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BIOGAS PRODUCTION FROM DAIRY CATTLE MANURE, UNDER ORGANIC AND CONVENTIONAL PRODUCTION SYSTEMS

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ABSTRACT: The purpose of this study was to evaluate the production of biogas, as well as the biogas production potential resulting from the anaerobic biodigestion of dairy cattle manure under organic (CMOS) and conventional (CMCS) production system. Also, the concentration of thermotolerant coliforms was evaluated after the biodigestion process. Therefore, bench biodigesters prototypes were supplied with CMOS and CMCS for 30 weeks. The experimental design was completely randomized with four repetitions for each treatment. Analysis of total solids (TS), volatile solids (VS), biogas production potential, most probable number (MPN) of thermotolerant coliforms were made. The cumulative biogas production was 6.18 L and 11.15 L, when using the CMOS and CMCS, respectively. Average biogas production potential of CMCS were 0.2; 2.6 and 2.9 L kg^{-1} substrate, ST and SV added, respectively and for CMOS 0.1; 1.4 and 1.9 L kg^{-1}substrate, ST and SV added, respectively. After the anaerobic biodigestion process of CMOS and CMCS, it was observed that the concentrations of thermotolerant coliforms were well below than the limit established by law.

KEYWORDS: anaerobic biodigestion, biodigester, agricultural waste.

INTRODUCTION

The production of milk in Brazil stands out as one of the main agricultural activities, due to its capacity to generate employment and income, and the connection with other agroindustrial sectors (Ferreira et al., 2008).

In the second quarter of 2015, milk production in the country was about 5.64 billion liters. Of this total production, 41.3% was located in the Southeast of the country, highlighting the State of Minas Gerais, with a 26.7% share of the national production. The herd of cows milked in Brazil is 22,954,537 heads and the number of animals slaughtered was 7,732 in the first quarter of 2015 (IBGE, 2015).

The quality and efficiency standards in the milk production have been required in recent years with the objective of intensify even more the production system (Rodrigues et al., 2014a). As a consequence, there is an increase in the amount of residues generated during the milk productive chain (Matzembacher et al., 2013), which can lead to a contamination of the soil, the water and the air. Among the solutions, FAO (1995) recommends the use of biodigester in rural properties, as a viable, rational and practical alternative of reuse of these organic residues (Ribeiro, 2011).

Anaerobic biodigestion of organic waste is a biochemical process, which occurs without the presence of oxygen and uses bacterial action to convert complex compounds into simpler ones, producing a combustible gas, called biogas, composed of methane, carbon dioxide and other gases (Agne & Restiola, 2015). It is presented as an alternative for the treatment and energy recycling of the nutrients contained in animal waste and vegetal residues, reducing the polluting potential and sanitary risks, besides promoting the generation of biogas and biofertilizer (Rodrigues et al., 2014b).

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The objective of this study was to evaluate the biogas production, as well as the production potential resulting from the anaerobic biodigestion of dairy cattle manure under organic (CMOS) and conventional (CMCS) production system, as well to evaluate the concentration of thermotolerant coliforms, after the biodigestion process.

MATERIAL AND METHODS

The experiment was conducted at the Universidade Federal Rural do Rio de Janeiro (UFRRJ), Seropédica campus, whose geographical coordinates are: 22º 45'33"S and 43º 41'51". The climate of the region is classified as Aw, according to the classification of Köppen, with concentrated rainfall from November to March, average annual precipitation of 1213 mm and average annual temperature of 24.5 °C (Carvalho et al., 2006; Silva et al., 2013). The anaerobic biodigestion system was installed at the Laboratory of Rural Electrification and Alternative Energies, at the Institute of Technology - Department of Engineering, UFRRJ.

In order to accomplish the experiment, were built eight prototypes of benchtop biodigesters, being the supply system discontinuous, that is, in batch supply system (Figure 1).

FIGURE 1. Prototypes of biodigesters in batch supply system.

The biodigesters consisted of a fermentation chamber or biodigestion, bell or gasometer and a manometer of water column. The system, biodigestion chamber and gasometer, were inserted into a vessel filled with water, to serve as a support for the gasometer to float, provide anaerobic conditions and store the produced gas (Figure 2).

