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A highly concentrated diet increases biogas production and the agronomic value of young bull's manure

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ABSTRACT

The increasing demand for animal protein has driven significant changes in cattle breeding systems, mainly in feedlots, with the use of young bulls fed on diets richer in concentrate (C) than in forage (F). These changes are likely to affect animal manure, demanding re-evaluation of the biogas production per kg of TS and VS added, as well as of its agronomic value as a biofertilizer, after anaerobic digestion. Here, we determined the biogas production and agronomic value (i.e., the macronutrient concentration in the final biofertilizer) of the manure of young bulls fed on diets with more (80% C + 20% F; 'HighC' diet) or less (65% C + 35% F; 'LowC' diet) concentrate, evaluating the effects of temperature (25, 35, and 40 °C) and the use of an inoculum, during anaerobic digestion. A total of 24 benchtop reactors were used, operating in a semi-continuous system, with a 40-day hydraulic retention time (HRT). The manure from animals given the HighC diet had the greatest potential for biogas production, when digested with the use of an inoculum and at 35 or 40 °C (0.6326 and 0.6207 m^3 biogas/kg volatile solids, or VS, respectively). We observed the highest levels of the macronutrients N, P, and K in the biofertilizer from the manure of animals given HighC. Our results show that the manure of young bulls achieves its highest potential for biogas production and agronomic value when animals are fed diets richer in concentrate, and that biogas production increases if digestion is performed at higher temperatures, and with the use of an inoculum.

1. Introduction

The anaerobic digestion of cattle manure (generated by animal farming) produces clean energy in the form of biogas, and also converts manure into biofertilizers that can be used for plant nutrition (Cestonaro et al., 2015). Biogas production from cattle manure is highly influenced by manure chemical composition (Orrico et al., 2010). Feeding cattle diets containing high levels of concentrate increases the biogas production from manure, due to the generation of higher levels of soluble organic-C during anaerobic digestion (Orrico et al., 2010, 2012; Costa et al., 2013). Animal nutrition also affects the composition of manure-derived biofertilizers, altering directly the levels of the macronutrients N, P, and K (Orrico et al., 2012).

Despite the overwhelming effect of manure chemical composition on biogas production, the latter can also be modulated by temperature (Cavinato et al., 2013; Gou et al., 2014; Kinnunen et al., 2014), and by the use of an inoculum (Saidu et al., 2013; Hidalgo and Martín-Marroquín, 2014; Gu et al., 2014), especially in reactors operated in semi-continuous systems.

The increasing demand for animal protein has led to worldwide changes in meat production systems, particularly in intensive farming and industrial settings. Brazilian meat cattle breeding systems have undergone structural and conjunctural adjustments, with increased use of modern agricultural technologies and meat exporting, as well as alterations in herd geographical distribution (Oaigen et al., 2013). These changes enabled a significant expansion of herds toward the Midwest and North, as a response to the competition for agricultural areas in the Southeast and South of Brazil.

Competition for livestock area and the search to improve meat quality have not only intensified feedlot production, but also reduced slaughter age. This is a central aspect of the Brazilian model for raising young bulls, which is characterized by

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confinement of animals after weaning, and slaughter at the early age of 15 months (Silveira, 1995). At this age, animals have a minimum live weight of 450 kg and a coverage of subcutaneous fat in the upper housing of 4 mm, which, together with their considerably young age, ensures a better quality of meat. The model, then, explores biological efficiency (live weight gain relative to energy consumption) and combines the effects of genetic and environmental factor manipulation in tissue transformation during accelerated growth (Rubiano et al., 2009).

Besides these aspects related to efficiency, Lovett et al. (2003) also alert for the problem of CH_4 emissions derived from enteric fermentation. The authors comment about many potential strategies as a means by which CH_4 production (resulting from enteric fermentation) could be reduced and one of them is the alteration of ruminal fermentation patterns through dietary manipulation; primarily the substitution of structural by non-structural carbohydrates. The authors concluded that the feeding of low F/C ratio diets to finishing beef animals is an effective means to reduce CH_4 output per unit of product while simultaneously improving animal productivity. Conclusion also obtained by Aguerre et al. (2011) working with dairy cows and measuring the CH_4 emissions and for Mathot et al. (2012) who evaluated the effect of cattle diet and manure storage conditions on carbon dioxide, methane and nitrous oxide emissions from tie-stall barns and stored solid manure. These important changes in the calf raising model, based on the use of young bulls, are expected to affect directly the quantitative and qualitative characteristics of manure. Thus, manure produced from young bulls needs to be evaluated for its pollution potential. Also, it is important to determine the agronomic potential of manure produced according to the current calf raising model, by using anaerobic digestion systems to estimate the production of clean energy in the form of biogas, and the quality of the final biofertilizer.

