METHANE YIELD FROM CATTLE, SHEEP, AND GOATS HOUSING WITH EMPHASIS ON EMISSION FACTORS: A REVIEW

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ABSTRACT
Global methane (CH$_4$) concentrations are increasing in all parts of the world. This review study intends to provide an integrative approach to the complex relationships between environmental systems of farm animals. It reveals that more data are needed to better quantify CH$_4$ emissions from farms. Methanogenic microbial functional groups play an important role in total methane flux from agroecosystems. The factors that regulate the activity of these organisms (temperature, diet composition, feeding technique, manure management) have been documented. The research based on the literature available presented was conducted under extensive and intensive management conditions. In principle, the approaches discussed can be applied to any dairy, beef or sheep production system because their aim is increasing productivity at the herd level. Recent studies on the effects of environmental temperature, feeding, internal and genetic factors, and emission from excrements on CH$_4$ production are discussed. Finally, emission factors for dairy and beef cattle, as well as goats and sheep, are listed in tables.

Key words: methane; dairy cattle; beef cattle; goat; sheep; emission; manure

INTRODUCTION
Greenhouse gas emissions (GGE) from livestock and their impact on climate changes are a major concern worldwide. Enteric CH$_4$ production from ruminant livestock accounts for 17–37% of global anthropogenic CH$_4$ emissions, with 89% of these livestock-derived emissions arising from enteric fermentation (Steinfeld and Wassenaar, 2007; Jiao et al., 2014). With regard to CH$_4$, the global livestock sector is responsible for 37% of all human-induced CH$_4$ emissions, with 89% of these livestock-derived emissions arising from enteric fermentation (Steinfeld and Wassenaar, 2007; Jiao et al., 2014).

Methane emissions from ruminants are the focus of scientists (Sejian et al., 2011; Ramin and Huhtanen, 2013; St-Pierre and Wright, 2013). With the relative global warming potential of 25 compared with CO$_2$, CH$_4$ is one of the most important GGE (Pinares-Patiño et al., 2007; Sejian et al., 2011). Decreasing methane emissions by livestock has therefore become a priority and an integral part of climate control (Martin et al., 2010). The leading role of livestock in methane emission has long been established (Charmley et al., 2008; Chagunda et al., 2009; Mihina et al., 2012).

In ruminant production systems, enteric CH$_4$ production is the largest contributor to GGE followed by CH$_4$ from manure systems, main emission sources are enteric fermentation, feed fertilization, and land application (Hensen et al., 2006; Klevenhusen et al., 2011; Hristov et al., 2013; Montes et al., 2013). Dairy cattle and beef cattle generate similar amounts of GGE, but on the basis of the numbers of animals beef production contributes 41% of total sector emissions while emissions from milk production amount to 20% of total sector emissions (Gerber et al., 2013a). Methane emissions from grazing cattle are a significant source...
of agricultural GGE, however, these emissions are difficult to quantify because of the sparse and roving nature of the source (HUART et al., 2010; McGINN et al., 2011).

**Methane creation**

Ruminant animals are the principal source of emissions because they produce the most CH$_4$ per unit of feed consumed. Ruminal gases, generated during the fermentative process in rumen, represent a partial loss of feed energy and are also pointed to as important factors in greenhouse effect (COTTLE et al., 2011). Around 90% of the enteric CH$_4$ produced by ruminants has its origin in the rumen (McALLISTER and NEWBOLD, 2008; ECKARD et al., 2010; DINI et al., 2012).

The rumen is characterized as a large fermentation vat. Ruminant animals have coevolved with a complex gut microbiota in a manner that has mutually improved the efficiency of digestion of complex plant polymers. In ruminants, microbial fermentation primarily takes place in the pre-gastric reticulum and rumen, where fluid mixes freely through the reticulo-rumen fold in adult ruminants. The development of a multi-chambered fore-stomach allows for increased retention time of ingested plant biomass and therefore a greater degree of microbial fermentation of non-labile C in the form of lignin, cellulose and hemicellulose (FINN et al., 2015).

The total number of rumen archaeal species is unknown (JANSSEN and KIRS, 2008), but has been estimated to be approximately 360 to 1,000 on an operational taxonomic unit basis (KIM et al., 2011; KONG et al., 2013). These complex anaerobic microbial communities consist of many species from divergent groups such as protozoa, fungi, bacteria and archaea (ST-PIERRE and WRIGHT, 2013). The microbes ferment the plant material consumed by the animal through a process known as enteric fermentation (CASSANDRO et al., 2013). Representatives from the following orders of methanogens have been identified in rumen microbial communities: *Methanococcales, Methanobacteriales, Methanomicrobiales, Methanosarcinales and Thermoplasmatales* (JANSSEN and KIRS 2008; POULSEN et al., 2013). Three major genera and 3 minor genera of methanogens belonging to the Archaea domain have been identified, although it is likely that more exist (WRIGHT et al., 2006; JANSSEN and KIRS, 2008; LIU and WHITMAN, 2008). Only 8 methanogen species have been cultured (KONG et al., 2013). Methanogens are found in the hindgut as well as the rumen, although the population structure, ecology, and microbial metabolism differ between the 2 compartments (KNAPP et al., 2014). Methanogenic microorganisms remove H$_2$ produced during fermentation of organic matter in the rumen and hind gut (COTTLE et al., 2011). Enteric fermentation is thermodynamically favourable only when a hydrogen sink is present and the major hydrogenutilising microorganisms in the rumen are hydrogenotrophic methanogens. Hydrogenotrophic species belonging to the genus *Methanobrevibacter* are frequently the most active and abundant methanogens in the rumen of cattle and sheep (WRIGHT et al., 2008).

A primary factor for enteric methane production is dietary carbohydrate, which influences the rate of fermentation, rate of rumen passage, and animal intake (JOHNSON and JOHNSON, 1995). The digestibility of ingested plant biomass, which is determined by the ratio of insoluble cell wall fibre to soluble carbohydrates, directs enteric fermentation to the preferential production of certain end products (MIGWI et al., 2013). Highly fibrous, poorly digestible plant biomass leads to the production of higher proportions of methanogenic substrates and reduces rumen passage rates, resulting in higher rates of methane production (ELLIS et al., 2009). Organisms involved in cellulose, hemicellulose, cellobiose, xylan, lipid and protein metabolism are important for animal. Most of these organisms are closely associated with particulate plant biomass and other microflora to facilitate syntrophic interactions such as plant biomass degradation and interspecies electron transfer (EDWARDS et al., 2008; LENG, 2014; FINN et al., 2015).