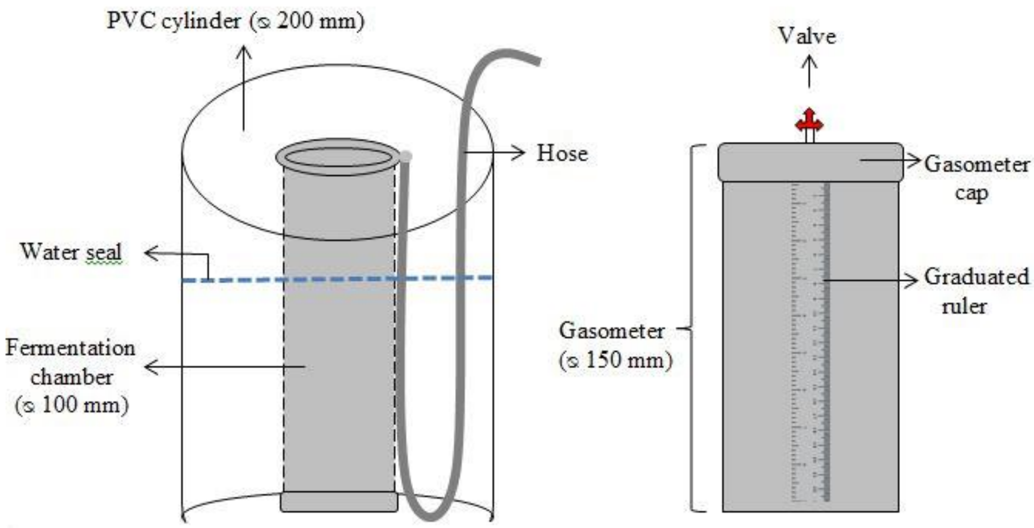

FIGURE 2. Detail of the fermentation chamber, the gasometer and the water column manometer of the biodigester used.

Thus, for the operation of the gasometer was adopted the floating system. By this system, as the production of biogas occurred, there was a displacement in the vertical direction from the gasometer. This displacement was measured by a graduated ruler, from 0 to 30 cm, which was fixed to the gasometer. The displacement values were later used to calculate the volume of biogas produced. The total volume of the biodigestion chamber was 2.35 L.

The treatments evaluated were: a) CMOS–cattle manure under organic production system, from Fazendinha Agroecológica km 47, located in the city of Seropédica, in the state of Rio de Janeiro. The cattle herd of Fazendinha Agroecológica km 47 counts with the number of 50 head of dairy cattle Girolando breed. These animals are fed on *Brachiaria* pasture, organically managed, without mineral fertilization and during the dry season they are fed in the trough when available, grass, sugarcane and leguminous, also from organic production. The cleaning of the facilities is performed only with water, and the removal of manure from the corral was done by scraping and; b) CMCS – cattle manure under a conventional production system, from the dairy cattle sector of the Agricultural Research Company of the State of Rio de Janeiro - PESAGRO-RJ, also located in the city of Seropédica (RJ). The herd of the estate counts with the number of 180 head of cattle from the Girolando breed. These animals are fed with a *Brachiaria* pasture, but also consume commercial feed with 20% crude protein, as well as cotton seed meal, corn, soybeans and macronutrient and micronutrient supplementation. The calves are fed with feed based on corn, soybean and mineral salt. Cleaning of facilities and milking equipment are carried out with soap, alkaline and acid detergent. The removal of manure from the corral was done by scraping.

After the collection for the preparation of the substrate, was initially determined the total solids (TS), based on the methodology described by APHA (2005), as recommended by CONAMA Legislation 357/06 (Brasil, 2006). From the results observed in the TS analysis, the amount of water to be added to the raw material was determined in order to obtain a concentration of 8% of TS in all eight biodigesters.

The volume of biogas produced daily was determined by the product of the vertical displacement of the gasometer and its internal transversal section area of 0.02 m².The biogas production was calculated based on the gasometer displacement and the biodigester area. The correction of the biogas volume under the conditions of 1 atm and 25 °C, was done by the expression resulting from a combination of the Boyle and Gay-Lussac laws (Eq. 1):

$$\frac{V0 \times P_0}{T_0} = \frac{V1 \times P_1}{T_1} \quad (1)$$

in which,

V_0 = corrected volume of biogas, m^3;

P_0 = biogas corrected pressure, 10,322.72 mm of H_2O;

T_0 = biogas corrected temperature, 293.15 K;

V_1 = volume of gas in the gasometer, m^3;

P_1 = biogas pressure at the time of reading, mm of H_2O; and

T_1 = biogas temperature in K at the time of reading.

