Estimation of Enteric Methane Emissions in Ruminants Using $CO_2:CH_4$ Ratio Obtained with a Wavelength-scanned Cavity Ring-down Spectrometer

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Abstract

Experimental measurements of enteric methane (CH_4) involving either individual animals or a group of animals are usually complex and expensive. As a result, models are heavily relied upon when it comes to predicting enteric CH_4 emissions at global, regional, or even local levels. In this work, results on enteric methane measurements based on a direct experiment strategy that uses carbon dioxide (CO_2) as a tracer gas are presented. A calibrated, wavelength-scanned cavity ring down spectrometer (Picarro G2401) is utilized to make simultaneous measurements of dry mole fractions of CH_4 and CO_2 from a beef cattle feedlot located at the Hyder-Burks Agricultural Pavilion farm in Cookeville, Tennessee (36º11'53" N, 85º32'19" W). Heat production unit (HPU) is determined using the animal body weights, milk production, and days of pregnancy to yield CO_2 production (L/day) from ruminants. The value for the total CO_2 production is then combined with the experimentally calculated CH_4:CO_2 ratio to estimate CH_4 emission factors in Putnam County and Tennessee. Using a CH_4:CO_2 ratio of 52.90 ± 3.00 ppb/ppm and the respective livestock populations, we estimate an annual enteric CH_4 emission of 117 ± 7 Gg yr^{-1} and 1.43 ± 0.08 Gg yr^{-1} for Tennessee and Putnam county, respectively. The values obtained from this study are in close agreement to the ones reported by the Environmental Protection Agency's inventory on enteric methane in the United States obtained using the metabolizable energy intake data of nutrients fed to ruminants.

Introduction

Methane Production from Enteric Fermentation

$$CO_2 + 8H \rightarrow CH_4 + 2H_2O \text{ (methanogenesis)}$$

- Methane is produced as an end product of microbial fermentation of ingested feeds in the rumen.
- It is estimated that 2-12% of the total gross energy intake by cattle is converted into CH_4.
- The difficulties and complexities associated with the accurate determination of enteric CH_4 hinders the development of proper enteric CH_4 mitigation strategies.

