COMPARING THE CARBON DIOXIDE AND METHANE EMISSIONS OF HOLSTEIN AND JERSEY COWS IN A KIKUYU PASTURE-BASED SYSTEM

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SUMMARY

The aim of this study was to estimate enteric carbon dioxide (CO_2) and methane (CH_4) production in Holstein and Jersey cows and compare the enteric gas emissions of the two breeds by parity and lactation stage. Data were test-day records of 122 Holstein and 99 Jersey cows from October 2005 to September 2014. Cows were kept on kikuyu pasture and received on as-fed basis 7 kg of a concentrate mixture containing 17% crude protein (CP) fed in two equal portions after each milking throughout the lactation period. The DMI of cows was estimated using the National Research Council method (NRC, 2001) and the pasture intake as the difference between the DMI and concentrate DMI. The Cornell Net Carbohydrate and Protein System equations (CNCPS) were used to estimate CH_4 (g/d) and CO_2 (kg/day) production. Holsteins produced more CO_2/day and CH_4/day than Jerseys. The production of the two enteric gases increased with lactation stage and parity in both breeds. When CO_2 and CH_4 were expressed as proportions of dry matter intake (DMI) or 100 kg body weight (BW), Holsteins had lower emissions both by parity and lactation stage. With CO_2/kg energy corrected milk (ECM), breeds did not differ; however, Jerseys produced lower CH_4/kg ECM. It is concluded that enteric CO_2 and CH_4 emission is affected by breed, lactation stage and parity. It is therefore recommended that the two production stages be accounted for when estimating the methane emission factor (MEF, CH_4/head/year).

INTRODUCTION

Carbon dioxide and CH_4 are natural by-products of enteric fermentation (Hook *et al*. 2010). Although the production of CH_4 (methanogenesis) is an essential process, it constitutes energetic inefficiency. Depending on feed composition and quality, methanogenesis represent a loss of about 2 to 12 % of dietary gross energy consumed by the host animal (Hook *et al*. 2010) with high-producing lactating animals losing at least 6% (Qiao *et al*. 2014). Enteric gases also contribute to greenhouse gas (GHG) concentrations in the atmosphere that are linked to global climate change (Broucek 2014). Methane has a global warming potential 25 times that of CO_2 (Broucek 2014). Although the CO_2 emitted is considered neutral as it arises from metabolism of plant-derived feeds (Smith *et al*. 2014), the inclusion of CO_2 emissions when balancing for carbon flows in the farm is essential to ensure that all sources of carbon emission are accounted for (Chianese *et al.* 2009).

As methanogenesis is inevitable and essential for rumen functioning, more studies are required to find ways to reduce CH_4 emissions. This would improve feed efficiency in ruminants as well as assist in mitigating their effects on global climate change. Breed comparison on enteric CH_4 emissions per unit of DMI or kg product produced is one strategy to be considered. In studies comparing Holstein and Jersey cows (Münger & Kreuzer 2006; Capper & Caddy 2012; Olijhoek *et al.* 2018), conflicting results on breed differences were obtained. Furthermore, the Intergovernmental Panel on Climate Change (IPCC 2006) is encouraging the development of country-specific MEF for different animal categories to enable close estimation of the country's emissions. Estimating emissions by sub-categories such as production stage, e.g., lactation stage and parity, will bring better accuracy as herd population vary throughout the year. According to Mangino *et al.* (2003), overlooking the effects of the production stages assumes that individual animal characteristics remain constant throughout a given year. No literature could be found on the effect of production stages on enteric gas emissions. The aim of this study is therefore to estimate enteric CO_2 and CH_4 production of Holstein and Jersey cows and compare breeds as affected by parity and lactation stage.

