Rangeland Ecology & Management 93 (2024) 77–80

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: www.elsevier.com/locate/rama

Original Research

Snapshot of Enteric Methane Emissions from Stocker Cattle Grazing Extensive Semiarid Rangelands

Edward J. Raynor[1], Ashley Schilling-Hazlett[1], Sara E. Place[1], Juan Vargas Martinez[1], Logan R. Thompson[2], Melissa K. Johnston[3], Tamarah R. Jorns[3], Matthew R. Beck[4], Larry A. Kuehn[5], Justin D. Derner[6], Kimberly R. Stackhouse-Lawson[1,*]

[1] *AgNext and Department of Animal Sciences, Colorado State University, Fort Collins, CO 80523, USA*
[2] *Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS 66506, USA*
[3] *Rangeland Resources and Systems Research Unit, US Department of Agriculture–Agricultural Research Service, Nunn, CO, 80648, USA*
[4] *Livestock Nutrient Management Research Unit, US Department of Agriculture–Agricultural Research Service, Bushland, TX, 79012, USA*
[5] *Genetics and Animal Breeding Unit-Meat Animal Research Center, US Department of Agriculture–Agricultural Research Service, Clay Center, NE 68933, USA*
[6] *Rangeland Resources and Systems Research Unit, US Department of Agriculture–Agricultural Research Service, Cheyenne, WY 82009, USA*

A R T I C L E I N F O

Article history:
Received 5 December 2023
Accepted 5 January 2024

Key Words:
Animal origin
CH_4 emissions
Emission intensity
GHG mitigation strategies
Livestock grazing
Shortgrass steppe

A B S T R A C T

Enteric methane (CH_4) emissions from cattle grazing extensive semiarid rangelands are largely unknown and represent a considerable knowledge gap for the beef cattle industry. Knowledge of baseline enteric CH_4 emissions is beneficial for understanding the range of variability in individual animal emission production (g CH_4 head [hd]$^{-1}$ d^{-1}) and emission intensity (g CH_4 kg^{-1} average daily gain [ADG]$^{-1}$). Here, we used field-based technology to determine enteric CH_4 emissions from yearling steers grazing the North American shortgrass steppe in northeastern Colorado in midsummer 2022. Twenty-six animals were acclimated for 30 d (1–30 June) to the sampling equipment in the field before the measurement of emissions (1–31 July). Twelve (46%) yearling steers fully acclimated, with mean CH_4 emissions ranging from 113.3 to 261.7 g hd^{-1} d^{-1} across the sampling period. Daily CH_4 production values were 20% higher for steers ($n = 9$) from a local ranch compared with steers ($n = 3$) that originated from a mixed-grass prairie in south-central Nebraska (202.63 vs. 169.03 g CH_4 hd^{-1} d^{-1}). ADG of local steers was three times greater than their counterparts (0.54 vs. 0.18 kg hd^{-1} d^{-1}), resulting in lower emission intensity (g CH_4/ADG; emission intensity) from local steers compared with the naïve steers (237.6 vs. 418.5 emission intensity). In addition, we compared measured CH_4 emissions with predicted emissions calculated using the Intergovernmental Panel on Climate Change tier 2 methodology; measured emissions were 31% greater than predicted for the local steers and 18% greater than steers from nonlocal steers. Results indicate that further research addressing grazing animal enteric CH4 emissions in extensive rangelands is needed. Further, efforts should be context specific for comparative efforts across rangeland ecosystems and animal origin to inform more accurate assessments of sustainability of grazing beef cattle related to greenhouse gas mitigation strategies.

