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Comparative enteric-methane emissions of dairy farms in northern Victoria, Australia

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ABSTRACT

Context. Enteric methane (CH_4) is a source of greenhouse gas (GHG) in agriculture, which needs to be reduced. A variety of feeding systems for dairy production is being used in south-eastern Australia, but there are few studies that compare CH_4 emissions and emission intensity (EI) of milk production across these systems. **Aims.** The objective was to estimate the lactating cows' enteric-CH_4 emissions, EI and their seasonal changes, across different feeding systems in northern Victoria, Australia. **Methods.** A Tier 2 inventory methodology was used to estimate the enteric-CH_4 emissions and EI. Four case-study farms were selected to represent a range of feeding systems, Farms A, B, C and D were categorised as System 4–5 (hybrid–total mixed ration system), System 4 (hybrid system), System 2 (moderate–high bail system) and System 2 respectively. Monthly feed, animal and production data were sourced from June 2019 to May 2020. **Key results.** Average enteric-CH_4 emissions of Farms A and B (13.1 and 12.9 kg CO_2e/head.day respectively) were greater than those of Farms C and D (11.7 and 11.6 kg CO_2e/head.day respectively). Furthermore, CH_4 EI was greater in Farms C and D (0.49 and 0.48 CO_2-e kg/kg fat- and protein-corrected milk (FPCM) respectively) and it was lower in both Farms A and B (0.46 CO_2-e kg/kg FPCM). Overall, Farms A and B using Feeding-system 4–5 with greater-producing cows produced more CH_4 but with less CH_4 EI than did the Farms C and D, which are mainly pasture-based. **Conclusions.** These findings suggest that to reduce CH_4 EI requires a move towards Feeding-system 4–5. However, on the basis of the results of the current study, pasture-based systems have an advantage over hybrid/total mixed ration feeding systems, as these farms have lower absolute CH_4 emissions, which helps address climate change. **Implications.** Estimation of CH_4 emissions, EI and seasonal changes in them gives farmers the opportunity to identify the mitigation strategies and plan specific strategies that fit the particular feeding system and season. However, more research needs to be conducted to check the feasibility of doing this.

Keywords: Australia, bovine, climate change, emissions, evaluation, greenhouse gas, lactating cattle, sustainability.

Introduction

As the world human population is increasing, access to sustainable diets, which are nutritionally balanced, economically viable and produced responsibly, is crucial. The dairy industry has an important role to support global sustainable food production. Therefore, working towards more productive and environmentally friendly dairy production systems is essential (Miller and Auestad 2013). The dairy industry in Australia is the third-largest rural industry, producing approximately 8.6 billion litres of milk in 2021–22 (Dairy Australia 2022). Wales and Kolver (2017) highlighted that Australian dairy farms must be operated with a vision of reducing the environmental footprint, so as to allow the dairy industry to remain competitive in the changing global dairy markets.

According to the Department of Agriculture and Water Resources ABARES (2020), the most important agricultural commodity in Victoria is milk and dairy production in Victoria

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represents 63.4% of total national milk production. Dairy production in Victoria is distributed over three major dairy regions namely, northern Victoria, south-western Victoria and Gippsland. Among them, northern Victoria is one of the most diverse dairy production regions in terms of feeding systems, accounting for nearly 19% of the national milk production (Agriculture Victoria 2021). Traditionally, dairy production in northern Victoria has relied heavily on grazing irrigated pasture (Wood *et al.* 2007). In recent years, the diverse geography, climatic conditions and volatile milk and water prices in the region have induced major changes in dairy farming systems. Farmers have moved towards more brought-in/supplementary feed-based systems (Murray Dairy 2019). This leads to changes in feed management, milk production but also livestock emissions.

Enteric CH_4 is a major environmental pollutant that results from dairy operations, which affects environmental degradation while causing inefficiencies (e.g. represents 2–12% of gross energy-intake loss; Johnson and Johnson 1995) in the dairy production systems. Enteric CH_4 is a by-product of microbial fermentation in the rumen (Johnson and Johnson 1995). Mitigating enteric-CH_4 emissions is crucial for reducing the carbon footprint of the Australian dairy industry (Moate *et al.* 2016) and optimising production efficiency (Eckard *et al.* 2010).

