Effect of concentrate level on enteric methane emissions, production performance, and rumen fermentation of Jersey cows grazing kikuyu-dominant pasture during summer

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ABSTRACT

The effect of concentrate feeding level on enteric CH₄ emissions from cows grazing medium quality summer pasture is yet to be investigated. Sixty multiparous Jersey cows (9 rumen-cannulated) were used in a randomized complete block design study (with the cannulated cows in a 3 × 3 Latin square design) to investigate the effect of concentrate feeding level (0, 4, and 8 kg/cow per day; as-fed basis) on enteric CH₄ emissions, production performance, and rumen fermentation of dairy cows grazing summer pasture (17 cows plus 3 cannulated cows per treatment). Enteric CH₄ emissions were measured from 11 cows per treatment group during one 7-d measurement period using the sulfur hexafluoride tracer gas technique. Pasture dry matter intake (DMI) was determined parallel with the CH₄ measurement period using TiO₂ as an external marker, and milk yield, milk composition, cow condition, and pasture pre- and postgrazing measurements were also recorded. Daily total DMI (11.2 to 15.6 kg/cow), milk yield (9.1 to 18.2 kg/cow), energy-corrected milk (ECM; 11.2 to 21.6 kg/cow), and milk lactose content (44.1 to 46.7 g/kg) increased linearly, whereas pasture DMI (11.2 to 8.4 kg/cow) decreased linearly with increasing concentrate feeding level. Daily CH₄ production (323 to 378 g/d) increased linearly due to the increase in total DMI, whereas CH₄ yield (29.1 to 25.1 g/kg of DMI) and CH₄ intensity (35.5 to 21.1 g/kg of milk yield; and 28.8 to 17.6 g/kg of ECM) decreased linearly with increasing concentrate feeding level. Diurnal ruminal pH (6.45 to 6.32) and in sacco DM and neutral detergent fiber disappearance decreased linearly. Acetic and propionic acid were unaffected by treatment, whereas butyric acid (5.21 to 6.14 mM) increased linearly and quadratically with increasing concentrate feeding level. It was concluded that a high concentrate feeding level

not only increases animal efficiency but is moreover a viable CH₄ mitigation option for dairy cows grazing kikuyu-dominant pasture in late summer when pasture is inherently fibrous.

Key words: pasture-based, methane mitigation, SF₆, tropical pasture

INTRODUCTION

Climate change transforms and threatens current and future global natural resources. Globally, the livestock sector is responsible for approximately 14.5% of all anthropogenic greenhouse gas (GHG) emissions of which approximately 39% is in the form of CH₄ (Gerber et al., 2013). In addition, CH₄ is a potent GHG with 28 times the greenhouse potential of CO₂ over a 100-yr period (Myhre et al., 2013). In South Africa, the cattle industry produced approximately 27.1 megatonnes of CO₂-equivalent during 2010 of which 98.6% was represented by enteric CH₄ emissions (du Toit et al., 2013). The need to verify national GHG inventories and to validate on-farm GHG mitigation strategies has become a growing concern on an international level.

It is well documented that concentrate in diets has a profound negative effect on CH₄ intensity (g/kg of milk or meat) when fed at increasing levels (Beauchemin et al., 2008; Martin et al., 2010; Knapp et al., 2014). The decrease in CH₄ intensity can mainly be ascribed to a shift in the NDF:NFC ratio that, in combination, provides for a higher net energy intake that can favor animal production, and alters rumen fermentation in such a way that alters CH₄ production. Most grazing studies that evaluated concentrate supplementation as CH₄ mitigation strategy in dairy systems utilized high quality pasture, predominantly ryegrass pasture or a dominant mix thereof, during spring (Jiao et al., 2014; Muñoz et al., 2015). None of these grazing studies compared CH₄ emissions from cows fed concentrate to that of cows on a pasture-only diet; also, none explored the treatment effect on rumen function. Including a pasture-only treatment is not only important for con-

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trol comparison purposes but also for GHG inventory resolutions because some dairy farmers still implement once-a-day milking on pasture without concentrate supplementation. Although it is common practice to graze year-round in the southern hemisphere and that the challenge of seasonal variation in pasture availability and nutritive quality is well documented (Roche et al., 2009), little is known on the effect of summer pasture (low to medium quality), with or without supplementation, on CH₄ emissions of dairy cows.

Thus, the aim of the study was to determine the effect of different concentrate levels (including a zero level) on CH₄ emissions, production performance, and rumen fermentation of Jersey cows grazing kikuyu-dominant pasture during summer. We hypothesized that dairy cows supplemented with concentrate grazing medium quality pasture in summer will emit less CH₄ emissions, yield, and intensity compared with cows receiving pasture only.

MATERIALS AND METHODS

The study was conducted at the Outeniqua Research Farm of the Western Cape Department of Agriculture, Western Cape, George (33°58'S, 22°25'E) during the beginning of 2017. The area is characterized by a coastal temperate climate with long-term mean annual precipitation of 732 mm, spread throughout the year, and a mean daily minimum and maximum temperature range of 7 to 15°C, and 18 to 25°C, respectively. The soil was characteristic of a Podzol soil type as described in detail by Swanepoel et al. (2013). Institutional animal care and use was obtained from the Western Cape Department of Agriculture (Elsenburg, South Africa) before commencement of the study (Departmental Ethics Committee for Research on Animals approval number: R14/115) and unnecessary discomfort to the animals was avoided at all times.

Animals, Experimental Design, and Treatments

Fifty-one multiparous (mean parity, 4.1 ± 1.57 SD) Jersey cows were selected from the Outeniqua dairy herd with a mean pre-experimental milk yield of 16.5 (±1.97 SD) kg/d and a mean of 99 (±46) DIM at the onset of the study. Cows were blocked (17 blocks) according to pre-experimental milk yield, DIM, and parity (covariate data), in 1 of 3 treatment groups on January 25, 2017. Additionally, 9 lactating rumen-cannulated Jersey cows (previously fitted with Bar Diamond #1C rumen cannulas; Bar Diamond Inc., Parma, ID) were randomly, evenly allocated to the same 3 groups. Each treatment group (consisting of 20 cows) was then

randomly assigned to 1 of 3 treatments. Treatments consisted of 3 concentrate feeding levels: 0, 4, and 8 kg/cow per day (as-fed basis). Concentrate was offered individually to cows in pellet form in 2 equal portions during milking. The ingredient composition of the concentrate offered was (g/kg, as-fed basis) as follows: 740 maize, 175 soybean oilcake, 50 sugarcane molasses, 22 limestone (CaCO₃), 3 monocalcium phosphate, 6 salt, 3 magnesium oxide, and 1 trace minerals and vitamins (containing 4 mg of Cu/kg, 10 mg of Mn/kg, 20 mg of Zn/kg, 0.34 mg of I/kg, 0.2 mg of Co/kg, 0.06 mg of Se/kg, 6 × 10⁶ IU of vitamin A/kg, 1 × 10⁶ IU of vitamin D₃/kg, and 8 × 10³ IU of vitamin E/kg). Cows were subject to a 14-d dietary adaptation period that started February 9, followed by a 47-d data collection period that commenced February 23 and ended April 11. The rumen-cannulated cows formed part of a 3 × 3 Latin square design with 20-d periods (14 d of adaptation and 6 d of data collection).