The final products of enteric fermentation include acetate, formate, methanol, carbon monoxide, carbon dioxide and hydrogen gas, all of which are substrates for methanogenesis (JOHNSON and JOHNSON, 1995; MOSS et al., 2000; MERINO et al., 2011). It was found that 89% gases are excreted through the breath and only 11% through the anus (MADSEN et al., 2010).

**Manure methane production**

Animal manure is a valuable source of nutrients and renewable energy in the agriculture. On the other hand, livestock manure management is extremely challenging and resultant gaseous emissions may contribute to global warming. Manure from livestock operations is most often stored in solid or liquid form before being applied to agricultural land.

Methane is produced from freshly deposited manure due to bacterial processes, and from storage lagoons and settling basins due to anaerobic degradation (HENSEN et al., 2006; CHAGUNDA et al., 2009; BORHAN et al., 2011a). Many of the emission pathways are controlled by microorganisms, and thus, by the optimum temperature for each specific microorganism involved (CHIANESE et al., 2009). KLEVENHUSEN et al., (2011) and BELL et al., (2011a) support the hypothesis that slurry methanogenesis strongly depends on storage temperature and duration, with the diet type being less important. The variation in CH$_4$ emission from slurry stored at cold temperature for 15 weeks was of low
Methane production in ruminants

Methane emissions in animal husbandry originate from fermentative digestion in animals, natural anaerobic ecosystems, storage of manures, and field application. Within livestock, ruminants (cattle, sheep, and goats) are the primary source of emissions. Other livestock (swine, horses, and poultry) are of lesser importance for nearly all countries. Among the ruminants, cattle population contributes most towards enteric \( \text{CH}_4 \) production (Johnson and Johnson, 1995; Zijderveld et al., 2011; Sejian and Naqvi, 2012). Emissions from enteric fermentation exceed those from storage of slurry and manure and are regarded a key source in greenhouse gas emission reporting. However, the assessment of emissions from stored manures is difficult due to lack of experimental data (Dämmgen et al., 2012).

The amount of \( \text{CH}_4 \) produced by ruminants is affected by various factors including animal type and size, growth rate, level of production, and energy consumption, digestibility, and quantity of feeds, intake of dry matter, total carbohydrates, digestible carbohydrates, and environmental temperature. Both animal and dietary factors play an important role in predicting \( \text{CH}_4 \) production (Johnson and Johnson, 1995; Yan et al., 2000; Monteny et al., 2006; Chianese et al., 2009; Shibata and Terada, 2010).

Enteric fermentation emissions for ruminants are estimated by multiplying the emission factor for each species. The emission factors are an estimate of the amount of \( \text{CH}_4 \) produced (kg) per animal, and are based on animal and feed characteristics data, average energy requirement of the animal, the average feed intake to satisfy the energy requirements, and the quality of the feed consumed. The country level emission from enteric fermentation is computed as a product of the ruminant population under each category and its emission coefficient (Chhabra et al. 2009; Sejian and Naqvi, 2012).

Environmental temperature

Environmental temperature also influences \( \text{CH}_4 \) production and the production rate. Since the digestibility of feed tends to increase with the lower feed intake and slower rates of passage under high temperatures, it may be considered that energy loss as \( \text{CH}_4 \) decreases. However, in a high temperatures environment, the contents of the cell wall, acid detergent fiber and lignin tend to increase, causing lower digestibility of feed and higher energy loss, and resulting in an increase in \( \text{CH}_4 \) production per unit of product through the decrease in the efficiency of animal production. These phenomena occur in tropical regions but will also occur more and more frequently in temperate regions as global warming progresses (Shibata and Terada, 2010).
Eckard (2011) and Cottle et al. (2011) found that mature beef cows emit approximately 350 g CH\textsubscript{4} daily in the tropics and 240 g daily in temperate zones; dairy cows emit approximately 430 g.d\textsuperscript{-1} at peak lactation down to 250 g.d\textsuperscript{-1} as milk yield declines. Kurihara et al. (1999) reported that the amount of CH\textsubscript{4} production in dry cows was decreasing as the environmental temperature was increasing because of decreased feed intake. However, CH\textsubscript{4} production per DMI increases under high temperatures. Kurihara et al. (1995, cited by Shibata and Terada, 2010) established a significant regression equation between DMI and CH\textsubscript{4} production at 18 °C and 30 – 32 °C, respectively, and concluded that CH\textsubscript{4} production per DMI increased at high temperatures and was about 10 % higher at temperatures above 26 °C than at 18 °C in cows at the maintenance level of feeding. The same authors also found that the effects of environmental temperature were different depending on the type of feed given: CH\textsubscript{4} production per DMI in lactating cows increased with temperature in high-roughage feeding while there were no significant differences among temperatures in high-concentrate feeding (Shibata and Terada, 2010). Temperature and manure storage time are the most important factors influencing CH\textsubscript{4} emissions because substrate and microbial growth are generally not limited (Monteny et al., 2001; Chianese et al., 2009).

Feeding

The type and amount of feed consumed are the primary drivers affecting emissions (Sejian and Naqvi, 2012). Daily CH\textsubscript{4} emissions were higher in grass-based systems than in intensive systems (Arias et al., 2015). Gerber et al. (2013b) wrote that higher emission intensities are in low productivity systems. It can be explained by low feed digestibility (leading to higher enteric and manure emissions), poorer animal husbandry and lower slaughter weights (slow growth rates leading to more emissions per kg of meat produced) and higher age at slaughter (longer life leading to more emissions). Generally, the CH\textsubscript{4} emission intensity of milk production is the lowest in industrialized regions of the world, compared with regional averages. Better animal feeding and nutrition reduce CH\textsubscript{4} and manure emissions.

But sometimes there are contradictory results. According to Pedreira et al. (2009), intensive managed pasture systems, with fertilized pasture and concentrate use, do generate more CH\textsubscript{4} methane emission by heifers grazing fertilized pasture was greater than that of heifers on unfertilized pasture.

Emissions from enteric fermentation and manure are also influenced by the composition of ruminants diets (Beauchemin et al., 2008; Sasu-Boakye et al., 2014). A large proportion of the variation in enteric CH\textsubscript{4} emissions from animals can be explained by diet composition and feed intake (Bell et al., 2012; Bell et al., 2014a). Ricci et al. (2014) observed significant differences between diets in finishing steers, emissions were greater for the low concentrate ration than the high concentrate ration. Jiao et al. (2014) demonstrated that offering concentrates to grazing dairy cows increased milk production per cow and increased CH\textsubscript{4} emissions per unit of milk produced. Methane emissions of grazing animals are strongly related to feed intake, which is likely to vary with seasonal pasture conditions. When the beef cattle were grazed on pasture, they produced significantly (3.5 times) higher CH\textsubscript{4} than the same cattle fed a highly digestible, high-grain diet. These measurements clearly document higher CH\textsubscript{4} production for cattle receiving low quality, high-fiber diets than for cattle fed high-grain diets (Harper et al., 1999).

