Thekkoot, D., Gillespie, J., Powell, T., Osterstock, J. (2026) Scaling methane phenotyping in beef cattle: integrating high-throughput methane sensors into feed intake nodes for simultaneous measurement of methane and feed intake, *Proceedings 13th World Congress on Genetics Applied to Livestock Production* 23496: https://doi.org/10.31274/wcgalp.23496

Scaling methane phenotyping in beef cattle: integrating high-throughput methane sensors into feed intake nodes for simultaneous measurement of methane and feed intake

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Introduction

Livestock produce methane by anaerobic fermentation in the rumen and release it mainly by eructation and respiration. Reducing these emissions has the potential to lower the environmental impact of beef production. Methane production in beef cattle is moderately heritable (0.27; Donoghue *et al*., 2016), making genetic selection a viable mitigation strategy. However, an effective genetic selection program requires high-throughput phenotyping systems capable of measuring methane emissions on large number of animals under commercial conditions. Automated spot-sampling systems based on voluntary animal visits have been used in phenotyping beef cattle. However, this approach can result in variable visitation patterns, uneven data capture and participation bias (Manafiazar *et al*., 2016). In addition, dedicated methane measuring equipment can increase capital costs and technical complexity.

Traditionally methane is measured as methane production in g/d. Measuring methane concentration (parts per million, ppm) in expired gases provides a practical alternative as it is highly genetically correlated with methane production (0.76; van Breukelen *et al*., 2023). Feed intake is a key driver of methane emissions in beef cattle and is strongly genetically correlated with methane production (0.84; Donoghue *et al*., 2016). This highlights the importance of high-throughput phenotyping of both traits for improving the accuracy of genetic evaluation programs targeted for reducing emission, particularly in the context of animal performance and efficiency of production.

Integrating methane sensors into automated feed intake nodes addresses these constraints by measuring methane concentrations during natural feeding events. To test this approach, we installed methane sensors developed by Integrity Communication Solutions Ltd., CO, USA along with Vytelle SENSE™ feed intake nodes.

The objective of this study was to evaluate the performance of integrated methane concentration and feed intake phenotyping systems under commercial settings. Specifically, we aimed to: 1) characterize the methane concentration phenotypes in growing beef cattle; 2) determine the measurement duration required to achieve a target phenotypic accuracy; and 3) assess the biological validity through correlations with average daily feed intake in two independent production environments.

Materials & Methods

Methane Measurement System. The Methane concentration was measured using the Methane Remote Gas Evaluator (Integrity Communications Solutions Inc., CO, USA), which utilizes nondispersive infrared (NDIR) detection via a mid-infrared LED and a photovoltaic detector (range: 15 to 5,000 ppm). A pump was used to draw air from an inlet installed on the feed bunk through a dual-filtration system. The sample chamber was calibrated every 60 min using ultra-high pure nitrogen. Methane concentration was calculated based on the attenuation of infrared light intensity relative to the nitrogen baseline. The methane sensors were mounted on the Vytelle SENSE feed intake nodes. Each feed intake node consists of a feed bunk mounted on a load cell that records weight at 1 second intervals. Radio frequency identification (RFID) technology continuously reads the animal identification every second while an animal is present at the feed intake node. A feeding event was defined as the continuous period during which an individual animal was detected at a feeding node by RFID, from first detection (arrival) to the last detection (departure). When an animal is detected, the RFID system triggers the methane sensor and transmits the animal's electronic identification to link the methane measurement to the individual animal. The methane sensor then initiates air sampling and continues measuring at intervals throughout the feeding event, capturing multiple methane concentration measurements during the periods of active feed consumption. Feed consumed during each feeding event was calculated as the difference between bunk weight at arrival and bunk weight at departure. Daily feed intake for each animal was calculated as the sum of feed consumed across all feeding events across all feeders in a 24-hour period.

Animals and Experimental Design. Two trials were conducted using sequential versions of the methane sensor. A first-generation sensor was used at a commercial facility (Alberta, Canada) with 44 Hereford heifers (395 ± 7.9 d of age; 320 ± 21.4 kg BW) for 37 d (March–April 2025). An updated version was used at West Virginia University (WVU; Wardensville, WV, USA) with 34 Charolais bulls (313 ± 19.1 d of age; 434 ± 51 kg BW) for 50 d (August–October 2025). Animals were group housed in a single pen with ad libitum access to water and a corn silage-based total mixed ration. WVU had 6 feed intake nodes (4 with methane sensors) and the commercial facility had 5 nodes (3 with methane sensors) in the pen. Feed delivery at WVU occurred predominantly once a day, typically between 0700 and 1100 h, while the commercial facility followed a twice-daily feeding schedule, typically between 0400 to 0700 h and 1800 to 2100 h. As the animals were part of an independent feed efficiency trial, actual delivery times varied and were subject to daily facility management and operational requirements.