Introduction

Approximately 70–80% of the US beef industry's greenhouse gas (GHG) emissions result from pastoral-based systems, namely because of the cow-calf and stocker sectors' enteric methane (CH_4) emissions. These sectors have relatively large enteric CH_4 emissions due to high forage diets and relative inefficiency of production compared with more confined operations further down the US supply chain (Rotz et al. 2019). The US Environmental Protection Agency estimates enteric CH_4 emissions from US beef cattle following Intergovernmental Panel on Climate Change tier 2 methodology recommendations (IPCC 2019), which accounts for dry matter intake (DMI), digestibility of feeds, and CH_4 yield per unit of gross energy the animal consumes. Enteric CH_4 emission estimates from extensively grazed beef cattle in semiarid environments are severely lacking in the literature. This means that es-

* Correspondence: K. R. Stackhouse-Lawson, AgNext and Dept of Animal Sciences, Colorado State University, Fort Collins, CO 80523, USA.

E-mail address: kim.stackhouse-lawson@colostate.edu (K.R. Stackhouse-Lawson).

https://doi.org/10.1016/j.rama.2024.01.001

timates derived from the IPCC tier 2 methodology are based on data from other systems, instead of using location-specific information (Thompson and Rowntree 2020). In fact, when examining publicly available regionally specific emissions, the estimates from rangeland-based production regions have remained largely static in the past decade. Thus, there is an emergent need to quantify enteric CH_4 emissions from cattle grazing semiarid rangelands to provide baseline values to develop more accurate location-specific prediction equations and GHG mitigation strategies.

Cattle are selective grazers in extensive rangeland systems (Provenza and Balph 1987). Their foraging decisions can influence individual DMI and the quality of selected diets, resulting in different enteric CH_4 emissions. In contrast to well-known intake and diet quality attributes of pen-fed cattle (Cordova et al. 1978), free-ranging livestock intake amounts, dietary quality, and CH_4 emission at the individual animal level remain difficult to quantify (Arndt et al. 2022). Experienced cattle are expected to employ more efficient forage selection tactics than naïve animals (Ganskopp and Cruz 1999), potentially modifying CH_4 emissions. Research efforts designed to capture the range of variability in individual absolute CH_4 production (g CH_4 hd^{-1} d^{-1}), emission intensity (EI; g CH_4 per kg^{-1} average daily gain $(ADG)^{-1}$, and CH_4 yield (g CH_4 kg^{-1} DMI) would be beneficial to encompass the inherent differences among grazing animals, due to their individual intake and selected diet quality.

To begin to address this gap in knowledge, we used field-based technology to determine enteric CH_4 emissions from naïve and local yearling steers grazing the North American shortgrass steppe. We measured individual steer ADG and enteric CH_4 emissions to provide CH_4 production, CH_4 intensity, and CH_4 yield values. This work represents an initial pilot study to obtain more accurate measured baseline CH_4 emissions for free-ranging yearling steers grazing extensive rangeland.

Methods

Study area

This study was conducted at the US Department of Agriculture (USDA)–Agricultural Research Service (ARS) Central Plains Experimental Range (CPER) near Nunn, Colorado, United States (40°50′N, 104°43′W), which is a USDA Long-Term Agroecosystem Research site. This pilot study was conducted in a single, moderately stocked 129-ha pasture dominated by the Sandy Plains ecological site (Ecological Site ID: R067BY024CO), where C_3 midheight grasses (western wheatgrass *[Pascopyrum smithii]* and needle-and-thread *[Hesperostipa comata]*) dominate with blue grama *(Bouteloua gracilis)* as subdominant species and a sparse shrub layer of fourwing saltbush *(Atriplex canescens)* present (USDA 2007). Herbaceous biomass (forage) production for the 2022 season, calculated using the methodology of Kearney et al. (2022), was 317 kg DM ha^{-1}. Due to drought, this value represents one third of the expected forage production, which was also responsible for the short duration of emissions data collected in this experiment.

Livestock

All research followed the Institutional Animal Care and Use Committee protocol (CPER#9) approved March 2022 by the USDA–ARS in Nunn, Colorado.