Here, we evaluated biogas production from the manure of young bulls fed on diets differing in the ratio of concentrate (C) to forage (F). Biogas production during anaerobic biodigestion was evaluated in reactors operated in a semi-continuous system, at three different temperature levels, with or without the use of an inoculum. Also, we measured the levels of macronutrients in the final biofertilizer produced by anaerobic digestion, to evaluate the agronomic value of the manure generated under different conditions.

2. Materials and methods

2.1. Animals

The manure residues used in this work were collected from Brangus breed cattle kept in the feedlot area of the Lageado Farm (Faculty of Veterinary Medicine and Animal Husbandry, São Paulo State University – FMVZ/UNESP – Botucatu, SP, Brazil). In a covered confinement area, each 5 × 5-m masonry bay housed 6 animals, with a suspended and perforated floor that facilitated manure collection from the lower part of the bay. Manure collection was performed 1 week after the initiation of feeding with experimental diets.

2.2. Biodigesters and experimental design

Anaerobic digestion of cattle manure was performed in PVC bench digesters with 10-L capacity and fed in a semi-continuous system, as described in Hardoim (1999). Anaerobic digestion experiments followed a randomized factorial design comprising 12 treatments (2 diets × 3 temperature levels × presence or absence of an inoculum in the digestion mixture), with two replicates each, totaling 24 digesters. The duration of the assay was 58 days, but the period in which the data was collected was 31 days. The first 9 days and the last 17 days were discarded.

The manure used was produced by young bulls that had received one of the following two diets, which differed in the ratio of concentrate (C) to forage (F): 65% C + 35% F ('LowC' diet) and 80% C + 20% F ('HighC' diet). This proportion is in the dry matter basis. The diets were formulated using corn silage (whole plant and wet grain), pre-dried alfalfa and mineral mix. The bromatological characteristics of the two diets given to the animals are shown in Table 1.

The composition of the manure produced by cattle fed on each diet and used to compose the daily loading is shown in Table 2.

Anaerobic digestion was performed at 25, 35, or 40 °C. For temperature control, anaerobic digesters were placed in 500-L fiber cement boxes (in batches of 8 digesters/box). Boxes were thermally insulated through a 3-cm polystyrene (Styrofoam) wrap containing 270 L of water, which was heated to the desired temperature thorough a heating system with electrical resistances of 1000, 3000, and 5000 W (for temperatures of 25, 35, and 40 °C, respectively) and a thermostat (20 A). Homogenization was ensured by the use of a 150-W water pump in each box, which triggered water movement whenever the thermostat activated the heating system (Souza et al., 2005).

To start the process, within each batch of eight digesters kept at a set temperature condition (25, 35, or 40 °C), half (4/8) were filled with substrate containing manure from animals fed on the LowC diet while the other half contained manure from animals given the HighC diet. Substrates (LowC and HighC) were obtained from bench digesters (10 L) operated in batch system for 172 days. Also, 2 digesters in each group of 4 contained an inoculum. The inoculum used was the effluent of real scale digester (5.5 m^3) operated with beef cattle manure and water (8% TS) with 30 days of hydraulic retention time (HRT) on semi-continuous system. The real scale digester is located at São Paulo State University – Department of

Table 1
Bromatological composition of the diets given to animals during anaerobic digestion assay.

Diet	DM	CP	CF	EE	NFE	TDN	NDF	ADF	MM
	%DM								
LowC	48.1	19.6	19.5	5.28	50.1	68.9	51.2	21.0	5.49
HighC	55.6	15.8	10.7	4.44	63.9	74.2	40.3	14.2	5.08

DM: dry matter; CP: crude protein; CF: crude fiber; EE: ether extract; NFE: nitrogen free extract; TDN: total digestible nutrients; NDF: neutral detergent fiber; ADF: acid detergent fiber; MM: mineral matter.

Table 2
Characterization of manure produced by cattle fed on diets containing 65% concentrate + 35% forage ('LowC' diet) and 80% concentrate + 20% forage ('HighC' diet).

Components	LowC diet	HighC diet
TS (%)	20.0 ± 0.21	24.2 ± 2.7
VS (%)	82.7 ± 1.12	87.0 ± 0.10
N (%)	2.15 ± 0.05	2.20 ± 0.02
P (%)	0.27 ± 0.00	0.26 ± 0.02
K (%)	1.71 ± 0.01	2.44 ± 0.04
CF (%)	22.81 ± 1.96	17.7 ± 1.67
NDF (%)	53.07 ± 3.04	47.6 ± 1.60
ADF (%)	34.2 ± 3.39	30.6 ± 3.98
NFE (%)	47.83 ± 3.04	50.30 ± 2.67
MM (%)	14.24 ± 1.26	16.40 ± 1.48
CP (%)	14.16 ± 1.10	13.47 ± 0.16
EE (%)	1.96 ± 0.71	2.16 ± 0.44
TDN (%)	62.60 ± 1.26	64.32 ± 1.80

TS: total solids; VS: volatile solids; N: nitrogen.