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Biogas production from ruminant and monogastric animal manure co-digested with manipueira

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Additional keywords
Alkalinity.
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SUMMARY

The aim of this study was to evaluate ruminant and monogastric animal manure co-digested with 10% of manipueira through process monitoring parameters and biogas production. In this study, eight semi-continuous digesters, with a capacity of 7.8 liters of substrate in fermentation, operated with 30 days of hydraulic retention time, were used. Monitoring analyses were performed in order to assess: pH, total ammonia nitrogen (TAN) concentration, partial alkalinity (PA), content and biogas yield ($m^3 \cdot kg \cdot$Volatile Solids $(VS)_{added}^{-1}$). There was no statistic difference for all the pH values, which reached values around 6.8 to 8.0. For PA, all the substrates reached higher than 1.200 $mg \cdot L^{-1}$ values as recommended. During the process, there was no risk of failure due to TAN concentration. The average biogas productions accumulated per week were 0.00676; 0.01167; 0.01515 and 0.01856 m^3 for substrates composed by dairy cattle, sheep, poultry and swine manure co-digested with manipueira, respectively. The biogas yield for those respective substrates were 0.122; 0.275; 0.535 e 0.843 $m^3 \cdot kg \cdot VS_{added}^{-1}$. The highest biogas yield was obtained for anaerobic co-digestion of swine manure with 10% (volume/volume) of manipueira.

Produção de biogás por dejetos de ruminantes e monogástricos co-digeridos com manipueira

Palavras-chave adicionais
Alcalinidade.
Amônia.
Biodigestor.
Mandioca.
pH.

RESUMO

Objetivou-se avaliar o uso de manipueira na co-digestão anaeróbia com dejetos de animais monogástricos e ruminantes, por meio de parâmetros de monitoramento do processo e da produção de biogás. Foram utilizados oito biodigestores semicontínuos com volume útil de 7,8 L de substrato em fermentação operados com tempo de retenção hidráulica de 30 dias. Realizou-se análises de pH, nitrogênio amoniacal, alcalinidade parcial (AP), sólidos totais (ST), sólidos voláteis (SV), e rendimento do biogás (m^3 kg $SV_{adicionados}^{-1}$). Os valores de pH e concentrações de AP apresentaram-se na faixa ideal para a ocorrência do processo de digestão, de 6,0 a 8,0 e acima de 1.200 $mg \cdot L^{-1}$, respectivamente. Durante o processo não houve risco de falência por concentrações de nitrogênio amoniacal. As produções médias de biogás acumuladas semanais foram de 0,00676, 0,1167, 0,01515 e 0,01856 m^3, respectivamente para substratos formados por dejetos de bovinos de leite, ovinos, aves e/ou suínos codigeridos com manipueira. Os rendimentos para os respectivos substratos foram 0,122, 0,275, 0,535 e 0,843 m^3 kg $SV_{adicionados}^{-1}$. Maiores produções de biogás são obtidas na co-digestão anaeróbia de dejetos de suínos com 10% (volume/volume) de manipueira.

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INTRODUCTION

In 2015 the Brazilian cassava production reached 24,154,377 million tons of roots (IBGE, 2015). This tuberous root is considered a popular product for Brazilians with cultural, nutritional and economic importance. Large portion of this production is destined to industry, which is responsible to generate derivatives such as cassava flour. According to Souza and Otsubo (2002) the generation of cassava flour have produced considered amounts of cassava wastewater (manipueira), yellow liquid residue from crushing and washing of cassava, considered harmful for the environment due to its high content of organic compounds (Ribas and Barana, 2003).

Nevertheless, livestock production generates as much waste as the cassava processing does. Residues from agro industry such as animal manure, wastewater, straws, shells and pulps might be used for energy and nutrient recovery. Recycling of these wastes can be done through a process for renewable energy production, the anaerobic digestion. This process is performed by anaerobic microorganisms through breakdown of complex organic matter, resulting mainly in the release of methane gas (CH_4) that can be converted into energy

Table I. Composition of the manure used in the substrates to the daily feeding of the digesters (Composição dos dejetos utilizados nos substratos para alimentação diária dos biodigestores).

	Total solids (%, fresh matter)	Volatile solids (%, in dry matter)	Volatile solids (%, fresh matter)
Dairy cows	19.46	79.46	15.46
Sheep	37.03	76.49	28.32
Swine	37.99	60.66	23.04
Poultry	60.21	59.31	35.71

while the sludge can serve as crop fertilizers due to its agronomic profile.

