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Compost barns **na região subtropical brasileira (Parte 2): classificação por meio de análise multivariada**

Compost barns in Brazilian Subtropical region (Part 2): classification through multivariate analysis

Compost Barns **en la región subtropical brasileña (Parte 2): clasificación mediante análisis multivariante**

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Resumo

O objetivo foi classificar as propriedades leiteiras que utilizam *Compost Barn* CB na região subtropical brasileira, em termos de estrutura da propriedade, aspectos construtivos, características ambientais e de compostagem da cama, além de relatar a variabilidade entre estas características. Além disso, esta pesquisa identificou fatores estruturais e de gerenciamento que interferem na qualidade das camas. Foram visitadas propriedades (n = 30) (entre janeiro a março de 2017), localizadas na região subtropical do Brasil, onde foram realizadas mensurações, e observações dos manejos e dos animais alojados em cada CB. A análise de *Cluster* foi realizada com a metodologia *Kmeans* para definir os grupos e, por meio de interações, o número ideal de grupos foi determinado de acordo com o método *Silhouette*. Estatísticas descritivas foram usadas para os diferentes grupos de propriedades. A análise de agrupamento, baseada em 12 variáveis, resultou na formação de três grupos: "CB convencional e adaptado" (n = 18, com instalações novas e adaptadas, de diferentes tamanhos, usadas em tempo integral, com ou sem características de cama adequadas), "CB convencional grande" (n = 6, instalações maiores, mais semelhantes aos modelos americanos, com uso em período integral) e "CB de uso parcial" (n = 6, usado nas horas mais quentes do dia ou na estação chuvosa, com melhores características de cama entre os grupos, embora não possuam ventilação mecânica e a cama era revolvida apenas uma vez por dia). Os sistemas de CB são heterogêneos e as instalações são caracterizadas por seus tamanhos distintos ou diferentes períodos de utilização. O grupo "CB de uso parcial" apresentou melhores características de cama, mesmo com manejo menos intensivo e sem ventilação mecânica.

Palavras-chave: Produção animal; Vacas leiteiras; Sistemas agrícolas.

Abstract

The objective was to classify the dairy farms that use Compost bedded pack barn (CB) in the Brazilian subtropical region, in terms of farm structure, building aspects, environmental and compost bedded pack characteristics, and reports the variability among them. Additionally, this research identifies structural and management factors that interfere in the compost bedded pack quality. Farms (n = 30) were visited (January-March 2017), located on Subtropical region of Brazil, where CB measurements, managements and herd observations were performed. The cluster analysis was performed with the kmeans methodology to define the groups, and through iterations, the optimal number of groups was determined according to the Silhouette method. Descriptive statistics were used for the different groups of farms. The

clustering analysis, based on 12 variables, resulted in the formation of three groups: “Conventional and adapted CB” (n=18, with new and adapted barns, of different sizes, full time using, with adequate pack characteristics or not), “Large conventional CB” (n = 6, larger barns, more similar to American models, full time using) and, “CB of partial use” (n = 6, used in hottest hours of the day or rainy season, with better pack characteristics among groups, although do not have fans ventilation and the bedded pack is stirring only once a day). The CB systems are heterogeneous, and the barns are characterized by their distinct sizes or period of utilization. The group “CB of partial use” presented better bedded pack characteristics even with less intensive bedding management, and without fan ventilation in the barns.
Key words: Animal production; Dairy cows; Farming systems.

Resumen

El objetivo fue clasificar las propiedades lácteas que usan (*Compost Barn)* CB en la región subtropical brasileña, en términos de estructura de la propiedad, aspectos de construcción, características ambientales y compostaje del lecho, además de informar la variabilidad entre estas características. Además, essa investigación identificó factores estructurales y de gestión que interfieren con la calidad de las camas. Se visitaron propiedades (n = 30) (entre enero y marzo de 2017), ubicadas en la región subtropical de Brasil, donde se realizaron mediciones y observaciones del manejo y animales alojados en cada CB. El análisis de Cluster se realizó utilizando la metodología Kmeans para definir los grupos y, a través de las interacciones, se determinó el número ideal de grupos de acuerdo con el método de Silhouette. Se utilizaron estadísticas descriptivas para los diferentes grupos de propiedades. El análisis de conglomerados, basado en 12 variables, dio como resultado la formación de tres grupos: "CB convencional y adaptado" (n = 18, con instalaciones nuevas y adaptadas, de diferentes tamaños, usadas a tiempo completo, con o sin características adecuadas de cama), "CB convencional grande" (n = 6, instalaciones más grandes, más similares a los modelos estadounidenses, con uso a tiempo completo) y "CB de uso parcial" (n = 6, utilizado en las horas más calurosas del día o en la temporada de lluvias , con mejores características de cama entre los grupos, aunque no tienen ventilación mecánica y la cama se voltea solo una vez al día). Los sistemas CB son heterogéneos y las instalaciones se caracterizan por sus diferentes tamaños o diferentes períodos de uso. El grupo de "uso parcial CB" mostró mejores características de la cama, incluso con un manejo menos intensivo y sin ventilación mecánica.
Palabras clave: Producción animal; Vacas lecheras; Sistemas agrícolas.