Pasture and Grazing Management

Cows grazed kikuyu-dominant (*Pennisetum clandestinum*) pasture as one group throughout the study period during late summer. The experimental paddock size was 8.55 ha with permanent sprinkler-irrigation divided into 15 m × 150 m strips with electric fence. Pre-experimental botanical composition of the pasture (at point of grazing; n = 18) consisted of 49.8% kikuyu, 32.4% perennial ryegrass (*Lolium perenne*), 14.0% other grass (*Lolium multiflorum* and *Paspalum dilatatum*), 2.1% white clover (*Trifolium repens*), and 1.7% broad-leaf weeds. Irrigation was scheduled by irrometer tensiometers (Calafra SA, Nelspruit, South Africa) installed at a depth of 150 mm. Irrigation was initiated at a tensiometer reading of -25 kPa and ended at a reading of -10 kPa. Pasture strips were top-dressed with limestone ammonium nitrate (containing 280 g of N/kg) after each grazing at a rate of 42 kg of N/ha. Cows were grazed in a rotational system with fresh pasture allocated twice daily after milking, with grazing areas being back-fenced. The daily herbage allowance (**DHA**) was continuously adjusted throughout the study to ensure a target postgrazing height of 5.5 cm aboveground. This was achieved by measuring pre- and postgrazing sward height with a rising plate meter (Jenquip folding plate pasture meter; Jenquip, Feilding, New Zealand) by taking 100 readings in a zigzag pattern across the grazing area. Mean above-ground pre- and postgrazing herbage masses were estimated using the following site-and-season-specific linear regression equation: herbage mass (kg of DM/ha) = [87.8 × sward height (rising plate meter reading)] - 32.7 (R² = 0.94).

According to this equation, a residual herbage mass of 933 kg of DM/ha was attained at the target postgrazing height of 5.5 cm above ground.

Measurements

Animal Performance. All cows were milked twice daily at 0700 and 1500 h in a dairy parlor equipped with a 20-point swing over milking machine with weigh-all electronic milk meters (Dairymaster, Causeway, Co. Kerry, Ireland). Milk composition was determined weekly from composite morning and afternoon milk samples using a Milkoscan FT+ milk analyzer (FOSS Analytical, Hillerød, Denmark) for determining milk fat, milk protein, milk lactose, and MUN, and a Fossomatic FC (Foss Analytical) for determining SCC. Fat corrected milk standardized to 4.0% fat was calculated using the equation of Gaines (1928): $FCM = [0.4 \times \text{milk yield (kg)}] + [15 \times \text{milk fat (kg)}]$ and ECM was calculated using the equations of Tyrrell and Reid (1965) as presented by Muñoz et al. (2015). Milk parameters of the rumen-cannulated cows were excluded from the treatment group mean due to the crossover design.

All cows were weighed over 2 consecutive days and BCS recorded before afternoon milking at the start and the end of the study period. Body weight was recorded electronically with a fixed weighing scale (Tru-Test EziWeigh v. 1.0 scale, 0.5 kg accuracy, Auckland, New Zealand) and BCS was determined using the 1 to 5 scale scoring system of Wildman et al. (1982).

DMI. Individual pasture DMI of intact cows was estimated with the use of TiO_2 as an external marker to determine fecal output and indigestible NDF as an internal marker to determine forage digestibility. Cows in block 1 to 11 of each treatment group were used for estimating pasture DMI and 1 additional cow per treatment was included for background TiO_2 analysis. The TiO_2 method (dosing 3 g of TiO_2 /cow twice daily for 10 d and collecting a.m. and p.m. fecal samples on d 5 to 10) of Pinares-Patiño et al. (2008) was implemented from March 22 to 31, 2017. Fecal samples were immediately oven-dried (65°C, 72 h), pooled within animal, and analyzed for TiO_2 concentration by the method of Myers et al. (2004). Fecal output was calculated from the daily TiO_2 dose and TiO_2 concentration in feces as described by de Souza et al. (2015).

During the DMI measurement period, representative pasture samples were cut daily before p.m. milking on the successive grazing-strip, at a stubble height of approximately 5 cm above ground. Samples were immediately oven-dried (55°C, 72 h), pooled, and milled to pass a 1-mm sieve. The indigestible NDF concentration

of the concentrate, forage, and fecal samples were determined according to Krizsan et al. (2015) by incubating samples in sacco for 288 h in polyester bags (07–11/5 Sefar Petex cloth, Sefar AG, Heiden, Switzerland) with a sample size to surface area ratio of 12 mg/cm². After incubation, bags were inserted in an Ankom²⁰⁰ fiber analyzer (Ankom Technology Corp., Fairport, NY) with the inclusion of heat-stable α -amylase and anhydrous sodium sulfite following the procedure of Robertson and van Soest (1981). Finally, pasture DMI was calculated using the following equation (Cabral et al., 2014): $\text{pasture DMI (kg/d)} = \{[\text{FO (kg/d)} \times \text{iNDF}_{\text{feces}} \text{ (kg/kg)}] - \text{iNDF}_{\text{intake}_{\text{concentrate}}} \text{ (kg/d)}\} / \text{iNDF}_{\text{forage}} \text{ (kg/kg)}$, where FO = fecal output and iNDF = indigestible NDF.