Twenty-six yearling steers grazed the pasture from May 23 to July 31, with the grazing season shortened from a typical October exit. Nineteen steers (initial entry shrunk body weights of 285.9 ± 23.8 kg) were from a local ranch, and seven steers (initial entry shrunk BW of 348.9 ± 61.8 kg) naïve to the shortgrass steppe were from a red composite (1/4 Angus, 1/4 Hereford, 1/4 Simmental, 1/4 Gelbvieh) herd originating at the USDA-ARS, US Meat Animal Research Center in south-central Nebraska. Yearlings were individually weighed at the beginning (16 May) and end (29 July) of the growing season, as well as 2 wk (16 June) before the start of the emissions measurement trial (1 July) and 28 d later (14 July). A shrink adjustment (e.g., ~7–9%) was applied to each steer weight (Derner et al. 2016). Diet quality was assessed weekly through the collection of fecal samples collected directly after defecation; composite samples contained subsamples of fresh fecal pats from four individual steers of each origin. Samples were analyzed by the Grazingland Animal Nutrition Laboratory (Texas A&M University, Temple, Texas, United States) for fecal crude protein (fCP) using near-infrared reflectance spectroscopy.

Figure 1. Yearling steer using automated head chamber system (GreenFeed, C-Lock Inc., Rapid City, SD) on native shortgrass steppe rangeland near Nunn, Colorado, United States. (Photo credit: Inés Mesa.)

Emissions measurements

Enteric CH_4 emissions were estimated using the Automated Head Chamber System (AHCS; GreenFeed, C-Lock Inc., Rapid City, SD), which was located adjacent to the single water tank in the pasture (Figure 1). The AHCS is an automated system to monitor gas fluxes from the breath of individual ruminant animals. Individual animals identified by RFID ear tags were acclimated to the AHCS for 30 d (1–30 June) in the study pasture before the emissions measurement trial period, which lasted 31 d (1–31 July). Animals were allowed a maximum of six AHCS visits daily, with eight 35 g bait pellet drops per visit and a drop dispense interval of 30 sec. This schedule was set to encourage animals to remain in the partially enclosed chamber for a minimum of 3 min, as Velazco et al. (2016) recommended. This time represents a "good" visit that captures several eructation events. Visits $<$ 3 min were removed from analyses.

Absolute enteric CH_4 production values were estimated using the AHCS. Emission intensity was calculated for individual animals using the shrunk weights before and near the terminus of the emissions measurement trial period. Individual BW and ADG were used to parameterize a forage intake model for predicting DMI of grazing steers (Minson and McDonald 1987). CH_4 yield was calculated by dividing daily CH_4 production by predicted DMI.

Statistical analysis

To determine potential differences in ADG, absolute CH_4 production, EI, and CH_4 yield between the two steer origins, we analyzed the variance of individual steer means using the *aov* function in R (R Development Core Team 2023). We assessed normality, equality of variance, and independence among samples before conducting analysis of variance; all assumptions necessary to conduct ANOVA were met. To account for the difference in entry weight of steers of each origin, we included initial body weight (IBW) as a covariate in each model. Models included origin and IBW as fixed effects. The ADG was calculated using each weight collected from the midpoint of the acclimation period (6/16) to the final weight of the season (7/29) via linear regression. To evaluate whether emissions changed over the measurement period, linear regression was used to regress absolute CH_4 emissions over day of measurement.

Results

Visitation

Twelve of 26 steers (nine local and three naïve) voluntarily used the AHCS during the 30-d acclimation period (1–30 June), and they continued use during the 31-d emissions trial period (1–31 July). All visits occurred during daylight hours, spanning 0700–2100. The number of "good" visits per individual did not differ by origin ($P = 0.69$; Table 1), nor did the time of day that visits occurred ($P = 0.44$; Figure 2), indicating equitable visitation behavior among steers of different origins.

Weight gains and enteric emissions

Initial BW at the midpoint of the acclimation phase was 10% greater for naïve steers than locally sourced steers ($P = 0.04$; see Table 1). Predicted DMI did not differ ($P = 0.41$). Intake of AHCS bait pellet did not differ among origins ($P = 0.85$). In addition, fecal CP was 8% greater for local than naïve yearling steers ($P = 0.04$). Weight gains during the emissions measurement period were greater for local steers (mean ± SE; 23.03 ± 3.45 kg^{-1}) than naïve steers (6.19 ± 5.98 kg^{-1}; $P = 0.03$), resulting in three times greater ADG ($P = 0.03$). After accounting for initial BW, final BW of local steers was 3% greater than naïve steers.