1. Introduction

The compost bedded pack barn (CB) is a confinement system for dairy cattle that aims to provide greater comfort, well-being and longevity in the productive life of the animals (Barberg et al., 2007), which was developed by dairy farms in the American state of Virginia in the 1980s and 1990s. However, only after 2001 was the largest spread in other American states (Janni et al., 2007). In CB the animals has free access to a bedded pack area composed of organic material, usually sawdust, which is revolved daily for incorporation of oxygen and the animal feces. This process favors the development of aerobic microorganisms that perform the composting of the residues present in the medium, which causes the decrease of its humidity and results in a dry and comfortable place to the animals (Shane et al., 2010).

The success of the system depends primarily on a bedded pack management for constant composting process maintenance, and the balance between various physical and chemical factors in the environment is paramount. According to Black et al. (2013), the maintenance of the composting process depends on the C:N ratio, on the temperature, humidity, bedded pack stirring and pH of the bedding in equilibrium, to provide a dry bedding with low pathogenic microbial populations. These factors can be directly affected by the constructive characteristics of the dairy farms, the bedded pack management, the resting space adopted and other characteristics not yet described or understood.

According to US publications (Janni et al., 2007; Barberg et al., 2007; Black et al., 2013), CB dairy farms follow certain structural standards, they have a variety of equipment that helps to maintain a suitable environment for both animals as to maintain the quality of the bedding, and has the well-established composting process characteristics. However, in recent years there has been a dissemination of this technology, that is, the use of CB for countries that are improving the activity of dairy cattle, as is the case in Brazil. However, its development presents certain peculiarities, even among the Brazilian regions due to the great environmental and climatic diversity of the country. This situation causes a certain diversity in the constructive characteristics, as well as in the management patterns adopted. In view of the above, the hypothesis is that there is variability between the characteristics of CB installed in the Brazilian subtropical region. Finally, the aim of the authors with this research are to classify the CB dairy farms in the Brazilian subtropical region, and compare them in terms of building layout and structural and environment measurements, bedded pack characteristics; and, identify structural and management factors that interfere in the main characteristics of the quality of this bedding.

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2. Material and Methods

The experimental protocol of this study was approved by the Institutional Animal Care and Use Committee (CEUA) of the Santa Catarina State University under N. 7896060317. The study was conducted in eight municipalities in the Western region of Santa Catarina State, between January and March 2017. The localization of dairy farms that used the CB system was done through consultation in municipal secretariats of agriculture, public and private companies providing technical assistance for dairy cattle, and professionals linked to the productive chain that serve rural producers, in the West region of Santa Catarina State, since there are no official state controls.

The building layout and constructive characteristics, ambient variables (indoors and outdoors), characteristics and measurements of animal welfare, as well as the farm, husbandry and herd characteristics, and bedded pack measurements are fully described in a companion paper (Radavelli et al., 2020). The collected data were quali-quantitative, as described in Pereira et al. (2018), which were further submitted to a multivariate analysis.

A multivariate analysis was performed, with the reduction of the data dimension, in which the variables most significant for variability were selected through principal component analysis. From the new dimension of the data, the cluster analysis was performed with the *Kmeans* methodology to define the groups, and through iterations the optimal number of groups was determined according to the Silhouette method as an adjustment measure. Fischer's discriminant analysis was used to evaluate the quality of group definition. Analysis of variance and Tukey's test or Pearson chi-square test were performed for the variables present in the reduced data, to evaluate the effect of the groups in each variable. Descriptive statistics were used for the different groups of farms, which were defined through cluster analysis. Statistical analyzes were performed using the "stats", "factoextra", "MASS" and "cluster" packages of the statistical Software R.