Due to lacking of knowledge from farmers, many liquid and solids residues from agriculture and livestock system are daily produced and improperly disposed. In this backdrop, the anaerobic co-digestion may be an alternative to treat these different sources of organic waste.

The co-digestion process is able to process various biomass substrate at the same time, leading to an increase of precursors of biogas; better balance of nutrients in the system; mitigation of toxic compounds already present in the waste or formed during the process, and provide better buffer condition due to the incorporation of distinct organic wastes (Alvarez and Lidén, 2009; Holm-Nielsen *et al*., 2009; Mao *et al*., 2015).

The use of manipueira in anaerobic digestion process to biogas production may be restricted due to high contents of easily soluble components (Panichnumsin *et al*., 2012), leading to improper balance of volatile fatty acids and causing instability in the process. Due to that fact, anaerobic digestion of manipueira as unique substrate does not occur successfully; it always needs adding buffering substances, long hydraulic retention time, dilution on water, separation of phases and/or anaerobic co-digestion.

On the other hand, livestock waste is wealthy in components that have low degradability rates, when compared to those present on manipueira. Moreover, they might contribute in the buffering capacity of the substrate when co-digested with other residues (Molinuevo-Salces *et al*., 2013).

Using manipueira and livestock's waste as substrate of anaerobic digesters in adequate proportion may facilitate manipueira recovery and thus, adding economic, environmental and social value, once that significant part of cassava producers come from familiar units located in small rural communities (Bringhenti and Cabello, 2005).

Therefore, the primary aim of this study was to evaluate the process of anaerobic co-digestion and biogas production of dairy cow, poultry, swine or sheep manure with manipueira in semi-continuous anaerobic digesters.

MATERIAL AND METHODS

The anaerobic digestion assay was carried out in the laboratory of Biomass and Water Quality at State University of Mato Grosso do Sul located in Aquidauana – MS, Brazil (Latitude 20º28'S; Longitude 55º48'W). The experiment was conducted during the rainy season, when the average temperature was 29.02 °C.

This assay was performed in two phases, which consisted of 35 days of start-up and 90 days of daily feeding. Substrates for start-up contained 2% of total solids (TS) and for daily feeding, 4% of TS. During daily feeding, the hydraulic retention time was 30 days.

Table II. Composition of the substrates (kg) used in the digesters (Composição dos substratos (kg) utilizados nos biodigestores).

	Manure	Water	Manipueira	Sodium bicarbonate
Start-up				
Dairy cows	0.79	6.71	0.000	0.039
Sheep	0.42	7.08	0.000	0.039
Swine	0.41	7.09	0.000	0.039
Poultry	2.58	4.92	0.000	0.039
Daily feeding				
Dairy cows	0.05	0.21	0.026	0.0013
Sheep	0.03	0.23	0.026	0.0013
Swine	0.03	0.23	0.026	0.0013
Poultry	0.02	0.24	0.026	0.0013

Manure used to start the daily feeding of the digesters were collected at the dairy cow, poultry and sheep complex at State University of Mato Grosso do Sul and the swine manure were collected in an experimental farm at Federal University of Mato Grosso do Sul.

Pantaneira breed lactating cows were fed with 60% of forage and 40% of concentrate ratio. Concentrate was compound by corn, soybean meal, urea and mineral supplementation. Santa Inês breed and crossbred sheep were kept in rotated grazing fed with piatã forage, massai forage and mineral supplementation.

Hy line poultry housed on conventional cage system were fed with diet based on corn and soybean meal. Pietran/Duroc x Large White/Landrace fattening pigs housed on deep bedding were fed with diet based on corn and soybean meal.

Dairy cow and sheep manure were collected through scrapping the floor just after being produced. Swine manure was removed from bed and free of straw. In order to collect poultry manure, plastic tarp was placed below the cages in order to collect the manure after 24 hours. The manipueira was obtained from small producers of a rural zone in Anastácio – MS. All collected waste was packed in plastic bags, identified according to each animal species and stored in a freezer at -15°C.

Eight semi-continuous digesters of 7.8 L capacity were used. Distinct parts compounded the digester. Each digester used had a hose barb connected to a hose through which gas was collected. In order to store the gas were used cylindrical PVC gas collectors. This apparatus comprised an inner and outer PVC cylinder, whose purpose was to store and allow the quantification of the gas produced. All digesters were kept in environment temperature housed from solar light and rain.

Fresh manure from dairy cows, sheep, poultry and swine were used to the start-up phase and daily feeding. For the start-up phase the amount of TS used to calculate the substrate of each treatment were 19.46; 36.74; 6.05 and 37.99% respectively. The amounts of TS and VS from manure used in the daily feeding are presented on **tables I** and **II**.