Absolute enteric CH_4 production did not show a trend of increasing or decreasing from the start to the end of the 31-d emissions measurement trial ($P = 0.47$), nor did steer origin interact with day ($P = 0.43$). Absolute CH_4 production across the trial period was 20% greater for local steers ($P = 0.04$). Due to the greater ADG of local steers, EI was 43% lower for local than naïve steers ($P = 0.04$; see Table 1). CH_4 yield did not differ among origins ($P = 0.18$). Using IPCC (2019) methodology, predicted absolute CH_4 production values were 25% less, on average, than our in-field measurements.

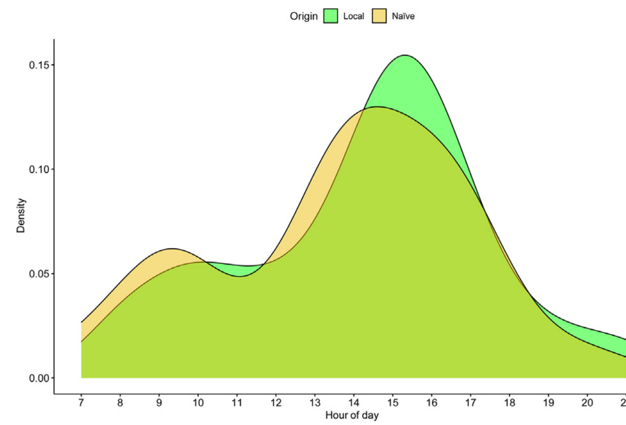

Figure 2. Density plot of automated head chamber system visitation for local and naïve yearling steers during the 2022 grazing season in sandy plains (Ecological Site ID: R067BY024CO) pasture at the US Department of Agriculture–Agricultural Research Service Central Plains Experimental Range near Nunn, Colorado, United States.

Table 1
Mean (±standard of error) of automatic head chamber system (AHCS) visitation, animal performance, fecal protein, dry matter intake (DMI) predicted (Minson and McDonald [1987]), and enteric methane (CH_4) emissions for experienced (local) and nonlocal (naïve) yearling steers during the 2022 grazing season (1–31 July) on a sandy plains (Ecological Site ID: R067BY024CO) pasture at the US Department of Agriculture–Agricultural Research Service Central Plains Experimental Range near Nunn, Colorado, United States. Statistics for yearling steers that acclimated to the AHCS are presented.

Metric	Local ($n = 9$)	Naïve ($n = 3$)	F	P
AHCS visits (n individual)	9.4 (1.0)	8.7 (1.2)	0.164	0.69
Initial body weight (kg)	332.08 (9.20)	375.69 (15.94)	5.62	**0.04**
Final body weight (kg)	364.32 (3.53)	354.24 (6.85)	16.29	**0.003**
Fecal crude protein (%)	8.7 (0.15)	8.0 (0.28)	5.66	**0.04**
Average daily gain (ADG; kg)	0.54 (0.07)	0.18 (0.12)	6.12	**0.03**
Live weight gain (kg $period^{-1}$)	23.03 (3.45)	6.19 (5.98)	5.94	**0.03**
Total DMI (kg d^{-1})	7.35 (0.17)	6.85 (0.34)	0.45	0.52
Forage DMI (kg d^{-1})	7.04 (0.17)	6.54 (0.33)	0.44	0.53
AHCS bait pellet DMI (kg d^{-1})	0.31 (0.03)	0.31 (0.06)	0.04	0.85
CH_4 production (g hd^{-1} d^{-1})	202.63 (7.28)	169.03 (12.62)	5.31	**0.04**
CH_4 intensity (g CH_4 kg^{-1} ADG)	237.56 (39.88)	418.52 (69.07)	5.15	**0.04**
CH_4 yield (g kg^{-1} DMI)	29.25 (1.39)	25.26 (2.41)	2.05	0.18