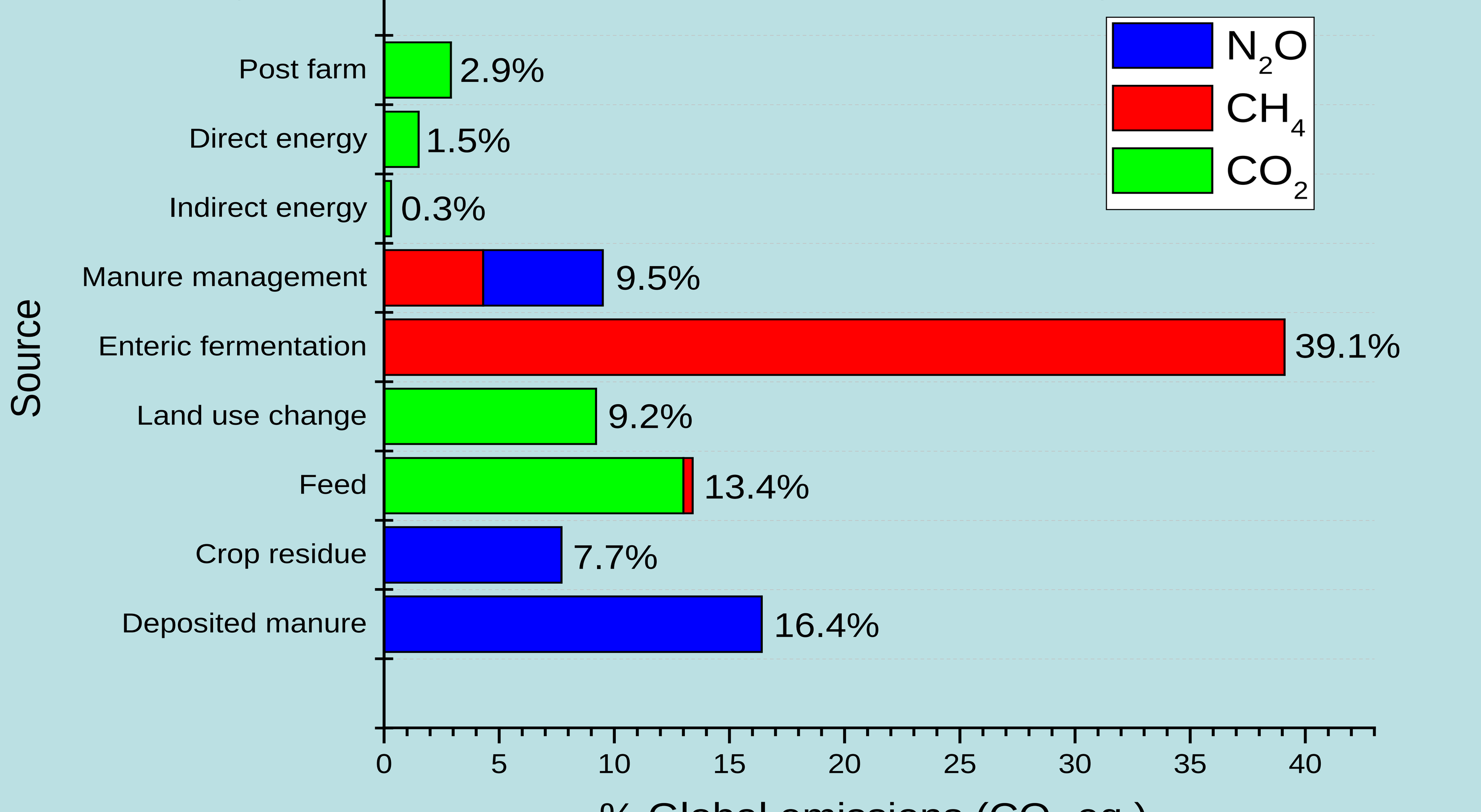

Figure 1: Percentage of global greenhouse gas emissions (CO_2 eq.) from different sources of livestock sector.

Techniques and Methods

Cavity Ring-Down Spectroscopic technique:-

- Simultaneous concentrations of CH_4 and CO_2 from beef cattle at Hyder-Burks pavilion.
- Background concentrations of CH_4 and CO_2 taken at the open field (figure 3).

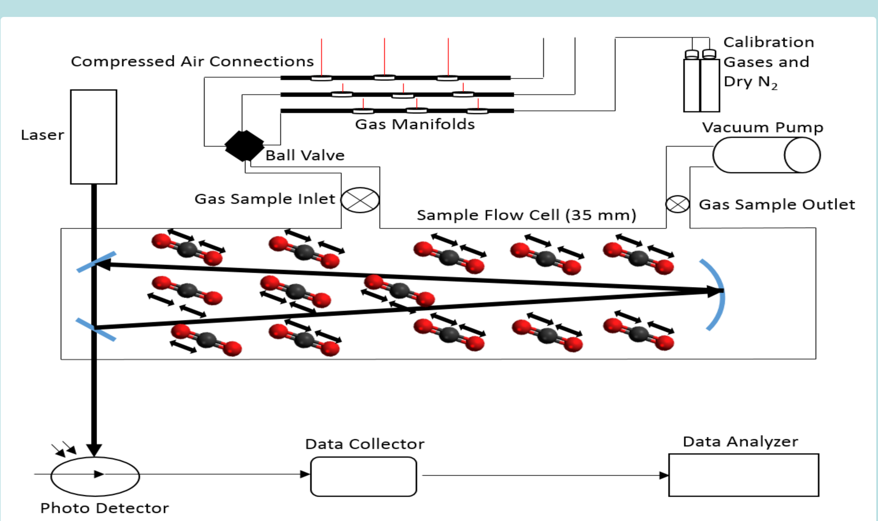

Figure 2: The schematic diagram of Cavity ring-down spectroscopy set-up and the associated components in the laboratory.

