conditions for the animals, thus improving wellbeing and thereby contributing to increased productivity (Costa & Silva, 2014).

Among the systems of confined production of dairy cattle, the compost barn (CBP, Compost Bedded Pack) appears as a viable alternative to the conventional systems used in milk production. According to Barberg et al. (2007), the system consists of the confinement of the animals in a large common area, covered by bed in comfortable material that under appropriate conditions of temperature and humidity undergoes the composting process over time. The advantages of the system are the improvement in the comfort and well-being of the herd, the gains in productivity and sanity, the reduction of production costs, as well as the correct destination of the organic wastes, through the composting process of the wastes produced by the animals (Black et al., 2013).

The construction of CBP should consider several factors, especially the ventilation system employed, which is responsible for maintaining a comfortable environment for the animals, for the removal of gases and heat, and for drying the bed material (Janni et al., 2007; Lobeck et al., 2011; Angrecka & Herbut, 2014, Lendelova et al., 2017). In some CBP where it is not possible to naturally achieve the volume of air necessary to promote animal comfort and bed drying, mechanical ventilation is the preferred solution. The main types of fans used in the facilities are the high volume and low rotation – HVLS and low volume and high rotation - LVHS (Leso et al., 2018).

Some milk producers and researchers have been looking for the assistance of innovative methods, computational tools for evaluation and decision support to control the welfare of confined animals for better evaluation of the animal production (Borges et al., 2010; Herbut & Angrecka, 2015). Among the methods used, we highlight the evaluation of the spatial distribution through geostatistics, which allows the interpretation of the results from the natural structuring of the data, based on spatial dependence in the sampling interval considered (Cambardella et al., 1994; Vieira, et al., 2000). Thus, the variability of the attributes of interest and their influence on the environment can be understand (Silva Neto et al., 2012).

The objective of this work was to evaluate the spatial distribution of thermal conditions and bed variables in compost dairy barns with different ventilation systems, through the technique of geostatistics.

MATERIALS AND METHODS

Characterization of animal facilities

The study was carried out during April 2017 in two milk farms located in the Madre de Deus de Minas, Minas Gerais state, Brazil (latitude 21° 29' 2" S, longitude 44° 19' 58" W, and altitude 985 m). The climate of the region, according to Köppen climatic classification, is classified as Cwa - temperate humid, with dry winter and rainy summer, subtropical, with dry winter and warmest month temperature higher than 22°C (Sá Júnior et al., 2012).

In this study, three compost dairy barns (CBP) were evaluated in two milk farms close to each other (about 2.0 km away). Two CBP facilities were located on the same milk farm and had the same constructive characteristics, such as: 17.0 m wide and 33.2 m length, 4.6 m eave height, roof pitch of 16°, and cover with metallic tiles (thickness of 0.50 mm), with orientation in the northeast-southwest direction (Fig. 1, a). In the first CBP, the ridge opening was closed and the ventilation system was LVHS: four box fans, 4.5 m of height and slope of 45° (Mamute®, diameter of 2.0 m, number of propellers 5, rotation 1,750 rpm, power of 2.2 kW or 3.0 hp, flow of 120.000 $m^3 h^{-1}$).

The second CBP had an elevated ridge opening and natural ventilation (VN), without the use of mechanical ventilators. In both CBP, the feed alley had a line of sprinklers, which were operated for 1.0 min and disconnected for 5 min. The sprinkler system was manually switched on whenever the temperature was found to be above the suitable temperature for the animals (23.0 °C).

In the third CBP evaluated, the constructive characteristics were based on: 17.5 m wide and 48.6 m length, 4.2 m eave height, roof pitch of 16° and overshot ridge opening, with metallic structure, coverage in metal tiles (thickness of 0.40 mm), and orientation in the east-west direction (Fig. 1, b). It was equipped with a HVLS ventilation system: two fans allocated at 3.8 m (BigFan®, diameter 7.5 m, power of 2.2 kW and air flow of 650.000 $m^3 h^{-1}$).

In all CBP, the bedding material was wood shaving, and the depth of the bed was approximately 0.40 m. The bed aeration of bed in the first and second CBP was done only once per day, using a rototiller. In the third CBP, the aeration of bed was performed twice daily during the milking period using a field cultivators adapted to the property.

In the CBP with LVHS, 79 Holstein dairy cows were kept, with a mean milk production of 30 kg $animal^{-1}$ day^{-1}. Furthermore, 105 Holstein dairy cows were housed in the CBP with natural ventilation, average milk production of 28 kg $animal^{-1}$ day^{-1}. In the CBP with HVLS ventilation system, 126 Holstein dairy cows were housed, with an average milk production of 30 kg $animal^{-1}$ day^{-1}.

