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# Twinning in cattle: a pathway for reducing the methane intensity of beef

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## ABSTRACT

**Context.** Reducing livestock emissions, the largest single contributor to agricultural emissions, is increasingly recognised as a high priority. The low biological efficiency of beef cattle, due to their long gestation period, long generational interval, and propensity to be uniparous, contributes to the high methane emissions intensity (kg $CO_2$-e/kg product) of beef compared to most other food products. **Aims.** We evaluate the potential of increasing the frequency of multiparous births (twinning) as a pathway to reducing the methane intensity of beef and the net methane emissions of intensive beef systems. **Methods.** We simulate a uniparous herd structure and emissions profile using GrassGro™ livestock systems modelling software and then calculate the effects of an increasing frequency of multiparous births (twinning), up to 1.53 calves per cow joined, on methane emissions. **Key results.** Our results demonstrate that beef from calves reared as twins has a 22% lower methane intensity than beef from a single reared calf. Although twinning reduces the methane intensity of beef, at the herd level, net methane emissions could rise by as much as 23% at 1.53 calves per cow joined if overall herd size is allowed to grow through an increased number of calves. If we decrease stocking rates, whilst also increasing twinning rates, it is possible to reduce net emissions by up to 14%, without changing productivity. **Conclusions.** Our results illustrate the significant potential of twinning to decrease the methane intensity of beef and to increase the productivity per cow in intensive beef systems. **Implications.** Despite this, twinning is unlikely to be a viable net emissions reduction pathway – as twinning will increase stocking rate unless herd structure is altered – unless a commercial or policy driver to reduce net methane emissions is established.

**Keywords:** Beef, biological efficiency, calving rate, enteric fermentation, GrassGro™, livestock emissions, methane intensity, twinning.

## Introduction

Agriculture, Forestry and Other Land Use (AFOLU) accounts for around 23% of global greenhouse gas (GHG) emissions (Shukla *et al.* 2019), contributing to dangerous anthropogenic climate change. Livestock production, including associated land use change, accounts for over 80% of total food system emissions (Vermeulen *et al.* 2012) with methane ($CH_4$) emissions from enteric fermentation the single largest contributor (FAO 2020). With a growing population and increasing affluence, demand for meat is forecast to increase significantly (Hocquette and Chatellier 2011; Wiedemann *et al.* 2015*a*; Shukla *et al.* 2019). As a result, emissions from the ruminant livestock sectors are likely to increase unless management changes are made (Opio *et al.* 2013) or there are breakthroughs in the development and application of other mitigation strategies, such anti-methanogenic compounds (Beauchemin *et al.* 2020).

Industry bodies (NFU 2019; NFF 2020; MLA 2022) and international organisations (Pachauri *et al.* 2014; Willett *et al.* 2019) have increasingly made commitments and invested in research to reduce emissions attributed to the ruminant livestock sector. The beef sector, which produces around 35–41% of global (Gerber *et al.* 2013; Opio *et al.* 2013) and 50% of Australia's agricultural emissions (Australian Government 2020), has received particular attention, due to the high emissions intensity (kg $CO_2$-e/kg beef; where $CO_2$-e denotes carbon dioxide equivalents) of beef compared to other sources of animal and plant based proteins (Clune *et al.* 2017).

One of the reasons that beef has a high emissions intensity is that beef cattle have low biological efficiency (Small *et al.* 2000; Çobanoğlu 2010). Over 50% of total feed intake – which is closely correlated to methane output (Hegarty *et al.* 2010) – is required for maintenance of the breeding herd (Webster 1989; Gregory *et al.* 1990). This is driven by the fact that cattle are generally uniparous; producing only one offspring per pregnancy (Komisarek and Dorynek 2002). Cattle also have a long gestation period (compared to other production animals; DPIRD 2021), and have a long generational interval; heifer calves generally take at least 24 months to produce their first calf (Baharin and Beilharz 1977; Barlow *et al.* 1994), which will in turn take more than 12 months to reach slaughter weight (Barlow *et al.* 1994; Davies *et al.* 2009).