At each reading, the pressure (mm H_2O) of the biogas was measured using a water column manometer coupled to the biodigester, and the ambient temperature in degrees Celsius (° C), with the use of a thermometer coupled to a thermocouple.

The time of the anaerobic biodigestion was 30 weeks (while maintaining the biogas production). The records of the biogas production behaviors of each treatment (CMOS and CMCS) were measured daily at 10 am up until the fifth month of experiment (150 days), being measured for intermittent days after that period.

For the calculation of the biogas production potential, it was used the weekly production data and the amounts of substrate, TS and VS added in the biodigesters. The values were expressed in L of biogas per kg of substrate, of TS and of VS. The experimental design was completely randomized, with two treatments, being four replications for each treatment and was carried out three sampling per replicate.

Statistical procedures were performed with the aid of the statistical program "R-Project" version 3.2.3 (R Development Core Team, 2014). The analysis consisted of the normality test (Shapiro Wilk) and the homoscedasticity (Bartlett). After verification of the normality and the homogeneity of the data, the analysis of the variance was realized, applying the F test to test significance (P = 0.05).

RESULTS AND DISCUSSION

The results of the normality test (Shapiro Wilk) and homoscedasticity (Bartlett Test) and the analysis of the variance (ANOVA) for Total Solids (TS) and Volatile Solids (VS), between CMOS and CMCS treatments, are presented in Tables 1 and 2. The results showed that the data have normal distribution and that the variance of the treatments is homogeneous. According to the analysis of variance, it can be observed that only the VS (affluent) presented a significant statistical difference (P = 0.05). According to Gomes et al. (1990), the coefficient of variation observed for TS and VS analysis is considered low (less than 10%).

TABLE 1. Results of the variance analysis and the normality test (Shapiro Wilk) and homoscedasticity (Bartlett test) for total solids of the affluent and effluent material between the CMOS and CMCS treatments.

	DF	SqS	MSq	Fc	P	Shapiro Wilk	Bartlett Test
				TS (affluent)			
Treatment	1	1.25e-05	1.2500e-05	0.4286	0.537	0.0569	0.8179
Residue	6	1.75e-04	2.9167e-05				
Total	7						
CV	0.5%						
				TS (effluent)			
Treatment	1	0.15961	0.159612	4.0192	0.09181	0.8229	0.1016
Residue	6	0.23827	0.039712				
Total	7	0.39788					
CV	3%						

DF- degree of freedom; SqS- square sum; MSq- mean square; Fc-F calculated.

TABLE 2. Results of variance analysis, normality test (Shapiro Wilk) and homoscedasticity (Bartlett test) for volatile solids (VS) of the affluent and effluent material between CMOS and CMCS treatments.

	DF	SqS	MSq	Fc	P	Shapiro Wilk	Bartlett Test
				VS (affluent)			
Treatment	1	0.04805	0.048050	34.735	0.0010592	0.0500	0.7399
Residue	6	0.00830	0.001383				
Total	7	0.05635					
CV	0.5%						
				VS (effluent)			
Treatment	1	0.00080	0.00080	0.026763	0.87542	0.5957	0.1920
Residue	6	0.17935	0.029892				
Total	7	0.18015					
CV	3%						

DF- degree of freedom; SqS- square sum; MSq- mean square; Fc-F calculated.

The results of the average contents of total solids (TS), volatile solids (VS) and the reduction of TS and SV contents obtained with anaerobic biodigestion of cattle manure are described in Table 3. It was observed a reduction of 29 and 31% of VS in the anaerobic biodigestion process in the CMOS and CMCS treatments, respectively, which was consistent with the biogas productivity at the end of the process. Local temperature variations may have influenced directly the temperature of the biodigesters, and, consequently, the reduction of solids (TS and VS).

TABLE 3. Average contents of total solids (TS) and volatile solids (VS) in the affluent and effluent and its reduction after anaerobic digestion process.

Treatments	TS (%)	VS (%)	TS (%)	VS (%)	TS	VS
	Affluent		Effluent		Reduction (%)	
CMOS	8.27 A	7.02 B	6.25 A	4.96 A	25	29
CMCS	8.20 A	7.18 A	5.96 A	4.97 A	27	31

* Averages followed by the same letter in the columns do not differ statistically from each other by the F test (P = 0.05).