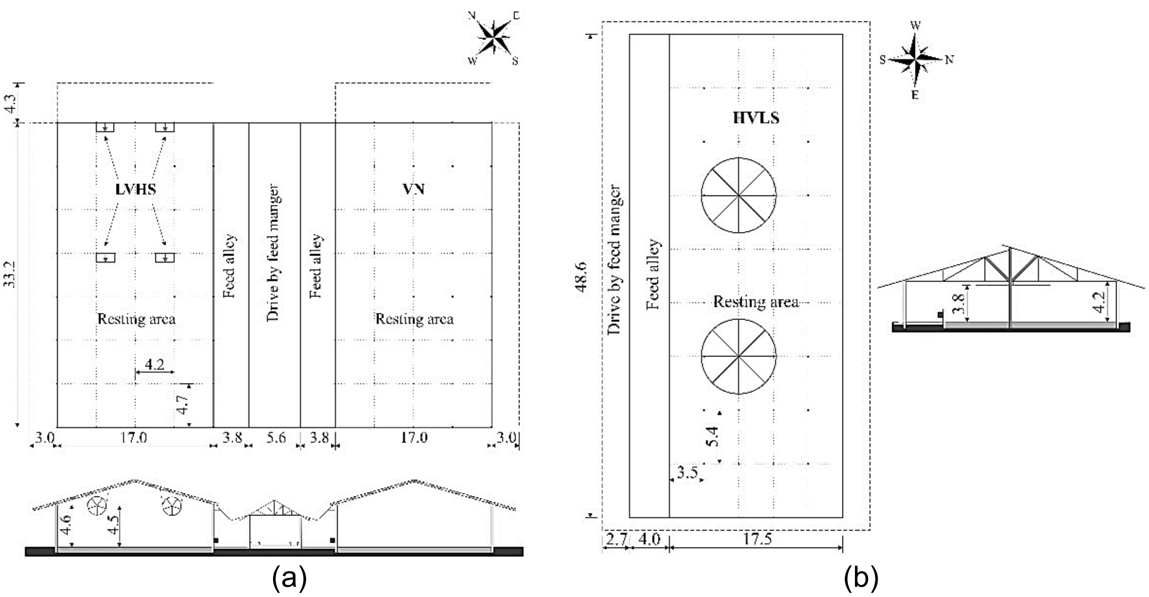

Figure 1. Schematic representation of CBP with different ventilation systems: a) LVHS and VN; b) HVLS. Dimensions in meters (m).

Instrumentation and data collection

For the collection of data, the interiors of the CBP facilities were divided through meshes points composed of 40 equidistant points, such divisions being made according to the constructive characteristics of the CBP facilities. All data collections were carried out during 12:00 to 16:00 hours. The schematic representations of the CBP facilities with meshes points used to measure the data is illustrated in Fig. 1.

The environmental variables were collected near the geometric centres of the animals (1.5 m height above the ground, simulating the height of the dorsum of the animal). A portable digital thermo-higro-decibel-lux meter was used to collect air temperature (t_{db}), relative humidity (RH) and noise level (Instrutherm®, model THDL-400, with accuracy of ± 3.5%). The air velocity was measured by means of a hot wire anemometer (Instrutherm®, model TAFR-190, with accuracy of ± 0.1 m s^{-1}).

For the evaluation of the thermal comfort inside the CBP, the Temperature and Humidity Index (THI) was used, according to the equation proposed by Buffington et al. (1983):

$$THI = 0.8 \cdot t_{bs} + RH \cdot \left(\frac{t_{bs} - 14.3}{100} \right) + 46.3 \quad (1)$$

where t_{db} is dry-bulb air temperature (°C); and RH is the relative humidity (%).

For dairy cattle, the limits of THI that characterize a situation of comfort or discomfort are not fully shared among the scientific community. In general, the limits proposed by Thom (1959) and Hubbard et al. (1999), for dairy cattle are: THI < 74 - thermal comfort condition; $74 \leq$ THI < 79 - an alert condition for producers; $79 \leq$ THI < 84 - a hazard condition, and safety measures must be taken to prevent disastrous losses, especially for confined herds; and, THI > 84 - emergency situation, and urgent steps must be taken to avoid loss of staff. However, THI values above 72 represent a stressor condition for Holsteins cows, which may lead to reduced productivity (Johnson, 1980; Herbut et al., 2015).