Enteric CH_4 . Cows from block 1 to 11 (highest milk producers) of the experimental cow group were selected for enteric CH_4 measurement. Methane emissions from individual cows were recorded parallel to the DMI measurement period using the SF₆ technique as described by O'Neill et al. (2011) for free-ranging dairy cattle. This measurement period prolonged for a maximum of 7 consecutive days (March 26 to April 2) to ensure at least 4 representative 24 h gas samples per cow after the completion of the measurement period. Empty permeation tubes (P&T Precision Engineering Ltd., Naas, Co. Kildare, Ireland) used within this study were filled with 3.0 (± 0.19 SD) g of SF₆ gas during January 2017. Filled tubes were calibrated in a dry incubator (Labcon Incubator Model FS1M8, Ferndale, Johannesburg, South Africa) set at 39.0°C for 4 wk weighing the tubes (Sartorius BP210S, Sartorius AG, Goettingen, Germany; 0.0001 g accuracy) every third morning to produce a 9-point regression curve ($R^2 > 0.9993$). The experimental mean release rate of the SF₆ gas from the permeation tubes was 4.9 (± 0.26 SD) mg/d and ranged from 4.4 to 5.3 mg/d 1 wk before dosing. The permeation tubes were blocked by release rate and randomly allocated to both experimental treatment and cow within treatment. Tubes were individually placed in a size 10 gelatin capsule (Torpac Inc., Fairfield, NJ) and dosed per os using a plastic capsule-dose-applicator on March 17 (9 d before the measurement period).

Cylindrical, back-mounted polyvinyl chloride gas-collection canisters of 1,700 mL with an initial sampling rate of approximately 0.54 mL/min were used to continuously sample eructated gasses over a 24-h period. The given sampling rate allowed for the evacuated canister to fill to 45% over a 24-h sampling period. Canisters were mounted on the back of the cows using the back-mounted harness of van Wyngaard et al. (2018a). Canisters were flushed prior use, which encompassed 5 cycles of evacuating to 98 kPa vacuum, filling with

ultra-high-purity nitrogen gas (999.99 g of nitrogen/kg) and evacuating again to 98 kPa vacuum. Initial sampling rate was obtained by restricting flow with a stainless-steel capillary tube (0.16 cm o.d. $\times$ 0.05 cm i.d., YY-RES-21503, Leco Co., Saint Joseph, MI) cut to 50 mm length and crimped using a table top vice-grip until the specified flow was attained.

Background (ambient) emissions of SF₆ and CH₄ were sampled by using 3 additional cows without permuta-tion tubes (block 12), equipped with the same saddle and canister as those used by the experimental cows for one exclusion that the flow inlet was on the back of the animal and not above the nostrils. The background cows and the experimental cows were kept in one group at all times (grazing and milking). Background emis-sions were averaged per day to give a single estimate for all experimental cows. The same oil vacuum gauge [SA Gauge (Pty.) Ltd., Durban, South Africa] was used to measure vacuum of evacuated canisters prior daily connection and removal of sample canisters.

Undiluted gas samples were extracted and sub-sampled into three 12-mL glass vials (Labco Exetainer, Labco Ltd., Lampeter, Ceredigion, UK) from the sample canisters by means of a piston sub-sampler [National Institute of Water and Atmosphere (NIWA) Ltd., Auckland, New Zealand] and shipped to NIWA for gas analysis (analyzed approximately 14 d after sampling).

Gas samples were analyzed using an automated gas analyzer equipped with a Gilson Sample Changer (Gil-son Inc., Middleton, WI) modified at NIWA to analyze pressurized air samples in Labco Exetainers, and a GC equipped with a flame-ionization detector (FID) and an electron-capture detector (ECD; Hewlett Packard Model 6890, Palo Alto, CA). Separation of CH₄ and SF₆ from the other air components was achieved using 2 Alltech Porapak-Q 80–100 mesh columns (3.6 m $\times$ 3 mm stainless steel; Grace Davison Discovery Sciences, Deerfield, IL) in parallel configuration, one for each detector. The ECD operated at 400°C and the FID at 250°C using 10% Ar/CH₄ and ultra-high purity nitro-gen gas as carrier gas at 30 mL/min flow, respectively. The sample loops were flushed in a direction away from the FID so the CH₄ in the ECD carrier gas was not car-ried through to the FID. A suite of 3 standards of SF₆ and CH₄ mixtures (NIWA) were associated with the analyses of each batch. Each of the 3 standards was run in triplicate before each batch's analysis and again at the end of the batch to characterize GC performance. Methane production (g/d) was calculated using equa-tion 2 from the study of Williams et al. (2011).

Rumen Fermentation. Ruminal pH, fermenta-tion end products, and in sacco pasture DM and NDF

disappearance were determined using the 9 cannulated cows during each 20-d sampling period. Diurnal pH patterns were measured over a 72-h period (10 min frequency) with Indwelling TruTrack pH Data Log-gers (model pH-HR mark 4, Intech Instruments Ltd., Riccarton, Christchurch, New Zealand) attached to the rumen cannula. The loggers were calibrated with buffer solutions of pH 4 and 9, and verified with pH 7 buffer solution. After calibration, the loggers were placed in distilled water for 18 h where pH was monitored with a calibrated handheld pH logger (pH340i pH meter/data logger attached with a Sentix 41 pH electrode; WTW, Weilheim, Germany). Any drift in pH recorded during this time was used to correct the pH data after incuba-tion. A total of 100 mL of ruminal fluid was collected from each cow in 8-h intervals (0600, 1400, and 2200 h) using a vacuum pump and a sampling tube placed into the ventral sac of the rumen via the cannula. After sampling, ruminal pH was immediately measured with the handheld pH logger (spot sample pH). Subsequent-ly, samples were filtered through 4 layers of cheesecloth, subsampled in airtight containers, and immediately fro-zen for subsequent NH₃-N (Broderick and Kang, 1980) and VFA (Filípek and Dvořák, 2009) analysis. Ruminal disappearance of the kikuyu-dominant pasture was de-termined using the nylon bag procedure of Cruywagen (2006). The bags were incubated for 6, 18, and 30 h to determine DM and NDF disappearance. The rate of NDF disappearance (NDF k_d) was calculated accord-ing to van Amburgh et al. (2003). Bag residues were analyzed for DM content (AOAC International, 2000; method 934.01), NDF content (as described before), and ADL content (Goering and van Soest, 1970).

