ENTERIC METHANE EMISSION AND ITS MITIGATION FROM BEEF CATTLE PRODUCTION SYSTEMS IN THE TROPICS

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ABSTRACT

Beef cattle production systems and its supply chain contribute significantly to emission of methane and its global impact on climate change. The loss of enteric methane energy from ruminant feeding system is a problem not only with respect to climate change impact as the global greenhouse gas emissions, but also to less feed energy utilization efficiency and thus, low livestock productivity. The present paper highlights recent research on enteric methane emission and how beef production systems can be mitigated. The enteric methane conversion factor (Y_m) is a key important country-specific value for the provision of precise enteric methane emissions national inventory reports. Our results suggested that the Y_m values ranged from 3.1 to 13.7%, with Y_m value of 6.7% of gross energy intake (average 100 g daily methane emission per cattle) based on data derived from 33 in vivo feeding experiments of Zebu (Bos indicus) beef cattle breeds fed low quality crop residues and by-products for tropical developing countries. The IPCC default model underestimated the Y_m value by 3.1%. Also, this paper provided a recently develop and extant Y_m model for estimating enteric methane from Zebu (Bos indicus) beef cattle breeds fed low quality crop residues and by-products for tropical developing countries. The composition of feed ingredients, feed nutritive values, feeding level, type and stage of cattle production are critical factors in controlling the amount of enteric methane emitted. The large variations of methane emission present a great opportunity for methane mitigation strategy for native or Zebu crossbred cattle adapted in the hot climate environment. It is concluded that there is opportunity to use tropical feed resources and feeding innovations in beef cattle to improve productivity and environmental sustainability.

Keywords: Climate Change, Feeding, Greenhouse Gas, Methane, Ruminant, Zebu

INTRODUCTION

There is growing interest in avoiding the “dangerous” facet of climate change and global warming by mitigating emissions of greenhouse gases from animal agriculture farming (Lasse, 2007; Chuntrakort et al., 2014; Chaokaur et al., 2015; Gerber et al., 2015; Tangjitwattanachai et al., 2015; Ogino et al., 2016). Ruminant animals, particularly cattle (Bos taurus and Bos indicus) produce significant amounts of methane via anaerobic gut digestion. Beef and dairy cattle are the major contributors, because of their larger size, energy intake, and populations compared with others, producing 61% of
all domestic animals (Gerber et al., 2015) and emitted enteric methane energy the losses of which ranged from 2 to 12% of gross energy intake (Johnson and Johnson, 1995).

The enteric methane is formed in the rumen of ruminants by a group of rumen methanogens microbes, which form a subgroup of the domain Archaea (Leahy et al., 2010). Moss et al. (1995) reported that, the use of low-quality forages will increase the amount of methane produced per a unit of animal product while the use of forages with high-solubility carbohydrates reduces the level of hydrogen available for methane production. In the tropical developing countries, beef cattle production might be high in methane emission because the major feeding system utilize low quality roughage sources (WTSR, 2010). The shortage of roughage quantity and low quality in the dry season forces the farmers to use rice straw and/or other crop residues which limits voluntary intake, digestibility, nutrient and energy balance and thus low production efficiency as well as excreted environmental stresses. One challenge is the lack of data available to predict methane emission for Zebu beef cattle. This is a particular problem given that stocks of Zebu (Bos indicus) cattle in developing countries in tropical regions now account for more than half of the global beef cattle population (FAO, 2015). The objectives of this review were to analyze published data on enteric methane emission and how beef production systems in the tropics can be mitigated.

**RUMEN METANOGENESIS**

In ruminants, digestion of feed is primarily carried out by the microflora in the rumen, which is intrinsically tightly regulated with redox potential of –300 to –350 mV, temperature 38 °C to 42 °C and pH 6 to 7 (Van Soest, 1994). In the first stage, the complex plant material, such as cellulose, hemicellulose, starch, and proteins are decomposed. The monomers are then fermented. As illustrated by Mitsumori and Sun (2008), for instance, the carbohydrates are degraded to hexose in producing volatile fatty acids (VFAs), carbon dioxide (CO₂), hydrogen and methane (Figure 1). To clear the rumen end products, VFAs are transported across the rumen walls, whereas CO₂ and methane are released to the head space of the rumen and are lost through eructation or transported via circulation to the lungs until they respire (Hill et al., 2016).

