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The effect of increasing sward species diversity on enteric methane emissions from Holstein-Friesian and Holstein-Friesian × Jersey crossbred dairy cows in a rotational grazing system

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ABSTRACT

An experiment was conducted to investigate the effect of sward system and dairy cow breed on enteric methane emissions from spring-calving grazing dairy cows using GreenFeed technology (C-lock Inc.). The study comprised 3 sward systems: a perennial ryegrass (*Lolium perenne* L.) monoculture receiving 250 kg N/ha per year (PRG), a perennial ryegrass white clover (*Trifolium repens* L.) sward receiving 125 kg N/ha per year (PRGWC), and a multispecies sward sown with grasses, legumes and herbs receiving 125 kg N/ha/yr (MSS). Each sward system had its own herd of dairy cows on a total area of 18.7 ha divided into 20 paddocks. Each herd comprised Holstein-Friesian (HF) purebred and HF × Jersey crossbred (JFX) animals which were divided equally across each sward system. Milk production and methane emissions were measured from mid-May to mid-October, and DMI and rumen characteristics were measured in late-July and early-October (165 and 228 DIM, respectively). Milk solids (milk fat + protein; MSo) was greatest for cows grazing MSS due to an associated increase in DMI. The greatest average daily methane output across the study was observed for cows grazing PRGWC (311 g/d) while those grazing PRG and MSS were similar (294 and 297 g/d, respectively). Methane intensity (g methane/kg MSo) was reduced for the MSS cows compared with both the PRG and PRGWC cows (208, 217, and 219 g/kg MSo respectively). The lowest methane yield (methane per kg of DMI) was also observed for the MSS cows (15.5 g/kg), whereas there was no difference between the PRG and PRGWC cows (17.6 and 17.7 g/kg, respectively). Greater VFA concentrations were observed for both the MSS and PRG cows compared with the PRGWC cows, whereas the MSS cows had a greater butyrate proportion compared with the cows grazing both other sward systems. Breed also had a significant effect on both milk and methane production characteristics with JFX animals having increased fat and protein concentration and increased MSo production compared with HF. The JFX cows also had reduced BW. Breed had no effect on DMI or methane yield, but JFX also had improved feed efficiency, both per kilogram of DMI and per kilogram BW. The HF cows had an increased methane intensity (223 g/kg MSo) compared with JFX (207 g/kg MSo). Rumen ammonia concentration and acetate-to-propionate ratio were increased for JFX, whereas VFA propionate proportion was decreased, and butyrate proportions were increased compared with HF. The results of this study highlight the potential for more diverse swards and Holstein-Friesian × Jersey crossbreeding to reduce enteric methane emission intensity within pasture-based dairy systems.

Key words: pasture-based milk production system, environmental sustainability, multispecies, clover, breeding

INTRODUCTION

Pasture-based dairy systems located in temperate regions, such as northwestern Europe and New Zealand, emphasize milk solids (milk fat + protein; **MSo**) production through the utilization of low-cost grazed pasture (Ramsbottom et al., 2015; Hennessy et al., 2020). The low-cost nature of these systems offers a competitive advantage to producers (Neal and Roche, 2020), although as with all systems of milk production, they also contribute to anthropogenic GHG emissions (Sorley

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et al., 2024). Methane emissions from enteric fermentation are the primary source of GHG emissions from pasture-based systems, followed by nitrous oxide (N_2O) associated with the application of artificial nitrogen (N) fertilizer (Herron et al., 2022). In temperate regions, the focus on simple and productive forage systems has resulted in swards dominated by perennial ryegrass (*Lolium perenne* L.). Such swards are capable of high levels of productivity and nutritional value over a long growing season (Baker et al., 2023) to support increased agricultural intensity and food production per hectare (Delaby et al., 2020). The continued intensification of such systems is now questioned, due to their high reliance on artificial N fertilizer inputs, which increase agricultural GHG emissions and the risk of nutrient losses to air and water (Lüscher et al., 2014).

The integration of legumes such as white clover (*Trifolium repens* L.) into grazing swards can reduce artificial N fertilizer requirements (Murray et al., 2024) therefore reducing N_2O emissions (Herron et al., 2021). Research has shown that in some cases, clover inclusion can reduce methane yield (methane/kg of DMI) compared with grass-only swards (Lee et al., 2004; Enriquez-Hidalgo et al., 2014). However, there is also evidence that white clover inclusion increases total enteric methane output per cow due to associated increases in total DMI (Lee et al., 2004; Dwan et al., 2025). The inclusion of alternative pasture species or "herbs," such as plantain (*Plantago lanceolata* L.) and chicory (*Chicorium intybus* L.), in grass-clover swards has recently received growing interest due to potential environmental benefits such as improved drought tolerance (Grange et al., 2021), reduced urinary nitrogen excretion (Minnée et al., 2020) and reduced nitrate leaching (Navarrete et al., 2018, Egan et al., 2025). The inclusion of a multispecies sward (**MSS**) in a livestock farming system may also potentially aid the reduction in carbon emissions by offsetting the methane produced by the grazing or feeding of the sward to ruminant livestock (Cooledge et al., 2022). Studies comparing swards dominated by herbs to grass or grass and white clover have shown reduced methane output from herbal swards (Wilson et al., 2020; Della Rosa et al., 2022). However, there have also been conflicting findings with some studies showing similar and sometimes greater methane emissions for MSS (Jonker et al., 2019; Loza et al., 2021). Previous research has sometimes been limited to short measurement periods. The proportions of grass, clover and herb components have also tended to vary considerably both within and between years, hence, further research is warranted to measure methane emissions from dairy cows grazing PRG, PRGWC, and MSS over a prolonged study period, to determine a more conclusive outcome.

An additional requirement of sustainable pasture-based dairy systems in the future will be to identify and select dairy cows with low environmental footprints, particularly in relation to enteric methane emissions (Roche et al., 2018). A significant level of genetic variation has been observed for enteric methane output among dairy cows (Pszczola et al., 2017; Manzanilla-Pech et al., 2022). At present however, a major obstacle to the direct inclusion of methane emissions in dairy breeding programs is access to large amounts of individual animal intake and methane emissions data from dairy cows (de Haas et al., 2017). Genetic and phenotypic traits associated with BW have been associated with methane output per cow, methane per unit of MSo (methane intensity) and methane per unit of DMI (methane yield; Dwan et al., 2025; Lassen and Løvendahl, 2016; Giagnoni et al., 2024). Furthermore, Yan et al. (2010) demonstrated that more feed efficient dairy cows also have reduced methane yield and intensity. Previous studies consistently demonstrate that crossbred Holstein-Friesians × Jersey (**JFX**) cattle have superior feed efficiency to Holstein-Friesian (**HF**) within pasture-based systems (Prendiville et al., 2009; Coffey et al., 2017; Evers et al., 2021) due to their lower BW, increased DMI capacity (DMI per unit BW) and increased MSo production (Prendiville et al., 2009; Beecher et al., 2014; Evers et al., 2023). These characteristics contribute to superior production efficiency and profitability within pasture-based systems, bolstering JFX's compatibility with such systems compared with HF animals (Lopez-Villalobos et al., 2000; Prendiville et al., 2011; Coffey et al., 2016). It could also be considered that, based on the aforementioned characteristics and associated impacts, JFX cattle would also have reduced methane output and methane intensity compared with their HF contemporaries, although there is a paucity of evidence within the recently published literature.

The current study therefore had 2 objectives: first, to quantify the enteric methane emissions of dairy cows grazing a PRG monoculture, a binary mix of PRGWC and a MSS comprising grasses, clovers, and herbs, and second to compare the enteric methane emissions of HF and JFX dairy cows within predominantly pasture-based grazing systems.