MATERIALS AND METHODS

The CNCPS equations were used to estimate CH_4 (g/day) and CO_2 (kg/day) emissions of cows (Van Amburgh *et al*. 2015). The MEF was calculated as daily $CH_4 \times 365$ days. Data used as input in the models were from test-day records of 122 Holstein and 99 Jersey cows from the Elsenburg Research Farm of the Western Cape Department of Agriculture collected from October 2005 to September 2014. Cows were in a kikuyu pasture-based system and were supplemented with a7 kg/cow/day concentrate mixture containing 17% CP on as-fed basis, fed in two equal portions after each milking throughout the lactation period. The DMI of cows was estimated using the National Research Council method (NRC 2001) and the pasture intake was estimated as the difference between the estimated DMI and concentrate DMI. Cow parity varied from 1 to 7. Milk yield and components data were collected on test dates of approximately 35-days intervals in each lactation period, the same intervals were used for modelling enteric gases emitted. Lactation period was divided into four stages by creating class intervals from the test-day production data as follows: calving to 30 days as post-calving transition period (will just be referred to as transition period); 31 to 100 days as early lactation; 101 to 200 days as mid-lactation and above 201 days as late lactation. Data were analysed using the repeated measure methods of the PROC MIXED procedure of SAS Enterprise Guide version 7.1. The main effects were breed, parity and lactation stage, the interaction effects were breed × lactation stage, and breed × parity. The cow was fitted as a random effect while the response variables (CH_4, CO_2, and their efficiency measures) were repeated measurements within a cow at fixed test-dates of approximately 35 days intervals within parities. The between-breeds, between parity and between lactation stage variations and their interactions were compared using Bonferroni test and were declared different at $P < 0.05$. The following equation was used for statistical analysis:

$$Y_{ijkl} = \mu + B_i + P_j + LS_k + (B \times P)_{ij} + (B \times LS)_{ik} + cow_l(B_i) + \varepsilon_{ijkl}$$

RESULTS AND DISCUSSION

Holstein and Jersey cows had overall average BW of 567±3.5 vs. 411±3.8 kg, DMI of 17.8±0.11 vs.14.4±0.12 kg/day and produced 23.8±6.2 vs.17.9±4.4 kg milk/day, which when corrected for fat and protein contents was 22.7±5.9 vs. 19.4±4.8 kg ECM/day, respectively. The CO_2 produced by cows in this study ranged from 6.54 to 15.8 kg/day in Holstein cows and 6.3 to 14.1 kg/day in Jersey cows. Comparable results on kg CO_2 produced per day were reported but only on Holsteins, by Kinsman *et al.* (1995) using infrared gas analyser; Chianese *et al.* (2009) using the Integrated Farm System Model, and Lee *et al.* (2017) using the sulphur hexafluoride tracer technique.

In this study, Holsteins produced more CO_2 than Jerseys; however, when expressed as CO_2/kg DMI or CO_2/100 kg BW, Holstein had lower CO_2 emissions (Table 1). This is because the DMI/kg BW in this study was lower in Holsteins than Jerseys (3.1% vs. 3.5%). Similarly, Muller and Botha (1998) also reported lower DMI/kg BW (3.4 vs. 4.0% DMI/kg BW) in Holsteins than Jerseys, respectively. The CO_2/kg DMI decreased from primiparous to second lactation, then levelled so that the third lactation and mature cows did not differ. With lactation stage, CO_2/kg DMI was higher in transition stage followed by a decline that levelled from early lactation (Table 1). The CO_2/100 kg BW decreased with parity while it increased with lactation stage reaching a plateau in mid-lactation, followed by a decline in late lactation stage (Table 1). This seems to indicate that the higher DMI and heavier BW of multi-parous and later lactation stage cows had a diluting effect on CO_2 emitted, resulting in lower CO_2/kg DMI and lower CO_2/kg BW.