The methanogenesis is facilitated by methanogenic archaea (Hill et al., 2016). Methanogens appeared on earth some 3.5×10⁹ years ago or earlier (Mitsumori and Sun, 2008). However, only six genera of methanogenic archaea are in the rumen: Methanobrevibacter, Methanomicrobium, Methanosphaera, Methanosarcina, Methanobacterium, and Rumen Cluster C archaea (Hill et al., 2016). A phylogenetic tree of methanogens in the rumen of native Thai cattle is illustrated in Figure 2 (Kaewpila et al., 2012). This figure shows that the major genera are as follows: Methanobrevibacter (64.0%), Methanomicrobium (7.0%) and Rumen Cluster C archaea (27.2%).

**ENTERIC METHANE MEASUREMENT**

Several comprehensive reviews have been published recently, which describe a number of potential methods for measuring methane emission from ruminants (Bhatta et al., 2007; Hill et al., 2016; Patra, 2016; Suzuki et al., 2008). The most techniques are designed to obtain methane emission from the rumen. Here, the major methods for measuring enteric methane emission with their advantages and disadvantages are reviewed.

**In vitro methods**

With the specific aim to estimate methane emission potential of feedstuffs as well as to screen methane inhibitors, a range of in vitro gas production techniques have been utilized. For instance the screening in common feedstuffs (Lee et al., 2003; Kaewpila et al., 2010; Kaewpila, 2016) foliage, seeds, fruits and
medicinal plants (Soliva et al., 2008; Sommart and Kongphitee, 2012; Norrapoke et al., 2014), grass silage, grass hay, a mixture of grass silage, and barley (Ramin et al., 2015). In practice, the in vitro gas production techniques would be rapid and inexpensive works. An agreement between in vitro methane and in vivo methane have been reported (Bhatta et al., 2007). Conversely, they should be viewed as an indirect measurement (Patra, 2016). In vitro method measurement has several significant limits, including possible synthetic incubation periods, a single end-point that is used to conclude degradation of organic matter, VFAs and gas production, and the possibility that the steady-state conditions of fermentation may not be reached (Hill et al., 2016).

Respiration chamber methods

To obtain an in vivo methane emission, the practice reaches direct measurement (Blaxter, 1967; Galyean et al., 2016). Direct measurements of enteric methane emissions are useful to quantify the magnitude and variation to evaluate mitigation of this significant greenhouse gas source. These direct measurement techniques include total or partial enclosure of animals e.g., respiration chambers and head hoods (Bhatta et al., 2007; Hill et al., 2016; Suzuki et al., 2008). In this kind of measurement an energy balance trial is the basis, as is methane energy loss. Further, when it is conducted with the feeding trial, the methane intensity (animal emission per production unit) is obtained. However, it should be also careful that the feeding protocols may not simulate those of the grazing animal (Lassey, 2007; Hill et al., 2016). The disadvantage of the approach is that the animal is often fed at maintenance, measurements are completed over short periods, and the eating and/or behavior of the animal does not reproduce the free-ranging outline (Suzuki et al., 2008; Hill et al., 2016).

Tracer methods

There is recently interest in developing indirect tracer methods because they can be used when the animal is grazing freely and their behavioral processes are not limited by a chamber (Hill et al., 2016; Patra, 2016). In this kind of measurement the most used technique is sulfur hexafluoride (SF6) tracer technique which pioneered by Johnson et al. (1994). This is because of SF6 is a gas that is not produced as part of any biological process, inert, easily measurable, and traceable at low concentrations. In protocol, methane is measured as the ratio of this gas when the animal rumen is orally/fistula placed by the brass permeation tube (i.e., source of SF6). Paradoxically, SF6 is a persistent greenhouse gas. Further, the variation (%CV) between measurements using SF6 and respiration chambers is 10% or more (Bhatta et al., 2007; Hill et al., 2016; Suzuki et al., 2016).

Modeling prediction methods

The enteric methane conversion factor (Ym) is an important country-specific value for the provision of precise enteric methane emissions inventory reports. Currently, enteric methane emissions for cattle globally are estimated from energy requirements by using the enteric methane conversion factor (Ym, % of GE intake), according to the IPCC (2006) standard. Practically, the Ym default model of “Ym = 6.5 ± 1% of GE intake” of IPCC (2006) is used worldwide to upscale national estimations and obtain accurate cattle population and related activity data. In practice, the prediction models are developed from in vivo methane database. These measurements are viewed as the predictive methane to estimate national methane inventories (IPCC, 2006) and to guide methane emission mitigation strategies (Hill et al., 2016). Exactly, the extant models can be classified into two principal groups: empirical (statistical) or dynamic mechanistic models (Kebreab et al., 2008).