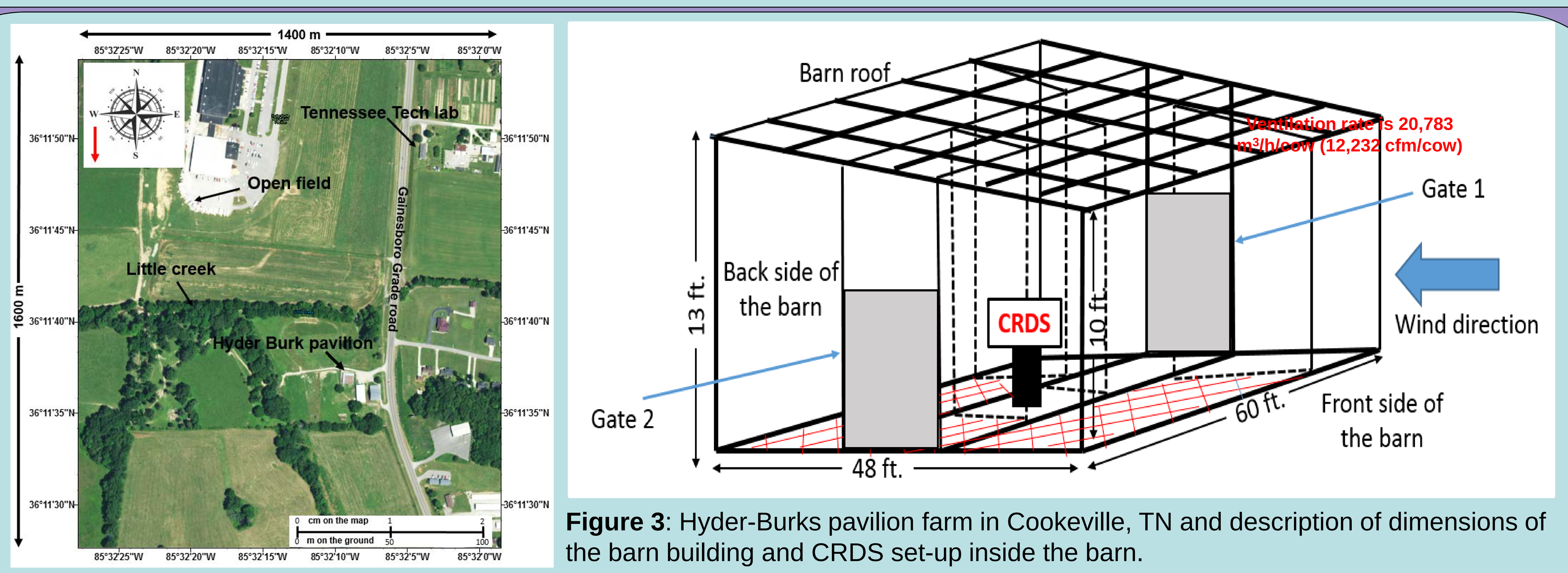

Figure 3: Hyder-Burks pavilion farm in Cookeville, TN and description of dimensions of the barn building and CRDS set-up inside the barn.