Improving the biological efficiency of beef cattle through increasing the frequency of multiparous births (twinning) has been highlighted as an opportunity to increase herd productivity and efficiency (Guerra-Martinez *et al.* 1990; de Rose and Wilton 1991; Echternkamp *et al.* 2007). Twinning naturally occurs at a rate of 1–4%, with a higher prevalence in dairy than beef cattle (Baharin and Beilharz 1977; Komisarek and Dorynek 2002; Nephawe 2002; Wakchaure and Ganguly 2016). Increasing calving rates through increasing the rate of twinning in cattle could improve cow productivity by enhancing reproductive efficiency by 20–30% (Echternkamp *et al.* 2007) and by increasing the total kilograms of calf weaned per cow by 40% or more (Gregory *et al.* 1990). Research to date has focused on pathways to increase the rate of twinning, practical aspects of managing twinning cattle and the potential downsides associated with twinning; reduced calf survival and birthweight, decreased re-conception rate, and increases in dystocia and placental retention (Cummins 1992; Echternkamp and Gregory 1999; Echternkamp *et al.* 2007; Çobanoğlu 2010; Cummins and Cummins 2018). While twinning in cattle has a low heritability, it is highly correlated with pubertal ovulation rate in heifers, which is more heritable (Komisarek and Dorynek 2002) and therefore selecting for twinning through ovulation rates is an effective avenue for increasing the rate of twin births (Van Vleck *et al.* 1991). Other modern breeding techniques, such as in vitro fertilisation (IVF), embryo transfer (ET) or hormonal stimulation (exogenous gonadotrophin), may also facilitate the increased frequency of twinning (Gordon *et al.* 1962; Cummins 1992).

Using ovulation rate as the selection criterion for twinning, the United States Meat Animal Research Centre successfully increased calving rate by around 3% per annum to achieve a maximum calving rate per parturition of 1.56 (Cummins *et al.* 2008). Despite this potential to increase herd productivity and reproductive efficiency, producers often have a negative perception of twinning due to its associated downsides (Kirkpatrick 2002). Twinning in dairy cows is considered particularly disadvantageous, due to the occurrence of freemartins, focus on milk production and the metabolic disorders that can be associated with twinning (Hossein-Zadeh 2010). As a result of the negative producer perception, with the exception of a few niche herds, twinning has not been selected for or adopted (Cummins *et al.* 2008).

The downsides associated with twinning are exacerbated by the fact that twinning is generally unanticipated (Nephawe 2002). Many of the issues may be reduced or overcome through identification of pregnancy status (e.g. through ultrasound scanning) and development of appropriate husbandry procedures (Guerra-Martinez *et al.* 1990; Kirkpatrick 2002; Echternkamp *et al.* 2007; Cummins and Cummins 2018). In addition to pregnancy scanning, optimising nutrition and enhancing management at calving can improve outcomes, particularly as – post the initial neonatal period (~72 h) – mortality is not significantly different for single vs twin calves (Koong *et al.* 1982; Gregory *et al.* 1990). Despite twin born calves being born at significantly lower birth weights (around 25%) than single born calves, by the point of slaughter they have only a marginally lower weight (around 5%) than single born calves (de Rose and Wilton 1991; Patterson *et al.* 1993; Gregory *et al.* 1996; Cummins *et al.* 2008). In the longer term, some of the issues associated with dystocia may also be partially overcome through the use of conventional genetic selection (Cummins *et al.* 2008; Çobanoğlu 2010). Issues with cow re-conception can also be significantly alleviated by early weaning and provision of sufficient pre- and post-partum nutrition (Gregory *et al.* 1990; Nephawe 2002).

Because of the necessity for more intensive husbandry procedures to minimise the downsides and risks of twinning, more intensive beef systems, where appropriate husbandry procedures can be more readily implemented, are likely to be better able to manage and benefit from the prospect of increased twinning rates (Gregory *et al.* 1990). Major beef producing regions where herds tend to be more intensively managed include the higher rainfall regions of southern Australia, south-eastern USA, much of continental Europe, and parts of Argentina (Hocquette and Chatellier 2011; Drouillard 2018; DEFRA 2019; Gonzalez Fischer and Bilenca 2020; Pulina *et al.* 2021).

One aspect that has received little research attention to date is that increasing the rate of twinning may also offer a pathway to reducing the emissions intensity of beef by increasing the output per breeding female. In the context of both the increasing pressure on the sector to reduce its contribution to global GHG emissions and the increasing global demand for beef (Pulina *et al.* 2021), twinning may provide an opportunity to increase production whilst maintaining or decreasing net sectoral emissions.