Lovett et al. (2005) found that CH\textsubscript{4} production, kg MY\textsuperscript{-1} was unaffected by concentrate supplementation, but CH\textsubscript{4} production.kg FCM\textsuperscript{-1} decreased with increasing concentrate feed level. Young and Ferris (2011, cited by Jiao et al., 2014) observed that daily CH\textsubscript{4} emissions were unaffected by concentrate feeding, however, CH\textsubscript{4} emissions per kg DMI\textsuperscript{-1} and per kg ECM\textsuperscript{-1} decreased with increasing concentrate level.

The CH\textsubscript{4} production during feed ration 30 % hay and 70 % concentrate was significantly lower than that in 70 % hay and 30 % concentrate (Shibata et al., 1992). It is also known that fat supplements reduce CH\textsubscript{4} production (Beauchemin et al., 2009; Ramin and Huhtanen, 2013; Moate et al., 2014). Fraser et al. (2015) indicated that forage type had a greater impact than breed type on CH\textsubscript{4} emissions from growing weaned lambs.

Internal and genetic factors

Variation in enteric CH\textsubscript{4} emission has been reported between animals, between breeds, and across time, providing potential for improvement through genetic selection (Haas de et al., 2011). It was concluded that CH\textsubscript{4} emissions vary considerably between dairy cows housed under commercial conditions, but ranking of cows for CH\textsubscript{4} emissions is consistent across time. Variation is related to LBW, MY, parity, and stage of lactation, in accordance with changes in metabolizable energy requirements (Garnsworthy et al., 2012b). There was no indication of individual cows with persistently low or high CH\textsubscript{4} yield.kg DMI\textsuperscript{-1} and CH\textsubscript{4} yield.kg MY\textsuperscript{-1} (Münger and Kreuzer, 2008). Piñeres-Patiño et al. (2008) tested low bloat vs. high bloat cows. The mean CH\textsubscript{4} emissions were not different from each other.

CH\textsubscript{4} production is significantly different among animal species and breeds. Heifers produced about 7 times and 9 times as much as sheep and goats, respectively (Pedreira et al., 2009). Lactating cows produced more methane than dry cows and heifers.
Holstein cows produced less CH$_4$ per unit of dry matter intake than the crossbred (Pedreira et al., 2009). Holstein and Simmental cows had a similar CH$_4$ emission rate for dry period and entire lactation, while that of the Jersey cows was lower (Münger and Kreuzer, 2008). CH$_4$ values were significantly higher for the crossbred steers with 67% of Angus (limousine 33%) compared with 67% of Limousine (33% Angus) (Ricci et al., 2015). Higher DM intake and a longer lactation period were positively correlated with lower lifetime CH$_4$ emissions (Bell et al., 2011a).

**E mission from excrements**

Manure has often been identified as a significant source of CH$_4$ production. It carries an appropriate population of microorganisms, and has a readily available supply of substrate carbon (Saggar et al., 2004). Methane emission rates vary depending on the type of dung. Measurements made by Jarvis et al. (1995) on dung patches from dairy cows, heifers, calves, and steers fed various diets at different times of the grazing season, showed a good deal of variability in emission rates amongst dung types. The total CH$_4$ emissions during a 10-day measurement period ranged between 300 and 2040 mg.m$^{-2}$ of dung pat. Williams (1993) also noted that CH$_4$ emission rates with dung from similar types of animals varied markedly, and suggested this might reflect the variation in the number of dung microorganisms that are responsible for CH$_4$ production. Williams (1993) measured methane emissions from fresh cattle faecal deposits and found the emissions were low but highly variable, and the dung deposits quickly dried out in the hot, dry climate. Rahman et al. (2013) reported CH$_4$ emission rates from the pen surface of a beef feedlot 38 g.d$^{-1}$.

Methane emissions from animal excreta are influenced by how they are stored (Saggar et al., 2004). The same authors concluded that CH$_4$ emission from dung would be greatly reduced if the cattle were allowed to spend most of their time in pastures during the grazing season. The highest emission measured from the pat in the field was only 11% of the emission that would have resulted from solid manures, or 4% of that from slurry. Methane emission factors from cattle manure produced under diverse climates (cool, temperate, and warm), systems (intensive, semi-intensive, and extensive) and cattle production functions (dairy, non-dairy, and dual purpose) have recently been studied (González-Avalos and Ruiz-Suarez, 2001). Results suggest that the dominant factor in CH$_4$ emissions is the feed ration, followed by fermentation temperature and the excreta moisture content.

Methane is also generated when manure is stored in anaerobic and warm conditions (Cassandro et al., 2013). Most of the CH$_4$ emission from manure is produced under anaerobic conditions during storage with very little following land application. Manure produces less CH$_4$ when handled as a solid (e.g., in stacks or pits) or when deposited on pasture or rangelands. Therefore, opportunities to reduce CH$_4$ emission are centred on preventing anaerobic conditions during storage or capturing and transforming the CH$_4$ that is produced, if anaerobic conditions are present (Montes et al., 2013). Data summarized by Chianese et al. (2009) indicate average CH$_4$ emissions from covered slurry, uncovered slurry, and stacked manure to be 6.5, 5.4, and 2.3 kg.m$^{-2}$yr$^{-1}$ although rates vary with temperature and time in storage. CH$_4$ emissions from manure storage averaged 4.5 kg.m$^{-2}$yr$^{-1}$ being about half that from stacked manure.

It was observed that the faecal matter of animals grazing in the morning emitted much more methane than that of steers grazing in the afternoon. The difference in the emissions was in qualitative agreement with the pronounced loss of organic matter from the morning samples (Priano et al., 2014).