When studying the codigestion of dairy cattle manure and discard oil in batch biodigesters, Orrico et al. (2016) observed reductions of 47.53% of TS and 51.28% of VS. While Salminen & Rintala (2002), in an experiment of anaerobic biodigestion of poultry slaughter residues in biodigesters kept at a constant temperature of 31ºC, observed reductions of 63; 31; 74 and 76% in four different concentration loads and four retention times (13, 25, 50 and 100 days, respectively). Orrico Júnior et al. (2010) justified the largest VS reductions due to the maintenance of the temperature of the biodigesters (31ºC) and the longer times retention.

Costa et al. (2016) studied the potentials of biogas production in bench biodigesters operated in the batch system, fed with manure of super precocious steers who received two diets differentiated by the proportions between roughage (B) and concentrate (C). The biodigesters fed with wastes from animals that received diet 2 (80% B + 20% V) presented the highest reductions of TS and VS, corroborating with the present study, where greater reductions of VS and TS correspond to the treatment (CMCS) in which animals that received diet based on roughage and concentrated.

The accumulated biogas production was 6.18 L, from the biodigestion of the CMOS and 11.15 L of biogas to the CMCS (Figure 3).

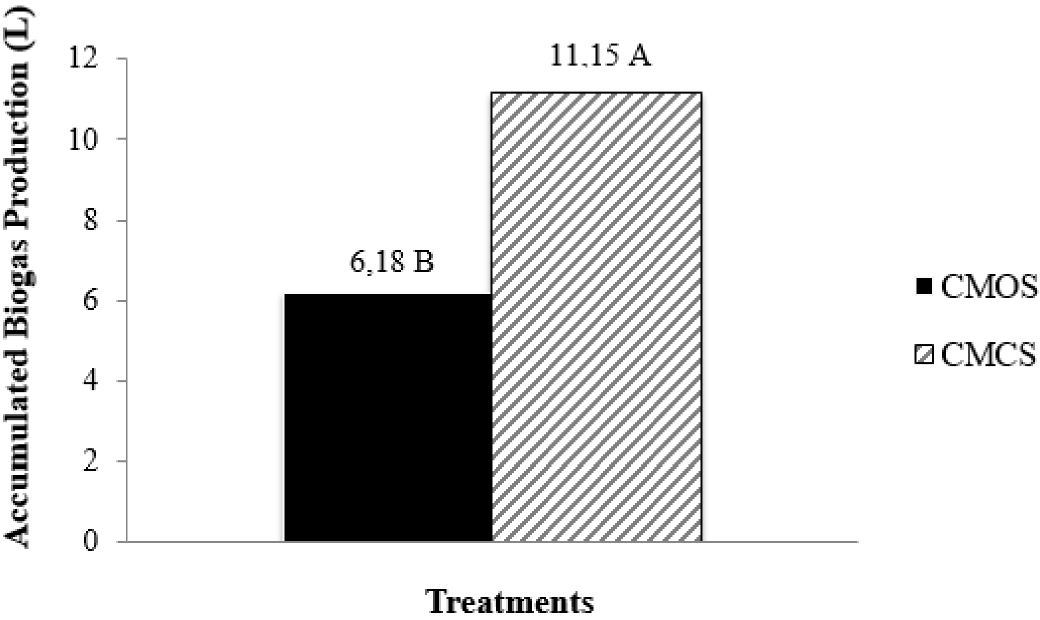

FIGURE 3. Accumulative biogas production (L) during the entire anaerobic biodigestion period (210 days). Values followed by the same letter do not differ statistically from each other by the F test (P = 0.05).

In the CMCS treatment, the characteristic of the diet (combination of concentrate and roughage) may have contributed to a greater degradation of the wastes and, consequently, a larger production of biogas. The animals in the organic system did not receive any type of concentrate in their diets. This fact justifies the lower biogas production of this treatment, corroborating with a study by Orrico et al. (2007), which also showed that a greater degradation of the waste from the diet with a higher proportion of concentrate that reflects directly on production and biogas production potential . According to the authors, as the proportion of concentrate in the diet increased, the biogas productions increased.