MATERIALS AND METHODS

The current experiment was undertaken between May and October 2023 at Curtin's Research Farm, Teagasc Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland (50°7N; 8°16W). The experiment was completed in conjunction with a full lactation, multiyear farm systems study described by Jezequel et al. (2024b). All experimental procedures on the animals in this study were approved

Table 1. The mean Economic Breeding Index (EBI), subindices, and PTA for Holstein-Friesian (HF) and Holstein-Friesian × Jersey (JFX)

Item	HF	SD	JFX	SD
EBI (€)	234	43.6	228	42.4
Subindex (€)				
Milk	65.2	24.0	73.6	0.4
Fertility	104	34.7	93.5	9.4
Carbon	13.3	10.5	20.1	7.9
Calving	46	9.4	44	13.2
Beef	−21	11.5	−38.8	14.3
Maintenance	18	7.4	29.0	6.9
Health	7.8	8.5	4.1	8.2
Management	1.1	4.5	3.0	4.3
PTA				
Milk (kg)	−41.4	144.5	−107.8	137.2
Fat (kg)	10.7	4.6	13.0	4.2
Protein (kg)	6.7	4.3	6.3	3.6
Fat (%)	0.22	0.10	0.31	0.11
Protein (%)	0.14	0.05	0.17	0.05

by the Health Products and Regulatory Authority of Ireland under the project authorization AE19132/P176. The study comprised 3 sward treatments: perennial ryegrass receiving 250 kg N/ha per year (**PRG**), perennial ryegrass and white clover receiving 125 kg N/ha per year (**PRGWC**) and an 8 species mix receiving 125 kg N/ha per year (**MSS**). The MSS were sown as a mix of perennial ryegrass, timothy (*Phleum pratense* L.), meadow fescue (*Festuca pratensis* L.), white clover, red clover (*Trifolium pratense* L.), alsike clover (*Trifolium hybridium* L.), plantain and chicory. The establishment of the swards and artificial fertilizer application strategy are described in detail by Jezequel et al. (2024b). Briefly, 64% of the experimental site was reseeded in 2020 and the remaining 36% reseeded in 2021; as such, the swards were 2 to 3 yr old when the current study was undertaken. An equal number of HF and JFX dairy cows were assigned to each grazing treatment in 2021 with replacements added in each subsequent year at a rate of 20% (Jezequel et al. (2024b). During the current study there were 47 cows in each sward system balanced for breed, genetic merit in terms the Irish total merit index (the Economic Breeding Index; **EBI**; www.icbf.com), calving date, parity, milk yield, and BW. For the purpose of enteric methane measurement, a representative subset of 36 cows that calved before April 1, 2023, were selected from each treatment group. The sample size was selected to detect at least a 5% difference in methane output. Their mean (SD) calving date was February 12 (19.9 d), and their mean lactation number was 3.0 (1.86). On average, the JFX had 42.2% (14.28%) Jersey genetics with a range of 25% to 68.8%. Both breed groups had an average EBI within the top 10% of cows nationally in 2023. The mean EBI value, individual subindices, and potential transmitting abilities of milk production traits for each breed are shown in Table 1 (confidential data retrieved in September 2023 from the Irish Cattle Breeding Federation; www.icbf.com).

Grazing Management and Measurement

A detailed account of the grazing management for the study has been reported by Jezequel et al. (2024a). Briefly, all treatments were managed within set rotational grazing systems with daily herbage allocations to achieve a target postgrazing sward height of 4.0 to 4.5 cm. Daily herbage allocations were controlled with a temporary electric fence. Herbage supply for each treatment was monitored weekly by visual assessment and recorded using the online decision support tool PastureBase Ireland (Hanrahan et al., 2017). Surplus herbage during periods of elevated growth were harvested as bale silage. In addition to the cows' respective herbage allocation, they were supplemented with 1 kg fresh weight of concentrate through the GreenFeed units daily. Cows with reduced visit frequency to the GreenFeed received additional concentrate in the milking parlor such that all cows received a similar daily concentrate amount. This was checked twice weekly and adjustments were made based on the previous few days average concentrate intake. Additional concentrate supplementation was offered in the parlor to all cows for 3 wk of the study due to reduced herbage growth; in mid-July they received an additional 2 kg during one week and 3 kg during a second week, and in late-September cows required supplementation of 1 kg for 1 wk also.

Pregrazing herbage yield, postgrazing sward height, and sward botanical composition were determined as described by Jezequel et al. (2024a). Briefly, pregrazing herbage yield was measured before each grazing in the paddock by harvesting and weighing 2 strips (10 m × 1.2 m) to a 4-cm cutting height above ground level. The DM content was determined by drying a subsample of 100 g at 90°C for 16 h. Postgrazing sward height was measured using a rising plate meter (Jenquip Ltd.) by taking 30 compressed sward heights across the paddock after each grazing. Botanical composition was measured before each grazing event by randomly sampling herbage (>4 cm) across the paddock with electronic shears. A subsample of 200 g was then separated into each treatment's respective components (grasses, legumes, plantain chicory, and weeds) and dried at 90°C for 16 h to determine DM content. For chemical analysis, another 100 g was subsampled and analyzed for ash, CP, NDF, ADF, and organic matter digestibility (**OMD**) as described previously by Jezequel et al. (2024b). Gross energy content of the herbage and concentrate samples collected during the DMI measurement periods (outlined below) was determined using a Parr 6050 compensated jacket calorimeter (Parr Instrument Company).

Table 2. The mean (SD) GreenFeed visitation statistics[1]

	PRG		PRGWC		MSS	
Item	HF (n = 17)	JFX (n = 16)	HF (n = 12)	JFX (n = 16)	HF (n = 18)	JFX (n = 18)
Daily visits per cow	2.0 (0.69)	2.1 (0.65)	1.9 (0.71)	2.1 (0.72)	1.8 (0.62)	2.0 (0.67)
Visit duration (s)	206 (17.6)	202 (19.1)	197 (15.7)	192 (13.7)	196 (14.6)	195 (13.1)
Average airflow per visit (L/s)	40.5 (1.89)	40.3 (1.91)	39.9 (1.74)	40.2 (1.74)	40.7 (1.33)	40.8 (1.34)

[1]PRG = perennial ryegrass 250 kg N/ha; PRGWC = PRG with white clover 125 kg N/ha; MSS = multispecies sward 125 kg N/ha; HF = Holstein-Friesian; JFX = Holstein-Friesian × Jersey.

Animal Measurements

Milking took place twice daily at 0730 and 1500 h. Each cow's milk yield was recorded using electronic milk meters (Dairymaster, Causeway, Co. Kerry, Ireland) and weekly milk samples were collected on the Monday p.m. and Tuesday a.m. milkings. These samples were analyzed using mid-infrared spectrophotometry (Milkoscan 203 [DK-3400], Foss Electric, Hillerød, Denmark) to determine milk constituents. Every fortnight, individual animal BW was measured using an electronic scale (Tru-Test Ltd.) and BCS was also assessed fortnightly on a scale of 1 to 5 (1 = emaciation and 5 = obesity; Edmonson et al., 1989).

Enteric methane and CO_2 emissions were measured using 3 trailer-mounted GreenFeed units (C-Lock Inc., Rapid City, SD). The GreenFeed units were introduced to the cows in mid-April, and they were trained to the units for 1 mo before the experiment as per the methods described by Lahart et al. (2024). Of the 36 cows in each sward treatment group, 34 PRG, 28 PRGWC, and 36 MSS cows became regular visitors to the GreenFeed units by the start of the experiment. Across the sward treatments, 47 HF and 50 JFX cows were regular visitors. During the experimental period, a maximum of 4 visits to the units per day were allowed, with an interval of 5 h between visits. The cows received a maximum of 10 concentrate drops at each visit, which were separated by 18-s intervals. The mean visits per day, visit duration and sample airflow rate for the treatments and breed groups during the experimental period are shown in Table 2. The GreenFeed sensors were autocalibrated every 2 d with a zero and span gas provided by the manufacturer. A CO_2 recovery was carried out monthly as per the manufacturer's instructions. Mean (SD) CO_2 recovery results were 99.7% (1.27%), 100.3% (2.02%), and 106.5% (4.57%) for each respective GreenFeed unit. Air filters were switched and cleaned fortnightly. To account for possible bias, the GreenFeed units were rotated between the sward treatments approximately every 4.6 d such that the animals in each sward system had an equal duration with each unit within each 2-wk period. A malfunction in one GreenFeed unit caused a loss of data for 3 wk in July where data collected after ~1500 h each day was not saved to the system. All cows still had a satisfactory daily visit profile due to the fact that the units were rotated between treatments. Furthermore, a statistical model was used to account for any potential impact on the average gaseous emissions profile of the groups.