In order to test if the characteristics present in the structure of the CB sheds had an influence on bed quality, a variance analysis was performed, defining the models with better adjustments for each variable using the Akaike criterion, using a stepwise model. The standard model for all variables was:

$$AR = DM + PH + OM + TEMP.B + C.N. + W + DENS + DEPTH + SURF.B + TEMP.D + OUTDOOR.T + RH + RH.O + REST.SPACE + VENT + RIDGE + CBAREA + \mathrm{SIDE.HEIG} + \mathrm{RIDGE.HEIG} + \mathrm{ORIENT} + \mathrm{USECB} + \mathrm{AC.B.DEPTH} + \mathrm{MAT.BEDDED} + \mathrm{DEPHT.ST} + \mathrm{FREQ.ST} + \mathrm{TIME}$$

Where: DM is the dry matter content; MO is the organic matter content; TEMP.B is the temperature in depth before the stirring; C.N. is the carbon:nitrogen ratio; W is the water retention capacity; DENS is the density of the bedding; DEPHT is the depth of the bedding; SURF.B is the surface bedded pack temperature before stirring; TEMP.D is the 20-cm deep bedded pack temperature; OUTDOOR.T is the outdoor temperature; RH is the relative humidity; RH.O is the outdoor relative humidity; REST.SPACE is the resting space per cow; VENT is the use of fan ventilation; RIDGE is the presence of ridge opening with cap; CBAREA is the CB area; SIDE.HEIG is the sidewall height; RIDGE.HEIG is the ridge height; ORIENT is the barn orientation; USECB is the farmer uses the compost barn the entire year; AC.B.DEPTH is the actual bedded pack depth measured *in loco*; MAT.BEDDED is the type of bedded pack material; DEPHT.ST is the depth of the stirring; FREQ.ST is the stirring frequency; TIME was how long was the bedded pack usage.

3. Results and Discussion

Some studies were carried out in the sense of characterizing production systems in the geographic region that was the object of this research (Wernke et al., 2016), which characterized production systems based on milk quality. However, there is little literature describing the dairy production systems in confinements in Brazilian subtropical regions.

Specifically, the works of Janni et al. (2007), Barberg et al. (2007), Damasceno (2012) and Black et al. (2013), described the main characteristics of the CB system in the United States, but did not elaborate a classification of dairy farm that use this system of production, and evaluate if there are any differences in management or system characteristics among dairy farms. The dairy barns appear to be more homogeneous among them, as to the structural and bedded pack characteristics of CB. In this context, this is the first research that classifies and identifies differences among dairy farms that use the CB system, which is in full expansion in Brazil. This study showed that dairy farms that use CB systems in Brazilian subtropical regions are somewhat heterogeneous, due to the identification of three different groups, through cluster analysis. The differences among groups were due to the following variables: OM, DM, pH, C:N ratio, water retention capacity and bedded pack density, available resting space per cow, barn width, presence of fan ventilation, surface bedded pack temperature before stirring, and 20-cm deep bedded pack temperature before stirring. The three groups were given the following denominations: “Conventional and adapted CB”, “Large conventional CB”, and “CB of partial use”.

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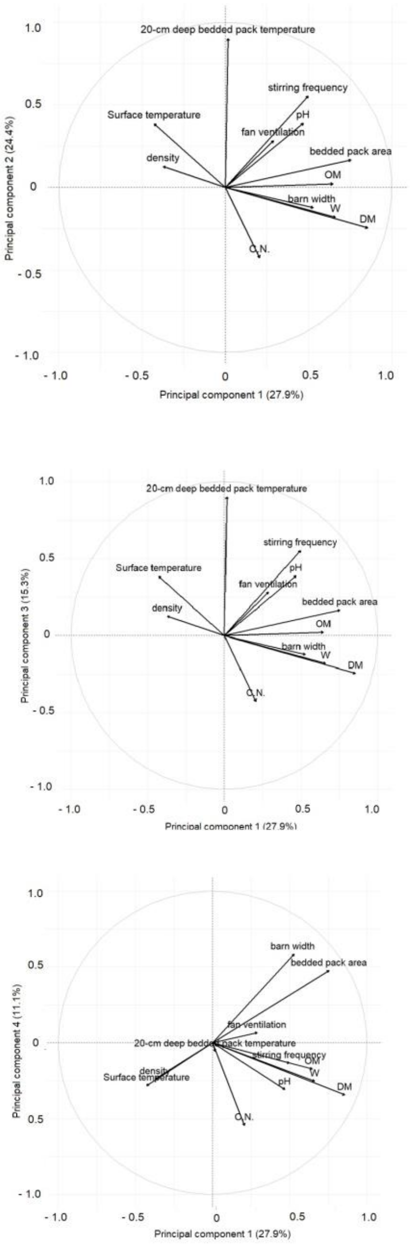
According to the Brazilian Institute of Geography and Statistics (IBGE, 2016), the properties evaluated in this research are located in eight municipalities that together accounted for 6.8% of the state's milk production in 2016.