Statistical and geostatistics analysis

Statistical analyses of variance were performed using the data collected to verify the influence of the different types of ventilation on the analysed variables and the results of the analyses were all significant. Thus, we analysed the differences between means, which were compared by Tukey's test ($p < 0.05$), using statistical software R (Development Core Team, 2016).

In order to verify the spatial behaviour of the variables within the CBP facilities, as well as to predict their levels in non-sampled locations and the occurrence of spatial dependence, the geostatistical technique was used. The analyses were performed using the R (Development Core Team, 2016) software, through the geoR library (Ribeiro Junior & Diggle, 2001). The evaluation of the spatial dependence of the variables inside the CBP facilities was made through semivariogram adjustments. For the estimation of the semivariogram we used the estimator of Matheron (1962):

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

where $N(h)$ corresponds to the number of experimental pairs of observations $Z(X_i)$ and $Z(X_i + h)$, separated by a distance h.

The coefficients of the theoretical model for semivariogram, called nugget effect – C_0, plateau – $C_0 + C_1$, and reach – a, were obtained from a mathematical model for the calculated values of Bachmaier & Backers (2008).

The degree of spatial dependence (GDE) was determined by the ratio between the nugget effect (C_0) and the threshold ($C_0 + C_1$), multiplying by 100. Dependency analysis was performed using Cambardella et al. (1994). According to this classification, it is considered as a strong spatial dependence the semivariograms that have nugget effect of less than 25% of the plateau, moderate spatial dependence that have a nugget effect between 25% and 75% of the plateau and weak spatial dependence of the semivariograms that present nugget effect greater than 75% of the plateau.

Due to the small grouping of data, the Restricted Maximum Likelihood Estimation (REML) method was used, as suggested by Marchant & Lark (2007). The model tested for the adjustment of the experimental semivariogram was the Spherical, a model widely used in geostatistics and that returns good results.

In order to make maps of the spatial distribution of the levels of variables within the CBP facilities, the ordinary data kriging technique was used. From the interpolated data, response surface maps were generated, using the ArqGIS® software, version 10.1.

The descriptive statistics were used to determine the fraction of area occupied by the intervals of each of the analysed variables and to better characterize the spatial distribution of the variables inside the CBP facilities.

RESULTS AND DISCUSSION

The mean values of t_{db}, RH, THI, V_{air}, and noise within the CBP facilities are listed in Table 1. There was a statistically significant difference between the means of all variables analysed, at the level of 5% probability using the Tukey test. In relation to the t_{db}, RH, THI attributes, the highest mean values were verified for the CBP with VN, while the lowest values were found inside the CBP with HVLS ventilation system. According to the classification suggested by Warrick & Nielsen (1980), the variability of these variables and index was low (CV < 12%). The average THI values inside the CBP facilities were higher to Holsteins cows, which is 72 (Johnson, 1980).

Table 1. Mean values of dry-bulb air temperature (t_{db}, °C), relative humidity (RH, %), temperature and humidity index (THI), air velocity (V_{air}, m s^{-1}), and noise (dB)

Ventilation	t_{db} (°C)		RH (%)	THI		V_{air} (m·s^{-1})		Noise (dB)	
VN	28.8 (±0,5)	a	53.0 (±2)	77.0 (±1)	a	0.3 (±0.1)	c	49.9 (±1.3)	c
LVHS	28.1 (±0,4)	b	46.0 (±2)	75.0 (±1)	b	1.0 (±0.5)	a	72.2 (±2.3)	a
HVLS	27.0 (±0,4)	c	43.0 (±1)	74.0 (±1)	c	0.8 (±0.6)	b	53,9 (±1.8)	b
CV (%)	1.57		3.49	0.65		62.66		3.19	

* Means followed by the same letter do not differ statistically at the 5% level of significance, by the Tukey test; VN – natural ventilation; LVHS – mechanical ventilation of low volume and high rotation; HVLS – mechanical ventilation of high volume and low rotation; CV – coefficient of variation.

Regarding V_{air} and noise level, there was a significant increase of their levels with the use of forced ventilation, being greater when using LVHS ventilation. Considering the classification suggested by Warrick & Nielsen (1980), the variation of the noise level was low (CV < 12%). On the other hand, for the V_{air}, a high variability condition (CV > 60%) was observed. Since it is an attribute with high spatial and temporal variability, which can change its magnitude and direction abruptly (Faria et al., 2008), the heterogeneity of the data is a common occurrence.