In another study evaluating the influence of period, of genotype and the diet on the anaerobic biodigestion of beef cattle, Orrico Júnior et al. (2012) observed that only the diet had an effect under the biodigestion process. The authors observed that the proportion with the highest amount of concentrate (40% roughage and 60% concentrated) led to greater efficiency in the gas production compared to the 60% roughage and 40% concentrated diet with a biogas production potential of 420 L kg^{-1} VS.

Barros et al. (2009) evaluated the biogas production in an Indian biodigester with a capacity of 7 m³, using, as substrate, cattle manure. In the two-month period, the authors observed a cumulative production of 5.025 L. On the other hand, Weber (2014) while studying the production routine of dairy cattle manure in order to analyze the biogas production using a vertical biodigester and of continuous hydraulic regime, with a capacity of 20 m³, observed a production of 396.850 L of biogas in four months.

The results of the normality test (Shapiro Wilk) and homoscedasticity test (Bartlett Test) for the production potentials between the CMOS and CMCS treatments, showed that the data have a normal distribution and that the variance of the treatments is homogeneous. According to Gomes et al. (1990), the coefficient of variation for the average potential of biogas production per kg of substrate and per kg of VS is considered high (CV between 20-30%).

Table 4 presents the results of the analysis of variance, of the normality and homoscedasticity tests for the production potentials between CMOS and CMCS treatments. The analysis of the variance showed that the average of the CMOS and CMCS treatments, for the biogas production per kg of substrate and per kg of TS, are different (P = 0.05).

TABLE 4. Analysis of the variance for the average biogas production potential, per kg of substrate, per kg of TS and per kg of VS added for CMOS and CMCS treatments.

	DF	SqS	MSq	Fc	P	Shapiro Wilk	Bartlett Test
Biogas production potential / kg of substrate							
Treatment	1	1.1401e-08	0.1401e-08	16.5124	0.04338	0.3958	0.8066
Residue	6	1.0504e-08	1.7506e-09				
Total	7	2.1905e-08					
CV	24%						
Biogas production potential / kg of TS							
Treatment	1	1.6653e-06	1.6653e-06	6.5092	0.04341	0.3915	0.7967
Residue	6	1.5351e-06	2.5584e-06				
Total	7	3.2004e-06					
CV	2%						
Biogas production potential / kg of VS							
Treatment	1	2.0523e-06	2.0523e-06	5.9198	0.05095	0.3686	0.8217
Residue	6	2.0802e-06	3.4669e-07				
Total	7	4.1325e-06					
CV	24%						

TABLE 5. Average of biogas production potential (per kg of substrate, TS and VS added).

Treatments	Average biogas production potential		
	(L of biogas/kg substrate)	(L of biogas/kg ST)	(L of biogas/kg SV)
CMOS	0.1 B	1.6 B	1.9 A
CMCS	0.2 A	2.6 A	2.9 A

* Averages followed by the same letter in the columns do not differ statistically from each other by the F test (P = 0.05).

The results of the biogas production potentials obtained with the anaerobic digestion of cattle manure are presented in Table 5. It can be observed that the biogas production per kg of substrate and per kg of TS presented a statistical difference between them, which did not occurred for the production of biogas per kg of VS. The differences of production observed in the literature when related to the present study can be justified by the biodigester model used, the way of feeding it (continuous or batch), the different hydraulic retention times and the characteristics related to the substrates to be digested. Larger biogas production can be achieved with the addition of inoculum from the beginning of the anaerobic biodigestion process. According to a study by Xavier & Lucas Junior (2010), higher biogas production potentials were obtained with the use of 40% of inoculum in biodigesters using dairy cows manure.

In the literature, there are few studies comparing the effect of the organic and conventional dairy cow production system on biogas production. One of these is de Vedrenne et al. (2008), in which the authors compared the effect of different feeding regimes under conventional and organic dairy cow management on biogas production. Dairy cows receiving conventional feed had 296 LCH_4/kg of VS production. For the cows organically fed, a production of 234 L CH_4/kg of VS was observed. These results corroborate with the present study in which higher biogas production was observed in the treatment in which the cows were fed in the conventional way.

The addition of the concentrate to the animal diet may favor biogas production by reducing the fibrous constituents. This lower concentration of fibrous in the diet may favor a greater reduction of total and volatile solids (Orrico Júnior et al., 2012) and consequently to a greater biogas production potential for CMCS.