Feed Sampling and Analysis

Concentrate and pasture (representative of that grazed) samples were collected weekly. A pasture sample consisted of 6 pooled pasture samples cut ap-proximately 5 cm aboveground from the successive grazing-strip. Samples were thoroughly homogenized, dried at 55°C for 72 h (initial DM), ground to pass through a 1-mm sieve (SMC hammer mill), and stored at –18°C pending analyses. Samples were analyzed for DM, ash, CP (N content determined using a Leco Trumac N Determinator, Leco Corporation, Saint Jo-seph, MI), and ether extract, according to procedures of AOAC International (2000; methods 934.01, 942.05, 968.06, and 920.39, respectively). The NDF content was determined as described before. The ADF (using the Ankom²⁰⁰ fiber analyzer) and ADL content were determined according to Goering and van Soest (1970). Samples were also analyzed for gross energy (GE; oper-

ator's manual, MC-1000 modular calorimeter, Energy Instrumentation, Sandton, South Africa) and in vitro OM digestibility (IVOMD; Tilley and Terry, 1963; using rumen fluid from a rumen-cannulated SA Mutton Merino ram fed good-quality alfalfa hay). The ME was calculated using the equations of MAFF (1984): $ME_{\text{concentrate}} = 0.84 \times GE \times IVOMD$ and $ME_{\text{pasture}} = 0.81 \times GE \times IVOMD$. Mineral composition was determined according to the procedure of AgriLASA (1998; method 6.1.1).

Statistical Analysis

Milk parameters (yield and composition) and body condition parameters over the course of the study (17 blocks) and for the duration of the CH₄ emissions measurement period (11 blocks) along with DMI and CH₄ emissions parameters were analyzed as a randomized complete block design with ANOVA to test for differences between treatment effects. The residuals were acceptably normal with homogeneous treatment variances, except for SCC, which were then log (base 10) transformed. Pre-experimental milk yield (for 2 mo), DIM, and parity were used as covariate to test for significant (linear) relationships between the before and after measurements over the course of the study and subsequent for differences between treatment effects. If the relationship was not significant, then ANOVA was used to test for differences between treatment effects on the after measurements. Covariate analysis was done on milk yield, milk fat content, milk protein:fat ratio, milk lactose content, and milk lactose yield.

The pH measurements over 24 h, time spent below ruminal pH, in sacco disappearance, and rumen fermentation end products were analyzed as a triplicated 3 × 3 Latin square with ANOVA to test for differences between treatment effects.

The recorded daily CH₄ emission of individual cows was averaged to yield a single daily value for each cow representative of the entire sampling period. A 90% successful collection rate was achieved from the 213 gas samples collected. The remainder was lost due to blockages in the capillary flow restrictor, leaking gauges, and broken sampling lines during the 24-h collection periods. The modified Z-score was used to identify outlying CH₄ data using norm permeation tube rate [net SF₆ (ppt) divided by the SF₆ release rate of the permeation tube] and CH₄/SF₆ ratio. Data associated with modified Z-scores of >3.5 (absolute value) were labeled as outliers. Only 8 outliers were identified with the norm permeation rate.

Treatment means were compared using Tukey's least significant difference test at the 5% level of significance

(Snedecor and Cochran, 1980). Data were analyzed using the statistical program GenStat (Payne et al., 2014).

RESULTS

Feed Chemical Composition and Pasture Measurements

The chemical composition of the dairy concentrate and pasture offered averaged across the 7-wk study period and the CH₄ measurement period are presented in Table 1. Pasture grazed during the CH₄ measurement period was fairly representative to the pasture grazed throughout the study period, except for having a lower EE, OM digestibility, GE, ME, Ca, P, and Na content, and a higher K content.

The pre- and postgrazing measurements of the offered pasture between the 7-wk study period and the CH₄ measurement period were relatively comparable (Table 2). Cows were offered pasture at 11.7 kg of DM/cow per day above 5 cm ground level, given a pasture yield of 2.2 t of DM/ha. According to the pre- and postgrazing measurements, cows consumed daily only approximately 52% of the pasture offered.

Milk Production, Milk Composition, and Cow Condition

Milk production and cow condition measurements over the 7-wk study period are presented in Table 3. Milk yield, including FCM and ECM, were affected by treatment and increased linearly and quadratically ($P < 0.05$) with increasing concentrate feeding level. Similarly, milk fat and milk lactose yield also increased linearly and quadratically ($P < 0.05$), whereas milk protein yield only increased linearly ($P < 0.001$) with increasing concentrate feeding level. A milk response of 1.24 and 0.93 kg of milk/kg of concentrate was achieved between the 0 and 4 kg groups, and between the 4 and 8 kg groups, respectively. Milk fat content decreased linearly ($P = 0.006$) with increasing concentrate feeding level, whereas the pasture-only group produced a greater (+6.1 g/kg; $P = 0.016$) milk fat content than the 8 kg group but similar ($P > 0.05$) to the 4 kg group. Milk lactose content increased linearly and quadratically ($P < 0.05$), whereas cows on both the 4 and 8 kg concentrate level had a greater ($P < 0.001$) milk lactose content compared with cows on the 0 kg concentrate level. Milk protein content and SCC were unaffected by treatment. Milk solids content was unaffected by treatment but tended to decrease linearly with increasing concentrate feeding level. Milk protein to fat ratio

Table 1. Chemical composition of the concentrate offered and of the pasture offered averaged over both the 7-wk study period and CH₄ measurement period

Item	Concentrate (n = 6)	Pasture	
		7-wk study (n = 6)	CH ₄ measurement period (n = 5)
Initial DM (%)	89.9	17.8	17.3
DM composition (g/kg of DM)			
CP	133	208	193
Ether extract	36.7	30.1	26.0
NDF	107	574	591
ADF	39.4	293	299
Ash	78.3	104	114
OM digestibility (g/kg of DM)	946	740	627
Gross energy (MJ/kg of DM)	17.2	18.0	17.7
ME ¹ (MJ/kg of DM)	13.7	10.8	8.98
Mineral composition			
Ca (g/kg of DM)	15.6	4.61	3.85
P (g/kg of DM)	5.95	4.20	3.42
Mg (g/kg of DM)	4.40	4.97	5.07
K (g/kg of DM)	9.70	26.1	42.9
Na (g/kg of DM)	2.27	8.25	1.86
Mn (mg/kg of DM)	82.6	34.7	49.8
Cu (mg/kg of DM)	27.7	7.85	7.58
Fe (mg/kg of DM)	110	95.7	98.7
Zn (mg/kg of DM)	130	54.9	57.2

¹Calculated.

increased linearly with increasing concentrate feeding level, whereas the 8 kg group had a greater ($+0.07$; $P = 0.004$) ratio than both the 0 and 4 kg group that were similar. Individual MUN concentrations decreased linearly and quadratically ($P < 0.001$) with increasing concentrate feeding level, whereas both the 0 and 4 kg groups produced greater ($P < 0.001$) MUN concentrations than the 8 kg group. Initial BW and BCS of all the groups were similar. In contrast, BW change and BCS change increased linearly ($P < 0.05$) with increasing concentrate feeding level. The 8 kg group gained more ($+17.5$ kg of BW/cow; $P < 0.004$) BW than the 0 kg group, whereas the 4 kg group remained unaffected.