3.1 Analysis of main components and definition of the number of groups

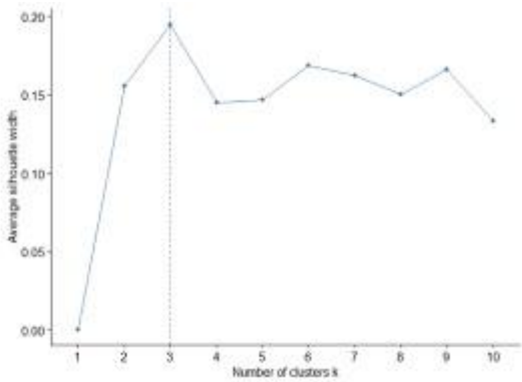
Figure 1 - Principal component 1 and perpendiculars Principal components 2, 3 and 4 showing the variance of each variable on each component (where DM: compost bedded pack dry matter; Fan ventilation: presence of fan ventilation at the CB).



Source: Authors' elaboration.

In Figure 1, we present the 12 representative variables, arranged in the Cartesian plane, and their influence on the four dimensions, represented by the four Principal components. Principal component 1 corresponds to 27.9% of variability, and the Principal components 2, 3 and 4 represent 24.4%, 15.3% and 11.1% of the data variability. That is, the analysis of the Principal components represented by the four dimensions are responsible for 78.7% of the variance of the data analyzed. The variables dry matter (DM), organic matter (OM), bedded pack area, water retention capacity (W), stirring frequency and bedded pack pH were the ones that had the greatest influence on the variability of the data belonging to the Principal component 1. The variables that had the greatest influence on the variability of data in Principal component 2 were the nitrogen carbon ratio (C:N), bedded pack OM, W and pH, presence of fan ventilation in the bedded pack area, barn width and superficial temperature prior to the bedded pack stirring. For Principal component 3, the variables with the greatest influence on the variability of the data were the 20-cm deep bedded pack temperature and stirring frequency. In addition, in the fourth Principal component, the variables that influenced the variability of the data were bedded pack area, barn width and bedded pack density. It is noteworthy that these variables that showed influence on each main component are the result of the dimensional reduction of all variables, that is, only 12 remained in the data file.

Figure 2 - Determination of the optimal number of clusters using the *Silhouette* method, by the highest degree of fit.



Source: Authors' elaboration.

The determination of the ideal number of groups was given by statistical methods, not by imposition of a predetermined number of groups. In Figure 2 above, according to the *Silhouette* method, it was possible to observe that the value closest to one (representing similarity within the group, but representing maximum Euclidean distance between groups)

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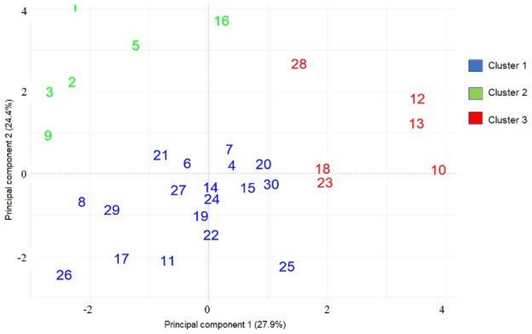
was obtained when three groups were considered. Additionally, it was verified that there was no overlap of the groups, as observed in the Fischer linear discriminant analysis (Figure 3).

Figure 3 - Loading plots of 30 compost bedded pack dairy farms, considering the Principal components 1 and 2 and the three clusters, identified by colors.



Source: Authors' elaboration.

3.2 Classification and characterization of CB dairy farms groups

From the survey of numerous characteristics related to the dairy farms and the production system (Appendix), the analysis of main components pointed out that only 12 of the total variables were responsible for the greater variability of the data. Therefore, these 12 variables were used to classify the farms into distinct groups, which are: OM, DM, pH, C:N ratio, water retention capacity and bedded pack density, barn width, bedded pack area, stirring frequency, presence of fan ventilation in CB, surface bedded pack temperature before stirring and 20-cm deep bedded pack temperature before stirring (Table 1).

Table 1. Mean values, standard deviations, minimum and maximum variables analyzed in compost bedded pack barns in the Brazilian subtropical region (n = 30), by grouping according to the classification obtained by multivariate analysis.

Variables	Group	Mean + SD	Minimum	Maximum
Bedded pack organic matter (%)	1	59.50 b ±10.47	36.91	77,25
	2	82.90 a ±6.37	73.8	90,47
	3	70.73 a ±14.01	52.92	90,21
Bedded pack water retention capacity (%)	1	73.41 b ±4.74	59.94	79,26
	2	79.95 a ±3.47	74.62	83,28
	3	75.50 a ±3.36	71.32	79,68
Barn width (m)	1	17.06 b ±5.45	10	30