Presently, there are limited assessments of emissions from different dairy systems in northern Victoria, apart from Christie *et al.* (2012) and Gollnow *et al.* (2014), despite this being an important assessment to establish baseline/benchmark and support decision-making in sustainable dairy production. Further, apart from estimating the annual CH_4 emissions, the profiling of seasonal CH_4 emission changes on a farm is also an important aspect to be considered (Orcasberro *et al.* 2021). Such information provides the opportunity to utilise different mitigation strategies at different times of the year by using locally available resources (e.g. tannin-containing grape marc is produced in autumn and summer in Australia; Wu *et al.* 2022). Therefore, the aim of this study was to estimate lactating dairy cows' annual and seasonal enteric-CH_4 emissions by using a case study approach in northern Victoria.

Materials and methods

This study was conducted to estimate the enteric-CH_4 emissions and its intensity differences of lactating dairy cows (except dry cows and replacement stocks) in northern Victoria. To achieve this, four case-study farms (Farms A, B, C and D) with diverse feeding strategies were investigated. A purposive sampling method was used to select case-study farms with available data to ensure that the diverse feeding systems in northern Victoria were covered. The case-study farms were classified into the Australian five farm-feeding systems (Table 1) on the basis of the amount of pasture and concentrate feeding and feeding infrastructure on the farm (Wales and Kolver 2017). According to the classifications, Farm A showed characteristics between two consecutive systems as a result of feed availability in different seasons. For instance, Farm A showed several characteristics of Feeding-system 4 during winter and spring. However, during summer and autumn, the milking herd was fed with the total mixed ration (i.e. Feeding-system 5; Table 1).

Along with the different feeding systems used on the case-study farms, there were differences in herd size, calving patterns, concentrate feeding levels, cow liveweight and milk production (Table 2). In general, the more intensive feeding systems (Farms A and B) had larger herd sizes and greater milk production per cow than did the pasture-based feeding systems (Farms C and D).

The Australian National Greenhouse Gas Inventory (NGGI) methodologies and algorithms (Department of Environment and Energy 2017) were used to estimate enteric-CH_4

Table 1. Case-study farm feeding-system classification.

Farm	System	Characteristics of the feeding system
Farm A	System 4–5	Offers TMR and grazing (annual ryegrass from June to October)
		Fully TMR (from November to May)
		The herd is split into high- and low-production groups, separated by stages of lactation and litres produced
		The cows producing 40 L or more (the high-producing cows) are milked three times a day, housed in the barn and are given the greatest-quality rations compared with low-producing cows
Farm B	System 4	Pasture grazing (Italian rye/Shaftal clover) for ~ 9 months/year (from April to November/December)
		PMR on feed pad and grain-fed during milking
Farm C	System 2	Pasture grazing most of the year (perennial ryegrass/white clover), forages during summer (sorghum and lucerne) and ~2.5 t DM/head.year grain fed during milking
		Hay fed year-round (except October) and silage fed from April to June
Farm D	System 2	Pasture grazing (annual ryegrass and Shaftal clover, grazing barley, and grazing wheat) from April to November), ~2.2 t DM/head.year grains fed during milking
		Hay fed year-round, and silage fed from October to January

TMR, total mixed ration; PMR, partial mixed ration; DM, dry matter.

Table 2. Characteristics of the dairy production systems on the case-study farms.