A number of extant models to predict Ym values are presented (Table 1). However, an extant model estimation for cattle in North America and European situations may not perform accuracy and precision enteric methane emission for national inventory report (Kaewpila, 2016). Recently, Kaewpila (2016) suggest a new Ym model for estimating Zebu beef cattle production in tropical developing countries. A meta-analysis was carried out to develop and evaluate the empirical Ym models by using datasets derived from 33 in vivo feeding experiments from 1975–2015 of Zebu beef
cattle breeds fed low quality crop residues and by-products for tropical developing countries according to the IPCC’s categorization. Daily enteric methane emissions were 100 g head$^{-1}$ day$^{-1}$ (ranged in 17 and 311 g head$^{-1}$ day$^{-1}$). The observed $Y_m$ values ranged from 3.1 to 13.7%, with $Y_m$ value of 6.7% of gross energy intake. The IPCC default model underestimated the $Y_m$ value by 3.1% of gross energy intake. Six of the extant $Y_m$ models studied herein also showed inaccurately estimated $Y_m$ values. Two of the developed models showed a greater accuracy in this regard: (i) the IPCC method ($Y_m = 6.7\pm1\%$ of gross energy intake) and (ii) the regression method with the variables of dietary chemical compositions, intake, and energies.
Table 1. List of extent models to predict $Y_m$ values, and their predictive performance in Zebu beef cattle fed diets in the tropical regions

<table>
<thead>
<tr>
<th>Method category</th>
<th>Relationship†</th>
<th>RMSPE (‡)</th>
<th>Description</th>
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<tr>
<td>IPCC method</td>
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<tr>
<td>IPCC (2006)</td>
<td>$Y_m = 6.5 \pm 1.0$</td>
<td>33.3</td>
<td>These IPCC guidelines for the tier 2 level are used to upscale the measurements of national and global inventories. The model is developed from a database including dairy cows in New Zealand, dairy heifers and steers in the United States, and beef cows in France (i.e., animals grazing in temperate pastures). It is the currently suggested emissions inventory method for the enteric fermentation of cattle population categories fed low quality crop residuals and by-products in developing countries.</td>
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<tr>
<td>Kaewpila (2016) model A</td>
<td>$Y_m = 6.7 \pm 1.0$</td>
<td>32.7</td>
<td>This model developed a tier 2 level from a database including Zebu beef cattle fed diets in the tropical regions ($n = 213$).</td>
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<td>Regression method</td>
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<td>Blaxter and Clapperton (1965)</td>
<td>$Y_m = 1.30 + 11.2 \times \text{DE/GE} - [(2.37 - 5.00 \times \text{DE/GE}) \times \text{MEI}]$</td>
<td>58.8</td>
<td>This model is developed from a database including cattle and sheep fed roughages or mixed diets in the United Kingdom.</td>
</tr>
<tr>
<td>Yan et al. (2000) model A</td>
<td>$Y_m = [0.0877 - 0.0078 \times \text{(MEI - 1.00)}] \times 100$</td>
<td>34.9</td>
<td>This model is developed from a database including dairy cows and steers offered grass silage-based diets in Northern Ireland.</td>
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<tr>
<td>Yan et al. (2000) model B</td>
<td>$Y_m = [0.0522 + 0.0694 \times \text{ADFI/DMI}] \times 100$</td>
<td>32.4</td>
<td>See description of Yan et al. (2000) model A.</td>
</tr>
<tr>
<td>FAO (2010)</td>
<td>$Y_m = 9.75 - 0.005 \times \text{DMD}$</td>
<td>32.9</td>
<td>This model has been previously used to predict methane emissions from dairy cattle production in Sweden and Nigeria. No information on the database is available.</td>
</tr>
<tr>
<td>Ramin and Huhtanen (2013)</td>
<td>$Y_m = [-0.60 - 0.70 \times \text{DMIbw} + 0.076 \times \text{OMDm} - 0.130 \times \text{EE} + 0.046 \times \text{NDF} + 0.044 \times \text{NFC}] / 10$</td>
<td>28.2</td>
<td>This model is developed from a database including dairy and beef cattle and sheep fed a wide range of dietary composition in unspecified locations.</td>
</tr>
<tr>
<td>Patra (2013)</td>
<td>$Y_m = 7.10 - 0.0192 \times \text{EE}$</td>
<td>31.5</td>
<td>This model is developed from a database including dairy and beef cattle fed a wide range of dietary composition in unspecified locations.</td>
</tr>
<tr>
<td>Jaurena et al. (2015)</td>
<td>$Y_m = \text{Intercept alternatives}§ - 0.2430 \times \text{DMI} + 0.0059 \times \text{NDF} + 0.0057 \times \text{DMD}$</td>
<td>37.9</td>
<td>This model is developed from a database including beef cattle fed a wide range of dietary composition in unspecified locations.</td>
</tr>
<tr>
<td>Kaewpila (2016) model B</td>
<td>$Y_m = 25.25 - 0.019 \times \text{EE} - 0.27 \times \text{DMI} + 14.05 \times \text{DE/GE} - 28.09 \times \text{ME/DE} - 1.14 \times \text{MEI}$</td>
<td>20.2</td>
<td>See description of Kaewpila (2016) model A.</td>
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</table>