	2	29.33 a ±6.35		23	40
	3	20.53 b ±6.13		14.5	30,19
Bedded pack area (m^2)	1	686.31 b ±302.33		285	1300
	2	1711.83 a ±578.06		1116	2800
	3	668.45 b ±313.05		377	1175
Density (kg/m^3)	1	685.70 a ±134.23		445.26	945.88
	2	662.05 ab ±152.79		466.79	870.23
	3	533.52 b ±58.87		447.11	603.32
pH	1	8.80 a ±0.27		8.02	9.22
	2	8.93 a ±0.21		8.73	9.22
	3	8.08 b ±0.83		6.81	9.26
20-cm deep bedded pack temperature. before stirring (ºC)	1	41.29 ±5.94		30.67	49.83
	2	42.14 ±6.59		35.17	50.5
	3	46.61 ±8.07		38.17	58.83
Surface bedded pack temperature before stirring (ºC)	1	24.80 b ±1.42		20.75	26.83
	2	24.49 b ±0.78		23.08	25.33
	3	27.08 a ±2.00		23.58	28.83
Carbon:nitrogen ratio	1	2.88 c ±2.76		-1.79	8.1
	2	7.06 b ±2.29		3.06	10.04
	3	13.78 a ±4.13		7.89	18.7
Dry matter (%)	1	48.77 b ±7.19		36.99	66.71
	2	36.90 c ±8.29		25.91	45.9
	3	58.51 a ±8.25		49.76	67.21
Frequency of bedded pack stirring		Once a day	Twice a day	Three times a day	Once every two days
	1	38.89%	55.56%	5.56%	0.00%
	2	16.67%	83.33%	0.00%	0.00%
	3	66.67%	16.67%	0.00%	16.67%
Presence of fan ventilation in the CB		Yes		No	
	1	77.78% a		22.22%	
	2	66.67% a		33.33%	
	3	0.00% b		100.00%	

Group 1: “Conventional and adapted CB”; Group 2: “Large conventional CB”; Group 3: “CB of partial use”. Means followed by the same lower case letters in a column do not differ significantly by the Tukey test ($P < 0.05$). Source: Authors' elaboration.

Group 1 was composed of 18 dairy farms, and Group 3 by six dairy farms. As building layout characteristics of both groups, the barns had the smallest widths and the smallest bedded pack areas. Therefore, Group 2, composed of 6 dairy farms, was formed by facilities that had the largest CB. Still, it can be stated that in this group, CB were used for full-time animal confinement, with the largest number of waterers disposed inside the barn, due to the greater number of animals, which allows to meet the herd demand, which in some cases were separated by production lot. The higher number of wateres is important because of the dominance of some animals, decreasing disputes before these sites. The allocation of waterers should also be considered, which should be installed in the feed alley on the opposite side of the feeders, avoiding waterers in the bedded area (Ofner-Schröck et al., 2015). Due to the general characteristics found on Group 2, it was nominated “Large conventional CB”.

Regarding the physical and chemical characteristics of the bedded pack, the Group 3 had the lowest pH values, higher C:N ratios, higher DM content and higher surface bedded pack temperature before stirring. In addition, in Group 3 none of the CB had fan ventilation in the bedded pack area, and most of the stirring was performed only once a day, since 100% of the properties of this group only used CB facilities in the hottest periods of the day, or rainy seasons. Thus, Group 3 was denominated “CB of partial use”. The higher bedded pack surface temperature may be due to some specific characteristics of the dairy farms that set the Group 3. Among them, it is possible to highlight the lower bedding depth observed for this group, with values between 20 and 40 cm, which can lead to a more superficial composting process, consequently raising the bedding surface temperature. Another factor that may contribute to an increase in surface temperature is the absence of ventilation equipment, which leads to the accumulation of heat generated by the composting process and raise the surface temperature of the bedded pack. The lack of ventilation may also have been aggravated by the lower average ridge height (5.78 m) and also by the absence of ridge opening with cap (in 83.33% of CB). This opening at the top of the roof is intended to aid in the removal of hot air, maximizing ventilation of the facility, which contributes to the cooling of the environment.

In Group 1, the lowest levels of OM and W, and the C:N ratio were observed. It can be stated that all dairy farms that had CB adapted from other facilities belong to this group, and correspond to 22.2% of the total (4 dairy farms). Group 1 was named “Conventional and adapted CB”.

The amount of bedding replaced in the dairy farms of “Conventional and adapted CB” and “CB of partial use” groups was lower than for “Large conventional CB” group (Group 2).

This difference may possibly be due to the size of the bedded pack area between the groups, since Group 2 presents a significantly larger bedded pack area in comparison to the others, necessitating repositions that are more voluminous. Another difference in the "Large conventional CB" group refers to the frequency of bedded pack replacement, since all dairy farms in this group performed monthly replacements, unlike other groups where some farms perform monthly replacements, or less frequently, between 2 at 3 months. Among the structural features can also be highlighted the ridge height. This variable, although not part of the set of variables that were used for the formation of the groups, was tested independently. For the "Large conventional CB" group, mean height was higher than the other groups, with 8.57 m (being the same for the group of "Conventional and adapted CB", with 6.43, and "CB of partial use" group, with 5,78 m; P <0.02). This characteristic may be influenced by the fact that all "Large conventional CB" were designed as new facilities, that is, they were not adapted barns previously used for other activity, such as some farms present in Group 1 ("Conventional and adapted CB"). It is worth mentioning that ridge height, related to sidewall height, interfere with barn roof angularity, and this factor may exert a strong influence on the air circulation indoor (Janni et al., 2007).