Characteristic	Farm A	Farm B	Farm C	Farm D
Milking herd size	853	720	105	276
Breed	Holstein	Holstein Jersey	Holstein	Holstein Jersey Aussie Red
Concentrate/TMR feeding (t DM/cow.year)	8.7 (TMR)	2.5	2.5	2.2
Calving pattern	Year-round calving	Split calving	Split calving	Split calving
Average liveweight (kg)	693	579	623	535
Average winter MP (kg/head.day)	26.1	28.6	22.2	22.6
Average spring MP (kg/head.day)	28.2	28.9	25.4	28.9
Average summer MP (kg/head.day)	28.6	26.7	23.5	21.6
Average autumn MP (kg/head.day)	26.4	25.4	22.9	19.0
Average MP (kg/head.day)	27.3	27.4	23.5	23.0

DM, dry matter; TMR, total mixed ration; MP, milk production.

emissions. A simple and comprehensive spreadsheet was developed to collect all possible data that can be used for estimating enteric CH_4. The spreadsheet was mainly categorised into two groups, as follows.

1. Herd structure and milk production data – liveweight (kg/head), number of lactating cows (heifers and cows), monthly average milk production (L/month), monthly average milk fat (%) and milk protein (%) content
2. Feed-quality and -quantity data – feed types, allocation per feed type (t/month), wastage%, dry matter (DM) %, metabolisable energy (ME) content (MJ ME/kg DM), feed refusal (%)

Data from farm records for the 12-month period (June 2019–May 2020), which represent the whole four seasons (winter, spring, summer and autumn) consecutively, were used. Quality of the pasture and supplementary feeds (metabolisable energy content of the feed (MJ ME/kg DM) were provided by the farmers. Specifically, seasonal pasture-quality changes were estimated by the farmers on the basis of their experience. The liveweight gain of cows was assumed as 0 kg/head.day by assuming that any weight loss during the post-calving period was gained during the mid- to late-lactation period. Therefore, the net weight gain of the cows over a 1-year period was considered as zero (Christie *et al.* 2012). The dry-matter intake of a cow was calculated using the following equation:

$$\mathrm{DMI} = (1.185 + 0.00454W - 0.0000026W^2 + 0.315\mathrm{LWG})^2 \times \mathrm{MR} + \mathrm{MI} \quad (1)$$

where DMI = dry-matter intake (kg DM/head.day); W = live weight of a cow (kg); LWG = liveweight gain (kg/head.day); MR = increase in metabolic rate of the cow when producing milk (1.1); MI = additional intake for milk production (kg DM/head.day; Eqn 2).

$$\mathrm{MI} = \mathrm{MP} \times \mathrm{NE}/k/q/18.4 \quad (2)$$

where MP = milk production (kg/head.day); NE = net energy (3.054 MJ/kg milk; Standing Committee on Agriculture 1990); k = efficiency of use of feed ME for milk production (0.6); q = metabolisability of the diet (Eqn 3).

$$q = 0.00795\mathrm{MDMD} - 0.0014 \quad (3)$$

where MDMD = mean dry matter digestibility (%).

Mean dry-matter digestibility estimation (Minson and McDonald 1987)

$$\mathrm{DMD} = (\mathrm{ME} + 1.037)/0.1604 \quad (4)$$

where, DMD = dry-matter digestibility (%); ME = metabolisable energy content of the feed (MJ ME/kg DM).

Eqn 4 was used to find the DMD (%) of each feed component. Then MDMD (%) was obtained using approximate DMI of each feed type (kg DM/day.head) and their DMD (%). MDMD (%) was used to find the metabolisability of the diet (q) in Eqn 3.

The enteric-CH_4 emissions of a lactating cow were estimated using the following equation published in Charmley *et al.* (2016), which is included in the Australian NGGI approach:

$$\text{Enteric } CH_4 \text{ emission } (\text{g } CH_4/\text{head.day}) = 20.7 \times \mathrm{DMI}\ (\text{kg DM/head.day}) \quad (5)$$

where DMI = dry-matter intake.

Then, seasonal estimated enteric-CH_4 emissions (g CH_4/head.day) values were converted to carbon dioxide equivalent (CO_2e) by multiplying the global warming potential of the CH_4 (i.e. 28; Eqns 1, 2, 3, and 5 were based on Australian Government Department of Industry, Science, Energy and Resources 2021).