DMI and Enteric CH₄ Emissions

The effect of concentrate feeding level on DMI and CH₄ emissions, along with the milk production and milk composition recorded during this measurement period, are presented in Table 4. Fecal output was unaffected by treatment but tended to decrease linearly with increasing concentrate feeding level. Pasture DMI decreased linearly ($P = 0.010$) with increasing concentrate feeding level where the 0 kg group had a greater ($+2.84$ kg of DM; $P = 0.028$) pasture DMI than the 8 kg group but similar to the 4 kg group. Conversely, total DMI, DMI as % BW, GE intake, and ME intake

Table 2. Pre- and postgrazing measurements of the experimental kikuyu-dominant pasture averaged ($\pm$ SD) across the 7-wk study period and the CH₄ measurement period

Item	7-wk study (n = 89)	CH ₄ measurement period (n = 13)
Pasture height (cm)		
Pregrazing	12.7 $\pm$ 3.72	11.8 $\pm$ 1.46
Postgrazing	5.95 $\pm$ 0.98	6.35 $\pm$ 0.66
Pasture yield ¹ (kg of DM/ha)		
Pregrazing	2,197 $\pm$ 653.1	2,027 $\pm$ 256.4
Postgrazing	1,008 $\pm$ 172.0	1,082 $\pm$ 115.1
DHA ² (kg of DM/cow per day)	11.7 $\pm$ 1.49	11.3 $\pm$ 0.88
Daily grazed area (m ² /cow)	56.7 $\pm$ 13.94	56.3 $\pm$ 8.15
Pasture removed (kg of DM/cow per day)	6.11 $\pm$ 1.646	5.22 $\pm$ 0.917

¹Estimated 5 cm above ground using a rising plate meter.²Daily herbage allowance.

Table 3. The effect of concentrate supplementation level on milk production and cow condition of early lactation Jersey cows grazing kikuyu-dominant pasture in late summer during the 7-wk study (n = 17)

Item	Concentrate level (kg/d as fed)			SEM	<i>P</i> -value ¹		
	0	4	8		Con	Lin	Quad
Milk yield (kg/cow per day)	9.03 ^c	14.0 ^b	17.7 ^a	0.239	<0.001	<0.001	0.035
FCM yield (kg/cow per day)	11.4 ^c	17.4 ^b	20.8 ^a	0.32	<0.001	<0.001	0.003
ECM yield (kg/cow per day)	11.2 ^c	17.1 ^b	20.7 ^a	0.29	<0.001	<0.001	0.002
Milk fat (g/kg)	58.3 ^a	56.7 ^{ab}	52.2 ^b	1.46	0.016	0.006	0.43
Milk protein (g/kg)	38.0	37.3	37.6	0.51	0.60	0.56	0.42
Milk protein to fat ratio	0.66 ^b	0.66 ^b	0.73 ^a	0.016	0.004	0.002	0.13
Milk lactose (g/kg)	44.6 ^b	46.3 ^a	46.5 ^a	0.27	<0.001	<0.001	0.036
Milk solids ² (g/kg)	141	140	136	1.7	0.12	0.056	0.42
MUN (mg/dL)	15.5 ^a	16.2 ^a	13.6 ^b	0.36	<0.001	<0.001	<0.001
Log ₁₀ SCC	2.12	2.01	2.12	0.068	0.41	0.99	0.18
Milk fat yield (kg/cow per day)	0.52 ^c	0.79 ^b	0.91 ^a	0.019	<0.001	<0.001	0.005
Milk protein yield (kg/cow per day)	0.34 ^c	0.52 ^b	0.66 ^a	0.010	<0.001	<0.001	0.17
Milk lactose yield (kg/cow per day)	0.40 ^c	0.65 ^b	0.82 ^a	0.014	<0.001	<0.001	0.035
BW (kg)	385	389	388	6.4	0.91	0.78	0.75
BCS (scale 1 to 5)	2.02	2.03	2.02	0.017	0.79	1.00	0.49
BW change (kg)	-0.82 ^b	+4.53 ^{ab}	+16.7 ^a	3.51	0.004	0.001	0.43
BCS change	-0.05 ^c	+0.18 ^b	+0.29 ^a	0.032	<0.001	<0.001	0.19

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Con = contrast; Lin = linear; Quad = quadratic.

²Milk solids = milk fat + milk protein + milk lactose.

increased linearly ($P < 0.05$) with increasing concentrate feeding level, whereas NDF intake as % of BW tended to increase linearly with increasing concentrate feeding level. The 8 kg group had a greater ($P = 0.001$;

$P < 0.001$; and $P = 0.002$) total DMI, DMI as % of BW and GE intake, respectively, than both the 0 and 4 kg groups that were similar. Feed efficiency (kg of ECM/kg of DMI) increased linearly ($P < 0.001$) with increas-

Table 4. The effect of concentrate supplementation level on DMI and CH₄ emissions of early lactation Jersey cows grazing kikuyu-dominant pasture in late summer (n = 11)