In countries of tropical and subtropical climate, such as Brazil, the reduction of heat stress is necessary, so that the thermal comfort required by the animals can be assured. The solution most commonly employed by the producers is the use of environmental conditioning systems, which reduces the heat load on the animals to ensure adequate environmental welfare. Lack of homeostasis results in animal physiological reactions such as an increase in rectal temperature and respiratory rate (Frazzi et al., 1998; Godyn et al., 2019). The analysis of the results presented in Table 1 allows us to understand that the use of mechanical ventilation alone (LVHS and HVLS) provided a better thermal comfort condition within CBP facilities evaluated by increasing the velocity of the air around the animals and thus increasing the convection exchange, but it is not sufficient to promote adequate thermal comfort to animals. It is also observed that the use of ventilators caused an increase in sound pressure levels.

As a way to better evaluate the variables and index studied in a quantitative and qualitative way, the techniques of descriptive statistics and geostatistics were used, which provide important information regarding the area occupied by each class of the attribute, as well as to understand its variability and influence on the environment. In this way, the models and parameters of the experimental semivariograms adjusted for the variables and index of the thermal and acoustic environment in the three facilities are presented in Table 2. For these attributes, semivariograms conformed to the spherical model, which, according to Isaaks & Srivastana (1989), is considered transitive since it has a threshold.

Table 2. Estimated models and parameters of the experimental semivariograms adjusted for the attributes of the thermal and acoustic environment

Variable	Ventilation	Method	Model	C_0	C_1	$C_0 + C_1$	*a*	GDE
t_{db}	VN	REML	Spherical	0.00	0.15	0.15	14.88	0.00
	LVHS			0.00	0.18	0.18	4.39	0.00
	HVLS			0.00	0.13	0.13	4.48	0.00
RH	VN	REML	Spherical	0.00	5.25	5.25	12.10	0.00
	LVHS			1.50	2.01	3.52	17.80	42.73
	HVLS			0.00	1.63	1.63	29.72	0.00
THI	VN	REML	Spherical	0.00	0.39	0.39	11.93	0.00
	LVHS			0.00	0.32	0.32	17.30	0.00
	HVLS			0.00	0.05	0.05	33.49	0.00
V_{air}	VN	REML	Spherical	0.05	0.01	0.06	24.94	77.08
	LVHS			0.32	0.25	0.57	28.96	55.80
	HVLS			0.11	0.16	0.27	16.16	39.57
Noise	VN	REML	Spherical	0.00	3.53	3.53	4.52	0.00
	LVHS			0.00	3.90	3.90	35.90	0.00
	HVLS			0.00	3.78	3.78	19.17	0.00

* VN – natural ventilation; LVHS – mechanical ventilation of low volume and high rotation; HVLS – mechanical ventilation of high volume and low rotation; C_0 – nugget effect; C_1 – contribution; $C_0 + C_1$ – threshold; a – reach; GDE – degree of spatial dependence; t_{db} – dry-bulb air temperature; RH – relative air humidity; THI – temperature and humidity index; and Vair – air velocity.

The nugget effect (C_0) is an important parameter of the semivariogram, since it indicates the unexplained variability. The importance of this parameter is related to the discontinuity check of the semivariograms for distances less than the shortest distance between the collection points, being this discontinuity caused by errors of analysis and during the collection, local variations, among others, being impossible to perform the quantification of each of these components (Ferraz et al., 2017a).

In relation to the evaluated attributes, the values of C_0 were mostly equal to zero (t_{db}, RH, THI and noise), indicating that, in general, such variables did not present unexplained variability, semivariograms did not have discontinuity and characterizing dependency condition spatial distribution according to the classification of Cambardella et al. (1994). The exceptions were the RH (only in the CBP with LVHS) and V_{air} (all CBP evaluated), which presented non-zero C_0 values. In the LVHS ventilation system, the unexplained spatial variability of the RH variable at the threshold was 42.73%, indicating that the spatial dependence of this variable for this installation is moderate (GDE = 42.73%). The same was observed for the variable V_{air}, which presented initial variability higher than 25% of the level in the three facilities, being greater than 75% in the CBP with VN. The V_{air} presents high variability, being able to change of magnitude and direction abruptly and to present high variations in a small interval of time (Faria et al., 2008).

Since it is a very variable attribute in space and time, its measurement is difficult to perform, being subject to several sources of error, both related to its collection and to local variations. The occurrence of only moderate (25% < GDE $\leq$ 75%) and weak (GDE > 75%) spatial dependence, verified for V_{air} in mechanical ventilation and natural ventilation, respectively, is a function of the initial unexplained variability, common to such an attribute. For V_{air}, the lowest GDE was verified for the installation with HVLS mechanical ventilation (39.57%).

In relation to the acoustic environment, the contribution of C_0 in the level was equal to zero in the three installations, characterizing a condition of strong spatial dependence, in which there is no initial variability unexplained and there is no discontinuity in the semivariograms.