Data Processing and Quality Control. Raw methane data consisted of multiple concentration measurements in ppm, collected at 10 second intervals during each feeding event. Feeding events with methane measurement gaps >180 seconds was split into sub-events. Qualifying events required a duration ≥ 60 seconds and ≥ 4 methane readings. Biologically implausible measurements, including negative values and extreme outliers, were removed. For each qualifying feeding event, the methane emission was quantified as the area under the curve (AUC) per second, which represents the average methane concentration throughout the event, calculated by integrating methane concentration over time and dividing by duration of the event. Outliers were removed at the animal-node level using the median absolute deviation method. Animals with fewer than 150 qualifying feeding events were also excluded from the final analysis.

Statistical Analysis. Animal-level methane phenotypes were estimated using a linear mixed model in R (lme4 package) separately for each facility. The model included AUC per second as the response variable, with fixed effects for methane sensor, day of trial, and hour of day, and a random effect for animal. Individual animal methane phenotypes were derived by adding the best linear unbiased predictions (BLUPs) of the animal effects to the respective population mean. Repeatability was estimated as the proportion of total phenotypic variance attributable to animal. The duration required to achieve specific phenotypic accuracy was calculated based on these repeatability estimates as described by MacNeil and Waterman (2025).

Results & Discussion

After quality control, the dataset used for estimating methane phenotypes included 15,026 feeding events from WVU and 10,257 from the commercial facility. All 34 WVU animals met the inclusion threshold (≥ 150 events), whereas only 28 of 44 animals at the commercial facility were retained. The lower retention rate at the commercial facility was likely due to the combination of the shorter trial duration (37 vs. 50 days), the use of first-generation sensors and fewer methane sensor nodes per animal, all of which reduced each animal's opportunity to accumulate qualifying feeding events. Mean methane phenotypes were 170.2 ± 7.7 ppm at WVU and 119.5 ± 5.8 ppm at the commercial facility. These values were lower than the 325 ± 251 ppm reported in dairy cattle (van Breukelen *et al*., 2023); a similar trend was observed in methane production rates, which were significantly higher in lactating dairy cows (436±120 g/d; van Breukelen *et al*., 2023) compared to growing beef cattle (132±25.4 g/d; Donoghue *et al*., 2016). Differences in mean methane concentration between trials at the two sites could be associated with differences in average intake, body weight, breed, diet or sensor performance. Based on repeatability estimates, individual animal methane phenotypes required 28 d (WVU) and 30 d (commercial facility) to achieve an accuracy of 0.80. These estimates were based on an average of 9.6 and 6.6 qualifying feeding events per animal per day, respectively. In contrast, MacNeil and Waterman (2025) reported that 45 days were required to achieve comparable accuracy in beef heifers using the flux method. The shorter measurement period in the present study is likely due to the increased data density. By integrating methane sensors directly into Vytelle SENSE feed intake nodes, we captured methane data during every meal, whereas flux-based systems require animals to visit a separate station specifically for methane measurement.

Diurnal methane patterns, expressed as hourly least squares means, varied by site (Fig. 1). Emissions peaked at 1100 h at WVU, while the commercial facility showed bimodal peaks at 0500 h and 2100 h, aligning with the respective feeding regimes.