Results and Discussion

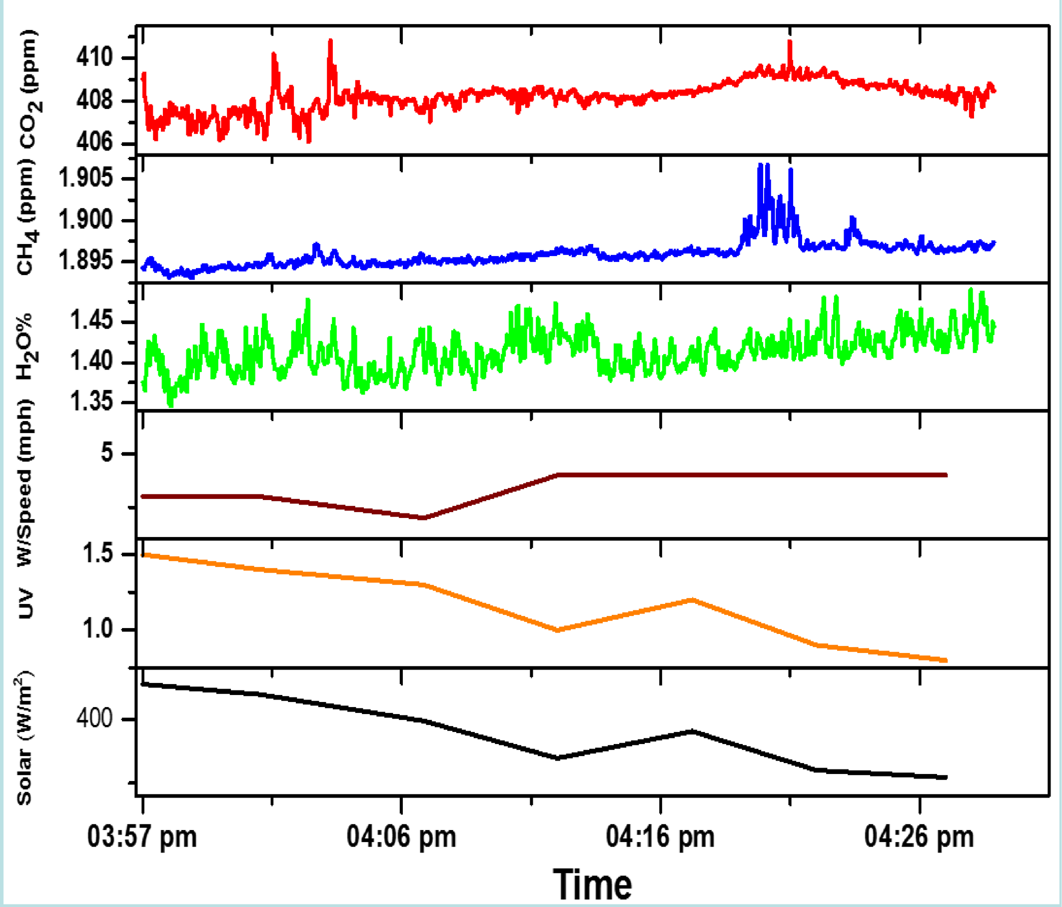

Figure 4: Ambient air measurements of CO_2, CH_4 and water vapor in an open field close to the livestock building where measurements were taken on 03/30/2017.

Table 1: Summary of daily average CH_4 and CO_2 mixing ratios observed at the feedlot (mean, standard deviation (std.), minimum (min.), maximum (max.), and number of data points of 5 sec. averages.

Day	No. of data points	CO_2 (ppm)				CH_4 (ppm)			
		Mean	Std.	Min.	Max.	Mean	Std.	Min.	Max.
1	24551	418.10	17.19	403.51	1047.08	2.515	1.418	1.891	74.311
2	19783	434.08	24.72	413.06	736.35	2.684	1.777	1.916	24.886
3	18512	416.86	23.15	404.88	817.85	2.353	1.730	1.932	46.149

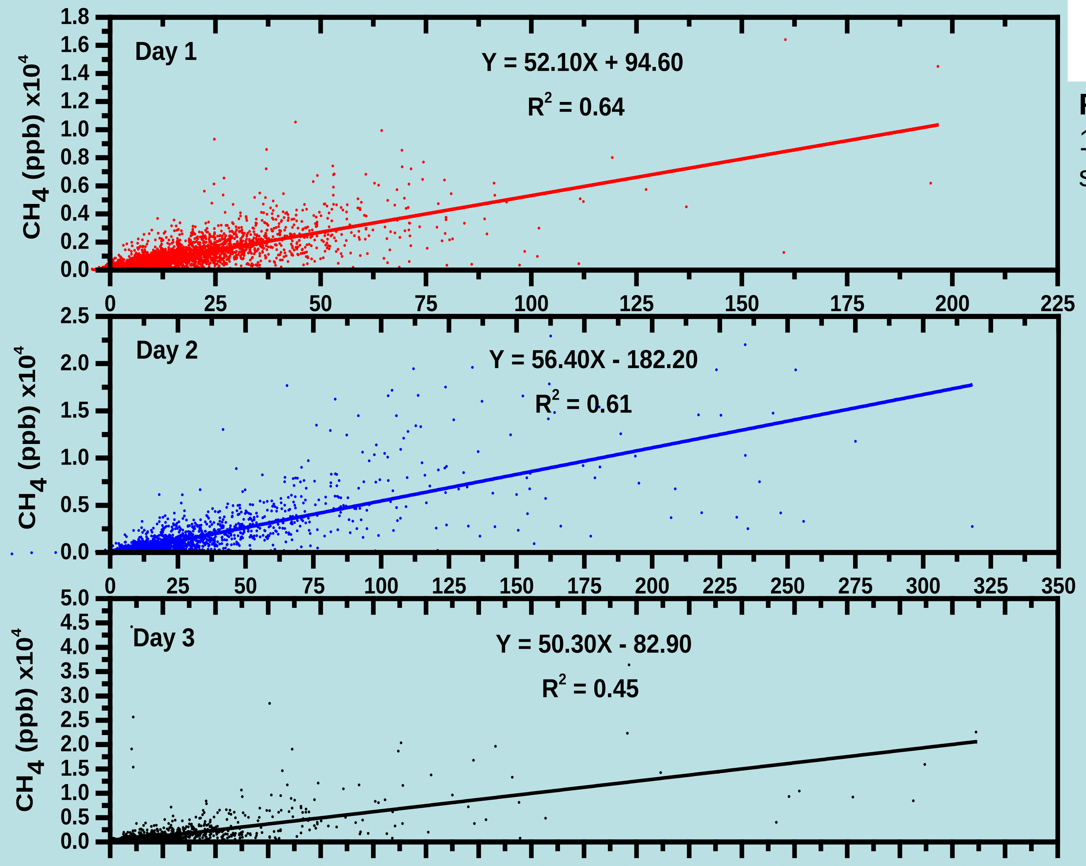

Figure 6: CH_4 above the baseline concentrations (ppb) vs CO_2 above the baseline concentrations (ppm) for Day 1, 2, and 3.