Item	Concentrate level (kg/d as fed)			SEM	<i>P</i> -value ¹		
	0	4	8		Con	Lin	Quad
BW (kg)	391	389	396	7.5	0.79	0.64	0.63
Fecal output (kg/cow per day)	3.36	2.82	2.78	0.228	0.16	0.087	0.38
Intake							
Pasture DMI (kg/cow per day)	11.2 ^a	9.19 ^{ab}	8.36 ^b	0.704	0.028	0.010	0.50
Total DMI (kg/cow per day)	11.2 ^b	12.8 ^b	15.6 ^a	0.70	0.001	<0.001	0.50
NDF intake as % of BW	1.69	1.50	1.45	0.095	0.18	0.083	0.54
DMI as % of BW	2.87 ^b	3.30 ^b	3.95 ^a	0.164	<0.001	<0.001	0.58
GEI ² (MJ/cow per day)	202 ^b	228 ^b	275 ^a	12.7	0.002	<0.001	0.50
MEI ³ (MJ/cow per day)	121 ^c	149 ^b	189 ^a	7.6	<0.001	<0.001	0.50
Feed efficiency (kg of ECM/kg of DMI)	1.01 ^b	1.37 ^a	1.46 ^a	0.065	<0.001	<0.001	0.11
CH ₄ emissions							
CH ₄ production (g/cow per day)	323	367	378	18.3	0.11	0.045	0.48
CH ₄ /DMI (g/kg)	29.1 ^a	28.9 ^{ab}	25.1 ^b	1.09	0.025	0.016	0.18
CH ₄ /milk yield (g/kg)	35.5 ^a	25.1 ^b	21.1 ^b	1.26	<0.001	<0.001	0.051
CH ₄ /ECM (g/kg)	28.8 ^a	21.2 ^b	17.6 ^c	0.98	<0.001	<0.001	0.12
CH ₄ energy (MJ/d)	17.8	20.3	20.9	1.01	0.104	0.045	0.48
Ym ⁴ (%)	8.91	8.97	7.85	0.341	0.052	0.039	0.17

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Con = contrast; Lin = linear; Quad = quadratic.

²Gross energy intake.

³Metabolizable energy intake.

⁴CH₄ energy per gross energy intake.

ing concentrate feeding level. The 4 and 8 kg group had similar feed efficiencies while being the lowest ($P < 0.001$) for the 0 kg group.

Daily CH_4 production (g/d) and CH_4 energy were unaffected by treatment but increased linearly ($P = 0.045$) with increasing concentrate feeding level. Individual CH_4 yield (g/kg of DMI), CH_4 intensity (g/kg of milk yield, and ECM), and CH_4 energy per gross energy intake (Ym) decreased linearly ($P < 0.05$) with increasing concentrate feeding level. Furthermore, CH_4 intensity (g/kg of milk yield) also tended to decrease quadratically with increasing concentrate feeding level. The 8 kg group emitted less (-4 g/kg; $P = 0.025$) CH_4 per kg of DMI than the 0 kg group but similar to the 4 kg group. Methane per kilogram of milk yield was similar for the 4 and 8 kg groups but greater ($P < 0.001$) for the 0 kg group, whereas CH_4 per kilogram of ECM decreased ($P < 0.001$) stepwise with increasing concentrate feeding level.

Rumen Fermentation

The effect of concentrate level on diurnal patterns of ruminal pH is presented in Figure 1. It was evident that ruminal pH decreased ($P < 0.05$) for cows in the 8 kg group 1 h after a.m. feeding of concentrate and remained lower ($P < 0.05$) than the other groups for

approximately 4 h before recovering. The same trend was evident 1 h after p.m. feeding of concentrate, where the ruminal pH of the 0 kg group was highest ($P < 0.05$), intermediate ($P < 0.05$) for the 4 kg group, and lowest ($P < 0.05$) for the 8 kg group for a short period. Thereafter, the 4 kg group recovered to a similar ruminal pH than that of the 0 kg group, whereas the 8 kg group remained low ($P < 0.05$). Throughout the night both the 4 and 8 kg group showed intermittent decreases ($P < 0.05$) in ruminal pH compared with the 0 kg group.

The treatment effect on mean ruminal pH, time spent below pH, VFA, and $\text{NH}_3\text{-N}$ concentrations, and DM and NDF disappearance are presented in Table 5. Diurnal ruminal pH and spot sample ruminal pH decreased linearly ($P < 0.05$) with increasing concentrate feeding level. During both measurement periods, ruminal pH was lowest ($P < 0.05$) for the 8 kg group compared with the 0 kg group, but similar to the 4 kg group. Time spent below pH of 6.6 tended to increase linearly with increasing concentrate feeding level. Total VFA, acetic and propionic acid, and $\text{NH}_3\text{-N}$ concentration were unaffected by treatment. Butyric acid increased linearly and quadratically ($P < 0.05$) with increasing concentrate feeding level. The 8 kg group had a similar butyric acid concentration to both the 0 and 4 kg group, whereas the 4 kg group had a greater ($P = 0.007$) butyric acid

Figure 1. The effect of concentrate supplementation level on diurnal ruminal pH of early lactation Jersey cows grazing kikuyu-dominant pasture in late summer ($n = 9$). Error bars indicate SEM, and arrows indicate when concentrate was fed.

Table 5. The effect of concentrate supplementation level on ruminal pH, VFA, $\text{NH}_3\text{-N}$, and pasture in sacco DM and NDF disappearance of early lactation Jersey cows grazing kikuyu-dominant pasture in late summer (mean of the rumen measurement periods; $n = 9$)

Item	Concentrate level (kg/d as fed)			SEM	<i>P</i> -value ¹		
	0	4	8		Con	Lin	Quad
Diurnal pH (over 72 h)	6.45 ^a	6.38 ^{ab}	6.32 ^b	0.029	0.029	0.010	0.82
Spot sample pH	6.38 ^a	6.25 ^{ab}	6.16 ^b	0.033	0.003	<0.001	0.70
Time below (h)							
pH 5.8	0.44	0.11	1.94	1.015	0.43	0.32	0.40
pH 6.0	1.67	1.33	3.39	1.175	0.44	0.32	0.43
pH 6.2	5.17	6.61	5.83	1.197	0.70	0.70	0.47
pH 6.4	10.9	12.6	13.2	1.71	0.63	0.37	0.81
pH 6.6	15.1	19.2	20.3	1.74	0.13	0.060	0.50
$\text{NH}_3\text{-N}$ (mg/dL)	10.8	12.8	12.1	0.58	0.10	0.14	0.10
Total VFA (mM)	94.6	92.7	91.1	5.96	0.92	0.69	0.98
Acetic (mM)	81.6	80.1	81.5	0.82	0.39	0.95	0.18
Propionic (mM)	11.8	11.9	11.2	0.54	0.65	0.48	0.56
Butyric (mM)	5.21 ^b	6.65 ^a	6.14 ^{ab}	0.252	0.007	0.027	0.010
Isobutyric (mM)	0.42	0.42	0.34	0.024	0.053	0.030	0.23
Valeric (mM)	0.38	0.36	0.35	0.031	0.82	0.54	0.94
Isovaleric (mM)	0.56 ^a	0.53 ^{ab}	0.43 ^b	0.032	0.030	0.012	0.40
Caproic (mM)	0.11	0.08	0.07	0.010	0.091	0.037	0.57
DM disappearance (coefficient)							
6 h	0.28 ^a	0.26 ^b	0.26 ^b	0.003	0.008	0.005	0.11
18 h	0.50	0.49	0.45	0.015	0.12	0.050	0.57
30 h	0.69 ^a	0.66 ^a	0.61 ^b	0.009	<0.001	<0.001	0.27
NDF disappearance (coefficient)							
6 h	0.13 ^a	0.11 ^{ab}	0.09 ^b	0.008	0.017	0.005	0.86
18 h	0.43	0.41	0.36	0.020	0.060	0.027	0.37
30 h	0.64 ^a	0.62 ^a	0.55 ^b	0.013	0.002	<0.001	0.17
NDF k_d ²							
6 h	0.027 ^a	0.022 ^{ab}	0.018 ^b	0.0016	0.012	0.004	0.82
18 h	0.045	0.044	0.035	0.0034	0.16	0.086	0.37
30 h	0.050 ^a	0.047 ^a	0.038 ^b	0.0020	0.004	0.002	0.23
Mean	0.040 ^a	0.038 ^a	0.031 ^b	0.0018	0.008	0.003	0.29