In this paper, we first evaluate the impact of different twining scenarios on the methane intensity at the cow and herd level. Second, we discuss the implications for national herd emissions and contextualise the potential impact of increasing rates of twining on the methane intensity of beef and net sectoral emissions.

## Methods

### Baseline herds

We use the livestock systems modelling software GrassGro™ (ver. 3.1.10) (Horizon Agriculture 2021) to evaluate the impact of twining on the methane intensity of beef produced (kg $CO_2$-e/kg product, where product is defined as carcase weight) at the cow and herd level. GrassGro™ is a biophysical model that has been extensively used to model animal and pasture data across southern Australia (Mokany *et al.* 2009; Alcock and Hegarty 2011; Harrison *et al.* 2014; Gebbels *et al.* 2022). The model combines animal growth rates (informed by the Australian Feeding Standards; Freer *et al.* 1997) and pasture growth data for a given location and soil type (Cottle *et al.* 2016), allowing the user to evaluate future scenarios based on local cost and price information, prior to or without the need to allocate resources to a given practice change (Alcock and Hegarty 2011). Methane production can also be simulated by GrassGro™, which applies the general equation of Blaxter and Clapperton (1965) as (Alcock and Hegarty 2011; Gebbels *et al.* 2022):

$$\%\ \mathrm{GE\ as\ CH_4} = 1.30 + 0.112D - L(2.37 - 0.05D),$$

where GE = percentage of gross energy lost, $D$ = digestibility and $L$ = level of feeding. We focus only on methane emissions, as methane accounts for the significant majority of emissions attributable to the beef sector (Vermeulen *et al.* 2012).

Baseline scenarios were modelled for a beef herd at two farm locations: Cape Naturaliste in Western Australia (33°32′S 115°01′E) and Hamilton in Victoria (37°50′S 142°04′E). These locations are representative of key beef producing regions in southern Australia.

Our baseline enterprises are a uniparous Angus-based (British Breed) breeding herd at Cape Naturaliste and a uniparous Charolais-based (Continental) breeding herd at Hamilton, with a calving rate of 0.98 – i.e. 98 calves born per 100 cows joined – applied to both herds (Table 1). We do not differentiate between the reproductive rate of cows vs heifers. These breeds differ significantly in their mature cow weight (Table 1) so that variation in the breed type and cow weight is incorporated into the evaluation. In both cases it was assumed that all calves produced were finished on farm rather than being sold for finishing. The calving interval – time between births – was set at 365 days, with cow emissions attributed as overhead emissions (essentially herd maintenance emissions) to each calf (Eady *et al.* 2011; Wiedemann *et al.* 2015*b*). We assume that no other emissions reduction strategies are applied concurrently.

**Table 1.** Baseline summary of GrassGro™ modelled beef systems used to calculate methane emissions of a uniparous beef herd.

| Farm Location | Cape Naturaliste | Hamilton |
|---|---|---|
| Annual rainfall (mm)[A] | 651 | 608 |
| Enterprise type | Self-replacing Angus herd | Self-replacing Charolais herd |
| Pasture base | Perennial ryegrass/ subterranean clover | Perennial ryegrass/ subterranean clover |
| Supplementary feed type | Hay, barley, lupins | Hay, barley, lupins |
| AE per ha[B] | 2.0 | 2.0 |
| Mature cow weight (kg) | 550 | 650 |
| Dry rate (% of cows not pregnant) | 2 | 2 |
| Cow mortality rate (%) | 2 | 2 |
| Replacement rate (%) | 12.5 | 12.5 |
| Calf mortality for single births (%)[C] | 6 | 6 |
| Average slaughter weight[D] (kg single: kg twin) | 532 : 506 | 619 : 588 |
| Age at slaughter (months) | 21–23 | 21–23 |
| Dressing (%)[E] | 53 | 53 |

[A]Mean annual rainfall 1990–2017.
[B]AE, animal equivalent. N.B. GrassGro™ reports DSE (dry sheep equivalent) and hence this value has been converted to AE at a rate of 1 AE per 8.4 DSE (DPIRD 2022).
[C]Based on the average reported by Cummins *et al.* (2008), de Rose and Wilton (1991), Gregory *et al.* (1996), Patterson *et al.* (1993).
[D]Average of heifer and steer slaughter weight (MLA 2021).
[E]Based on a Fat Score 3 steer (McKiernan 2007).