According to Ferraz et al. (2017a), which provides as information the distance that a variable is influenced by the space, making possible the determination of the spatial dependence limit. If the distance between sampling points is less than a, these points are correlated to each other, and interpolation techniques can be used to determine the levels of the variable in non-sampled locations. On the other hand, if the value of a is less than the shortest distance between collection points, the semivariogram is constant for any value, there is no spatial dependence and the geostatistical technique can not be applied (Vieira, 2000).

For all variables studied, the values of a were greater than the smaller distance between the points used in the CBP facilities. The lowest range values were verified for the variable t_{db} within the LVHS and HVLS ventilation installations (4.39 and 4.48 m, respectively), which were still higher than the smaller distance between sampling points (4.25 m). Since the values of a were different for each of the variables, it is inferred that it is possible to use different meshes for the sampling of the different attributes, being able to be used the same mesh in cases in which the variables present values of the next to each other. This makes it possible to reduce the number of collection points, since, in cases of occurrence of high values of a (as observed for the RH and V_{air} variables), meshes with a greater distance between collection points (> 10 m, for example).

From the knowledge of the existence of spatial variability, the geostatistical technique can be used to make maps of spatial distribution, through data interpolated through the ordinary kriging technique. These maps can be used to identify the areas with higher and lower value of the study variable, allowing the precise management of the necessary interventions in the areas where the technique is applied (Ferraz et al., 2017b).

In this way, the spatial distribution maps of the variables t_{db}, RH and THI for the CBP facilities equipped with different ventilation systems, as well as the graphs of cumulative frequency of the variables in each CBP facilities, facilitate the understanding of the data.

The variability of the t_{db} attribute was higher for the VN installation (Fig. 2, a), which presented a range of variation equal to 3.0 °C (27.0 to 30.0 °C). In such a CBP, the area with the highest temperature was observed in the northeast face, where the cut of a slope was made for the installation to be constructed. Due to its location close to the slope, natural ventilation on this face of the facility became reduced, reducing heat exchanges with the environment and making t_{db} higher. In the LVHS ventilation system, the t_{db} presented a lower amplitude of variation (2.0 °C), and the region with the highest temperature (28.0 to 29.0 °C) occurred near the southwest face, a region that received direct solar radiation in the afternoon absence of lateral closure. On the other hand, the HVLS mechanical ventilation system had milder temperatures (26.0 to 28.0 °C), and the region with the lowest t_{db} occurred near the west face, a region near the waiting and milking rooms, which operated as lateral closure, avoiding the incidence of direct solar radiation inside the CBP facilities.

According to Nääs (1989), the thermoneutrality zone for lactating cows is between 4.0 and 24.0 °C, and can be restricted to the range of 7.0 to 21.0 °C, according to the RH and incident solar radiation. For Holsteins cows, the temperature range characterized as thermoneutrality is between 4.0 and 26.0 °C (Huber, 1990). At the outside temperature of 35.0 °C the milk yield decreased by 33%, and at the temperature of 40.0 °C by 50% (West, 2003).

Inside of the three CBP facilities the t_{db} was above the upper recommended critical limit for lactating Holstein cows (26.0 °C), the most critical conditions being observed for the VN, which presented temperatures above 28.0 °C throughout the entire installation (99.9% of the bed area), a condition that may lead to a deterioration in welfare and thus reduced productivity of the animals (Fig. 2, b). Although the t_{db} were still above adequate, in the CBP facility provided with mechanical ventilation lower temperatures were observed, with the best results verified for installation with HVLS ventilation. In such an installation, the t_{db} was below 27.0 °C in 45.5% of the area, and at 28.0 °C in 54.5% of the bed area, being close but still above the upper critical temperature limit. In the LVHS ventilation system, in only 47.0% of the bed area, the temperature was below 28 °C, indicating that the ventilation system promoted the reduction of t_{db}, but it was not enough to reduce it to adequate levels.

Fig. 2, c shows the occurrence of higher RH and higher amplitude of variation in the VN installation, which presented regions with values between 45 and 60%. In such CBP facility, it can be inferred that the occurrence of higher values of humidity is due to the low capacity of removal of moisture provided by natural air currents. It is also worth noting that the region where the RH was highest is located near the feed alley, where the animals were cooled by wetting (sprinkling) during the hottest hours of the day. In the feed alley were also located drinkers, sources of elevation of the humidity of the environment. Also the water spill realized by the animals when they drink favours the increase of humidity, due to the evaporation of the water. On the other hand, in the installations provided with mechanical ventilation, RH was less than 50%, indicating that the ventilation systems used were effective in promoting the reduction of ambient humidity. The lowest RH values were verified in the LVHS ventilation installation, where the prevalence of RH was below 45%. As it is a system of ventilation with greater speed of rotation, it is possible to obtain a greater removal of humidity from the environment. In the installation with HVLS ventilation, the predominance of humidity values between 45 and 50%, with uniform distribution throughout the CBP facility, indicates that, despite the slower rotation speed, the use of fans of this type guarantees homogeneous RH conditions.