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Con = contrast; Lin = linear; Quad = quadratic.

²Rate of NDF disappearance.

concentration than the 0 kg group. Both isobutyric and capronic acid concentration tended to decrease linearly ($P < 0.10$) with increasing concentrate feeding level. Isovaleric acid concentration decreased linearly ($P = 0.012$) with increasing concentrate feeding level. The 4 kg group had a similar isovaleric acid concentration than both the 0 and 8 kg groups, whereas the 0 kg group had a greater ($P = 0.030$) isovaleric acid concentration than the 8 kg group.

In sacco DM and NDF disappearance, and NDF k_d decreased linearly ($P < 0.05$), irrespective of incubation period, with increasing concentrate feeding level. However, after 18 h of incubation DM disappearance and NDF k_d only tended to decrease linearly with increasing concentrate feeding level. After 6 h of ruminal incubation of the pasture: DM disappearance was similar for the 4 kg and 8 kg groups but greater ($P = 0.008$) for the 0 kg group, whereas both NDF disappearance and NDF k_d were greater ($P < 0.05$) for the 0 kg group

relative to the 8 kg group but remained unaffected for the 4 kg group. After 30 h of ruminal incubation, DM and NDF disappearance, and NDF k_d were similar for the 0 and 4 kg group but lowest ($P < 0.05$) for the 8 kg group. The mean NDF k_d was similar the 0 kg and 4 kg groups but lowest ($P = 0.008$) for the 8 kg group.

DISCUSSION

Pasture-based dairy systems are inevitably subject to several challenges involving animal and system parameters, such as seasonal variation in pasture availability and nutritive quality, which can influence DMI and the milk response to concentrate supplementation (Roche et al., 2009). Adding to that, DMI has been labeled as the main driver for enteric CH_4 emissions in dairy and beef cattle (Ellis et al., 2007). In view of this, it is expected that enteric CH_4 emissions of cows will vary across seasons, therefore highlighting the significance of

determining enteric CH₄ emissions from seasons other than spring, hence promoting more accurate emissions per annum for pasture-based systems.

The present study was conducted in late summer reflecting a sub-tropical (kikuyu) and temperate (ryegrass) pasture mix with a similar chemical composition as the pasture offered by Bargo et al. (2002), as supported by the similar NDF intake as % of BW for the 2 studies. Previous studies testing the effect of concentrate level on enteric CH₄ emissions used mostly temperate pasture during spring with NDF values below 48%, CP values between 21 and 25%, and ME values between 11 and 12 MJ/kg of concentrate DM (Jiao et al., 2014; Muñoz et al., 2015). Individual pasture DMI as determined with the rising plate meter was very low (6 kg of DM/cow per day). This was plausibly due to the mixed sward causing a discrepancy in pre-grazing height, hence giving rise to a misleading linear regression predicting pasture DM yield. Despite this, the target postgrazing height of 5.5 cm was achieved, indicating that the pasture was not over- or underutilized (Fulkerson et al., 1999).

Between the 2 extreme treatments, pasture DMI decreased with increasing concentrate feeding level whereas total DMI, GE intake, and ME intake increased, which is in agreement with Bargo et al. (2003). It was previously reported that concentrate supplementation in pasture-based systems reduced ruminal pH, increased total VFA concentration, reduced NH₃-N concentration, and when fed at high levels in corn-based form (>8 kg of DM/cow per day) it reduced the rate of pasture degradability (Bargo et al., 2002, 2003). This was also observed in the present study except for total VFA and NH₃-N being unaffected by treatment. Pasture substitution (kg of pasture DMI/kg of concentrate DMI) that occurred within this study (0.56: 0 vs. 4 kg; 0.23: 4 vs 8 kg; and 0.39: 0 vs. 8 kg concentrate treatment) was below average of previous reports (Bargo et al., 2003). Pasture substitution is less profound at low DHA than at high DHA (Bargo et al., 2002), as was seen here. The challenge of measuring accurate individual pasture DMI under grazing conditions is well known, even so it is essential when evaluating and expressing CH₄ emissions. Therefore, we decided on using an indirect marker (TiO₂) to account for between and within-animal variation, rather than using ME back calculations that does not account for this. The most recent grazing studies evaluating CH₄ emissions utilized the ME back calculation method to determine pasture DMI (Jiao et al., 2014; Muñoz et al., 2015).

An overall milk response of 1.38 and 1.20 kg of milk/kg of concentrate DMI was achieved moving from the 0 to 4 kg, and 0 to 8 kg concentrate feeding level, respectively, whereas a marginal milk response (4 vs. 8

kg concentrate level) of 1.03 kg of milk/kg of concentrate DMI was achieved. This milk response is on the high end of previous published responses (Lovett et al., 2005; Jiao et al., 2014; Muñoz et al., 2015), owing to the lower than average substitution rate of the current study and that milk response was calculated relative to an unsupplemented treatment; hence, an above average milk response was expected. Bargo et al. (2003) confirmed in a review study that substitution rate is negatively related to milk response. The milk composition response observed within this study was largely as described by Bargo et al. (2003), where milk fat decreases whereas milk lactose increases with increasing concentrate feeding level. The observed response in MUN was a result of the diluting effect imposed by the lower protein content of the concentrate fed relative to that of the pasture that was on offer. According to Seymour et al. (2005), DMI and milk production are positively related to propionic and butyric acid concentrations in the rumen, whereas milk fat content is positively related to acetic acid. The lack of a response in acetic and propionic acid as observed in the present study, unfortunately, failed to support the observed increase in milk yield and decrease in milk fat content, possibly owing to the similar NDF intakes as % of BW between treatments. However, the observed increase in butyric acid did support the observed increase in DMI and milk yield as concentrate level increased. The improved BW and BCS with increasing concentrate level reflect the increase in GE intake.