Composting is the natural biological breakdown of dung into more stable organic substances and is an alternative to conventional management of agricultural wastes. Composting reduces volume and mass and the composted product can be trucked further distances, stored, and spread on land with little or no odour, fly breeding potential, pathogens, or weed seeds. There are four general types of composting methods on farms: passive, windrows, aerated piles, and in-vessel composting. These results suggest that composting could contribute to about one-third of CH$_4$ emission from livestock agriculture (Saggar et al., 2004). Amon et al. (2001) found much higher CH$_4$ emissions during storage and after spreading of manure from the anaerobically stacked manure than from the composted manure. Soil type had no effect on these emissions, and interaction with soil appeared to be relatively minor. It is apparent that emissions from stored animal excreta are much higher than from the dung voided in the field.
List of abbreviations

AC = accumulation chamber
AL = ad libitum
ASDM = air sampled during milking
CM = concentrate mixture
CS = corn silage
d = day
DIM = days in milk
DMI = dry mater intake
ECM = energy corrected milk
FC = flux chamber
FCM = 4 % fat corrected milk
FMFT = flux method from feed trough
FS = fattening steers
FTIR = Fourier transform infrared spectroscopy
GA = gas analyzer
GC = gas chromatography
GF = green feed system (head position sensors)
GLAS = emissions measuring from ground-level area sources
GS = grass silage
H = hay
HA = haylage
HCD = high concentrate diet
HE = heifers
IPCC Tier 2 = guidelines for national greenhouse gas inventories, method Tier 2
LBW = live body weight
LBWG = gain of live body weight
LMD = laser methane detector
LU = live unit (500 kg of LBW)
M = month
MBIGA = mass balance method from 24 h gas sampling
MF = milk fat
MHA = methane hydrocarbon analyzer
MMT = micrometeorological mass technique
MP = milk protein
MR = milk replacer
MS = manure system
MULTI = multiparous
MY = milk yield
OMA = open-path methane analyser
OPL = open-path laser
PCM = protein–corrected milk
PRIMI = primiparous
RC = respiration chamber
S = silage
SF₆ = sulphur hexafluoride tracer technique
SMAMS = snifer method in automatic milking station
SMFT = snifer method from feed trough
TDL = tuneable diode laser absorption spectrometer
yr = year

Table 1: Methane production and emission factors of dairy cattle

<table>
<thead>
<tr>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calf, LBW 41 kg - 125 kg, LBWG 0.67 kg.d⁻¹; IPCC Tier 2, 9.4 kg.yr⁻¹ (Dämmgen et al., 2013)</td>
<td>23 - 50 Holstein, 1 yr; pasture, grass; FTIR, 342 g.d⁻¹ (Griffith et al., 2008)</td>
</tr>
<tr>
<td>12 Holstein heifers, 8 M, LBW 230 kg; rotationally grazed (flowers, clover, ryegrass); GF, 164 g.d⁻¹; 18.8 g.kg DMI⁻¹ (Hammond et al., 2015)</td>
<td>12 Holstein heifers, 8 M, LBW 230 kg; rotationally grazed (flowers, clover, ryegrass); SF₆, 186 g.d⁻¹, 21.5 g.kg DMI⁻¹ (Hammond et al., 2015)</td>
</tr>
<tr>
<td>4 Holstein HE, 14 M, LBW 317 kg; CS, GS; GF, 198 g.d⁻¹, 26.6 g.kg DMI⁻¹ (Hammond et al., 2015)</td>
<td>4 Holstein HE, 14 M, LBW 317 kg; GS; RC, GA, 164 g.d⁻¹, 21.5 g.kg DMI⁻¹ (Hammond et al., 2015)</td>
</tr>
<tr>
<td>4 Holstein HE, 14 M, LBW 339 kg; ryegrass HA, clover, trefoil and flowers; GF, 208 g.d⁻¹, 26.6 g.kg DMI⁻¹ (Hammond et al., 2015)</td>
<td>4 Holstein HE, 14 M, LBW 339 kg; ryegrass HA, clover, trefoil and flowers; RC, GA, 209 g.d⁻¹, 28.3 g.kg DMI⁻¹ (Hammond et al., 2015)</td>
</tr>
<tr>
<td>4 Holstein HE, 14 M, LBW 339 kg; ryegrass HA, clover, trefoil and flowers; RC, GA, 209 g.d⁻¹, 28.3 g.kg DMI⁻¹ (Hammond et al., 2015)</td>
<td>He, grass, clover (grazed), RC (750 cm²), GC, 1 kg dung, exposed 30 min., 1143 mg CH₄.m⁻² (Jarvis et al., 1995)</td>
</tr>
<tr>
<td>147 Holstein HE, feedlot; TMR, H; SF₆, 631 L.d⁻¹ (Kaharabata et al., 2000)</td>
<td>14 Holstein FS, LBW 334 kg; TMR, HCD; RC, MHA, 1.99 g.h⁻¹ (Stackhouse et al., 2011)</td>
</tr>
<tr>
<td>6 Holstein FS, LBW 334 kg; TMR, 41.4 % CS, 23.4 % grass H, 35.2 % CM; MBIAGA, 103 g.d⁻¹, 0.31 g.kg LBW⁻¹, 13.6 g.kg DMI⁻¹ (Newbold et al., 2014)</td>
<td>10 Holstein FS, LBW 215 kg; grazing morning, oat; RC, GC, 92.24 mg.kg fecal matter⁻¹, 576.5 mg.kg DM⁻¹, 0.067 g.kg⁻¹ (Priaño et al., 2014)</td>
</tr>
<tr>
<td>10 Holstein FS, LBW 215 kg; grazing afternoon, oat; RC, GC, 16.13 mg.kg fecal matter⁻¹, 89.6 mg.kg DM⁻¹, kg.yr⁻¹ (Priaño et al., 2014)</td>
<td>Holstein FS, alfalfa H, rice straw; RC, GA, 259.32 L.d⁻¹, 33.85 L.kg DMI⁻¹ (Shibata et al., 1993)</td>
</tr>
<tr>
<td>6 Holstein HE, LBW 401 kg, H 66.7 %, 33.3 % MC; RC, GA, 230.9 L.d⁻¹, 28.4 L.kg DMI⁻¹ (Shibata et al., 1992)</td>
<td>9 Holstein FS, LBW 150.5 kg; TMR, HCD; RC, MHA, 1.99 g.h⁻¹ (Stackhouse et al., 2011)</td>
</tr>
<tr>
<td>9 Holstein FS, LBW 336.4; TMR, HCD; RC, MHA, 3.16 g.h⁻¹ (Stackhouse et al., 2011)</td>
<td>9 Holstein FS, LBW 529.5 kg; TMR, HCD; RC, MHA, 4.15 g.h⁻¹ (Stackhouse et al., 2011)</td>
</tr>
<tr>
<td>4 Holstein HE, 18 M, LBWG 0.7 kg.d⁻¹; CS, alfalfa H; SF₆, 168 g.d⁻¹ (Westberg et al., 2001)</td>
<td>9 Holstein FS, LBW 150.5 kg; TMR, HCD; RC, MHA, 1.99 g.h⁻¹ (Stackhouse et al., 2011)</td>
</tr>
</tbody>
</table>
Table 2: Methane production and emission factors of dairy cows