Dry matter intake was estimated twice during the experiment using the ytterbium oxide (Yb_2O_3) technique (Delagarde et al., 2010; Pérez-Ramírez et al., 2012) as outlined previously by Jezequel et al. (2025). The first period took place from July 25 to August 4, and the second from September 26 to October 6. During these periods, cows were dosed with a paper bullet containing 0.8 g of Yb_2O_3 twice daily for 11 consecutive days. From d 7 onward, fecal samples were collected from each cow in the field, 1 h before each milking. Any cows not sampled in the field were rectally handled after milking. Fecal samples were then stored in a freezer at −20°C. The samples were then thawed, bulked by cow, dried in a 40° oven for 96 h and then milled through a 1-mm screen using a Cyclotech 1093 Sample Mill (Foss, DK-3400 Hillerød, Denmark). The ytterbium content of the feces was then measured using inductively coupled plasma optical emission spectroscopy as described by Pérez-Ramírez et al. (2012) and fecal CP and ADF content was determined by near-infrared spectroscopy as described by Jezequel et al. (2025). The fecal Yb_2O_3 content was used to determine fecal output and the fecal CP and ADF content was used to determine the OMD of the diet as described by Jezequel et al., (2025).

On the week following each intake estimation period, rumen samples were collected from a subset of 16 cows per sward treatment. After the p.m. milking before the collection day, all cows were offered a fresh pasture allocation, and the rumen samples were taken on the following morning after milking. Transesophageal samples were collected using a rumen scoop (Flora; Guelph, ON, Canada). Solid particulates were removed from the samples by passing it through cheesecloth. A 4-mL aliquot of rumen fluid was then added to 1 mL of 50% trichloroacetic acid before storing at −18°C. Insufficient fluid was collected from several cows on each sward treatment leaving 36 animals with samples collected across the 2 periods for further analysis (12 cows from PRG, 11 from PRGWC, and 13 from MSS; 16 from HF and 20 from JFX). The samples were analyzed for total VFA and individual VFA (acetic, propionic, butyric, valeric, isobutyric, and isovaleric acids) proportions, as well as ammonia concentration, as described previously by McAuliffe et al. (2022).

Data Handling

Only spot measurements from the GreenFeed units that were ≥2 min in duration were retained, with a total of 28,912 spot measurements in the data set. Outliers were identified and then removed using the method of Coppa et al. (2021). This involved regressing methane spot measurements against CO_2 spot measurements and dividing the residuals by the SD and removing values greater than 3. This was repeated with CO_2 against methane. After these procedures, 28,294 spot measurements remained.

Spot measurements were then adjusted for visit time to account for diurnal variation in methane emissions. This was achieved using the method of Fresco et al. (2023) using the coefficient estimates from the following mixed model, which was applied to each sward treatment separately:

$$Y_{ijut} = \mu + P_j + GF_u + H_t + DIM_{ij} + e_{ijut},$$

where Y_{ijut} is methane of the ith cow, of jth parity, measured with the uth GreenFeed, in the tth hour, μ is the mean, P_j is parity (j = 1 to ≥3), GF_u is GreenFeed unit (u = 1 to 3), H_t is hour of the day (t = 1 to 24), DIM_{ij} is DIM, and e_{ijut} is the residual error. Visits were then averaged over 11 fortnightly periods starting from May 15 and ending on October 15. Data from one cow was removed from the study due to mastitis. Following this, there were 1,067 records from 97 cows across the 11 periods. Any record with less than one visit per day to the GreenFeed was subsequently removed. The remaining number of records was 1,005 (341 PRG, 291 PRGWC, 373 MSS, 478 HF, and 527 JFX) with no cow absent from more than 5 periods. The range in methane records in the final dataset was 183 to 448 g/d, and the range for CO_2 was 7.9 to 14.2 kg/d

Methane intensity was calculated as the ratio of daily methane emissions to both daily MSo yield and fat- and protein-corrected milk (**FPCM**; IDF, 2022) for each measurement period. Total DMI was calculated for each cow in each DMI measurement period as the sum of average daily herbage DMI and average daily concentrate DMI across the 5 d of DMI measurement. Individual methane yield was calculated from the average daily methane emissions of a 2-wk period around each intake measurement period (period 1 = July 26 to August 8, period 2 = September 27 to October 10) divided by average daily DMI. The herbage and concentrate gross energy content during DMI measurement was used to calculate gross energy intake. This was used to calculate the proportion of gross energy intake lost to methane energy (**Y_m**).

Energy values of the herbage and concentrate were calculated from each week of DMI measurement using the Institut National de la Recherche Agronomique (INRA; French National Institute for Agricultural Research) net energy system where 1 unité fourragère lait (**UFL**) is the net energy for lactation of 1 kg of barley (INRA, 2018). These were used to calculate net energy intake (**NEI**) for each animal for each week of DMI measurement. Net energy requirements were calculated for lactation (NEL), maintenance (NEM), and growth, and the sum of these were subtracted from NEI to calculate energy balance (INRA, 2018). Outliers in the DMI estimation dataset were identified and removed if the animal's energy balance was greater or less than 3 SD from the mean. Further cows were removed if they had less than one visit per day to the GreenFeed unit in either DMI measurement period. Subsequently, there were 26 PRG (13 HF and 13 JFX), 23 PRGWC (11 HF and 12 JFX), and 26 MSS (14 HF and 12 JFX) individual cows.

Statistical Analysis

Grazing measurements and chemical composition were analyzed using the GLM procedure of SAS (9.4; SAS Institute Inc.) using the following model:

$$Y_{km} = \mu + S_k + R_m + (S_k \times R_m) + e_{km},$$

where Y_{km} is the response of the kth sward at the mth measurement period, μ is the mean, S_k is sward treatment (k = grass only, grass clover, or multispecies), R_m is the measurement period (m = 1 to 11), $S_k \times R_m$ is the interaction between sward treatment and measurement period, and e_{km} is the residual error.

Statistical analyses of animal measurements were undertaken using the mixed procedure of SAS (9.4). The model was as follows:

$$Y_{ijklm} = \mu + P_j + S_k + B_l + R_m + (P_j \times R_m) + (S_k \times R_m) + (S_k \times B_l) + C_{ijkl} + freq_{ijklm} + e_{ijklm},$$

where Y_{ijklm} is the response of the ith cow of jth parity of lth breed in the kth sward at the mth measurement period,