The International Dairy Federation (IDF) equation was used to correct milk volume to a standard of 4.0% fat and 3.3% protein content (IDF 2015), as follows:

$$\text{Fat and protein corrected milk production (kg/year)} = \text{milk production (kg/year)} \times ((0.1226 \times \text{fat\%}) + (0.0776 \times \text{protein\%}) + 0.2536) \quad (6)$$

Enteric-CH_4 emissions of lactating dairy cows in each farm were divided by fat- and protein-corrected milk (FPCM; kg/year) to get the enteric-CH_4 EI.

Results

Dry-matter intake and relative differences of the feed quality

Lactating dairy cows on Farms A and B showed greater DMI than did those on Farms C and D, on average. Across the four seasons, the greatest relative difference in DMI was reported on Farm D (23.9%), while the smallest relative difference was on Farm B (4.5%). Moreover, the average DMD% of feed was greatest on Farm C, followed by Farms A, B and D. The greatest relative difference of feed DMD% was reported in Farm C (6.4%) and the smallest relative difference in feed DMD% was reported in Farm B (2.4%; Table 3).

Emissions per lactating dairy cow

Annual average enteric-CH_4 emissions of Farms A and B (13.13 and 12.9 kg CO_2e/head.day) were comparatively greater than those of Farms C and D (11.69 and 11.57 kg CO_2e/head.day; Fig. 1). According to the seasonal breakdown of the emissions, Farms A and C showed their smallest enteric-CH_4 emissions during winter, while Farms B and D showed their smallest in autumn. In contrast, Farms A and C showed their greatest emissions in summer, while Farm D had its greatest during spring. Notably, Farm B emissions were largest during both winter and spring (Fig. 1).

Enteric-methane emission intensity (EI)

Average annual enteric-CH_4 EI (kg CO_2e/kg FPCM) was 6.3% and 4.3% greater on Farms C and D respectively, than on Farms A and B (Table 4). The greatest relative seasonal difference ((maximum seasonal EI − minimum seasonal EI)/((maximum EI + minimum EI)/2) × 100/1) of EI on Farms A, B, C and D was 2.2%, 8.7%, 12.2% and 14.1% respectively. Overall, Farms B, C and D reported greater relative differences in enteric-CH_4 EI than did Farm A (Table 4). According to the seasonal breakdown, Farms A and D showed their greatest EI during winter, while Farms B and C showed their greatest EI during spring and summer respectively. In contrast, Farm A showed its smallest EI in all other three seasons. Farm B showed its smallest during both summer and autumn, while both Farms C and D showed their smallest during spring.

Discussion

The enteric CH_4 is considered as the largest single source that contributes to the total on-farm greenhouse-gas emissions (Charmley *et al.* 2016). Therefore, monitoring, evaluation, and mitigation of enteric-CH_4 emissions from lactating dairy cows are of great importance to emissions management on farms. In the present study, the enteric-CH_4 emission factors of all four case-study farms were between 136.5 kg CH_4/head.year and 176.6 kg CH_4/head.year. This is similar to the findings of Gollnow *et al.* (2014), who collected data from 139 dairy farms across major dairy regions in Australia. That study estimated the enteric-CH_4 emissions of an Australian milking cow as 122 kg CH_4/head.year, ranging from 80 kg CH_4/head.year to 175 kg CH_4/head.year. Despite such similar results found between the present study and Gollnow *et al.* (2014), it is important to note that some of the methodologies and algorithms were different between the two studies. This is because methodologies and algorithms

Table 3. Estimated dry-matter intake (kg/head.day) and dry-matter digestibility (%) of the feed.

Farm	Winter		Spring		Summer		Autumn	
	DMI	DMD%	DMI	DMD%	DMI	DMD%	DMI	DMD%
A (System 4–5)	21.9	79.5	22.9	78.9	23.4	77.1	22.4	76.8
B (System 4)	22.8	75.3	22.8	75.8	22.2	73.9	21.2	75.8
C (System 2)	19.3	79.6	20.5	81.2	20.6	76.1	20.3	77.8
D (System 2)	19.6	74.5	23.0	72.3	19.3	74.0	18.1	74.3

DMI, dry matter intake (kg/head/day); DMD, dry matter digestibility (%).