### Modelling scenarios

The GrassGro™ model can only incorporate a calving rate of up to one calf per parturition. The baseline model outputs therefore provided the starting point for a spreadsheet-based model in which we calculated the impact of variations in calving rate (calves born per cow joined), twin calf mortality (%: single calf mortality rate held constant), and twin bearing cow recovery (kg required to return to pre-mating weight) on the methane intensity of beef produced. Methane intensity was evaluated at the cow level and at the herd level. Though this approach cannot fully take into account complex interactions between variables, and their impact on factors such as gross margin and pasture utilisation rate by season, our focus is on methane output and identifying the relationships between calving rate and methane intensity that can be evaluated in this way.

#### Calving rate

For our base herd we applied a calving rate of 0.98 claves born per cow joined, incorporating a dry (not pregnant) rate of 0.02 (2%) and assuming no twin calves are born. In our analysis, we evaluated a calving rate of up to 1.56 calves per parturition (equivalent to a calving rate of 1.53 calves born per cow joined when the dry rate is 0.02, i.e. 2%) for the multiparous herd, as this was the rate achieved by the United States Meat Animal Research Centre herd by 2004 (Cummins *et al.* 2008). Therefore, assuming a dry rate of 2%, in our multiparous herd this means that per 100 cows joined, 2 produce no calves, 40 give birth to a single calf, and 58 give birth to twins.

### Calf mortality

Elevated mortality of twin born calves is a risk associated with twinning (Echternkamp *et al.* 2007), though elevated mortality rates can be mitigated, to some extent, through enhanced management of multiparous cows. We use the minimum, average, and maximum rates of twin calf mortality and an average rate of single calf mortality documented in existing studies in our scenarios (Table 2; Bar-Anan and Bowman 1974; Guerra-Martinez *et al.* 1990; Kirkpatrick 2002; Echternkamp *et al.* 2007; Cummins *et al.* 2008; Sawa *et al.* 2015). Where mortality occurred, it was assumed that this occurred in the neonatal period at <72 h post partum.

### Cow recovery

There are several reports of post weaning weight differentials of twin versus single rearing cows, with twin cow weights reported as between 3.6 and 14.6% lower than singles (Guerra-Martinez *et al.* 1990; McCutcheon *et al.* 1991; Hennessy and Wilkins 2005). We apply a body weight reduction in twin rearing cows (i.e. below that of their single rearing counterparts) of −10%, and test a range between −5% to −15% (Table 2).

To calculate the energy cost of weight gain, we assume that gaining 1 kg of liveweight requires 49.7 MJ ME (mega joules of metabolisable energy) (the average of values reported by DEDJTR (2015), DPIF – QLD (2015), Moran (2005), Neville and McCullough (1969)). The ryegrass and sub-clover pasture mix (Table 1) has a typical feed value of 11.1 MJ ME/kg DM (Fulkerson *et al.* 1998; Bell *et al.* 2013), thus every kilogram of liveweight gain requires 4.48 kg of dry matter intake (DMI). To calculate the additional methane emissions that result from the additional feed intake required, we use the universal equation to predict methane production of forage-fed cattle in Australia developed by Charmley *et al.* (2016):

$$\text{CH}_4 \text{ production } (\text{g/day}) = 20.7(\pm 0.28) \times \text{DMI}(\text{kg/day})$$

**Table 2.** Animal-based input variables impacting the methane intensity (kg $CO_2$-e/kg product) of beef.

| Variable | Uniparous herd | Multiparous herd |
|---|---|---|
| Calving rate[A] | 0.98 | 1.53 |
| Calf mortality | 6% | 14% (9–19%) |
| Cow recovery (kg)[B] | $X$[C] | $X$-10% (−5 to −15%) |

[A]Calves born per cow joined.
[B]kg of liveweight gain required to return to pre-joining weight.
[C]$X$ = 60 kg at Hamilton and $X$ = 32 kg at Cape Naturaliste.

### Herd level scenarios

We also evaluated a series of herd level and net emissions scenarios. The herd level scenarios were modelled on a 100-cow herd.