†$Y_m$, methane conversion factor (% of GEI); DE, digestible energy (MJ kg⁻¹ DM); GE, gross energy (MJ kg⁻¹ DM); GEI, GE intake (MJ day⁻¹); MEI, metabolizable energy intake as multiple time of maintenance requirement (0.48 MJ ME kg⁻¹ BW⁰.⁷⁷, WTSR, 2010); ADFI, acid detergent fiber intake (kg day⁻¹); DMI, dry matter intake (kg day⁻¹); DMD, dry matter digestibility (g kg⁻¹); DMIbw, dry matter intake (g kg⁻¹ body weight); OMDm, organic matter digestibility (OMD) determined at a maintenance level of feeding (g kg⁻¹); OMDm = OMD (g kg⁻¹) + 1.83 × [DMIbw – 10]; NDF, neutral detergent fiber (g kg⁻¹ DM); EE, ether extract (g kg⁻¹ DM); NFC, nonfibre carbohydrates (g kg⁻¹ DM).

‡Root mean square prediction error in % of observed $Y_m$ values (evaluated in an external database including Zebu beef cattle fed diets in the tropical regions, $n = 107$).

§Intercept ranges from 1.0 to 5.1 depending on the source of roughage and level of concentrate.

Source: Kaewpila (2016)
Fig. 1. The estimated fermentation pathways of carbohydrates to methane in the rumen.
Source: Mitsumori and Sun (2008)
Fig. 2. A phylogenetic tree conducted from the methyl coenzyme M reductase A (mcrA) gene sequences of cultured methanogens obtained from Gen Bank and 456 cloned libraries taken from the rumen of Holstein cows fed concentrate with rice straw (Lib#2), and yearling native Thai cattle fed natural pasture (Lib#3) or timothy grass hay (Lib#4). Methanopyrus knudsenii was selected as out group (bootstrap values <800 not shown). The scale bar indicates 0.10 inferred nucleotide substitutions per position.

Source: Kaewpila et al. (2012)
METHANE MITIGATION STRATEGIES

Comprehensive reviews on enteric methane emission mitigation strategies and overall farm sustainable practice have been published (Boadi et al., 2004; Kumaret et al., 2014; Mitsumori and Sun, 2008; Hristov et al., 2013; Patra, 2016). Recently, a schematic presentation of mitigating strategies (Fig. 3) has been also introduced (Patra, 2016). The potential involve intervention are animal level, dietary level and inhibition of methanogens. A number of practical approaches to evaluate for enteric methane mitigation of beef cattle in the tropics are presented in Table 2.

Table 2. Enteric methane emission from beef cattle fed forage with or without concentrate supplementation1.

<table>
<thead>
<tr>
<th>References</th>
<th>Breeds</th>
<th>Stage</th>
<th>Animal (n)</th>
<th>BW (kg)</th>
<th>Forage (%)</th>
<th>DMI (kg/d)</th>
<th>GEI (MJ/d)</th>
<th>CH4 (L/d)</th>
<th>Ym (%GEI)</th>
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<td>8</td>
<td>367.3</td>
<td>100</td>
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<td>86.2</td>
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1TN, Thai-native beef cattle; Br, Brahman cattle; CB, crossbred cattle; S, Steer; G, growing; F, fattening; DMI, dry matter intake; GEI, gross energy intake; Ym, methane conversion factor.
Production system and feeding management