Discussion

This work provides a snapshot of enteric CH_4 emissions from free-ranging livestock grazing in semiarid rangelands during drought conditions. CH_4 production did not increase or decrease over the July sampling period; however, CH_4 production and EI differed between local and naïve origin steers. Local steers showed greater fecal crude protein concentration than naïve animals, suggesting the selection of forages with greater nutritive value. Thus, it is expected that improved diet quality promoted greater rumen fermentation and increased CH_4 production (Beauchemin et al. 2022). However, improving the nutritive value of the diet resulted in greater ADG and lower EI. Differential responses of CH_4 production and EI by the local and naïve steers demonstrate the need to measure both emissions and performance (i.e., weight gains) of individual animals.

This pilot study incorporated elements of a common garden plant experiment for the fields of rangeland animal science and sustainability by comparing different strains, families, or populations under identical environmental conditions (de Villemereuil et al. 2016). Our data suggest the need to be cognizant of differences in local and nonlocal grazing animals regarding reducing enteric CH_4 emissions in extensive grazing lands. Mechanistic explanations for observed differences in EI may include different rumen microbiome communities, animal genetic backgrounds, foraging strategies, and natal and learning behaviors (Launchbaugh and Provenza 1991).

Difficulty in obtaining emissions measurements for free-ranging livestock was also observed in this pilot study. Studies of grazing cattle in small pasture settings demonstrate a range of 10 to 38 "good" visits to the AHCS can be employed to test treatment differences for emissions production (Dressler et al. 2023). Gunter and Beck (2018) state forage rich in moisture can cause cattle not to water every day and concomitantly not use the AHCS; thus, it was a surprise that steers did not visit more often than we observed in this dry year. Moreover, this investigation demonstrates the difficulty in obtaining sufficient visits to describe the full

24-h emission cycle, as seen in confined settings (e.g., Manafiazar et al. 2017). While we desired to space out visits equally across a 24-h period, the diurnal pattern of enteric CH_4 emissions for steers grazing rangelands is not as significant as meal-fed cattle (Gunter and Beck 2018). We suggest future investigations of cattle emissions test alternative placement and experimentation with the spatial arrangement of AHCSs on rangeland. For instance, placing the AHCS under a shade source may result in more adequate visitation.

Implications

Measurements of only enteric CH_4 emissions for these yearling steers grazing shortgrass steppe would have resulted in findings lacking appropriate context. Local steers did have higher CH_4 production than naïve steers, but their performance was also much higher, resulting in lower EI, which is critical for ensuring food security. For the beef industry, knowledge of both CH_4 production and the performance of individual animals would benefit selection efforts for animals that fit the environment and/or production phase by being low emitters or high performers, or ideally both. While absolute emissions were low for naïve steers, their low performance in this rangeland system would not allow for an economically competitive stocker cattle operation.

Funding

Funding was received through the Western Sustainable Agriculture Research and Education (project GW22-232) grant program and Colorado State University AgNext. This research was a contribution from the Long-Term Agroecosystem Research (LTAR) network, which is supported by the US Dept of Agriculture (USDA). The USDA—Agriculture Research Service, Plains Area, is an equal opportunity/affirmative action employer, and all agency services are available without discrimination. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US government.

Declaration of Competing Interest

All authors acknowledge no conflict of interest is present in this manuscript.

Acknowledgments

We gratefully acknowledge the technical and logistical support from Jake Thomas, Matt Mortenson, and numerous student workers. The Crow Valley Livestock Cooperative Inc. and the USDA-Meat Animal Research Center provide yearling cattle.

References

Arndt, C., Hristov, A.N., Price, W.J., McClelland, S.C., Pelaez, A.M., Cueva, S.F., Oh, J., Dijkstra, J., Bannink, A., Bayat, A.R., Crompton, L.A., Eugène, M.A., Enahoro, D., Kebreab, E., Kreuzer, M., McGee, M., Martin, C., Newbold, C.J., Reynolds, C.K., Schwarm, A., Shingfield, K.J., Veneman, J.B., Yáñez-Ruiz, D.R., Yu, Z., 2022. Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 °c target by 2030 but not 2050. Proceedings of the National Academy of Sciences 119 (20), e2111294119.