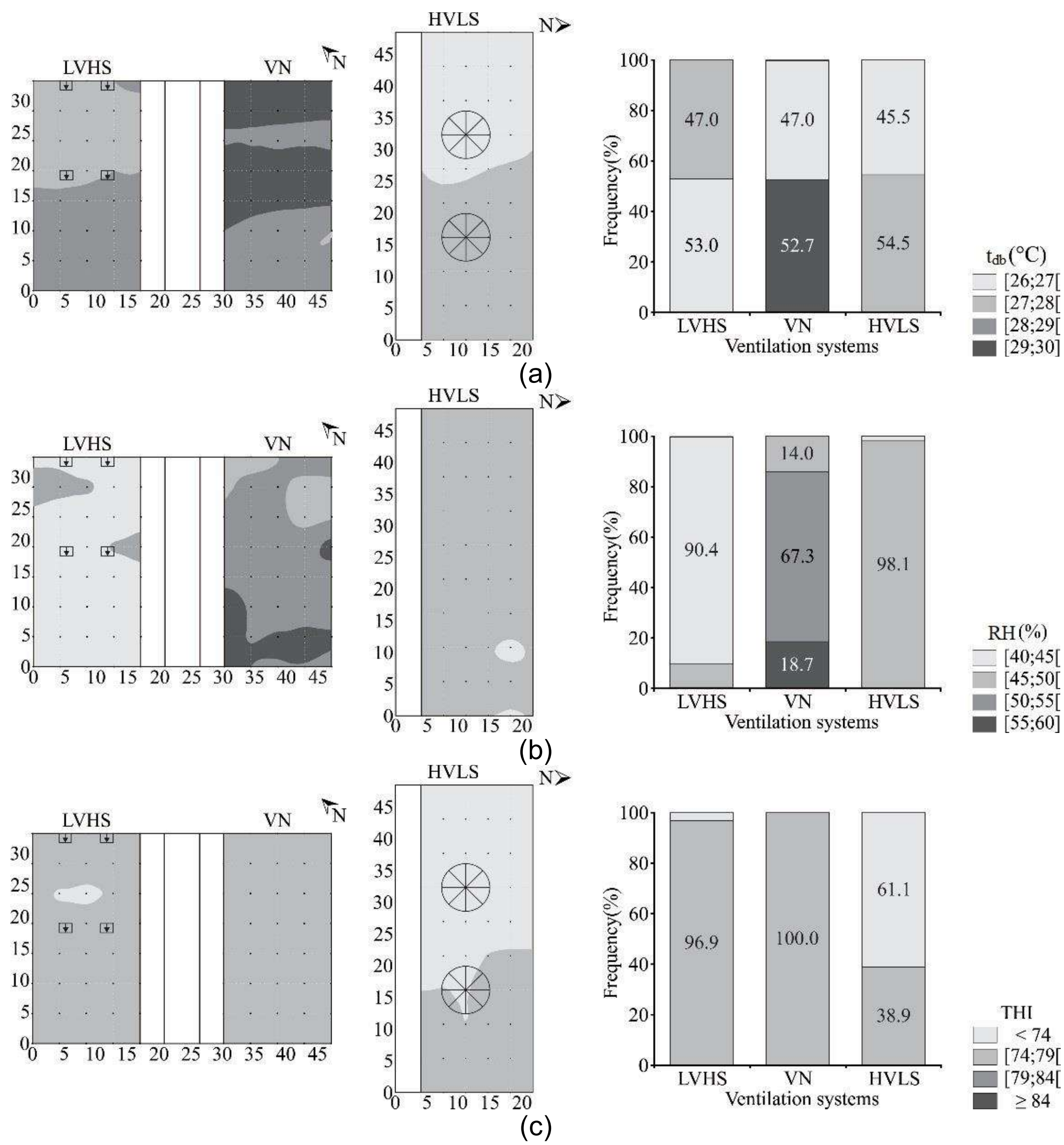

Figure 2. Spatial and frequency distribution of the variables: dry bulb air temperature – t_{db} (a), relative humidity – RH (b), and temperature and humidity index – THI (c) at the CBP facilities. * VN – natural ventilation; LVHS – mechanical ventilation of low volume and high rotation; HVLS – mechanical ventilation of high volume and low rotation. Dimensions in meters (m).