The difference observed for the DM content of the bedded pack may be related to the available to resting space per cow and the depth bedded pack temperature. Parameters that may be influenced by the climatic characteristics of each region, in which the temperature of the bed increases concomitantly with the increase in air temperature, and this association leads to the drying process of the bed through the loss of water by evaporative process. In a study developed by Janni et al. (2007), the authors describe the average bedded pack area of 9 m^2/animal, values that can reach 6 m^2/animal for small breeds, which can reach up to 15 m^2/animal in less frequent systems of bedding replacement (Klaas et al., 2010). The high standard deviation observed for the variables "bedded pack area per cow" and "depth bedded pack temperature " may have contributed to the absence of statistical differences between the groups evaluated. The "CB of partial use" group presented availability of 16.15 m^2/animal, the "Conventional and adapted CB" 14.38 m^2/animal and, the "Large conventional CB", 13.50 m^2/animal.

The variable "depth bedded pack temperature before stirring" could be considered as an indication if there was an adequate composting process between the period between the previous stirring and the current (evaluated) stirring of the bedding. It is expected that the better the composting process, the higher the temperature would be, as well as a lower moisture content (or higher DM content). The depth of the bed before the stirring did not differ between groups, and their mean values did not reach that recommended for Groups 1 and 2, as Janni et al. (2007) states that temperatures between 54 and 65°C maximize material degradation, because in these conditions there can be the elimination of pathogenic microorganisms that cause mastitis (Black et al., 2014). However, part of the dairy farms of all groups had a depth bedding temperature within the range considered ideal, especially those of Group 3 ("CB of partial use"). In addition to the degradation of the material, this temperature range, according to Black et al. (2013), helps to maintain a dry and comfortable bedded pack for animals. However, it can not be ruled out that 4 or 5 °C (numerical difference found between groups) could not interfere in the composting process and affect the DM content of the bedding, and this dynamic of temperature change of CB bedded packs between stirrings, and for longer periods, should be studied under different climatic conditions.

Among the factors that may contribute to the maintenance of high-bedded pack DM, can be highlighted the period of use of the CB, since all the farms that constitute the "CB of partial use" group, present a strategic use of the CB system, that is, the animals were housed only at certain times of the day. Usually, at warmer times of the day, or periods of high rainfall, which keeps the animals protected from adverse weather factors. However, care should be taken, as prolonged periods of high rainfall can result in high humidity in the bedded pack, compromise the composting process, and cause secondary problems to the herd.

Another variable that may suffer interference by the available bedded pack area per cow is the C:N ratio, which presented higher values in the "CB of partial use" group (Group 3). However, all the values observed were below the ideal ratio of 25 to 30:1 (NRAES-54, 1992; Bewley et al., 2013). It is worth mentioning that microorganisms need about 25 times more carbon than nitrogen (NRAES-54, 1992), and there is a direct relationship with the resting space per cow, which will determine the incorporation of feces and urine, carbon sources and nitrogen, for the composting process.

The longer time of bedded pack usage for Groups 1 and 2 ("Conventional and adapted CB" and "Large conventional CB"), may be related to the higher pH value found for these farms. A longer period of occupation leads to higher nitrogen uptake in the medium, confirmed by the C:N ratio, which was lower in these two groups, leading to an increase in bedded pack pH. According to Changirath et al. (2011), during the early stages of decomposition, there is formation of organic acids, and then continuous composting and the acids become neutralized, and the mature compound generally has a pH between 6.0 and 8.0. The values found were slightly higher than this recommended range.

The water retention capacity (W) did not differ between Groups 2 (“Large conventional CB”) and 3 (“CB of partial use”), but both differed from Group 1 (“Conventional and adapted CB”), which presented the lowest W. According to Changirath et al. (2011) and Damasceno (2012), materials that absorb a lot of water or urine are not suitable as bedding material, as they result in less porosity and hinder the composting process. In the research by Changirath et al. (2011), the authors observed that W increased with decreasing particle size, and materials with a large proportion of fine particles were not recommended. In this sense, research should be carried out to define bedding materials suitable for different technical characteristics (examples of resting space per cow, stirring frequencies, different climatic conditions, time bedded pack usage, etc.).