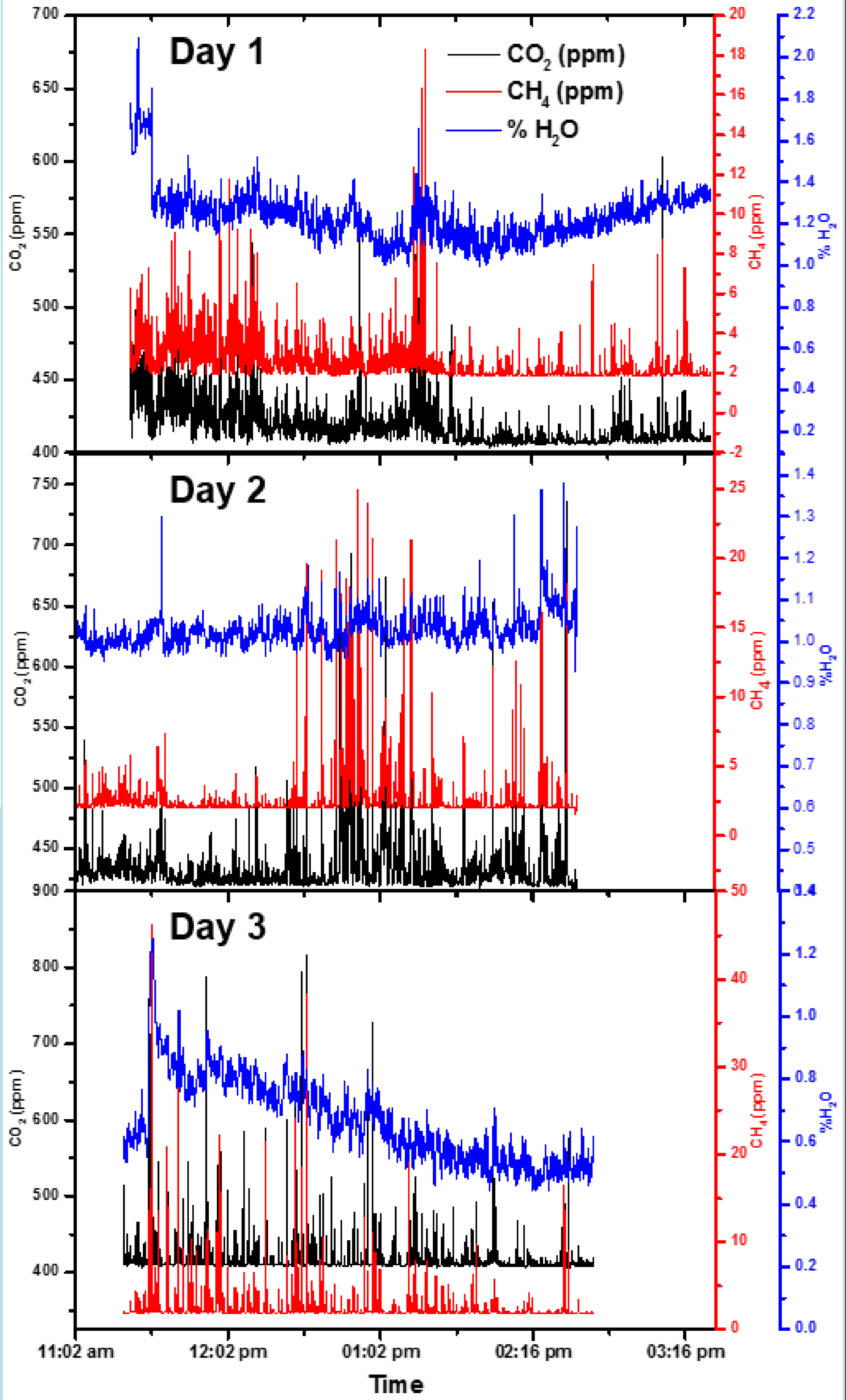

Figure 5: Ambient air measurements of CO_2, CH_4 on 03/30/2017 (day 1), 03/31/2017 (day 2) and 04/07/2017 (day 3) after background subtraction. In-situ % H_2O also included in blue color each day.