When comparing our enteric CH₄ results to previous studies utilizing predominantly ryegrass pasture (Lovett et al., 2005; Jiao et al., 2014; Muñoz et al., 2015; van Wyngaard et al., 2018b), we found discrepancies in the response of enteric CH₄ emissions toward concentrate supplementation. This could possibly be ascribed to different experimental designs, pasture management in terms of pasture quality and DHA, and methods on determining DMI and CH₄ emissions. Average enteric CH₄ emissions of the current study (357 g/d) closely resemble that of Lovett et al. (2005) and Muñoz et al. (2015), being 373 and 355 g/d, respectively. Both of these authors also reported increased CH₄ production with increasing concentrate level up to 6 and 5 kg of concentrate/d, respectively. Other grazing studies reported much lower average enteric CH₄ emissions with no treatment response, being 277 and 294 g/d for Jiao et al. (2014) and van Wyngaard et al. (2018b), respectively. Both of these studies had a maximum concentrate level of 8 kg/d. The majority of the studies also reported a reduction in CH₄ intensity with increasing concentrate feeding level, except for Muñoz et al. (2015). The reduced CH₄ yield reported in this study was also only reported by Jiao et al. (2014), highlight-

ing the noted discrepancy among the different grazing studies.

Even though the CH₄ emissions measured in this study seem high relative to previous grazing studies, it fits the universal linear relationship between CH₄ production and DMI as developed by Charmley et al. (2016). Dairy cows from that study were mainly fed a 70:30 forage (pasture, pasture hay, pasture silage, or lucerne hay) to concentrate (barley, triticale, or wheat) diet that was similar to the present study ranging from a 100% to a 54% pasture component of the diet. It has been established that diets containing a lower NDF:starch ratio will result in a lower CH₄ production (Moe and Tyrrell, 1979; Knapp et al., 2014). When transposed a higher NDF:starch ratio will result in a higher CH₄ production. Consequently, the higher CH₄ emissions of this study reflect the higher NDF content of the pasture offered in comparison with previous grazing studies. This is further supported by Lovett et al. (2005) who obtained similar CH₄ production values where cows were supplemented with a fiber-based concentrate while grazing a pasture mix high in NDF (50%) relative to previous grazing studies (<48%).

According to McAllister and Newbold (2008), a reduction in fiber intake, imposed by the addition of grain to a forage diet, reduces ruminal pH, affecting DM and NDF digestibility (as was seen in the current study), and favors propionate production rather than acetate in the rumen. In the current study, the decreasing tendency in NDF intake failed to increase propionate production even though ruminal pH and DM disappearance decreased linearly with increasing concentrate level. Perhaps the observed decrease in diurnal ruminal pH (from 6.45 to 6.32) was not enough to cause a major shift in the microbial population in favor of propionate production. This is also evident in the rather small observed decrease in DM and NDF disappearance. This is supported by Kolver and De Veth (2002), who reported that the optimal range for ruminal fiber digestion on pasture systems is at a ruminal pH of >5.8. The observed increase in butyrate supports the observed increase in CH₄ production as concentrate level increases, as butyrate and acetate are precursors for CH₄ production (Van Nevel and Demeyer, 1996). The potential of ruminal VFA and pH to act as proxies for enteric CH₄ emissions is variable (Negussie et al., 2017).

It was previously established in a meta-analysis that *Y_m* distinctly decreases when the grain component in a diet exceeds 35 to 40% inclusion dependent on the level of DMI (Sauvant and Giger-Reverdin, 2009). In agreement, the *Y_m* of the current study tended to decrease when the concentrate component increased from 0 to 46%. This was also the case in the study of Jiao et al.

(2014) when the concentrate component increased from 12 to 46% resulting in the decreased *Y_m*. The observed *Y_m* within this study (7.9 to 9.0%) is slightly higher than that reported by recent grazing studies (5.3 to 6.7%; Jiao et al., 2014; Muñoz et al., 2015). This could be attributed to the higher NDF content of the summer pasture grazed during this study relative to the spring pasture, with inherent lower NDF content, grazed during those studies. Lassey (2007) reported that ruminant livestock, across different production systems, has a typical *Y_m* range of 4 to 10%. Recently, a relative high *Y_m* value of 9.2%, similar to that of the current study, was reported by Dall-Orsoletta et al. (2016) where dairy cows in mid to late lactation on a partial TMR were allowed to graze Italian ryegrass for short periods. Furthermore, *Y_m* values of ruminants fed diets containing tropical grass diets (such as kikuyu) can range between 8.4 to 11.4% (Kurihara et al., 1999; Tangjitwattanachai et al., 2015), but can also be as low as 4.9% (Noguera and Posada, 2017).

The results of the current study demonstrated that concentrate supplementation on medium quality summer pasture can reduce CH₄ yield and intensity, but increases CH₄ production. The observed change in the rumen environment caused by the increased starch:NDF ratio was not great enough to favor propionate production, but rather favorable for butyrate production.

CONCLUSIONS

Enteric CH₄ emissions were measured from lactating Jersey cows grazing medium quality summer pasture under a restricted DHA supplemented with 3 levels of concentrate (0, 4, and 8 kg). Although enteric CH₄ production increased, CH₄ yield and intensity decreased with increasing concentrate level. Surprisingly, propionate production did not increase, but butyrate production increased with increasing concentrate level. Concentrate supplementation is a viable option as CH₄ mitigation strategy for dairy cows grazing pasture during the summer months. However, the effect of concentrate feeding on total GHG emissions and profitability should not be ignored. Furthermore, results from this study can be used for future studies to better understand rumen fermentation proxies for CH₄ emissions, and for meta-analysis studies in developing robust prediction equations, hence improving GHG inventories.

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