#### 1. Constrained animal equivalent (AE)

Under this scenario we constrained the maximum number of AE's to the level of the uniparous baseline herd. This necessitates adjustments to the ratio of breeders to calves, as the calving rate increases, to prevent overall increases in AE. To guide these adjustments, we apply an AE rate of 1.2 for a single bearing cow, 1.3 for a twin bearing cow, and 0.75 (average to slaughter) for progeny (adapted from: DPIRD 2022). This scenario reflects the fact that in many instances beef producers have constrained feedbase options and assumes that the simulated farms already maintain an optimised stocking rate.

#### 2. Unconstrained animal equivalent (AE)

In the unconstrained AE scenario, we do not apply a feedbase and AE limit to the herd, allowing the herd's AE to increase as the rate of twinning increases.

#### 3. Beef maintenance scenario

In the beef maintenance scenario, we evaluate the maximum reduction in net emissions that could be achieved, through increasing the rate of twinning, while holding beef production constant.

#### 4. Emission constrained

Finally, we evaluate the effect of a hypothetical emissions reduction requirement of 25%. We evaluate whether, and to what extent, increasing the rates of twinning could help producers to maintain beef productivity, and also meet the required net methane emissions reduction.

## Results

### Impact of twinning on the cow – methane intensity, net emissions and beef productivity

The methane intensity of beef from a single reared calf was 17.1 and 16.4 kg $CO_2$-e/kg product at Cape Naturaliste and Hamilton respectively. For calves reared as twins, the mean methane intensity of beef produced was 22% lower than single calves from the same herd; 13.4 and 12.8 kg $CO_2$-e/kg product at Cape Naturaliste and Hamilton respectively. The variation in the methane intensity of beef from twin calves (s.d. = ± 0.1 kg $CO_2$-e/kg product) is attributable to variation in the twin bearing cow recovery requirements (Table 2).

Net methane emissions from twin calves and their dam were, on average, 49% higher than net methane emissions from a single calf and its dam (Table 3). Of the additional methane

**Table 3.** Methane intensity of beef from single vs twin reared calves at Cape Naturalise and Hamilton study areas.

| Herd type | Cape Naturaliste | | Hamilton | |
|---|---|---|---|---|
| | Uniparous | Multiparous | Uniparous | Multiparous |
| Methane intensity (kg $CO_2$-e/kg product) | 17.1 | 13.4 (s.d. = ± 0.13) | 16.4 | 12.8 (s.d. = ± 0.12) |
| Calf LWT at slaughter (kg)[A] | 532 | 1011[B] | 619 | 1175[B] |
| Calf CWT[C] (kg) | 282 | 536[B] | 328 | 623[B] |
| Net emissions (kg $CO_2$-e)[D] | 4827 | 7216 (s.d. = ± 74) | 5370 | 8015 (s.d. = ± 84) |

s.d., standard deviation.
[A]LWT, liveweight.
[B]Combined twin calf weight.
[C]CWT, carcase weight.
[D]Attributable to each litter, i.e. cow plus calf (calves) emissions.

emissions, 94% is attributable to the additional calf with the remaining 6% due to additional dam emissions due to the increased feed intake required to support the increased gestational and lactational energy demand.

Twin rearing cows also produced on average 90% more beef per parturition (579 kg vs 305 kg carcase weight (CWT); averaged across both locations) than single rearing cows (Table 3). This is slightly less than twice that of single rearing cows due to the lower (−5%) slaughter weight of twin reared calves.

## Herd level impact of increasing calving rates

### Methane intensity

At the herd level (expressed per 100 cows) the average methane intensity of beef from a uniparous (single) herd averaged across the two sites was 17.4 kg $CO_2$-e/kg product (Table 4). The variation between the herd level and cow level values is explained by the carriage of overhead emissions associated with maintaining the 2% of dry cows within the herd, and maintenance of cows whose calves died prior to slaughter. Increasing the calving rate to 1.53 calves per cow joined decreased the methane intensity of beef at the herd level by 14.4%, to an average of about 15 kg $CO_2$-e/kg product (Table 4).

### Net emissions

Net methane emissions increased in both AE scenarios (+2% in the constrained, and +23% in the unconstrained models), when the herd fertility rate rose from 0.98 to 1.53 calves born per cow joined (Table 4). The 2% increase in the constrained AE scenario reflects a small increase in total herd feed intake due to the increased feed demands of twin rearing cows. For the unconstrained AE scenario, the increase is primarily due to the additional (twin) calf emissions.