Beauchemin, K.A., Ungerfeld, E.M., Abdalla, A.L., Alvarez, C., Arndt, C., Becquet, P., Benchaar, C., Berndt, A., Mauricio, R.M., McAllister, T.A., Oyhantçabal, W., Salami, S.A., Shalloo, L., Sun, Y., Tricarico, J., Uwizeye, A., De Camillis, C., Bernoux, M., Robinson, T., Kebreab, E., 2022. Invited review: current enteric methane mitigation options. Journal of Dairy Science 105 (12), 9297–9326.

Cordova, F., Wallace, J.D., Pieper, R.D., 1978. Forage intake by grazing livestock: a review. Journal of Range Management 31 (6), 430–438.

de Villemereuil, P., Gaggiotti, O.E., Mouterde, M., Till-Bottraud, I., 2016. Common garden experiments in the genomic era: new perspectives and opportunities. Heredity (Edinb) 116 (3), 249–254.

Derner, J.D., Reeves, J.L., Mortenson, M.C., West, M., Gonzalo Irisarri, J., Durante, M., 2016. Estimating overnight weight loss of corralled yearling steers in semiarid rangeland. Rangelands 38 (3), 101–104.

Dressler, E.A., Bormann, J.M., Weaber, R.L., Rolf, M.M., 2023. Characterization of the number of spot samples required for quantification of gas fluxes and metabolic heat production from grazing beef cows using a greenfeed. Journal of Animal Science 101.

Ganskopp, D., Cruz, R., 1999. Selective differences between naive and experienced cattle foraging among eight grasses. Applied Animal Behaviour Science 62 (4), 293–303.

Gunter, S.A., Beck, M.R., 2018. Measuring the respiratory gas exchange by grazing cattle using an automated, open-circuit gas quantification system. Translational Animal Science 2 (1), 11–18.

IPCC, 2019. Chapter 10: emissions from livestock and manure management Available at:. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch10_Livestock.pdf (Accessed 2 December 2023).

Kearney, S.P., Porensky, L.M., Augustine, D.J., Gaffney, R., Derner, J.D., 2022. Monitoring standing herbaceous biomass and thresholds in semiarid rangelands from harmonized landsat 8 and sentinel-2 imagery to support within-season adaptive management. Remote Sensing of Environment, 271112907.

Launchbaugh, K.L., Provenza, F.D., 1991. Learning and memory in grazing livestock application to diet selection. Rangelands 13 (5), 242–244.

Manafiazar, G., Zimmerman, S., Basarab, J.A., 2017. Repeatability and variability of short-term spot measurement of methane and carbon dioxide emissions from beef cattle using greenfeed emissions monitoring system. Canadian Journal of Animal Science 97 (1), 118–126.

Minson, D., McDonald, C., 1987. Estimating forage intake from the growth of beef cattle. Tropical Grasslands 21 (3), 116–122.

Provenza, F., Balph, D., 1987. Diet learning by domestic ruminants: theory, evidence and practical implications. Applied Animal Behaviour Science 18 (3—4), 211–232.

R Development Core Team, 2023. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rotz, C.A., Asem-Hiablie, S., Place, S., Thoma, G., 2019. Environmental footprints of beef cattle production in the united states. Agricultural Systems 1691–1713.

Thompson, L.R., Rowntree, J.E., 2020. Methane sources, quantification, and mitigation in grazing beef systems. Applied Animal Science 36 (4), 556–573.

USDA, 2007. Ecological site description for Sandy Plains (r067by024co) Available at:. https://edit.jornada.nmsu.edu/catalogs/esd/067B/R067BY024CO (Accessed 2 December 2023).

Velazco, J.I., Mayer, D.G., Zimmerman, S., Hegarty, R.S., 2016. Use of short-term breath measures to estimate daily methane production by cattle. Animal 10 (1), 25–33.