| Holstein, LBW 600 kg, 38.9 kg ECM, 48, 125, 164, and 212 DIM; CS, clover S, CM; RC, GA, 669 L.day⁻¹, 30.6 L.kg DMI⁻¹, 24.2 L.kg ECM milk⁻¹ (Alstrup et al., 2015) |
| Holstein, LBW 600 kg, 38.9 kg ECM, 48, 125, 164, and 212 DIM; CS, clover S, rapeseed, CM; RC, GA, 588 L.day⁻¹, 29.8 L.kg DMI⁻¹, 17.7 L.kg ECM milk⁻¹ (Alstrup et al., 2015) |
| Holstein, LBW 600 kg, 38.9 kg ECM, 48, 125, 164, and 212 DIM; CS, clover S, vegetable fat; RC, GA, 622 L.day⁻¹, 28.5 L.kg DMI⁻¹, 17.4 L.kg ECM milk⁻¹ (Alstrup et al., 2015) |
| Holstein, LBW 600 kg, 38.9 kg ECM, 48, 125, 164, and 212 DIM; CS, clover S, CM, calcium soaps of palm, hydrogenated palm; RC, GA, 564 L.day⁻¹, 25.6 L.kg DMI⁻¹, 14.9 L.kg ECM milk⁻¹ (Alstrup et al., 2015) |
| Holstein, LBW 600 kg, tie-stall, slurry MS or straw MS; mobile RC, FTIR, GC, 194.4 g.day⁻¹, 194.4 g.day⁻¹ (Amon et al., 2001) |
| Holstein, LBW 664 kg, MY 33.3 kg.d⁻¹; TMR, 36.0 GS, 21.0 CS, 17.8 WS; ASDM, 0.24 mg.L⁻¹ (Bell et al., 2014b) |
| Holstein, LBW 661 kg, MY 31.5 kg.d⁻¹; TMR, 36.1 CS, 19.3 GS, 18.4 WS; ASDM, 0.24 mg.L⁻¹ (Bell et al., 2014b) |
| Holstein, LBW 662 kg, MY 29.7 kg.d⁻¹; TMR, 22.6 GS, 25.3 CS, 21.5 WS; ASDM, 0.25 mg.L⁻¹ (Bell et al., 2014b) |
| Holstein, LBW 598 kg, MY 6970 L.lactation⁻¹, TMR, 379 g.day⁻¹; model, enteric 340 g.d⁻¹, manure 32 g.d⁻¹ (Bell et al., 2013) |
| Holstein, LBW 444 kg, MY 5030 L.lactation⁻¹, TMR, 379 g.day⁻¹; model, enteric 281 g.d⁻¹, manure 26 g.d⁻¹ (Bell et al., 2013) |
| Holstein, LBW 632 kg, lactation milk 8965 kg, milk fat 358 kg; model, enteric 395 g.d⁻¹, manure 114 g.d⁻¹, enteric 144 kg yr⁻¹, manure 42 kg yr⁻¹ (Bell et al., 2015) |
| 700 Holstein, FTIR, January, March, June, September, combined emissions (pens and storage pond) 0.34, 0.55, 0.21, and 0.20 kg.d⁻¹, combined emissions 120 kg yr⁻¹ (Bjorneberg et al., 2009) |
| 500 Holstein, free-stall, TMR, winter, 0.58, 0.27, 5.1, 40.9, 4.7, 0.05, 0.25 g.d⁻¹, total 52 g.d⁻¹ (Bell et al., 2011b) |
| 4 Holstein, LBW 592 kg, MY 34.3 kg, 143 DIM; 54 % CS, 46 % GS, forage to MC 50:50, supplements rapeseed meal, rapeseed cake, cracked rapeseed and rapeseed oil; RC, GA, 569 L.d⁻¹, 20.4 L.kg ECM⁻¹, 29.6 L.kg DMI⁻¹, 531 L.d⁻¹, 19.0 L.kg ECM⁻¹, 29.9 L.kg DMI⁻¹, 478 L.d⁻¹, 16.9 L.kg ECM⁻¹, 462 L.d⁻¹, 16.7 L.kg ECM⁻¹, 26.4 L.kg DMI⁻¹ (Brask et al., 2013) |
| 11 Holstein, MY 17.46 kg, 180 DIM, grass, CS, H, CM; SF₆, 429 g.day⁻¹, 21.9 g.kg milk⁻¹ (Dehareng et al., 2012) |
| 8 Holstein, LBW 528 kg, 45.5 % cracked corn grain, 44.6 % alfalfa H; SF₆, vs. RC, GA, 22.3 g.kg DMI⁻¹, 431 g.d⁻¹ vs. 21.9 g.kg DMI⁻¹, 455 g.d⁻¹ (Deighton et al., 2014) |
| 4 Holstein, LBW 542 kg, MY 16.9 kg; TMR ad libitum vs. reduced to 2/3 (70 % silage, 4 % hay, 26 % CM); RC, GA, 420 L.d⁻¹, 328 L.d⁻¹ (Derno et al., 2009) |
| 100 Holstein, MY 27.0 kg, TMR, TS, CS, CM; RC, GA, 381 g.day⁻¹, 21.5 g.kg DMI⁻¹ (Dijkstra et al., 2011) |
| 8 Holstein, LBW 536 kg, MY 24.9 kg, 195 DIM; grazing, grass vs. legume, SF₆, 372 g.d⁻¹, 521 L.d⁻¹, 20.6 g.kg FCM⁻¹, 22.7 g.kg DMI⁻¹ vs. 364 g.d⁻¹, 510 L.d⁻¹, 18.6 g.kg FCM⁻¹, 21.6 g.kg DMI⁻¹ (Dini et al., 2012) |
| 82 Holstein, LBW 454 to 786 kg, MY 11 to 61 L, DIM 20 to 430, parity 1 to 4; AL TMR; CM at milking; ASDM, GA, 369 g.d⁻¹ (Garnsworthy et al., 2012a) |
| 12 Holstein, MY 20 to 40 L; AL TMR, GS, CS, alfalfa H; CM at milking, RC, GA, 395 g.d⁻¹ (Garnsworthy et al., 2012a) |
| 215 Holstein, LBW 602 kg, MY 33 kg, DIM 161, parity 3; TMR AL, CM at milking; ASDM, 2.07 g.min⁻¹, 379 g.d⁻¹ (Garnsworthy et al., 2012b) |
| 18 Holstein, LBW 660 kg, MY 31.7 kg; TMR, CM 27.5 % vs. 21.7 % digestible carbohydrates; ASDM, 447 g.day⁻¹ vs. 438 g.day⁻¹ (Haque et al., 2014b) |
| 12 pregnant Holstein, LBW 646 kg, MY 38.4 kg, GS:CS 70 : 30 vs. 30 : 70; SF₆, 409 g.day⁻¹, 19.5 g.kg DMI⁻¹, 15.5 g.kg milk yield⁻¹, 316 g.kg milk fat⁻¹, 104 g.kg milk solids⁻¹ vs. 397 g.day⁻¹, 17.8 g.kg DMI⁻¹, 14.7 g.kg milk yield⁻¹, 349 g.kg milk fat⁻¹, 99 g.kg milk solids⁻¹ (Hart et al., 2015) |
| 16 Holstein, DIM 302.4, parity 2.8; group SL, TMR, GS 600 g.kg DMI⁻¹, CM 400 g.kg DMI⁻¹, starch fermentation slowly, inclusion level low; RC, GA, 597 L.d⁻¹ (Hatew et al., 2015) |