Under the beef maintenance scenario, net emissions fell by up to 14.3% with a corresponding decrease in AE and a reduction in breeder number from 100 to 70 (Table 4).

### Beef productivity

Under the constrained AE scenario, beef productivity (expressed in tonnes of carcase weight – CWT) increased +19% in the multiparous herd. This is despite the herd structural adjustments in breeder to calf ratio, which reduced cow number from 100 to 83 to accommodate the additional calves within the herd. Under the unconstrained AE scenario, beef production rose to 40.4 tonnes (+44%) per 100 cows in the multiparous herd, accompanied by a 23% increase in net methane emissions.

To meet the 25% reduction in emissions under the emissions constrained scenario, total AE was reduced, and beef productivity declined by 4 tonnes (−13%). Decreasing the breeder numbers (breeders decreased to 61, down from the base level of 100) only partially offset the AE reduction required to achieve the emissions reduction.

**Table 4.** Impact of variable rates of calving on herd level beef production, methane intensity, and net methane emissions.

| | Scenarios | | | | |
|---|---|---|---|---|---|
| | Base herd | Constrained AE | Unconstrained AE | Beef maintenance | Emissions constrained |
| Calves born per cow joined | 0.98 | 1.53 | 1.53 | 1.53 | 1.53 |
| Beef carcase weight (tonnes) | 28.1 | 33.4 | 40.4 | 28.1 | 24.5 |
| Cow number (head) | 100 | 83 | 100 | 70 | 61 |
| Calf number (head weaned) | 92 | 114 | 137 | 96 | 84 |
| Total AE | 186 | 187 | 226 | 159 | 139 |
| Net emissions (tonnes $CO_2$-e) | 488 | 498 | 600 | 418 | 366 |
| Methane intensity (kg $CO_2$-e/kg beef)[A] | 17.4 | 14.9 (s.d. = ± 0.35) | 14.9 (s.d. = ± 0.35) | 14.9 (s.d. = ± 0.35) | 14.9 (s.d. = ± 0.35) |

AE, animal equivalent.
[A]The standard deviation (s.d.) reported reflects the additive impact of variation in calf survival and cow body condition score recovery requirements (Table 2).

### Sensitivity analysis

Through a full factorial analysis, we evaluated the sensitivity of the results to variations in the input variables by varying calving rate, twin calf mortality, and cow recovery by 1% up or down. Methane intensity was most influenced by variation in calving rate. Increasing the calving rate by 1% decreased the methane intensity of beef produced by the herd by an average of 0.28%.

The sensitivity of methane intensity to a 1% change in twin calf survival was 0.05% at 1.53 calves born per cow joined. This limited impact of changes in twin calf survival reflects a low absolute mortality of twin born calves. The impact of variation in twin cow recovery requirements on methane intensity was also very limited, resulting in only a 0.01% variation in methane intensity per 1% change.

## Discussion

Selection for twinning in cattle has not been broadly adopted by beef producers (Cummins *et al.* 2008) despite the significant potential to lift herd productivity (Gregory *et al.* 1990; Small *et al.* 2000), profitablity in pasture based beef systems (Bergin *et al.* 2022), long-term selection programs demonstrating the capacity to increase rates of twinning (Echternkamp *et al.* 2007) and development of artificial breeding techniques that may aid genetic selection for twinning (Gordon *et al.* 1962; Cummins 1992).

One aspect of twinning in cattle that has not received significant research attention is the potential role that twinning could play in reducing the emissions intensity of beef through improving the biological efficiency of cattle. In support of this premise our results demonstrate that increasing the calving rate to 1.53 calves per cow joined could decrease the methane intensity of beef produced by the herd by about 14% as well as lifting herd beef production by up to 44% where the total AE is not constrained and 19% where AE is constrained.

However, despite the reduction in methane intensity achievable, at the herd level a calving rate of 1.53 calves per cow joined increased net herd methane emissions by up to 23% if AE are unconstrained. This is because twinning increases overall feed intake, due to the additional calves and the additional feed requirements of twin bearing cows, and therefore methane emissions. This is consistent with other studies where the relationship between increasing fecundity, methane intensity, and net emissions have been evaluated (Harrison *et al.* 2014; Gebbels *et al.* 2022). If AE is constrained, and the cow to calf ratio is decreased as the rate of twinning increases, the increase in net emissions is a modest 2% and there is an overall increase in beef production, of up to 19% at 1.53 calves born per cow joined.