According to Fig. 2, b, in 86.0% of the area of the CBP facility with VN the RH was superior to the one observed in installations with mechanical ventilation (RH ≥ 50%). With a lower RH and a better uniformity for such attribute among the evaluated facilities, the HVLS mechanical ventilation system had 98.1% of its RH area between 45 and 50%. In the facility with LVHS ventilation the RH was less than 45% in 90.4% of the area.

The THI had a uniform distribution throughout the CBP facility, with the highest uniformity verified inside the CBP with VN (Fig. 2, c). On the other hand, within this whole installation, an alert condition was observed, due to the combination of high tdb_{bs} and RH, verified in the same. A similar condition was found for the LVHS facility, which despite having lower RH values, showed t_{db} values still relatively high (27.0 to 29.0 °C), making the THI above comfort condition (THI ≥ 74). Since both facilities were separated only by the feed alley, located close to machine sheds and placed in a region with low wind speed (near slope), it is inferred that their location may have impaired ventilation, reducing heat exchanges by convection, and causing high values of THI.

The spatial distribution of the THI in the HVLS mechanical ventilation system showed better thermal conditions, characterizing an adequate comfort condition from the west face (48 m) to the location of the ventilator (15 m). In such an installation, only the area located near its eastern side was found to be alert condition, being a function of the highest t_{db} observed at this site. This region, for the absence of lateral closure, was exposed to direct solar radiation in the morning The increase of t_{db}, due to this reason, remained throughout the day. It is inferred that the use of lateral closure or auxiliary cover may contribute to the reduction of THI in this region, since it avoids direct exposure to solar radiation.

Fig. 2, c, which shows the frequency distribution of the THI classes, shows that only in the HVLS mechanical ventilation the thermal conditions were characterized as adequate comfort, corresponding to 61.1% of the bed area.

In all CBP facilities evaluated, the V_{air} was lower than the recommended (Fig. 3, a). According to Black et al. (2013), in CBP facilities, the ventilation should be provided such that the V_{air} is close to 1.8 m s^{-1} throughout the entire CBP, so that it can dry the bed, remove gases and favour the heat exchanges between the animal and the environment.

The worst situation was verified for the CBP with VN, where this attribute was less than 1.0 m s^{-1} in 99.9% of the bed area. On the other hand, in CBP with presence of LVHS and HVLS ventilation, V_{air} was greater than 1.0 m s^{-1} in 58.4% and 42.1% of bed areas respectively, showing that the systems used promoted the increase of such an attribute to levels close to adequate in most of the facilities (Fig. 3, a). Since they have not been able to maintain the V_{air} throughout the entire CBP area, it can be understood that the quantity and arrangement of the fans in the barn is not adequate, in relation to the design of facility. The results also show that the use of mechanical ventilation in tropical conditions is necessary for the proper functioning of the system, since only the VN was not sufficient to promote V_{air} values according to the recommendation for CBP barns.

The noise level distribution within the facilities was uniform, with a variation of approximately 10 dB for the three CBP facilities (Fig. 3, b). The most significant values were observed inside the LVHS ventilation system, which had a noise level higher than 70 dB near and throughout the region of influence of the fans, being a function of the rotation of the blades. In the CBP with HVLS ventilation the observed noise levels were lower and closer to that verified for VN. For this CBP, the noise levels varied between 50 and 60 dB, and the areas with higher values (> 55 dB) occurred immediately below the area where the fans were located, and their occurrence could be attributed to equipment rotation and noise characteristic of the engines. According to the manufacturer's catalogue of specifications (AIRWAY BIGFAN, 2018), the noise levels emitted by the fans used are between 50 and 63 dB, characterizing them as low emission. Therefore, it can be verified that the results found are in accordance with the specifications of the equipment. The lowest values of sound pressure were observed in the shed with NV. The areas with the highest values were located in the central-peripheral region of the facility and were caused by the vocalization of the animals, the management operations and external sources. Eventually, it was also verified the contribution of noises coming from the walking of employees and the traffic of machines in the vicinity of the facility.The frequency of occurrence of noise in the facilities was very different in the three CBP. In the VN the 56.2% of the area presented a noise less than 50 dB, in the HVLS the noise was higher than 50 dB in 99.4% of the area, and in the LVHS the noise was higher than 70 dB in 83.2% of the area (Fig. 3, b).