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(table continued from previous page)

16 Holstein, DIM 302.4, parity 2.8; group SH, TMR, starch fermentation slowly, inclusion level high, GS 600 g.kg DMI⁻¹, CM 400 g.kg DMI⁻¹; RC, GA, 545 L.d⁻¹ (Hatew et al., 2015)

16 Holstein, DIM 302.4, parity 2.8; group RL, starch fermentation rapidly, inclusion level low, GS 600 g.kg DMI⁻¹, CM 400 g.kg DMI⁻¹; RC, GA, 581 L.d⁻¹ (Hatew et al., 2015)

16 Holstein, DIM 302.4, parity 2.8; group RH, starch fermentation rapidly, inclusion level high, GS 600 g.kg DMI⁻¹, CM 400 g.kg DMI⁻¹; RC, GA, 557 L.d⁻¹ (Hatew et al., 2015)

7 Dairy farms, no straw bedding, total (animals and manure), mobile TDL, 700 g.d⁻¹ (Hensen et al., 2006)

3 Dairy farms with straw bedding, total (animals and manure), mobile TDL, 1400 g.d⁻¹ (Hensen et al., 2006)

7 Dairy farms, slurry manure storage, winter, 1200 m³, mobile TDL, 11 g.m⁻².d⁻¹ (Hensen et al., 2006)

32 Swedish Red, LBW 664 kg, MY 30.2 kg, DIM 134; TMR (60 % forages, 40 % CM), CM from feed trough units; FMFT, 453 g.d⁻¹; SMFT 1405 ppm (Huhtanen et al., 2015)

107 Holstein, LBW 675 kg, MY 29.5 kg, LBWG 0.55 kg, TMR (60 % forages, 40 % concentrates), CM from feed trough AMS; FMFTAMS 447 g.d⁻¹, SMAMS 758 ppm (Huhtanen et al., 2015)

Dairy cow, grass, clover (grazed), CM; RC (750 cm³), GC, 1 kg dung exposed 30 min., 1702 mg.m⁻² (Jarvis et al., 1995)

Dairy cow, S, CM; RC (750 cm³), GC, 1 kg dung exposed 30 min., 716 mg.m⁻² (Jarvis et al., 1995)

Dairy cow, fertiliser grass, CM; RC (750 cm³), GC, 1 kg dung exposed 30 min., 2040 mg.m⁻² (Jarvis et al., 1995)

40 Holstein (12 PRIMI, 28 MULTI), grazing ryegrass, CM (2.0, 4.0, 6.0, and 8.0 kg.d⁻¹); SF6, 287, 273, 272, and 277 g.d⁻¹, 20.0, 19.3, 17.7, and 18.1 g.kg DMI⁻¹, 15.4, 12.9, 11.2, 10.8 g.kg milk⁻¹ (Jiao et al., 2014)

36 Holstein, LBW 600 kg, MY 32.3 kg; diet 2.3 % fat; SF6, 16.2 g.h⁻¹, 543 L.d⁻¹, 16.8 L.kg milk⁻¹ (Johnson et al., 2002)

36 Holstein, LBW 600 kg, MY 39.3 kg; diet 4.0 % fat; SF6, 16.4 g.h⁻¹, 550 L.d⁻¹, 14 L.kg milk⁻¹ (Johnson et al., 2002)

36 Holstein, LBW 600 kg, MY 39.1 kg; diet 5.6 % fat; SF6, 19.0 g.h⁻¹, 637 L.d⁻¹, 16.3 L.kg milk⁻¹ (Johnson et al., 2002)

90 Holstein, LBW 600 kg; TMR and 1.5 kg H (timothy, alfalfa); SF6, 542 L.cow⁻¹.d⁻¹, 19 L.kg of milk⁻¹ (Kaharabata et al., 2000)

118 Holstein, tie-stall, LBW 602 kg, MY 28.5 kg; TMR, CM; MBIGA, 587 L.d⁻¹, after subtracting manure contribution 552 L.d⁻¹, 19.4 L.kg of milk⁻¹ (Kinsman et al., 1995)

67 lactating cows, LBW 583 kg, MY 17 kg; RC, 420 L.d⁻¹, 24.7 L.kg milk⁻¹ (Kirchgessner et al., 1991, cited by Boadi et al., 2004)

18 cows (11 Holstein, 7 Brown Swiss), LBW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0; TMR corn diet (corn, ryegrass, barley, mixture of forage and CM 0.45 : 0.55; RC, GA, 303 g.d⁻¹, 22.8 g.kg DMI⁻¹, 22.1 g.kg milk⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), LBW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0; TMR corn diet (corn, ryegrass, barley, mixture of forage and CM 0.45 : 0.55; slurry stored 7 weeks at 14 °C vs. 27 °C; RC, GA, 0.4 g.d⁻¹ vs. 9.8 g.d⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), LBW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0; TMR corn diet (corn, ryegrass, barley, mixture of forage and concentrate 0.45 : 0.55; slurry stored 15 weeks at 14 °C vs. 27 °C; RC, GA, 6.1 g.d⁻¹ vs. 131.3 g.cow⁻¹.d⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), LBW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0, TMR barley diet (barley, corn, ryegrass, mixture of forage and CM 0.45 : 0.55); RC, GA, 364 g.d⁻¹, 24.0 g.kg DMI⁻¹, 23.6 g.kg milk⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), LBW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0, TMR barley diet (barley, corn, ryegrass, mixture of forage and CM 0.45 : 0.55; slurry stored 7 weeks at 14 °C vs. 27 °C; RC, GA, 0.6 g.d⁻¹ vs. 7.5 g.d⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), BW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0, TMR barley diet (barley, maize, ryegrass), mixture of forage and concentrate (0.45 : 0.55; slurry stored 15 weeks at 14 °C vs. 27 °C; RC, GA, 5.6 g.d⁻¹ vs. 108.1 g.d⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), BW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0; hay-only diet (low starch); RC, GA, 338 g.d⁻¹, 25.1 g.kg DMI⁻¹, 23.6 g.kg milk⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), LBW 649 kg, MY 16.9 kg, 215 DIM, parity 3.0; hay-only diet (low starch); slurry stored for 7 weeks of storage at 14 °C vs. 27 °C; RC, GA, 1.5 g.d⁻¹ vs. 15.8 g.d⁻¹ (Klevenhusen et al., 2011)