Manipueira added to substrates during daily feeding averaged 5.5% TS, pH of 4.87 and total ammonia concentration (TAN) of 175 $mg \cdot L^{-1}$. Percentages of manipueira inclusion (10%, weight/weight) as well as the use of sodium bicarbonate ($NaHCO_3$) (0.5%, weight/weight) were defined in preliminary tests.

Determinations of the TS and VS concentration were done according to methodology described by APHA, AWWA, WPCF (2012).

Affluent and effluent samples from the digesters were analyzed for pH, TAN and partial alkalinity (PA) according to APHA, AWWA, WPCF (2012).

In order to measure the volume of gas produced, a scale was used to get the displacement of the gas collector as pressure mounts the generated gas. The value was multiplied by the inner transversal section area of 0.007854 m^2.

In order to correct the biogas volume at 1atm and 25°C, it was used an equation resulted from the combination of Boyle's and Gay-Lussac's law as described by Caetano (1985) in which: V_0 = corrected biogas volume, m^3; P_0 = corrected pressure of biogas, 10332.72 mm of water; T_0 = Corrected temperature of biogas, 298.15 (Kelvins); V_1 = volume of biogas in the gasometer; P_1 = biogas pressure at the reading, 22 mm of water; T_1 = biogas temperature at reading (K).

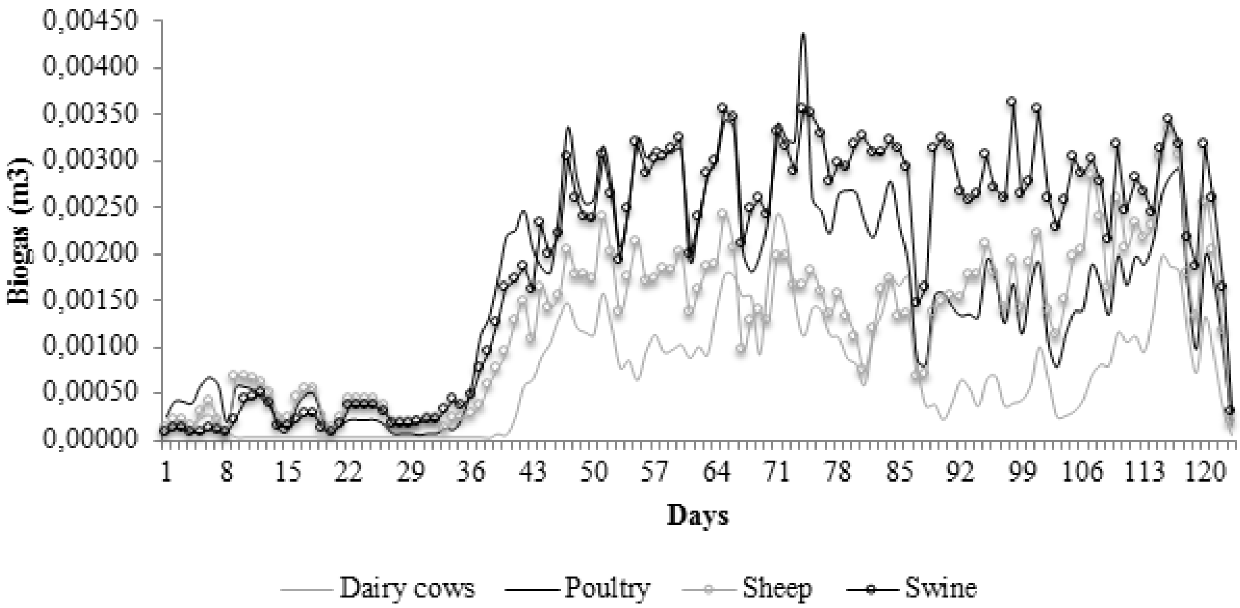

Figure 1. Daily biogas production (m^3) in semicontinuous digesters fed on ruminant and monogastric animal manure co-digested with manipueira (Produção diária de biogás (m^3) em biodigestores semicontínuos alimentados com dejetos de ruminantes e monogástricos codigeridos com manipueira).

Table III. **Solids reduction in digesters fed with dairy cow, sheep, poultry or swine manure co-digested with manipueira** (Redução de sólidos em biodigestores alimentados com dejetos de bovinos leiteiros, ovelhas, aves ou suínos codigeridos com manipueira).