Table 2: Summary of hourly ratio averages and daily averages

0.5 hours average	1 hour average	2 hours average	Daily average
55.38 ± 2.77	62.63 ± 3.13	52.51 ± 2.62	52.11 ± 2.60
69.87 ± 3.49			
33.69 ± 1.68	42.40 ± 2.12		
51.12 ± 2.56			
127.20 ± 6.36	76.36 ± 3.82	54.21 ± 2.71	
25.52 ± 1.28			
28.09 ± 1.40	32.06 ± 1.60		56.36 ± 2.82
36.03 ± 1.80			
49.34 ± 2.47	40.53 ± 2.03	57.82 ± 2.89	
31.71 ± 1.59			
99.61 ± 4.99	75.11 ± 3.76		
50.62 ± 2.53			
22.39 ± 1.12	29.30 ± 1.47	42.52 ± 2.13	
36.22 ± 1.81			
34.07 ± 1.70	55.74 ± 2.79		50.31 ± 2.51
77.41 ± 3.87			
103.50 ± 5.18	73.31 ± 3.66	59.79 ± 2.99	
43.11 ± 2.16			
66.08 ± 3.30	46.06 ± 2.30		
25.40 ± 1.27			

- Average CH_4:CO_2 ratio is 0.053 ± 0.003 ppm/ppm).

CH_4 Production Estimation in Ruminants

CH_4:CO_2 Correlation

- Average background concentrations of both CH_4 and CO_2 each day was determined.
- CH_4 and CO_2 concentrations above the background were obtained after subtracting average background concentrations.
- CH_4:CO_2 ratio was determined using above background measurements in each day.

CH_4:CO_2 Ratio Technique

❖ CO_2 production (L day^{-1}) = HPU $animal^{-1}$ * 180 L CO_2 $HPU^{-1}h^{-1}$ *24

❖ CH_4 production (L day^{-1}) = CO_2 production (L day^{-1}) * CH_4:CO_2 ratio

- CO_2 production in ruminant was calculated using above standard equations.
- HPU was calculated using body weight of cow, Average milk production and average days of pregnancy per year.
- CH_4 production was calculated using experimentally determined average CH_4:CO_2 ratio.

Table 3: Calculated CO_2 and CH_4 production based on the heat produced per cow with different sizes, and daily average milk production.

CH_4:CO_2 ratio (ppm/ppm)	Body weight (kg)	Average milk production kg/day	Average days pregnant	HPU per animal	CO_2 production in the ruminants (L/day)	CH_4 production (L/cattle. Day)
0.100[1]	400	20	100	0.957	4134	413
	400	30	0	1.177	5084	508
	600	0	0	0.679	2933	293
	600	20	100	1.135	4903	490
	600	30	100	1.355	5853	585
	600	40	0	1.559	6734	673
	647	32	210	1.576	6810	681
0.099[2]	674	32	190	1.556	6724	668
0.060[3]	400	20	100	0.957	4134	248
	400	30	0	1.177	5084	305
	600	0	0	0.679	2933	176
	600	20	100	1.135	4903	294
	600	30	100	1.355	5853	351
	600	40	0	1.559	6734	404
0.053±0.003[4]	400	9	283	1.063	4592	243 ±14
	600	9	283	1.241	5361	284 ±16
	647	9	283	1.281	5533	293 ±17
	674	9	283	1.303	5630	298 ±17
	680	9	283	1.308	5651	299 ±17

- Total enteric CH_4 in Tennessee based on 1,720,000 cows = 117 ± 7 Gg yr^{-1}.[4,5]
- Total enteric CH_4 emission in Putnam County, TN based on 21,000 cows = 1.43 ± 0.08 Gg yr^{-1}.[4,5]

Conclusions and Future Directions

- The similarity between the total amount of enteric CH_4 predicted by EPA inventory and the value obtained from the present study indicate a promising future application of the CH_4:CO_2 ratio method in measuring enteric CH_4 from larger groups of livestock in the United States.
- Further refinement of these measurements are needed to obtain a 24-h pattern more precisely with known dry matter intake from the grazing cattle.

Selected References

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Acknowledgements

- Financial support from Tennessee tech Faculty start-up grant
- Faculty development grant from College of Arts and Science
- Support from Chemistry department, TTU