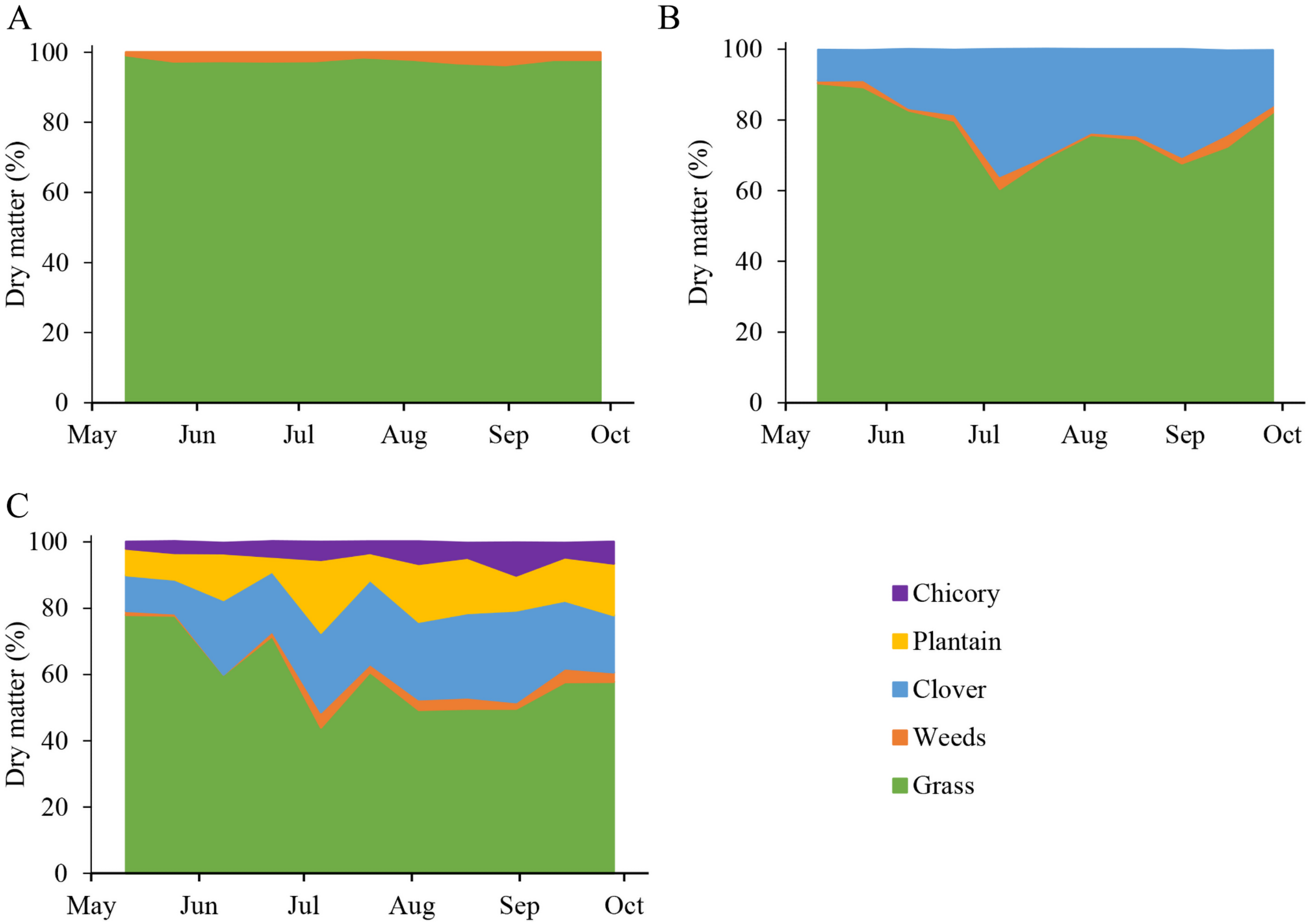

Figure 1. Botanical composition (% DM) of (A) perennial ryegrass (*Lolium perenne* L.) receiving 250 kg N/ha per year, (B) perennial ryegrass with white clover (*Trifolium repens* L.) receiving 125 kg N/ha per year, and (C) a multispecies sward system receiving 125 kg N/ha per year (MSS) across the study period. In MSS, grass includes perennial ryegrass, timothy (*Phleum pratense* L.), and meadow fescue (*Festuca pratensis* L.), and clover includes white clover, red clover (*Trifolium pratense* L.), and alsike clover (*Trifolium hybridium* L.).

μ is the mean, P_j is parity (j = 1 to ≥3), S_k is sward system (k = PRG, PRGWC, or MSS), B_l is breed (l = HF or JFX), R_m is measurement period (m = 1 to 11), $P_j \times R_m$ is the interaction between parity and measurement period, $S_k \times R_m$ is the interaction between sward system and measurement period, $S_k \times B_l$ is the interaction between sward system and breed, C_{ijkl} is the calving day of the year, $freq_{ijklm}$ is the frequency of GreenFeed visits in each period, and e_{ijklm} is the residual error. GreenFeed visit frequency was only included for gaseous emission variables. Measurement period was included as a repeated measure with individual cow as a random effect. A first-order autoregressive covariance structure was applied for the long-term data and a compound symmetry covariance structure was applied for the DMI measurement period data. All results are expressed as LSM. Multiple comparisons were adjusted using the Tukey–Kramer method.

RESULTS

Grassland Measurements

The profile of the botanical composition of the 3 sward treatments across the methane study are presented in Figure 1. The mean (SD) white clover content in PRGWC was 22.7% (12.59%) during the full methane study period. The MSS sward system had a mean (SD) clover (white, red, and alsike) content of 20.8% (12.26%), plantain content of 12.7% (9.86%) and chicory content of 5.1% (4.02%). The mean (SD) proportion of weeds in each sward was 2.3% (2.58%) in PRG, 1.7% (2.43%) in PRGWC and 2.5% (3.12%) in MSS.

Sward type had no effect on pregrazing herbage mass (1,834 kg DM/ha), whereas the postgrazing residual height of PRG (4.3 cm) was slightly higher ($P < 0.001$) than both PRGWC and MSS (4.1 and 4.2 cm, respec-

Table 3. Mean grazing measurements and chemical composition of the sward systems[1]

Item	PRG	PRGWC	MSS	SEM	*P*-value
Pregrazing yield (kg DM/ha)[2]	1,912	1,796	1,795	47.8	0.13
Postgrazing height (cm)	4.3[a]	4.1[b]	4.0[b]	0.04	<0.001
DM (%)	16.8[a]	16.1[ab]	15.6[b]	0.25	<0.01
Ash (g/kg DM)	91.3[a]	91.5[a]	104.5[b]	1.42	<0.001
CP (g/kg DM)	178.2	185.6	186.0	3.88	0.27
NDF (g/kg DM)	447.0	435.8	449.6	5.60	0.17
ADF (g/kg DM)	223.2[a]	223.2[a]	234.9[b]	2.14	<0.001
OMD (g/kg DM)	768.3	767.5	760.0	4.60	0.34

[a,b]Values in the same column not sharing a common superscript are significantly different ($P < 0.05$; Tukey–Kramer adjusted).

[1]PRG = perennial ryegrass 250 kg N/ha; PRGWC = PRG with white clover 125 kg N/ha; MSS = multispecies sward 125 kg N/ha; OMD = OM digestibility.

[2]Determined from 4 cm above ground level.

tively; Table 3). Pasture DM content was less ($P < 0.01$) in MSS (15.6%) compared with PRG (16.8%), whereas PRGWC was numerically intermediate but not statistically different to the other 2 sward systems (16.1%). Pasture quality was similar for all 3 sward types during the methane study in terms of CP, NDF, and OMD (184, 445, and 765 g/kg DM, respectively). The MSS sward system had increased ($P < 0.001$) ash and ADF contents (105 and 235 g/kg, respectively) compared with both PRG (91.3 and 223 g/kg DM, respectively) and PRGWC (91.5 and 223 g/kg, respectively). The mean ash, CP, and NDF content of the concentrate across the methane study were 95.6 g/kg, 128.0 g/kg, and 139.5 g/kg respectively. The sward measurement and chemical composition results for each 2-wk measurement period and each DMI measurement period have been made available in Supplemental Tables S1, S2, and S3 (see Notes).

Animal Performance

Greater mean daily milk yield was achieved by the cows grazing MSS (16.6 kg) compared with PRG (15.3 kg; $P < 0.01$), whereas PRGWC was numerically intermediate (15.9 kg) but not statistically different to the cows grazing the other 2 sward systems (Table 4). There was no difference in the milk fat and protein composition between the cows assigned to the 3 sward systems (50.9 and 38.5 g/kg, respectively). Cows grazing MSS achieved a greater mean daily MSo yield per cow (1.49 kg) compared with PRG (1.40 kg; $P < 0.01$) but not PRGWC, which was again, numerically intermediate (1.44 kg). Daily FPCM yield was also greater for the cows grazing MSS (19.3 kg) compared with the cows grazing PRG (18.1 kg; $P < 0.01$), while those grazing PRGWC were numerically intermediate (18.7 kg). There was no difference in BW or BCS between animals grazing the 3 sward types.

Breed had a significant impact on milk production performance but there were no significant interactions between breed and sward system for any performance measures evaluated. Daily milk yield tended to be greater for HF (16.2 kg) compared with JFX (15.7 kg; $P = 0.08$), and JFX had greater milk fat (55.2 g/kg; $P < 0.001$) and protein (40.3 g/kg; $P < 0.001$) contents compared with HF (51.0 and 38.2 g/kg, respectively). Consequently, JFX had an increased ($P < 0.01$) daily MSo yield (1.48 kg) compared with HF (1.41 kg), and FPCM also tended to be greater for JFX (19.0 kg; $P = 0.051$) compared with HF (18.4 kg). As the HF animals were heavier ($P < 0.001$, +25.8 kg) than JFX (470 kg), the JFX produced a greater level of MSo (0.31 kg) and FPCM (4.03 kg) per 100 kg of BW compared with HF (0.29 and 3.72 kg/100 kg, respectively; $P < 0.001$). There was no difference in BCS between the 2 breeds.