18 cows (11 Holstein, 7 Brown Swiss), LBW 649 kg, MY 16.9 kg, 215 DIM, parity 3, hay-only diet (low starch), slurry stored for 15 weeks at 14 °C vs. 27 °C; RC, GA, 1.2 g.d⁻¹ vs. 74.8 g.d⁻¹ (Klevenhusen et al., 2011)

10800 Holstein, 20 open-lot pens (60 ha), wastewater storage pond (10 ha), compost yard (10 ha), LBW 635 kg; TMR; MBIGA, 490 g.d⁻¹, 103 g.m⁻².d⁻¹, 13.5 g.m⁻².d⁻¹, combined emissions (lots, wastewater pond and compost) 1.39 kg.d⁻¹ (Leytem et al., 2010)

(table continued on next page)
Review

The perspective on the contribution of CH₄ emissions from agriculture is important in order to better establish typical emission ranges for farms and livestock products will affect future CH₄ emissions. Specifically, data are needed on CH₄ emissions from manure storage and housing facilities.

CONCLUSION

Agriculture is a major contributor to GGE, in particular of methane. The actual rate of CH₄ emission is highly dependent on the management strategies implemented on a farm. Consequently, improvements in management practices and changes in demand for livestock products will affect future CH₄ emissions.

Knowledge of experimental studies that quantify CH₄ production from agriculture is important in order to better establish typical emission ranges for farms and the effect of management factors on these emissions.

Further research will address these limitations through direct measurement of livestock methane emissions from a range of forages and through the integration of selected forage inputs. New approaches will be required in genetics and nutrition to provide perspective on the contribution of CH₄ emission from ruminants to global GHG emissions. Specifically, data are needed on CH₄ emissions from manure storage and housing facilities.
Table 3: Methane production and emission factors of beef cattle

Simbra HE (5/8 Brahman, 3/8 Simmental), 1 yr; grazing, bermudagrass, bahiagrass, and ryegrass, winter bahiagrass H, CM; SF, 89 – 180 g.d⁻¹ (DeRamus et al., 2003)

Simbra cows (5/8 Brahman, 3/8 Simmental), 3 to 7 yr; grazing, bermudagrass, bahiagrass, and ryegrass, winter bahiagrass H, CM, SF, 165 – 294 g.d⁻¹ (DeRamus et al., 2003)

4 Murray Gray x Charolais x Angus HE, 19 M, pregnant 3 M, LBW 435.5 kg; grazing, Yorkshire fog, Phalaris, Dead grass vs. feedlot, oats, alfalfa; MMT, 260 g.d⁻¹ vs. 66 g.d⁻¹ (Harper et al., 1999)

Calf, fertilized (N) grass (grazed); RC (750 cm²), GC, 1 kg dung exposed 30 min., 1143 mg CH₄.m⁻² (Jarvis et al., 1995)

Steer, low-N grass (grazed), RC (750 cm²), GC, 1 kg dung exposed 30 min., 406 mg CH₄.m⁻² (Jarvis et al., 1995)

Steer, unfertilized (N) grass (grazed), RC (750 cm²), GC, 1 kg dung exposed 30 min., 300 mg CH₄.m⁻² (Jarvis et al., 1995)

Suckler cow, rough grazing, RC (750 cm²), GC, 1 kg dung exposed 30 min., 922 mg CH₄.m⁻² (Jarvis et al., 1995)

13 Brahman steers (Bos indicus), LBW 227 kg; 22 diets, 5 tropical grass, 5 legumes; RC, GA, from 42.0 to 159.0 g.day⁻¹ or from 17.5 to 22.4 g.kg DMI⁻¹ (Kennedy and Charmley, 2012)

HE, enteric fermentation, 61 kg.yr⁻¹ (Lima et al., 2010; citated by Mazzetto et al., 2015b)

Cow, enteric fermentation, 63 kg.yr⁻¹ (Lima et al., 2010; citated by Mazzetto et al., 2015b)

Bull, enteric fermentation, 55 kg.yr⁻¹ (Lima et al., 2010; citated by Mazzetto et al., 2015b)

Calf, enteric fermentation, 42 kg.yr⁻¹ (Lima et al., 2010; citated by Mazzetto et al., 2015b)

Steer, enteric fermentation, 42 kg.yr⁻¹ (Lima et al., 2010; citated by Mazzetto et al., 2015b)

Beef cattle, 13,800, feedlot, LBW 265 - 620 kg; 16,500, feedlot, LBW 280 - 700 kg; high grain diets; OPL, model, 146 g.d⁻¹ vs. 166 g.d⁻¹ (Loh et al., 2008)

13,800 beef cattle, feedlot, Australia, LBW 350 - 600 kg vs. 22,500 beef cattle, feedlot, Canada, LBW 265 - 620 kg; high grain diets; OPL, model, 165 – 294 g.d⁻¹ (Ramírez-Restrepo et al., 2014)

72 Angus and Limousin crossbred, steers, LBW 673 kg, 16 M, low concentrate diet (48:52 forage to concentrate ratio (40 % grass silage, 35 % barley silage, 15 % barley grain, and 10 % maize distillers dark grains) vs. high concentrate diet (8:92 forage to concentrate ratio (12 % straw, 68 % barley grain, and 20 % maize distillers dark grains); RC, GA, 205 g.d⁻¹ vs. 145 g.d⁻¹ (Ricci et al., 2015)

9 Black Angus crossed steers, LBW 194 kg, high concentrate diet; RC, MHA, 2.85 g.h⁻¹ (Stackhouse et al., 2011)

9 Black Angus crossed steers, LBW 144 kg, high concentrate diet; RC, MHA, 4.18 g.h⁻¹ (Stackhouse et al., 2011)

9 Brahman (B. indicus) and 9 Belmont Red (Bos taurus x African Sanga) steers, LBW 222 kg; grazed, pasture Rhodes grass, OPL, 136.1 g.d⁻¹ (McGinn et al., 2015)