Substrates	Reduction (%)	
	Total solids	Volatile solids
Dairy cow manure + manipueira	39.20[b]	41.85[b]
Sheep manure + manipueira	37.60[b]	44.56[b]
Swine manure + manipueira	61.01[a]	68.30[a]
Poultry manure + manipueira	60.40[a]	69.90[a]
P value	<0.001	<0.001
Coefficient of variation (%)*	18.90	14.75

[a,b,c]Averages followed by the same letter in the columns do not differ among themselves through Tukey test at 5% of probability. *Main factor.

Considering the atmospheric pressure of 10293 mm of H_2O, we have as a result the following equation to the correction of biogas volume:

$V_0 = (V_1/T_1) * 297.6515$

Biogas yield was calculated using data of daily biogas production of each digester and the amount of VS added. The results were expressed in m^3 of biogas per kg of VS added.

The variables evaluated weekly were: weekly accumulated biogas production, biogas yield (m^3 kg of VS_{added}^{-1}), TS and VS reduction, pH, total ammonia concentration and partial alkalinity. All data obtained were submitted to ANOVA through a split-plot design where the main factor was the type of manure co-digested with manipueira and the second one was the week of analysis from the third retention time. When needed, the averages were compared by Tukey's test at 5% of probability.

RESULTS AND DISCUSSION

There was statistic difference for TS and VS reductions according to the manure's origin (from monogastric or ruminants). Greater TS and VS reductions occurred on digesters fed with monogastric's animal manure co-digested with manipueira **(table III)**.

Differences noticed in VS reduction might be explained by the distinct composition of the manure. Ruminant's manure have significant amount of lignin, which is a phenolic compound of difficult degradability and when complexed with cellulose and hemicellulose not allow conversion of these compounds in precursors of biogas (Angelidaki and Ahring, 2000; Vanholme *et al.*, 2010; Sawatdeenarunat *et al.*, 2015; Xavier *et al.*, 2015). On the other hand, in manure of monogastric species the nutrient become more accessible and thus rapidly available leading higher rates of biogas generation. Moreover, the anaerobic co-digestion of these manure with manipueira may had improved the carbon: nitrogen (C:N) balance of the substrate, contributing to higher biogas yield.

Higher VS reductions are correlated to higher biogas production. As noticed, higher biogas yields were from monogastrics' animal manure co-digested with manipueira **(table IV)**. Between them, swine manure co-digested with manipueira presented the higher potential for biogas production (0.843 m^3 VS_{added}^{-1}). Sheep manure presented higher biogas yield (0.275 $m^3 \cdot kg \cdot VS_{added}^{-1}$) between ruminants' manure co-digested with manipueira.

According to the literature, biogas yield from goat (almost similar to sheep), swine, dairy cattle and poultry manure as a sole substrate averaged 0.218; 0.645;

Table IV. **Weekly accumulated biogas production** and biogas yield of ruminant and monogastric animal manure co-digested with 10% of manipueira in semi-continuous digesters (Produção acumulada semanal e rendimentos de biogás de dejetos de animais ruminantes e monogástricos com 10% de manipueira em biodigestores semicontínuos).

Substrates	Weekly biogas production	Biogas yield
	m^3	$m^3 \cdot kg \cdot VS_{added}^{-1}$
Dairy cow manure + manipueira	0.00676[d]	0.122[d]
Sheep manure + manipueira	0.01167[c]	0.275[c]
Swine manure + manipueira	0.01856[a]	0.843[a]
Poultry manure + manipueira	0.01515[b]	0.535[b]
P value	<0.001	<0.001
Coefficient of Variation (%)*	8.34	12.09

Averages followed by the same letter in the columns do not differ among themselves through Tukey test at 5% of probability. *Main factor.

0.254 and 0.627 $m^3 \cdot kg \cdot VS_{added}^{-1}$ (Orrico *et al*., 2004; Xavier *et al*., 2010; Sakar *et al*., 2009; Miranda *et al*., 2012), respectively. Thus, manipueira incremented biogas yield in 26 ruminants

and 31% when co-digested with sheep and swine manure, respectively. However, a reduction of 52% and 15% was found for dairy cattle and poultry manure co-digested with manipueira compared to data from literature. Is worth noting that biogas production might be highly influenced by manure properties, animal species, energetic, protein and fiber content in the diet, digestibility, physiologic stage, age, animal production system and environmental conditions (Sakar *et al*., 2009) as well the addition of another substrate (anaerobic co-digestion).