Table 1. Mean enteric CO_2 and CH_4emissions and their efficiencies of Holstein and Jersey cows as affected by parity and lactation stage

	Parity										
	Parity 1		Parity 2		Parity 3		Parity 4+ (mature cows)		P-values		Intxn
	H	J	H	J	H	J	H	J	Breed	P	B×P
CO_2/day	10.2^{d}±0.05	8.9^{g}±0.06	11.0^{c}±0.06	9.4^{g}±0.06	11.5^{b}±0.06	9.9^{e}±0.06	11.8^{a}±0.06	10.1^{d}±0.06	<.01	<.01	<.01
CO_2/DMI	0.65^{c}±0.001	0.69^{a}±0.001	0.63^{d}±0.002	0.68^{b}±0.002	0.62^{e}±0.002	0.66^{c}±0.002	0.62^{e}±0.002	0.66^{c}±0.002	<.01	<.01	0.02
CO_2/BW	2.01^{e}±0.01	2.42^{a}±0.01	1.97^{f}±0.01	2.34^{b}±0.01	1.95^{g}±0.01	2.32^{c}±0.02	1.92^{h}±0.01	2.31^{d}±0.02	<.01	<.01	0.01
CO_2/ECM	0.56^{a}±0.01	0.56^{a}±0.01	0.51^{b}±0.01	0.53^{b}±0.01	0.50^{c}±0.01	0.50^{c}±0.01	0.48^{d}±0.01	0.49^{d}±0.01	0.38	<.01	0.08
MEF	124.8^{d}±0.78	102.5^{g}±0.86	137.5^{c}±0.87	112.0^{f}±0.93	143.6^{b}±0.95	119.5^{e}±0.97	147.7^{a}±0.97	123.8^{d}±0.98	<.01	<.01	<.01
CH_4/day	342^{d}±2.1	281^{g}±2.4	377^{c}±2.4	307^{f}±2.5	393^{b}±2.6	327^{e}±2.7	405^{a}±2.7	339^{d}±2.7	<.01	<.01	<.01
CH_4/kg DMI	21.7^{a}±0.03	21.6^{b}±0.03	21.4^{c}±0.03	21.7^{a}±0.03	21.2^{d}±0.04	21.7^{a}±0.04	21.1^{e}±0.04	21.6^{b}±0.04	<.01	<.01	<.01
CH_4/kg BW	67.4^{b}±0.4	76.3^{a}±0.5	67.2^{b}±0.5	76.0^{a}±0.5	66.8^{bc}±0.5	76.6^{a}±0.5	66.0^{c}±0.5	76.7^{a}±0.5	<.01	0.41	<.01
CH_4/ECM	18.7^{a}±0.1	17.6^{b}±0.2	17.5^{b}±0.2	17.2^{bc}±0.2	17.0^{c}±0.2	16.4^{de}±0.2	16.6^{cd}±0.2	16.1^{e}±0.2	0.01	0.01	<.01
	Lactation stage (days in milk)										
	Transition (<30)		Early lactation (31-100)		Mid-lactation (101-200)		Late lactation (201+)				
	H	J	H	J	H	J	H	J	Breed	LS	B×LS
CO_2/day	9.4^{e} ±0.07	8.3^{f}±0.07	11.4^{b}±0.05	9.8^{d}±0.06	11.9^{a}±0.05	10.2^{c}±0.06	11.8^{a}±0.05	10.1^{c}±0.06	<.01	<.01	<.01
CO_2/DMI	0.68^{b} ±0.002	0.72^{a}±0.002	0.62^{e}±0.001	0.66^{c}±0.002	0.61^{e}±0.001	0.65^{d}±0.002	0.62^{e}±0.001	0.65^{d}±0.002	<.01	<.01	0.03
CO_2/BW	1.70^{h} ±0.02	2.06^{f}±0.02	2.07^{e}±0.01	2.47^{b}±0.01	2.09^{d}±0.01	2.49^{a}±0.01	1.99^{g}±0.01	2.38^{c}±0.01	<.01	<.01	0.06
CO_2/ECM	0.40^{d} ±0.01	0.40^{d}±0.01	0.48^{c}±0.01	0.49^{c}±0.01	0.56^{b}±0.01	0.56^{b}±0.01	0.61^{a}±0.01	0.62^{a}±0.01	0.38	<.01	0.85
MEF	111.1^{e}±1.0	89.2^{f}±1.1	143.5^{b}±0.9	118.9^{d}±0.9	150.3^{a}±0.8	125.4^{c}±0.9	148.8^{a}±0.9	124.3^{c}±0.9	<.01	<.01	0.12
CH_4/day	304^{e} ±2.8	244^{f}±3.0	393^{b}±2.3	326^{d}±2. 5	412^{a}±2.3	344^{c}±2.4	408^{a}±2.3	341^{c}±2.4	<.01	<.01	0.12
CH_4/kg DMI	21.5^{b} ±0.04	20.7^{d}±0.05	21.5^{b}±0.03	22.0^{a}±0.03	21.2^{c}±0.03	22.0^{a}±0.03	21.3^{c}±0.03	22.0^{a}±0.03	<.01	<.01	<.01
CH_4/kg BW	54.5^{g} ±0.6	59.8^{f}±0.6	71.4^{d}±0.5	81.9^{b}±0.5	72.5^{d}±0.4	84.0^{a}±0.	68.9^{e}±0.5	79.9^{c}±0.5	<.01	<.01	<.01
CH_4/ECM	12.7^{d} ±0.2	11.4^{e}±0.2	16.7^{c}±0.2	16.3^{c}±0.2	19.4^{b}±0.2	19.0^{b}±0.2	21.1^{a}±0.2	20.7^{a}±0.2	<.01	<.01	0.02