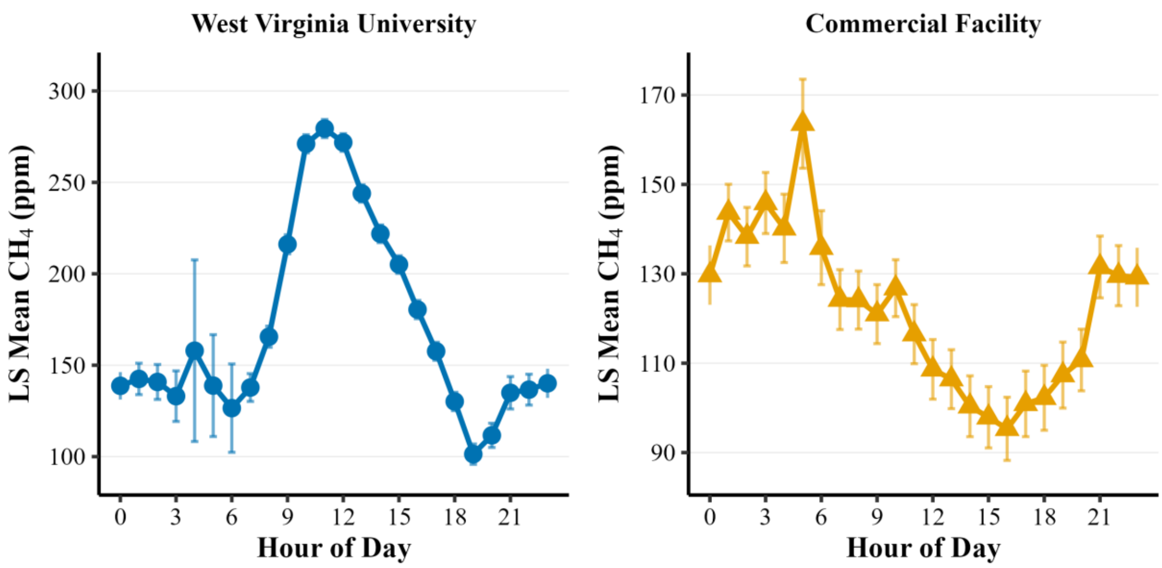

Figure 1. Hourly pattern of methane emissions (least squares mean ± SE) at West Virginia University and commercial facility.

Methane phenotypes were positively correlated with ADFI at both facilities (Fig. 2). At WVU, the Pearson correlation was 0.47 (95% CI: 0.16 to 0.70; $P < 0.01$), which is higher than the 0.31 reported by Ryan *et al*. (2022) in beef cattle. At the commercial facility, the relationship followed a similar positive trend (0.26; $P = 0.19$) but exhibited greater individual variability.

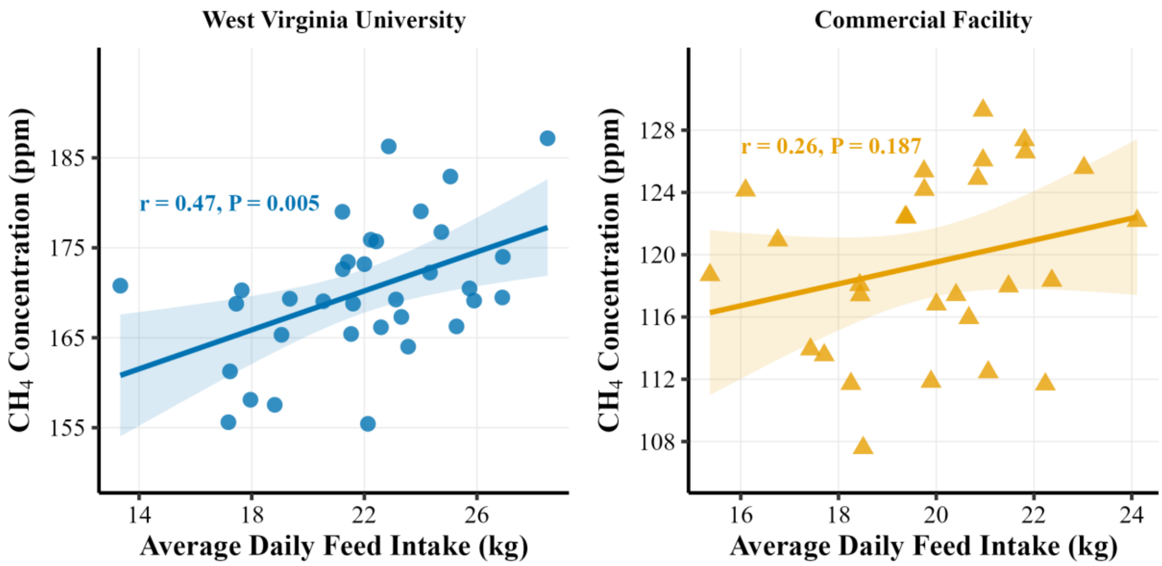

Figure 2. Relationship between methane phenotype and average daily feed intake at West Virginia University and a commercial facility.

Conclusions

In conclusion, integrating high-throughput methane sensors into automated feed intake nodes provides a scalable and practical framework for genetic evaluation of methane emissions in beef cattle. By capturing methane and feed intake measurements simultaneously during every natural feeding event, this system addresses the major limitations of traditional flux-based approaches—including high equipment costs, participation bias from "shy" animals, and the logistical challenges of managing voluntary-visit stations. The high data density achieved by recording every meal, rather than relying on intermittent visits, enabled phenotypic accuracy of 0.80 within 30 days of measurement. This integrated approach delivers a high-throughput, high-density feed and methane data required to calculate accurate breeding values in beef cattle, enabling selection for animals that are both feed-efficient and environmentally sustainable at a commercial level.

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