DMI and Feed Efficiency

Daily DMI and NEI were lowest for the cows grazing PRG (17.3 kg and 17.7 UFL, respectively) compared with the cows grazing MSS (20.2 kg and 20.3 UFL, respectively; $P < 0.001$), whereas those grazing PRGWC were intermediate (18.1 kg and 18.7 UFL, respectively; Table 5). Daily herbage DMI was also greatest in the cows grazing MSS (19.3 kg), intermediate in those grazing PRGWC (17.0 kg) and lowest in those grazing PRG (16.3 kg), whereas the cows in the PRGWC sward system had slightly greater daily concentrate intake (1.07 kg) compared with those in the PRG (0.95 kg; $P < 0.05$) and MSS (0.88 kg; $P < 0.001$) sward systems. Dry matter intake per 100 kg BW was also lowest for cows grazing PRG (3.48 kg) compared with those grazing MSS (4.09 kg; $P < 0.001$), whereas the cows grazing PRGWC were intermediate (3.74 kg). The cows grazing PRGWC tended to have greater ($P < 0.1$) MSo per DMI and less NEI required per kilogram of MSo produced (81.5 g/100 g and 12.9 UFL/kg, respectively) compared with those grazing PRG (76.6 g/100 g and 13.8 UFL/kg, respectively), whereas those grazing MSS were

Table 4. The effect of sward system (S) and breed (B) on animal performance[1]

Item	PRG		PRGWC		MSS		SE	*P*-value		
	HF	JFX	HF	JFX	HF	JFX		S	B	S × B
Milk yield (kg)	15.4	15.2	16.2	15.7	17.0	16.2	0.47	<0.01	0.08	0.73
Fat (g/kg)	51.4	56.4	51.2	55.6	50.5	53.6	1.27	0.18	<0.001	0.61
Protein (g/kg)	38.8	40.6	37.8	39.8	38.1	40.4	0.67	0.30	<0.001	0.91
MSo (kg)	1.36	1.45	1.42	1.47	1.47	1.50	0.033	<0.01	<0.01	0.53
FPCM (kg)	17.6	18.6	18.5	19.0	19.2	19.3	0.41	<0.01	0.05	0.46
BW (kg)	506	472	483	477	500	462	9.2	0.40	<0.001	0.11
BCS	3.01	3.01	3.00	2.99	2.99	2.98	0.013	0.10	0.96	0.85
MSo/100 kg BW (kg)	0.27	0.31	0.29	0.31	0.29	0.33	0.007	<0.01	<0.001	0.29
FPCM/100 kg BW (kg)	3.51	3.93	3.81	3.98	3.83	4.18	0.092	<0.01	<0.001	0.28

[1]PRG = perennial ryegrass 250 kg N/ha; PRGWC = PRG with white clover 125 kg N/ha; MSS = multispecies sward 125 kg N/ha; HF = Holstein-Friesian; JFX = Holstein-Friesian × Jersey; MSo = milk solids (milk fat + protein); FPCM = fat- and protein-corrected milk.

numerically intermediate (78.0 g/100 g and 13.3 UFL/kg respectively). Energy balance was greater ($P < 0.05$) for cows grazing MSS (4.81 UFL) compared with both PRG and PRGWC (3.54 and 3.70 UFL, respectively).

There was no difference in herbage DMI between the 2 breeds although the JFX cows had slightly higher ($P < 0.05$) concentrate intake per day (1.01 kg DM) compared with the HF cows (0.93 kg DM). Despite this, breed had no effect on total DMI or NEI. However, when expressed per 100 kg of BW, JFX had increased DMI (3.87 kg/100 kg) compared with HF (3.67 kg/100 kg; $P < 0.05$) and also produced more ($P < 0.01$) MSo per 100 g of DMI (81.2 and 76.2 g, respectively). The NEL tended to be greater ($P = 0.09$) in JFX (8.10 UFL) compared with HF (7.78 UFL), whereas NEM were lower ($P < 0.001$) for JFX (6.53 UFL) compared with HF (6.86 UFL). Consequentially, NEI required per kg of MSo produced was less ($P < 0.01$) for JFX (12.9 UFL) compared with HF (13.7 UFL). Finally, there was no significant differences in energy balance between breeds, nor were there any interactions between sward system and breed.

Gaseous Emissions

The methane emission profiles of the sward systems are presented in Figure 2. Greater mean daily methane emissions per cow were observed for PRGWC (311 g) compared with both PRG (294 g; $P < 0.01$) and MSS (297 g; $P < 0.05$; Table 6). There was no difference in methane intensity expressed per kilogram of MSo or FPCM between the cows grazing PRG and PRGWC. Lower methane emissions per kilogram of MSo (208 g/kg) were observed for the cows grazing MSS compared with those grazing PRG (217 g/kg; $P < 0.05$) and PRGWC (219 g/kg; $P < 0.01$). A similar result was observed for methane per kilogram of FPCM where cows grazing MSS (15.8 g/kg) produced less than those grazing PRG (16.5 g/kg; $P < 0.05$) and PRGWC (16.9 g/kg; $P < 0.001$). Sward type had no effect on mean CO_2 emissions over the full methane study period.

The daily methane emissions per cow during the DMI measurement periods of the MSS and PRGWC were similar (309 g) and were both greater ($P < 0.05$) than PRG (291g). Although cows grazing PRGWC had greater methane emissions than those grazing PRG, there was no difference in methane yield (methane per kg of DMI) between the cows grazing the 2 sward systems (17.4 and 17.2 g/kg respectively) due to the increased DMI of the cows grazing PRGWC. Methane yield was reduced for the cows grazing MSS (15.7 g/kg) compared with both those grazing PRG ($P < 0.01$) and PRGWC ($P < 0.001$). A similar result was observed for gross energy intake lost to methane (Y_m), with no difference between the cows grazing PRG and PRGWC (0.052), but a reduction ($P < 0.05$) was observed for the cows grazing MSS (0.048). Carbon dioxide emissions during the DMI measurement periods were less ($P < 0.05$) from the cows grazing PRG (10.6 kg) than those grazing MSS (11.4 kg), and the cows grazing PRGWC were numerically intermediate (11.0 kg).

Breed also had a significant effect on methane emissions (Figure 3). The JFX cows had reduced ($P < 0.05$) daily methane emissions (296 g) and methane intensity (207 g/kg MSo, 15.9 g/kg FPCM) compared with HF (305 g, 223 g/kg MSo and 16.9 g/kg FPCM, respectively). The JFX cows also tended to have increased methane per kg BW (0.63 g/kg; $P = 0.09$) compared with HF (0.62 g/kg). There was no difference in CO_2 emissions between the 2 breed groups, either across the full duration of the methane study or during DMI estimation periods. There was no difference in methane emissions during the DMI measurement periods between HF and JFX and no effect of breed on methane yield or Y_m. There were also no interactions between sward type and breed detected.

Rumen Characteristics

There was no difference in total VFA between cows grazing PRG (115 mmol/L) and MSS (128 mmol/L), but they were reduced for PRGWC (92 mmol/L; $P < 0.05$;

Table 5. The effect of sward system (S) and breed (B) on DMI and feed efficiency metrics[1]

	PRG		PRGWC		MSS			*P*-value		
Item	HF	JFX	HF	JFX	HF	JFX	SE	S	B	S × B
Herbage DMI (kg)	16.2	16.5	17.2	16.9	19.7	18.9	0.60	<0.001	0.55	0.60
Concentrate DMI (kg)	0.93	0.97	1.01	1.13	0.83	0.92	0.049	<0.001	<0.05	0.75
Total DMI (kg)	17.1	17.5	18.2	18.0	20.5	19.8	0.60	<0.001	0.67	0.62
MSo/DMI (g/100 g)	75.2	77.9	78.6	84.5	74.8	81.3	2.33	0.08	<0.01	0.64
DMI/100 kg BW (kg)	3.32	3.65	3.69	3.79	4.00	4.17	0.121	<0.001	<0.05	0.57
NEI (UFL)	17.6	17.9	18.8	18.6	20.7	19.9	0.62	<0.001	0.67	0.63
NEL (UFL)	7.03	7.31	7.90	8.32	8.40	8.67	0.245	<0.001	0.09	0.94
NEM (UFL)	6.97	6.56	6.70	6.53	6.90	6.50	0.092	0.26	<0.001	0.30
NEI/MSo (UFL/kg)	14.0	13.6	13.4	12.3	13.8	12.7	0.42	0.06	<0.01	0.65
Energy balance (UFL)	3.30	3.78	3.93	3.48	5.12	4.50	0.516	<0.05	0.62	0.47

[1]PRG = perennial ryegrass 250 kg N/ha; PRGWC = PRG with white clover 125 kg N/ha; MSS = multispecies sward 125 kg N/ha; HF = Holstein-Friesian; JFX = Holstein-Friesian × Jersey; MSo = milk solids (milk fat + protein); NEI = net energy intake; UFL = unité fourragère lait (forage unit for lactation) according to the INRA (2018) system.