[a-h] Means within rows with different superscripts differ at P<0.05

CO_2: carbon dioxide (kg/day), **CH_4:** methane (g/day),**MEF:** methane emission factor (kg/head/year),**DMI:** dry matter intake (kg/day), **BW:** body weight (100 kg), **ECM:** energy corrected milk (kg/day), **Intxn:** interaction

The CO_2/kg ECM increased with lactation stage and decreased with parity, but breed did not have an effect (Table 1). The increase in emitted CO_2/kg ECM can be related to reducing milk production with advancing lactation stages as nutrient partitioning shift in mid and late lactation towards supporting pregnancy and building body reserves in preparation for the next calving, while the decrease by parity is attributed to high milk volumes produced by older cows.

As expected, Holsteins produced more CH_4 than Jerseys both by parity and lactation stage (Table 1). In both breeds, daily CH_4 produced increased as parity and lactation stages progressed, mature Holstein cows produced 15.6% and Jersey cows 17.1% more CH_4 than their primiparous counterparts. With lactation stages, the highest CH_4 emissions were observed during mid-lactation, corresponding with the peak DMI. The increase in daily CH_4 emitted from the transition period to mid-lactation was 26.2% and 29.1% in Holstein and Jersey cows, respectively. This indicates that accounting for parity and lactation stages will bring more accuracy in estimating MEF. Similarly, to CO_2, Jerseys produced moreCH_4/kg DMI and CH_4/kg BW. TheCH_4/kg ECM was, however, lower in Jerseys than Holsteins (Table 1). In agreement, Dalla Riva *et al.* (2014) also found greater CO_2equivalent emissions per unit ECM production in Holsteins compared to Jerseys, while Olijhoek *et al.* (2018) reported no differences between Holstein and Jersey cows in CH_4/kg ECM.

CONCLUSIONS

Carbon dioxide and CH_4 emissions varied by breed, parity and lactation stage. Dry matter intake had a positive relationship with enteric gas emissions. Factors affecting DMI such as breed, parity, stage of lactation, milk production and BW have an indirect effect on enteric gases emissions. Because of major variations in enteric emissions caused by parity and lactation stages, it is concluded that accounting for production stages should result in a higher accuracy in estimating MEF.A study on estimating heritability and repeatability of enteric emissions is recommended to determine the extent of differences observed between and within breeds that can be associated with additive genetic variance.

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