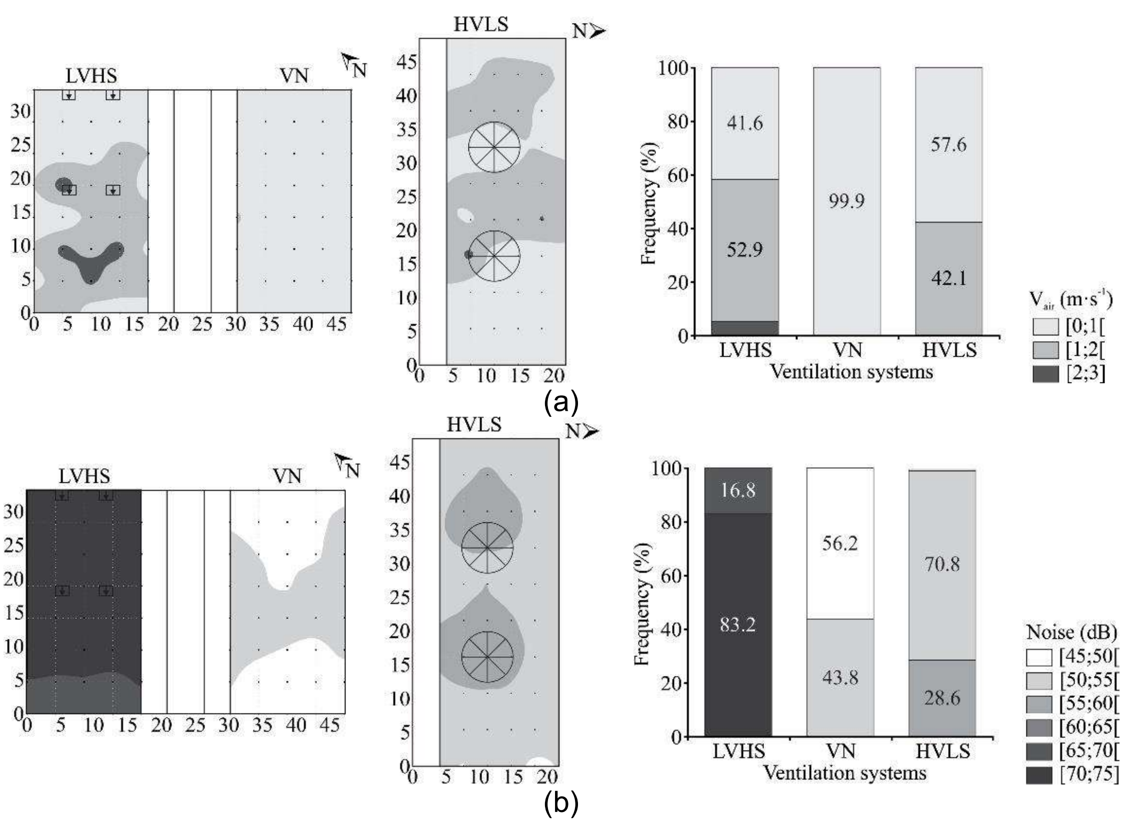

Figure 3. Spatial and frequency distribution of the variables: (a) air velocity and (b) noise level. * VN – natural ventilation; LVHS – mechanical ventilation of low volume and high rotation; HVLS – mechanical ventilation of high volume and low rotation; V_{air} – air velocity; Dimensions in meters (m).

With regard to the rearing of housed cattle, there is no applicable legislation laying down the minimum conditions of accommodation and, therefore, it is not possible to verify whether they meet the needs of the animals. In relation to work safety, the main norm related to the quantitative and qualitative evaluation of the noise to which the worker is exposed is Brazilian Regulatory Standards (Ministry of Labor and Employment, 1978), which establishes the limits of tolerance for continuous or intermittent noise to which he may be exposed without risk to his health. According to this standard, the maximum noise level at which the worker can be exposed during an 8-hour day's workload is 85 dB (A), and therefore normal animal handling activities at the facilities assessed do not pose a health risk of the professionals who carry them out.

CONCLUSIONS

The use of the geostatistics technique allowed to verify the occurrence of spatial dependence of the evaluated attributes, being predominantly strong for the variables of the thermal and acoustic environment.

The spatial distribution maps showed the occurrence of variability of the variables inside the facilities. Regarding the thermal environment, the best results were observed for the installation with high volume and low rotation ventilation (HVLS), which presented lower levels of dry bulb air temperature (t_{db}), relative humidity (RH), and temperature and humidity index (THI), as well as noise levels close to those found inside the facility with natural ventilation (NV).

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