Table 7). Rumen acetate concentrations were increased ($P < 0.001$) for the cows grazing PRG (86.0 mmol/L) and MSS (94.2 mmol/L) compared with the cows grazing PRGWC (68.7 mmol/L). Similarly, propionate concentrations were greater ($P < 0.01$) for cows grazing MSS (17.4 mmol/L) compared with PRGWC (12.9 mmol/L), whereas those grazing PRG were intermediate (15.7 mmol/L). Butyrate concentrations were greatest ($P < 0.001$) in the cows grazing MSS (12.3 mmol/L), intermediate for those grazing PRG (10.1 mmol/L) and lowest for those grazing PRGWC (7.7 mmol/L). Valerate and isobutyrate were also increased ($P < 0.01$) in the cows grazing MSS (1.23 and 1.44 mmol/L, respectively) and PRG (1.04 and 1.31 mmol/L, respectively) compared with those grazing PRGWC (0.77 and 0.94 mmol/L, respectively). Isovalerate was also increased ($P < 0.05$) in the cows grazing MSS (1.24 mmol/L) compared with those grazing PRGWC (0.92 mmol/L), whereas the cows grazing PRG were numerically intermediate (1.16 mmol/L). As a proportion of total VFA, there was no overall difference in acetate between the cows assigned to each sward system. An increased butyrate proportion was observed in the cows grazing MSS (9.64 mmol/100 mmol) compared with those grazing PRG (8.76 mmol/100 mmol; $P < 0.01$) and PRGWC (8.38 mmol/100 mmol; $P < 0.001$), whereas valerate also tended to be increased in the cows grazing MSS (0.97 mmol/100 mmol) compared with those grazing PRGWC (0.82 mmol/100 mmol; $P = 0.07$), and the cohort grazing PRG were intermediate (0.89 mmol/100 mmol). Sward type had no effect on branch-chained VFA proportions and ammonia levels.

There was no difference in the total VFA concentration between breed groups, although there were some differences in the proportion of individual VFA. The HF group had elevated propionate levels (14.2 mmol/100 mmol) compared with JFX (13.2 mmol/100 mmol; $P < 0.01$) whereas butyrate proportions were higher for JFX (9.36 mmol/100 mmol) compared with HF (8.49 mmol/100 mmol; $P < 0.001$). Acetate was not different between breeds but the ratio of acetate to propionate was increased for JFX (5.70 mmol/L) compared with HF (5.27 mmol/L; $P < 0.05$). There was also no difference in valerate or the branched-chain VFA between the 2 breeds. Ammonia levels were increased ($P < 0.05$) for JFX cows (90.6 μmol/L) compared with HF contemporaries (78.0 μmol/L).

DISCUSSION

Enteric methane is a major contributor to total agricultural GHG emissions (65% in Ireland; EPA, 2024), and so it is essential to investigate management strategies that can reduce enteric methane emissions within Irish pasture-based dairy production systems. Although many recent published studies have looked at such effects within short-term periods, this is the first such study to evaluate the effect of plant and animal breed diversity on enteric methane emissions within a full farm systems framework, as part of a larger project evaluating the effects of sward system and animal breed on the productivity of predominantly pasture-based systems (Jezequel et al., 2024b). The grazing characteristics and sward quality results observed during the current study are similar to previous studies (Egan et al., 2018; Murray et al., 2024) and consistent with the previous years of the current farm systems study (Jezequel et al., 2024a). The overall levels of milk production, enteric methane emissions and intensity of methane production recorded in the current study are also similar to previous studies under temperate grazing conditions (Lahart et al., 2024; Starsmore et al., 2024; Dwan et al., 2025) and are therefore, representative of the typical characteristics of modern grazing systems.

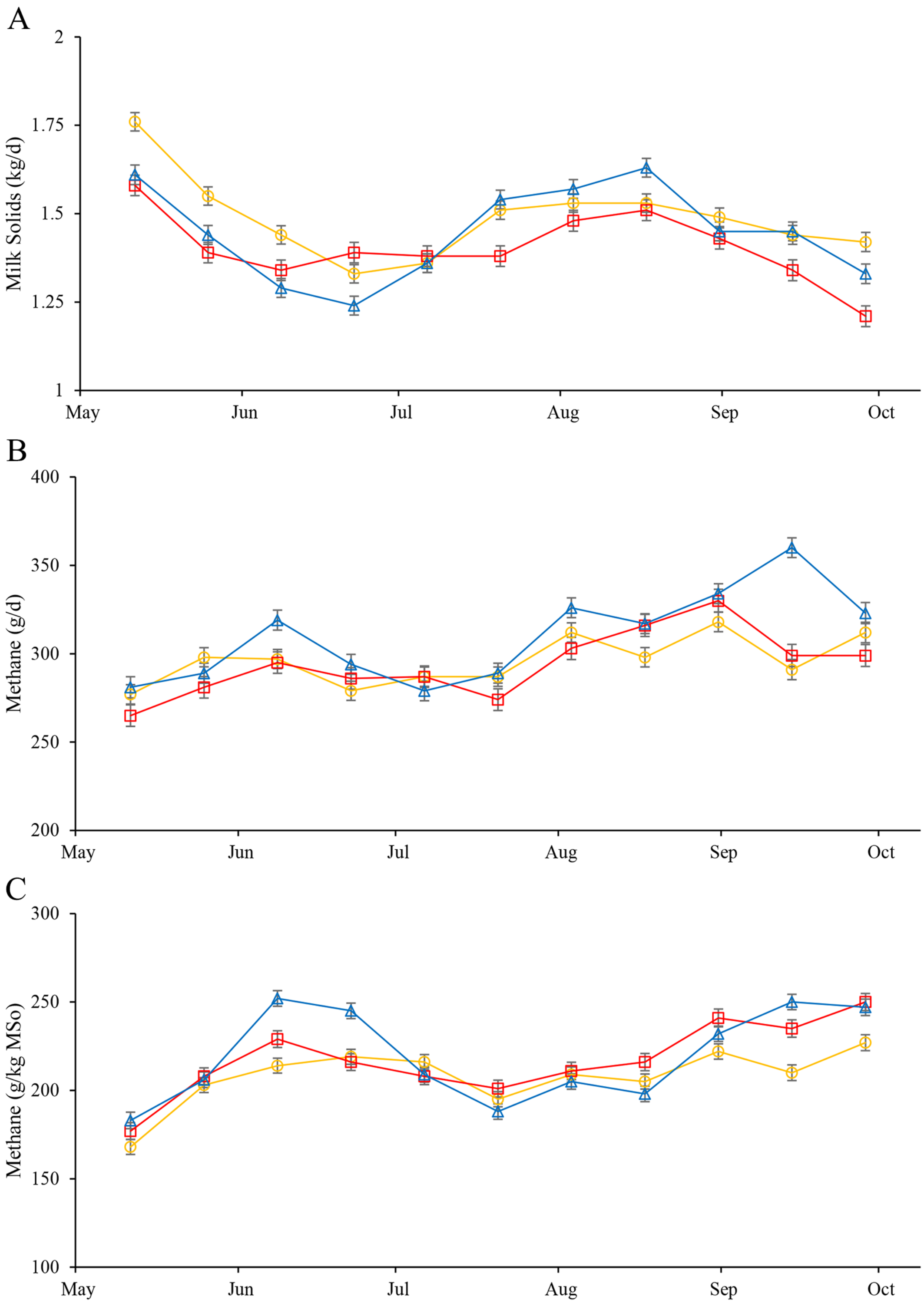

Figure 2. The profile of (A) milk solids (MSo; fat + protein), (B) methane emissions, and (C) methane per kilogram of MSo of cows grazing PRG (red squares), PRGWC (blue triangles), and MSS (yellow circles) across the methane study period. Error bars represent the SEM.