12 Bulls, LBW 498 kg, 9 M; pasture good (spring), poor (fall), winter feed diet; SF, 231 g.d⁻¹, 188 g.d⁻¹, 228 g.d⁻¹ (Westberg et al., 2001)

16 cows, LBW 585 kg, 4 yr; pasture, good (spring), poor (fall), winter feed diet, early lactating diet; SF, 231 g.d⁻¹, 188 g.d⁻¹, 211 g.d⁻¹ (Westberg et al., 2001)

12 HE, LBW 225 – 275 kg, 18 M; grower diet, good pasture, poor pasture; SF, 135 g.d⁻¹, 179 g.d⁻¹, 223 g.d⁻¹ (Westberg et al., 2001)
Table 4: Methane production and emission factors of goats and sheep

<table>
<thead>
<tr>
<th>Description</th>
<th>LBW (kg)</th>
<th>Forage</th>
<th>LMD (g/kg DMI)</th>
<th>DMI (kg/day)</th>
<th>DMI (g/kg LBWG)</th>
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<tr>
<td>4 Japanese goats, 2 years, H alfalfa H, corn, MC, RC, GA, 31 mL.g DMI (Bhatta et al., 2008)</td>
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<td>Sheep, Scottish grey face; grazing, ryegrass, 10.8 ha; OMA, 20.5 g.d$^{-1}$, 7.4 g yr$^{-1}$ (Dengel et al., 2011)</td>
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<td>16 weaned lambs, Welsh Mountain vs. Welsh Mule × Texel, fresh cut ryegrass, RC, GA, 15 g.d$^{-1}$ vs. 17 g.d$^{-1}$, 16.1 g.kg DMI vs. 16.7 g.kg DMI, 5.4 g.kg yr$^{-1}$ vs. 6.3 g.kg yr$^{-1}$ (Fraser et al., 2015)</td>
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<tr>
<td>16 weaned lambs, Welsh Mountain vs. Welsh Mule × Texel, fresh cut permanent pasture, RC, GA, 12 g.d$^{-1}$ vs. 14 g.d$^{-1}$, 16.7 g.kg DMI vs. 18.8 g.kg DMI, 4.3 g.kg yr$^{-1}$ vs. 5.1 g.kg yr$^{-1}$ (Fraser et al., 2015)</td>
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<td>9 lambs, 90 d, LBW 20.9 kg; grass H, GA, 19.9 g.d$^{-1}$, 116.3 g.kg LBWG$^{-1}$, 31.1 g.kg DMI$^{-1}$ (Haque et al., 2014a)</td>
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<td>9 lambs, 90 d, LBW 21.8 kg, 2.5 L.d$^{-1}$; 50:50 MR, dairy cream; GA, 3.2 g.d$^{-1}$, 11.5 g.kg LBWG$^{-1}$, 4.3 g.kg DMI (Haque et al., 2014a)</td>
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<td>9 lambs, 150 d, LBW 33.7 kg; grass H, GA, 19.1 g.d$^{-1}$, 113.9 g.kg LBWG$^{-1}$, 34.3 g.kg DMI (Haque et al., 2014a)</td>
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<tr>
<td>9 lambs, 150 d, LBW 34.7 kg, 2.5 L.d$^{-1}$; 50:50 MR, dairy cream; GA, 2.4 g.d$^{-1}$, 9.1 g.kg LBWG$^{-1}$, 1.1 g.kg DMI (Haque et al., 2014a)</td>
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<td>4 wether sheep, 1.5 yr, LBW 51.0 kg; white clover; RC, GA, 25.7 g.d$^{-1}$, 22.5 g.kg DMI$^{-1}$ (Hammond et al., 2014)</td>
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<tr>
<td>4 wether sheep, 1.5 yr, LBW 51.0 kg, ryegrass; RC, GA, 24.5 g.d$^{-1}$, 22.0 g.kg DMI$^{-1}$ (Hammond et al., 2014)</td>
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<td>30 wether sheep, 5x6, LBW 51.4 kg; ryegrass, 0.50, 0.76, 1.02, 1.26, 1.51 g.kg DM.d$^{-1}$; RC, GA, 13.1 g.d$^{-1}$, 27.0 g.kg DMI$^{-1}$; 19.5 g.d$^{-1}$, 27.0 g.kg DMI$^{-1}$; 23.2 g.d$^{-1}$, 25.2 g.kg DMI$^{-1}$; 27.1 g.d$^{-1}$, 25.3 g.kg DMI$^{-1}$; 31.9 g.d$^{-1}$, 23.9 g.kg DMI$^{-1}$ (Hammond et al., 2014)</td>
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<td>Sheep, H, CM; RC (750 cm$^2$), GC, 1 kg dung exposed 30 min., 598 mg CH$_{4}$ m$^{-2}$ (Jarvis et al., 1995)</td>
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<td>4 Korean native black goats, LBW 23.5 kg; 50:50 forage, CM; RC, GA, 11.6 g.d$^{-1}$, 24.7 g.kg DMI (Li et al., 2010)</td>
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<td>41 sheep, metaanalysis, LBW 47.6 kg; 19.0 g.d$^{-1}$, 20.3 g.kg DMI$^{-1}$ (Patra, 2014)</td>
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<td>20 Romney sheep, 14 M, LBW 45 kg; grazing, ryegrass, white clover; SF, 28.9 – 35.5 g.d$^{-1}$ (Pinares-Patiño et al., 2003)</td>
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<td>24 Scottish Mule ewes, 29 DIM, 5.5 yr, LBW 68 kg; alfalfa AL vs. restricted alfalfa (0.8 of AL); RC, LMD, 109.7 g.pair$^{-1}$; 83.2 g.pair$^{-1}$ (Ricci et al., 2015)</td>
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<td>160 ewes, 50:50 alfalfa H, oaten H; MBIGA, 22.2 g.d$^{-1}$ (Robinson et al., 2014)</td>
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<td>10 wethers sheep, Corriedale, LBW 71 kg; 66:33:3.3 H, CM; RC, GA, 34.3 L.d$^{-1}$, 25.9 L.kg DMI (Shibata et al., 1992)</td>
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<td>11 wether goats, Japanese native, LBW 39 kg; 66:33:3.3 H, CM; RC, GA, 25.2 L.d$^{-1}$, 27.1 L.kg DMI (Shibata et al., 1992)</td>
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<tr>
<td>Sheep, goats; H, CM; RC, GA, 28.55 L.d$^{-1}$, 26.70 L.kg DMI (Shibata et al., 1993)</td>
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