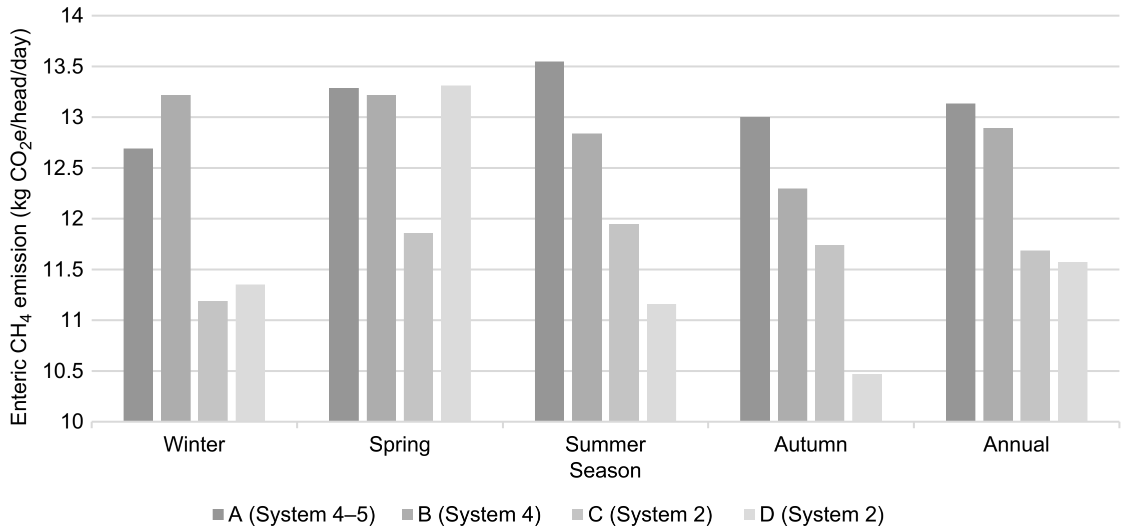

Fig. 1. Difference in seasonal enteric-methane emissions calculated for the case-study farms.

Table 4. Enteric-methane emission intensity (kg CO_2e/kg FPCM) calculated for the case-study farms.

Farm	Winter	Spring	Summer	Autumn	Average
A (System 4–5)	0.47	0.46	0.46	0.46	0.46
B (System 4)	0.47	0.48	0.44	0.44	0.46
C (System 2)	0.49	0.46	0.52	0.49	0.49
D (System 2)	0.53	0.46	0.47	0.47	0.48

continuously update with the new research findings to support the precise estimation of CH_4 (Christie *et al.* 2016). This highlights future research directly comparing literature and the latest study result should consider standardising calculations/models.

The absolute enteric-CH_4 emissions were greater on Farms A and B than on Farms C and D. This is because of the greater DMI of the animal as a result of the greater level of milk production in Farms A and B than in Farms C and D (Table 2). Notably, O'Neill *et al.* (2011) reported that TMR-fed cows produced 45% greater enteric CH_4 (g/cow.day) than did the dairy cows grazing perennial ryegrass. The same study also highlighted that this occurs at the expense of DMI and milk yield. Moreover, in the current study, seasonal enteric-CH_4 emissions also showed differences among farming systems due to changes in milk production and feed quality.