Table 6. The effect of sward system (S) and breed (B) on methane emissions across the full study period and across the 2 DMI measurement periods[1]

	PRG		PRGWC		MSS			*P*-value		
Item	HF	JFX	HF	JFX	HF	JFX	SE	S	B	S × B
Full study period										
CH_4 (g/d)	294	294	317	304	304	290	5.7	<0.01	<0.05	0.30
CH_4/MSo (g/kg)	229	212	229	211	217	199	4.4	<0.01	<0.001	0.61
CH_4/FPCM (g/kg)	16.9	16.2	17.5	16.3	16.3	15.3	0.34	<0.001	<0.001	0.70
CH_4/BW (g/kg)	0.58	0.62	0.65	0.64	0.61	0.63	0.012	<0.001	0.09	<0.05
CO_2 (kg/d)	10.6	10.8	11.0	10.8	11.1	10.7	0.16	0.18	0.19	<0.05
DMI measurement periods										
CH_4 (g/d)	291	291	314	304	317	300	8.0	<0.05	0.17	0.53
CH_4 yield (g/kg DMI)	17.3	17.1	17.6	17.1	15.8	15.7	0.49	<0.001	0.53	0.90
Y_m (MJ CH_4/MJ GEI)	0.052	0.052	0.052	0.052	0.048	0.048	0.0015	<0.05	0.55	0.91
CO_2 (kg/d)	10.5	10.7	11.2	10.8	11.7	11.1	0.21	<0.001	0.10	0.14

[1]PRG = perennial ryegrass 250 kg N/ha; PRGWC = PRG with white clover 125 kg N/ha; MSS = multispecies sward 125 kg N/ha; HF = Holstein-Friesian; JFX = Holstein-Friesian × Jersey; MSo = milk solids (milk fat + protein); FPCM = fat- and protein-corrected milk.

Sward System

The aim of this study was to evaluate enteric methane emissions from dairy cows grazing botanically diverse pasture mixtures with lower chemical N application levels (PRGWC and MSS) within compact calving pasture-based dairy systems relative to a monoculture of PRG with higher chemical N application rates. The daily milk production results per cow from PRG and PRGWC in the current study build on previous evidence that PRGWC sward systems perform at least as well as PRG-only sward systems, while receiving less artificial N application (Fitzpatrick, 2023; Murray et al., 2024; Dwan et al., 2025), with the level of white clover contribution (20%) in the PRGWC sward in the present study consistent with that in the aforementioned studies. The increased methane output of the PRGWC cows compared with the PRG cows is consistent with previous findings and is predominantly due to the increased DMI of the PRGWC cows (Lee et al., 2004; Dwan et al., 2025). The increased DMI of the PRGWC cows was also associated with a numeric increase in MSo production that resulted in no difference in methane intensity between the 2 sward systems, similar to the findings of Dwan et al. (2025). Increased DMI associated with white clover inclusion has been attributed to a faster rate of passage through the rumen (Steg et al., 1994; Ribeiro Filho et al., 2012), whereas the reduced total rumen VFA concentrations of the cows grazing PRGWC at the time of sampling were possibly due to an increase in passage rate (Bannink et al., 2012). At the same time, increased rumen passage rates are often associated with reduced methane yield (Janssen, 2010); however, unlike Lee et al. (2004) and Enriquez-Hidalgo et al. (2014), but similar to Dwan et. al. (2025), white clover inclusion in PRGWC did not reduce methane yield in the current study. As outlined by Dwan et al. (2025), the similarity in OMD across the 2 sward systems may explain this finding, a pattern also observed in the present study. Dwan et al. (2025) also observed slightly greater rumen acetate proportions from cows grazing PRGWC compared with PRG, that were postulated to result from pectin digestion. Pectin is a rapidly digestible carbohydrate present in clover (Ulyatt, 1971; Van Soest, 1994). In contrast, the current study found no difference in rumen VFA proportions between the 2 swards, which was possibly due to variations in pregrazing herbage mass between studies and associated influences on sward chemical composition.

Among all sward systems, MSS had the greatest daily milk production, MSo production and DMI per cow, aligning with the findings of McCarthy et al. (2023) and Roca-Fernández et al. (2016). Jonker et al. (2019) and Loza et al. (2021) also reported increased milk production in cows grazing MSS compared with others grazing PRGWC, although no differences in DMI were reported. In the current study, the cows grazing the MSS had greater DMI, yet reduced methane yield and methane intensity compared with cows grazing the PRG and PRGWC swards. In contrast, Jonker et al. (2019) reported increased methane yield from cows grazing a MSS and only observed a numeric reduction in methane intensity compared with others grazing PRGWC, whereas Loza et al. (2021) noted no difference in methane yield and increased intensity associated with MSS. It is, however, difficult to make comparisons across studies due to variation in pasture nutritive value and botanical composition between PRGWC and MSS (Loza et al., 2021; McCarthy et al., 2023), different sward species in the MSS (Roca-Fernández et al., 2016; Jonker et al., 2019; Loza et al., 2021) and large differences in pregrazing herbage mass (Jonker et al., 2019; McCarthy et al., 2023). In the current study, legume contents were similar between PRGWC and MSS; therefore, differences between the 2 swards can be attributed to the additional