Under the hypothetical 25% reduction in net methane emissions scenario, the beef production of our uniparous herd base herds fell by the same proportion (i.e. by 25%), reflecting the necessity for a reduced herd size to achieve the emissions reduction. However, increasing the calving rate to 1.53 calves per cow joined could achieve the 25% methane emissions reduction with a more modest 13% decline in beef production. This demonstrates that, while twinning can achieve some emission reduction, a 25% reduction in methane emissions will require a reduction in herd size. Nevertheless, modest reductions in net emissions (up to 14%) could be achieved without changing productivity, where the calving rate increases to 1.53 calves per cow joined, though this would necessitate a corresponding decrease in AE. This de-optimisation of stocking rate is unlikely to be voluntarily adopted by the industry without policy that constrains methane emissions, particularly if in the local context other viable enterprise options are limited e.g. in areas not suitable for crop production.

Increasing the rate of twinning is a clear pathway to enhancing the biological efficiency of beef cattle (Komisarek and Dorynek 2002) and to reducing the methane intensity of beef by increasing the proportion of feed resources allocated to the growth of calves rather than the maintenance of the breeding herd. To capitalise on the potential for twinning to increase herd productivity (de Rose and Wilton 1991; Echternkamp *et al.* 2007) and to decrease the methane intensity of beef, a paradigm shift in the management and genetic selection of beef cows is required. Management practices likely to be required to optimise outcomes include determination of pregnancy status and litter size (Guerra-Martinez *et al.* 1990), differential management based on litter size, intensive monitoring at calving, optimising the calving environment, targeted gestational, pre and post weaning nutrition (Gregory *et al.* 1996) and early weaning to allow cow recovery (Kirkpatrick 2002). In addition, longer term genetic selection programs to reduce the incidence of dystocia in twin bearing cows and increase calf rearing ability could further assist in minimising the potential for negative outcomes (Cummins *et al.* 2008; Çobanoğlu 2010). Advances in individual on-animal sensors may also enhance the management of twin bearing cows now and in the future. In particular, there are now a range of commercially available calving alert devices (Chapman 2016) that can notify a producer when a cow is calving, providing the opportunity to more closely monitor and potentially intervene, in the event of difficulties during or immediately post parturition.

Due to the necessary changes in herd management, if twinning is to be optimised, the practice is unlikely to be suitable for extensive pastoral beef production systems. However, much of the global beef herd is managed in more intensive systems (Hocquette and Chatellier 2011; Drouillard 2018), where management changes are more feasible. Though twinning is sometimes considered undesirable in dairy systems (Hossein-Zadeh 2010) there are several aspects related to dairy herds that make the prospect of increased rates of twining in these herds particularly appealing. First, dairy breeds have a higher naturally occurring rate of twinning than beef herds (Wakchaure and Ganguly 2016), which means that higher rates of twinning may be achieved more rapidly. Second, dairy herds are by nature more intensively managed than beef herds, simplifying the implementation of practices such as pregnancy scanning for litter size. Finally, in many countries, a significant proportion of beef production is already produced as a co-product from the dairy herd, and dairy cows make up around 18% (Utsunomiya *et al*. 2019; AHDB 2020) of global cattle numbers, increasing the scope for overall impact of adoption of the practice.

Given the significant pressure on the beef sector to reduce its emissions (Velazco *et al*. 2017; Gonzalez Fischer and Bilenca 2020), and the corresponding industry commitments to do so (MLA 2022), there is merit in revisiting the possibility of twinning in cattle as a pathway to reduce methane intensity and net methane emissions whilst maintaining productivity. As such, a comprehensive review of the opportunities and challenges of successful twinning in Australian cattle enter prises should be conducted. This review should consider enterprise suitability, management requirements, optimal pathways to increase twinning, the economic value propo sition and how future emissions policy – including a methane emissions cap or price – may impact the attractiveness of selecting for increased rates of twinning in cattle. The opportunity to stack twinning with other methane mitigating practices and technologies should also be considered.

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