Given the above, it can be considered that the partial use CB group presented the best bedded pack characteristics among the groups analyzed in the present research. It was this part-time use that somehow allowed these dairy farms not to have fan ventilation and stirring the bedded pack only once a day (which also reflected in lower costs and investments). This partial use makes the bedded pack did not receive the same amount of manure than in systems that animals are confined 100% of the time.

This part-time use of CB is a characteristic not yet reported in scientific research. And that, somewhat, misrepresents the use of CB systems as a confinement for intensive production, as the animals are released, especially for grazing, in the cooler hours of the day. However, although dairy farms in the partial-use group have the best bedded pack characteristics, without the most intensive management, and with lower investments, such as absence of fan ventilation, they are more subject to changes in bedded pack quality. Prolonged periods of climatic adversity may force these farms to use the CB intensively, and due to the lower frequency of stirring and absence of fans ventilation, a great impact on the composting process will may be observed, resulting in poor bedded pack quality.

Another negative point of the absence of the fan ventilation system in the CB, is that this equipment has the purpose of helping to remove moisture from the environment and improve the thermal comfort of the animals inside the barns. Although there were no differences in THI and BGTHI indices among the different groups (due to the absence of very adverse climatic conditions during the period of the research), these parameters can help and demonstrate the importance of the ventilation system for animal comfort.

In contrast, part of the farms evaluated for intensive uses, referred to here as "Conventional" (which are those designed as closely as possible according to American models), or with adapted facilities, regardless of their size (large, medium, small), generally need investments and management corrections to achieve optimal values for better composting of the bedded pack (and thus better manure degradation, adequate bedded pack drying, and improved animal environment).

3.3 Identification of the variables influencing the bedded pack quality of CB

Among the main factors that influence the maintenance of CB system functionality, the more important is the bedded pack quality, where animals stay the longest period of the day. In this sense, the authors of the present research sought to understand which are the main factors and characteristics that exert influence on the maintenance of bedding quality of CB (Table 2).

Table 2. Relationship between compost bedded pack barns qualitative characteristics (evaluated as response variables) and its respective significant variables for their variation, according to the analysis of variance, based on a survey of 30 dairy farms located in the Brazilian subtropical region.

Response variables					
DM	**OM**	**pH**	**W**	**C:N ratio**	**TempDepth**
W	DM	DM	DM	DM	
OM	C:N ratio	C:N ratio	OM	OM	
RH indoors in the CB	Presence of fan ventilation		Presence of fan ventilation	Presence of fan ventilation	Bedded pack density
Resting space per cow (m^2)	Bedded pack area (m^2)		Sidewall height	Surface bedded pack temperature before stirring	Surface bedded pack temperature before stirring
Use of bedded pack (full/partial)			Frequency of bedded pack stirring	Frequency of bedded pack stirring	Frequency of bedded pack stirring
			Depth of bedded pack stirring	Depth of bedded pack stirring	
			Bedded pack material		
			Depth of bedded pack		

DM: compost bedded pack dry matter; OM: compost bedded pack organic matter; W: water retention capacity; TempDepth = Temperature at depth before bedded pack stirring. All variables were significant ($P < 0.05$). Source: Authors' elaboration.

Among the most studied physical and chemical characteristics of the bedding evaluated in scientific research are: DM, temperature, OM, pH, W, C:N ratio and bedding density (Janni et al., 2007; Black et al., 2013; Ofner-Schröck et al., 2015). However, these characteristics may also be influenced by innumerable factors related to daily management, CB housing characteristics, and animal related aspects that are not yet fully understood and known. In this sense, we first list some of the main variables (response variables, Table 2), to be tested using the proposed model and the adjustments used. Thus, the variables that were significant ($P<0.05$) in the variation of that response variable were obtained, in order to identify other factors related to CB (mentioned above), which could interfere in characteristics already consolidated as a management key that are the DM, OM, pH, C:N ratio, W and bedding density, as well as their depth temperature.

According to Black et al. (2013), the composting process depends on several factors that must be in balance. Otherwise, in fact, the process can be compromised. In the present work, it was identified that OM showed influence on DM, W and C:N ratio, possibly because it provides substrate to the microorganisms that perform the composting process. However, this substrate must have a balance between the components, mainly regarding the C:N ratio, in order to maintain the balance between DM and bedding moisture. The composition of the OM also exerts an influence on the C:N ratio because when part of the available C is difficult to degrade from sources such as cellulose, hemicellulose and lignin, a higher initial C:N ratio is advisable because the bioavailable carbon is lower than total carbon (Valente et al., 2009).

The content of DM had influence on OM, pH, W and C:N ratio. In this sense, Liang et al., (2013) state that materials with 30% moisture inhibit microbial activity, and that a medium with humidity above 60% provides slow decomposition, which also causes anaerobiosis of the environment. In general, it can be stated that excess moisture causes oxygen shortage for the composting process, which inhibits the development of microorganisms that stop the composting process, which directly or indirectly interferes with all the factors mentioned above (NRAES-54, 1992; Bewley et al., 2013).