Enteric-CH_4 EI of the lactating dairy cow in the case-study farms of this study varied from 0.44 kg CO_2e/kg FPCM to 0.53 kg CO_2e/kg FPCM, across the seasons and among the farming systems. These findings fit into the range was found by Christie *et al.* (2012) and also the findings of Gollnow *et al.* (2014). According to Christie *et al.* (2012), enteric-CH_4 EI of Australian dairy farms varied from 0.39 kg CO_2e/kg FPCM to 0.88 kg CO_2e/kg FPCM. The findings of this study fitted into the lower end of the enteric-CH_4 range of Christie *et al.* (2012). This is because Christie *et al.* (2012) studied all stock classes in dairy farms, rather than depending only on the milking herd to find enteric-CH_4 EI as was the method in this study. Also, it is important to note that Christie *et al.* (2012) studied only Farming-systems 1–3 in the Australian five farm feeding-system classification as less than 10% of farms were recognised as Feeding-system 4–5 during that time. There are differences in enteric-CH_4 emissions and their intensities among the farms. Exploring the reasons for these differences will be important for finding potential mitigation strategies effectively. Importantly, the quality of the farm data is vital for the accuracy of the enteric-CH_4 estimation. This emphasises the need for farmers to increase the quality of the record-keeping on the amount of feed, feed wastage and changes in the quality of supplementary feed and pasture. It is important to assist farmers by providing a set of guidelines for future record keeping for the purpose of estimating enteric-CH_4 emissions. It will help farmers monitor and reduce seasonal enteric-CH_4 emissions. Further, quality records will improve the accuracy of future research to a greater extent.

Under the Paris Agreement, the overall goal is to reduce absolute emissions so as to keep the increase in temperature below 1.5°C compared with the pre-industrial levels (Allen *et al.* 2018). Notably, 195 countries, including Australia, committed to achieving these targets, which will require a reduction in overall emissions, including enteric CH_4. Therefore, on the basis of the findings of this study, pasture-based systems (Farm C and D) have an advantage over more intensive feeding systems (Farm A and B) in the future, because they have lower enteric-CH_4 emissions. Importantly, the systems need to be designed to reduce absolute emissions at a greater rate than the milk production increases. By doing so, not only will absolute emissions fall, but also the EI will reduce.

The current study used the NGGI methodology-based equation (CH_4 emissions = 20.7 × DMI), which was developed using a dataset from cattle fed with forage-based diets (forage >70%), including dairy cattle fed with temperate forages, beef cattle fed with temperate forages and beef cattle fed with tropical forages (Charmley *et al.* 2016). However, different studies reported different coefficient values. For instance, Moate *et al.* (2016) reported the coefficient value as 21.1 g CH_4/kg DMI for dairy, which was found using a dataset from 220 Holstein-Friesian cows from eight experiments. Dijkstra *et al.* (2011) reported a value of 23.1 g CH_4/kg DMI for the coefficient for dairy cows in Netherlands, while Hristov *et al.* (2013) derived a coefficient value of 19.14 g CH_4/kg DMI, which is lower than the above coefficient values, which is likely to be due to high-concentrate diets fed. This showed that the diets used in different systems could lead to different coefficients, which then could change the magnitude of the enteric-CH_4 emissions and CH_4 EI. Since most of the diets in this study were based on the forages (including pasture, hay and silage), using the same NGGI emissions factor was considered appropriate.

In conclusion, in the NGGI methodology, DMI is the biggest driver of enteric CH_4 (20.7 × DMI); and the DMI of a lactating cow is a function of liveweight, liveweight gain and milk production in the model. Therefore, Farms A and B utilising Feeding-system 4–5 with a larger body mass and greater-producing cows produced more CH_4 (kg CO_2e/head.day), but with less CH_4 per unit of product than did the pasture-based systems in Farms C and D. These case-study findings suggest that to reduce EI requires a move towards Feeding-system 4–5 with a greater production per cow. However, there is an imperative for dairy to reduce absolute enteric-CH_4 emissions to be consistent with the Paris Agreement targets, which can be achieved through pasture-based lower-input system (Feeding-system 2). However, Feeding-system 4–5 can be included in targeted mitigation strategies, if they are required to reduce absolute CH_4 emissions. Importantly, enteric-CH_4 emissions and EI are not only about the feeding system, but they are also about milk production and characteristics of the animal (i.e. liveweight in this study). Estimation of seasonal enteric CH_4 and intensities using on-farm data will allow farmers to identify their existing level of CH_4 emissions to plan specific mitigation strategies that fit the particular season. However, more research will be required to check the feasibility of doing this. Furthermore, it is important extend further research towards a cradle-to-farm-gate life-cycle analysis, as this framework provides a holistic picture of the GHG profile of a whole farming system, which will help implement targeted mitigation strategies.

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