In a study carried out with the objective of evaluating the effect of the seasons of the year on the anaerobic digestion of adult Saanen goats' residues in batch model biodigesters with a useful volume of 60 L of substrate and kept under ambient temperature, Amorim et al. (2004) verified an average production of 20 L of biogas/kg of substrate. Quadros et al. (2010) studied the use of sheepgoat manure in the semiarid in a continuous biodigester with a waterproof blanket gasometer, Canadian model, with 33 m³ of volume. The authors observed a biogas average production of 3L/kg of substrate, higher than that observed in the present study.

Xavier & Lucas Junior (2010) evaluated the biogas production and the reduction of volatile solids from the addition of inoculum in the anaerobic biodigestion of recycled waste of dairy cows in batch biodigesters with a capacity of 60 L. The authors observed a biogas production of 70 L/kg of substrate with the hydraulic retention time of 45 days. According to the authors, the use of inoculum is a method used to increase biogas production, which consists in adding to the material to be digested, a material that has already undergone the biodigestion process, providing an additional population of microorganisms.

In a study conducted by Orrico et al., (2016), it was evaluated the codigestion of the dairy cattle manure and the discard oil, by means of the specific productions of biogas in 28 batch biodigesters, supplied with substrates containing 4% TS and composed of dairy cattle manure, discarded oil in seven doses, inoculum and water for dilution. The authors observed that the inclusion of 4.63% of oil allowed to reach a biogas production of 0.25 L/g of added VS, which was 13% higher than the yield observed on substrates without oil.

Abubakar & Ismail (2012), studying the efficacy of cow manure for biogas production using a semi-continuous 10L bench biodigester, found that the biogas yield and methane content were 0.15 L / kg of VS and 47 %, respectively, much lower than that found in the present study.

The difference in the generation capacity and the quality of the biogas can be associated to factors such as the digestive system of the animal and the diets in which they are submitted, thus producing residues of different characteristics and potentialities regarding the production of biogas (Kunz & Oliveira, 2006). This difference can be observed in the study by Arellano et al., (2016) that evaluated the potential of biogas generation in a ranch, using swine manure (in proportions of manure: water of 1:1, 2:1 and 1:2) and bovine (1:1 and 1:3) in five biodigesters. The authors obtained the methane production for bovine manure of 9.20 and 15.28 L/kg of manure and for swine manure, 0.45, 0.13 and 0.37 L/kg of manure.

Orrico et al. (2007) evaluating the waste generated by Saanen goats, after biodigestion process, in four age categories and fed with three diets (D1: 80% roughage (R) and 20% concentrated (Con)); (D2: 60% R and 40% Con) and (D3: 40% R and 20% Con) observed for 1, 2 and 3 diets potential production of 243.4, 261 and 268 L kg^{-1} of VS, respectively.

These results are higher to those observed in this study for the average potential of CMOS and CMCS production, but also corroborate with the present study, in a meaning that higher biogas productions were also observed in biodigested animal waste that the diet went through an increase in feed concentrate.

The average results of the microbiological exams of biodigester effluents are presented in Table 6. The concentrations of thermotolerant coliforms observed are well below the standards established by CONAMA Resolution 375 (Brasil, 2006). The biodigestion process was effective in controlling the concentration of thermotolerant coliforms and, therefore, it is safe to use them in the soil with regard to pathogenic organisms.

TABLE 6. Concentration of thermotolerant coliforms (NMP/g TS) in the biofertilizers of bovine manure, under organic (CMOS) and conventional (CMCS) systems of production.

Treatments	Biofertilizer (NMP/g of TS)	Maximum concentration of pathogens allowed by CONAMA 375 (Brasil, 2006).
CMOS	54.83	Thermotolerant coliforms
CMCS	2.00	$<10^3$ NMP/g of TS

CONCLUSIONS

The organic and conventional management production of milk influenced the production of biogas. The anaerobic biodigestion using bovine manure from dairy herds under a conventional production system presented a higher accumulated biogas production with higher energy potential when compared to anaerobic biodigestion with cattle manure under organic production system.

The management adopted can have influenced the production of biogas through the feed supplied to the animal, demonstrating that in the conventional management a feed based on concentrate, roughage and commercial feed contributed in a more significant way for biogas production in relation to the one where the animals fed only from a roughage-based feed produced on organic property.

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