Among the management variables, we emphasized the frequency of bedded pack stirring, which exerts influence on the bedded pack temperature, W, and the C:N ratio. This daily management directly affects the incorporation of oxygen in the environment, a prime factor, since according to Janni et al. (2007), after a few hours of composting, the oxygen level falls to very low levels and the oxygen must be incorporated by the material's stirring. The presence of oxygen results in aerobic composting where the only products are CO_2, H_2O and energy. On the other hand, in anaerobic composting, CH_4 production occurs to organic acids of low molecular weight, which result in unpleasant odor (Kiehl, 2004). In this way, the presence of oxygen caused by the stirrings results in the maintenance of the composting process, which generates an increase of the temperature, which is a result of the degradation of the materials or substrates present in the bedding (carbon and nitrogen). In addition, it results in the evaporation of moisture and in dry and comfortable bedding to the animals.

The sizing of the installation also presented importance. Among them is the availability of resting space per cow, which exerted influence on the DM of the bedding. As discussed previously, this variable presents several recommendations in the literature. However, there are many factors that interfere with this recommendation. In region focus of the present study, the usual practical recommendations range from 10 to 14 m^2/animal. However, the smaller the area available per animal, the greater the incorporation of feces and urine into the bedded pack, which may lead to an increase in the moisture of the material, which will then require a more careful and adequate management, to not compromise the composting. In this sense, in order to avoid management errors, the producer must start with a smaller stocking rate, increase gradually, and monitor the conditions of the bedded pack, since animal and bedded pack management factors, local environmental conditions, and material characteristics used influence the quality of the bedded pack.

It was observed effect of the RH measured indoors the barns on the DM of the bedded pack. According to Black et al. (2014), the surface bedded pack temperature accompanies the environmental conditions, and RH from the air can also cause DM decrease mainly in the surface bedded pack layer. In addition, it may possibly hinder the evaporation of the moisture present in the bedded pack, by presenting high RH (Bewley et al., 2013). This factor may have a large impact on the farms belonging to the group of “CB of partial use”, that is, in periods with high rainfall, where the RH rises, and the maintenance of the animals inside the facilities is prolonged, as they may result in drastic changes in the quality of bedded pack, in short period of time. Factor that can be aggravated by the fact that dairy farms that use the CB in part-time present less intensive bedded pack management routines, such as less stirring frequency, besides not having fans ventilation.

The period of use of the CB barns (integral or partial) also had an effect on the DM of the bedded pack. Factor that possibly resulted in the highest DM of the bedding found in the CB of Group 3 that was determinant to be characterized as "CB of partial use". In these cases where the animals do not remain confined all day, the manure incorporation in the bedded pack area is lower, which can prolong the composting process, due to the lack of nitrogen for the microorganisms. According to Valente et al. (2009), N deficiency is limiting in the process because it is essential for the growth and reproduction of microorganisms. This lower manure incorporation also results in the maintenance of the higher DM, because these components present higher moisture than the bedded pack material.

In addition to the above factors, others may also have influence on the response variables. However, due to the interaction between these factors, more specific studies are needed, which will contribute to the identification of other variables that influence CB bedded pack quality.

4. Conclusions and suggestions

The compost barn (CB) systems are heterogeneous, and the barns are characterized by their distinct sizes, which are adapted from barns already present in the dairy farms, and part of them are built for exclusive use as a CB system. In an unprecedented way, the use of the CB system is reported partially, in periods of climatic adversities (hotter hours of the day and times of high rainfall). This fact influenced the named Group 3 ("CB of partial use"), which presented the best bedded pack characteristics (DM, C:N, pH and W), even with less intensive bedded pack management, and without fan ventilation in the barns. However, it is worth mentioning that the ventilation system, besides helping to remove moisture from the environment, also has the purpose of helping the thermal comfort of the animals, and it is recommended to use them even in dairy farms that use the CB partially.

In addition to the variables already studied and defined as fundamental for the composting process (DM, OM, pH, C:N, W, bedded pack density and temperature), the stirring frequency, resting space per cow, presence of fan ventilation in the barns, type of material used for bedding composition and local relative humidity, are factors that influence the main variables of the bedded pack, and can be a key point for the success of the CB system in subtropical regions of Brazil.

We suggest that more research be carried out to evaluate the behavior of the variables that regulate the bedded pack composting process in the different CB groups defined by multivariate analysis in the long term. Especially regarding the frequency of agitation, resting space per cow, presence of ventilation, type of material used for bedding and local relative humidity, because they are highly dependent on the region of the study.

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