Just after the beginning of daily feeding the biogas production of poultry manure was higher when compared to the other substrates. In the following 30 days, swine manure co-digested with manipueira showed the same behaviour. After which, there was a decrease in biogas production **(figure 1)**.

Variations in biogas production of all substrates can be explained by environment temperature fluctuations and manipueira composition along the assay. Composition and chemical profile of the manipueira may vary according to the specie, harvest age, soil quality and abiotic factors such as temperature, humidity and cassava's processing method as well (Fioretto, 1994).

During significant part of the assay, substrates composed by ruminant's animal manure and manipueira presented low biogas production when compared to those substrate composed by monogastric's animal manure and manipueira. Among them, dairy cattle manure showed the lowest biogas yield. That behaviour happened because ruminants present a better use of the diet nutrients when compared to swine and poultry, and therefore, their manure have significant amount of fibres of low degradability implicating in low nutrient available to the anaerobic digesters' microorganisms. In fact, the feed's digestion in ruminants occurs in lower rate than in monogastric; however, the complex organic matter of feed is much more altered in ruminants (Cunningham, 2004).

Average values for affluents and effluents pH of all digesters ranged from 6.92 to 7.95 (**table V**). Despite of monogastric manure co-digested with manipueira showed high initial pH values, all effluents presented pH values in the expected range for anaerobic digestion as suggested by Aragaw *et al*. (2013) of 6.0 to 8.0. The high value of pH was observed in effluent of poultry manure co-digested with manipueira, of 7.55.

Both affluent and effluent of the digesters operated with poultry manure and manipueira showed highest concentration of TAN when compared to the other substrates. There was no statistic difference between ruminants' manure co-digested with manipueira for TAN. For all substrates, TAN concentration reached values below of the inhibitory limit for anaerobic microorganisms of 1.000 $mg \cdot L^{-1}$ (Chernicharo, 1997).

The PA is a monitoring parameter of bicarbonate concentration and might indicate the stability of the anaerobic digestion process (Ward *et al*., 2011). In the present assay, the PA ranged from 3.431 to 7.715 $mg \cdot L^{-1}$, being higher than the operational limit suggested for anaerobic digestion system of 1.200 $mg \cdot L^{-1}$ according to Jenkins *et al*. (1991). Poultry manure co-digested with manipueira reached the highest values of PA when compared to the other substrates.

Higher values of pH, TAN concentration and PA for poultry manure co-digested with manipueira might be due to the C:N balance, once poultry manure present high amount of nitrogen (uric acid) and the manipueira has significant content of soluble carbohydrates. Usually the pH increases as TAN concentration get high, which promotes the increase of PA due to high concentration of ammonium bicarbonates, naturally formed during the breakdown of organic matter that mitigate the risk of inhibition by free ammonia.

CONCLUSION

Monogastric manure co-digested with manipueira (10%, volume/volume) showed the highest biogas yield. Swine manure reached 0.843 $m3 \cdot kg \cdot VS_{added}^{-1}$. All manure (dairy cattle, sheep and poultry manure) co-digested with manipueira showed low risk of inhibi-

Table V. Averages values of pH, total ammonia nitrogen (TAN) concentration and partial alkalinity of affluent and effluent of semi-continuous digesters fed with ruminant and monogastric manure co-digested with 10% of manipueira (Valores médios de pH, concentração de nitrogênio amoniacal (TAN) e alcalinidade parcial de afluentes e efluentes de biodigestores semicontínuos alimentados com dejetos de ruminantes e monogástricos codigeridos com 10% de manipueira).

Substrates	pH		TAN ($mg \cdot L^{-1}$)		Alkalinity ($mg \cdot L^{-1}$)	
	Affluent	Effluent	Affluent	Effluent	Affluent	Effluent
Dairy cow manure + manipueira	7.18^{c}	7.39^{c}	109^{c}	131^{c}	3847^{b}	5293^{c}
Sheep manure + manipueira	7.95^{a}	7.42^{b}	86^{c}	169^{c}	5350^{a}	6527^{b}
Swine manure + manipueira	6.92^{d}	7.41^{bc}	170^{b}	370^{b}	3431^{c}	5603^{c}
Poultry manure + manipueira	7.90^{b}	7.55^{a}	305^{a}	719^{a}	5212^{a}	7715^{a}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Coefficient of variation (%)*	0.76	0.44	14.95	0.76	0.44	14.95

[a,b,c]Averages followed by the same letter in the columns do not differ among themselves through Tukey test at 5% of probability. *Main factor.

tion by pH, total ammonia nitrogen concentration and partial alkalinity, which were kept below of the critic values for anaerobic co-digestion.

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