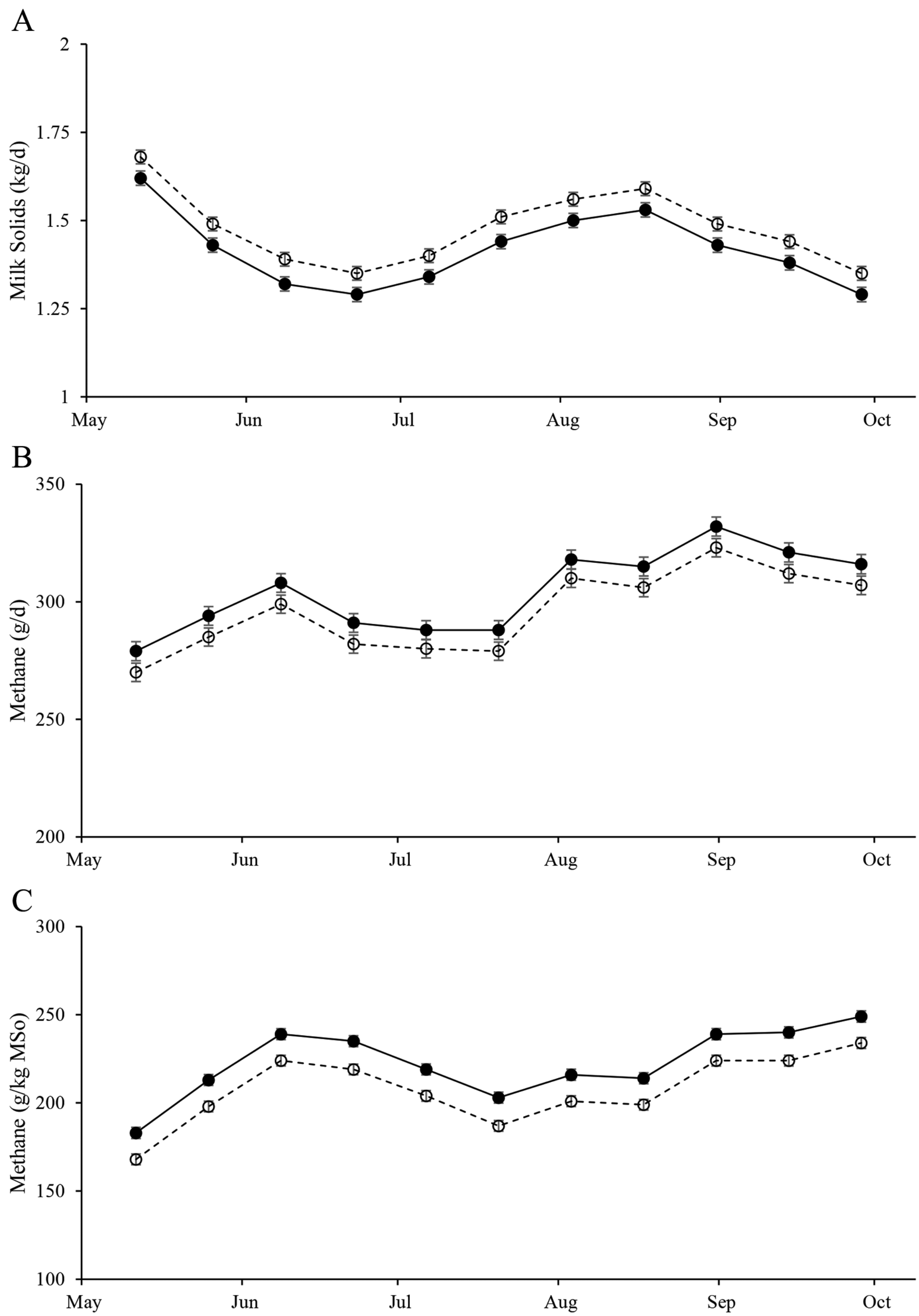

Figure 3. The profile of (A) milk solids (MSo; fat + protein), (B) methane emissions, and (C) methane per kilogram of MSo of Holstein-Friesian (black, solid line) and Holstein-Friesian × Jersey (white, dashed line) dairy cows across the methane study period. Error bars represent the SEM.

Table 7. The effect of sward system (S) and breed (B) on rumen fermentation characteristics[1]

	PRG		PRGWC		MSS			*P*-value		
Item	HF	JFX	HF	JFX	HF	JFX	SE	S	B	S × B
Ammonia (µmol/L)	68.6	106.2	89.6	89.5	75.7	76.1	8.26	0.13	<0.05	<0.05
VFA (mmol/L)										
Total	117	113	91	93	126	129	9.6	<0.001	0.99	0.92
Acetate	87.1	85.0	68.2	69.3	93.3	95.1	6.99	<0.001	0.96	0.94
Propionate	16.2	15.2	13.5	12.3	17.6	17.1	1.53	<0.01	0.41	0.96
Butyrate	9.93	10.24	7.10	8.33	11.54	12.96	0.905	<0.001	0.12	0.73
Valerate	1.16	0.93	0.76	0.77	1.24	1.22	0.117	<0.001	0.32	0.42
Isobutyrate	1.49	1.34	0.88	0.99	1.46	1.41	0.170	<0.01	0.42	0.29
Isovalerate	1.29	1.03	0.91	0.94	1.24	1.23	0.136	<0.05	0.41	0.41
Acetate:propionate	5.33	5.64	5.10	5.79	5.39	5.67	0.256	0.93	<0.05	0.59
VFA (% of total)										
Acetate	74.2	74.9	74.7	75.1	73.9	73.7	0.61	0.10	0.44	0.67
Propionate	14.0	13.4	14.7	13.1	13.9	13.2	0.52	0.62	<0.01	0.50
Butyrate	8.47	9.04	7.79	8.98	9.22	10.07	0.283	<0.001	<0.001	0.45
Valerate	0.98	0.80	0.84	0.80	0.98	0.96	0.073	0.07	0.11	0.37
Isobutyrate	1.24	0.98	0.97	1.03	1.12	1.12	0.114	0.39	0.39	0.22
Isovalerate	1.10	0.90	0.99	0.99	0.97	0.97	0.094	0.91	0.31	0.36

[1]PRG = perennial ryegrass 250 kg N/ha; PRGWC = PRG with white clover 125 kg N/ha; MSS = multispecies sward 125 kg N/ha; HF = Holstein-Friesian; JFX = Holstein-Friesian × Jersey.

presence of chicory and plantain in MSS. Previous studies have reported that plantain and multispecies swards have a smaller digestible NDF fraction, which has been attributed to their higher ADF contents (Della Rosa et al., 2022; Khan et al., 2023) as observed in the current study. Reducing NDF digestion shifts rumen fermentation away from hydrogen toward propionate and butyrate production consequentially reducing methane yield (Moe and Tyrrell, 1979; Janssen, 2010; Hammond et al., 2016). This may also explain the greater rumen butyrate concentrations and lower methane yield of the cows grazing MSS in the current study (Della Rosa et al., 2022). However, there has also been limited research to date assessing the persistence of plantain and chicory in a multispecies sward beyond 4 yr (Pinxterhuis et al., 2024) and existing evidence suggests that the persistency of herbs is reduced compared with perennial ryegrass and white clover (Grace et al., 2018, 2019), therefore the long-term potential of such swards to influence enteric methane requires further investigation.

Breed

Crossbreeding using HF and Jersey genetics is frequently used in the pasture-based dairy sector due to its favorable effects on milk constituents, cow fertility, longevity, feed efficiency, and farm system profitability despite reduced milk yield (Coffey et al., 2017; Evers et al., 2023). Despite its prevalence however, the effect of crossbreeding has not been widely studied in relation to the enteric methane emissions of dairy cows. Consistent with the aforementioned studies, the JFX cows within the current study had increased MSo production and superior feed efficiency compared with HF and this has been explained by the lighter BW yet greater intake capacity and diet digestibility of JFX (Beecher et al., 2014). Although digestibly was not measured in the current study, the ruminal VFA profiles of the 2 breed groups are in line with increased NDF digestion and rumen outflow rates in JFX, as higher NDF digestion is associated with greater acetate-to-propionate ratios (Van Soest, 1994) and greater butyrate concentrations are associated a greater liquid outflow rate from the rumen (Janssen, 2010). The increased butyrate concentrations in the JFX have been previously associated with increased milk fat contents (Huhtanen et al., 1993; Anger et al., 2024) and this is further substantiated by the results of the current study. Previous studies comparing HF and JFX over short measurement periods have reported no differences in total methane emissions between the 2 breeds (Deighton et al., 2011; Thackaberry et al., 2011). A similar observation was noted in the current study during the DMI measurement periods, though this was in contrast to a slight reduction in the methane output of JFX across the entire methane study period. This discrepancy could be due to differences in dietary effects over the full period versus only during the intake measurement periods. The greater methane production per kilogram BW of the JFX is consistent with an increased intake capacity, whereas methane yield and Y_m may also be expected to be greater in JFX due to their greater feed efficiency (Flay et al., 2019), superior diet digestion (Stepanchenko et al., 2023) and consequent effect on the ratio of acetate to propionate within the rumen (Smith et al., 2021). However, JFX's increased intake capacity would also be expected to reduce methane yield due to a faster rumen passage rate, reducing the pool of hydrogen available for methanogenesis (Pinares-Patiño et al., 2007; Aikman et al., 2008; Janssen, 2010). Therefore, any increase in methane yield associated with JFX's improved feed digestion and feed efficiency is likely counteracted by their increased intake capacity, facilitating their increased MSo production without a commensurate increase in methane output. As a result, JFX animals emitted 7% less methane per kilogram of MSo compared with the HF. These findings suggest that simultaneously breeding dairy cows for increased MSo production and reduced BW is a viable strategy to increase MSo production without increasing enteric methane output per cow and consequently reduce the environmental impact of milk production from pasture-based systems.

CONCLUSIONS

This study found that cows grazing PRGWC had similar methane yield to cows grazing PRG although the cows grazing PRGWC had increased total enteric methane output due to increased DMI. The MSS sward further increased DMI and milk production, while simultaneously reducing methane yield compared with PRG and PRGWC. This ultimately resulted in the cows grazing MSS having reduced methane intensity compared with PRG and PRGWC. This study also found that JFX cows have a reduced daily methane output and intensity compared with HF cows.

NOTES

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Nonstandard abbreviations used: B = breed; EBI = Economic Breeding Index; FPCM = fat- and protein-corrected milk; HF = Holstein-Friesian; JFX = Holstein-Friesian × Jersey; MSo = milk solids; MSS = multispecies sward 125 kg N/ha; NEI = net energy intake; OMD = OM digestibility; PRG = perennial ryegrass 250 kg N/ha; PRGWC = PRG with white clover 125 kg N/ha; S = sward system; UFL = unité fourragère lait; Y_m = gross energy intake lost to methane.

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