FAO reported that with feasible improvements in forage quality, animal health and husbandry and carbon sequestration, emissions could be reduced by 18 to 29% of baseline emissions or 190 to 310 million tons of carbon dioxide equivalent (Gerber et al., 2013). Chaokaur et al. (2015) suggested that increasing feeding level increased average daily gain of Brahman cattle and the observed increased energetic efficiency was attributed to reduced energy output in urine, methane and heat production. Methane emission rate decreased (from 11.5 to 7.3%) with increasing feeding level, yet these values are much higher than the IPCC recommended value (6.5%) for calculation of national inventory of enteric methane emissions. Tangjitwattanachai et al. (2015) confirmed that greater dietary intake feeding strategy in beef cattle fed above the maintenance level resulted in improved energetic efficiency utilization, and thus improved energy retention because of the reduction of enteric methane energy emission and heat production. The energy loss in feces and urine (% of gross energy intake) were not different (P> 0.05); however, enteric methane conversion rate (% of methane energy loss per gross energy intake) and heat energy production loss (% gross energy intake) were linearly decreased (P< 0.01) with increasing MEI levels. Methane conversion rates ranged from 8.4 to 10.0% and appeared to have been underestimated by the Intergovernmental Panel on Climate Change 6.5% default values set for cattle fed low quality crop residues and by-products.

Culling of unproductive animals on a farm can potentially both improve profitability and reduce methane (Eckard et al., 2010). In cow-calf production systems, shortening calving intervals by 1 month could reduce environmental impacts by 6% (Ogino et al., 2007). With earlier finishing of beef cattle in feed lots, slaughter weights are reached at a younger age, with decreased lifetime emissions per animal and thus proportionately less cattle producing methane (Ogino et al., 2004; IPCC, 2007).
Ogino et al. (2016) also demonstrated the environmental impacts of the extensive and intensive use of finishing zebu beef production systems. Records show that there were 14.0 and 10.6 kg CO\textsubscript{2} equivalents for climate change, 3.5 and 11.3 MJ for energy consumption, and 47.4 and 61.8 g SO\textsubscript{2} equivalents for acidification, respectively. The results suggested that the ongoing intensification in beef production in Thailand reduces greenhouse gas emissions while increasing impacts on energy consumption and acidification. Suzuki et al. (unpublished) estimated that average daily gains of native Thai beef cattle in intensive, semi-intensive, and extensive production systems were 0.91, 0.71 and 0.45 kg/day, respectively and those feeding systems required 10, 12, and 19 month, respectively to achieve targeted body weight of 350 kg from 100 kg. The total methane emissions decreased with decreasing of feeding period, i.e. in the order of extensive, semi-intensive and intensive feeding system (66.3, 34.9, and 25.9 kg, respectively). The results indicate that the farm with changing their feeding system from extensive to semi-intensive system can compress feeding period by 37% and this causes 47% reduction of methane emission. Moreover, the farm that changed their feeding system from extensive to intensive system can compress feeding period by 47% and this causes in 61% reduction of methane emission. Therefore, in practice, the potential of methane emission mitigation is suggested by changing feeding management from extensive to semi-intensive or intensive feeding management production system.

In addition, intensive feeding system in growing stage of native Thai beef crossbred (\textit{Bos indicus} x \textit{Bos taurus}), the relationship between the carbon footprint and the daily body weight gain or feed per gain (Figure 4) suggested that increasing the daily weight gain and decreasing the feed per gain could reduce the carbon footprint. That was presumably due to the reduced GHG emissions relative to the reduced total feed requirement (Kaewpila, 2016). Also, our study revealed a non-linear negative relationship between the daily BW gain and carbon footprint (Figure 4). This curvilinear relationship suggests that the carbon footprint is much high for a slow growth rate of a beef cattle production system.

Fig. 4. The relationship between (A) daily body weight gain and carbon footprint (\(n=18\), coefficient of determination = 0.820, \(P<0.001\), residual SD = 0.226), and (B) feed per gain and carbon footprint (\(n=18\), coefficient of determination = 0.823, \(P<0.001\), residual SD = 0.246) of backgrounding cattle fed fermented total mixed ration diets. CO\textsubscript{2}eq, carbon dioxide equivalent; DM, dry matter.

Source: Kaewpila (2016)
Feed and additives supplementation

Feedstuff selection: This should be viewed as the way for estimation of methane by using the feedstuffs component included in diets. It is basically known that quality and quantity of feedstuffs are influence enteric methane emission (Blaxter and Clapperton, 1965). Enhancing good forage quality, either through feeding forage with lower fiber and higher non-fiber carbohydrates, or even grazing on a younger forage, can decrease methane emission (Ulyatt et al., 2010). Beauchemin et al. (2008) revealed that methane emissions are normally lower with forage legumes feeding, because of the lower fiber content, the faster rumen escape rate, and in many cases, the source of condensed tannins. The use of grain in roughage diet increases starch and decreases fiber intake, reducing the ruminal pH and stimulating the pathway of propionate production (Kurihara et al., 1999). This improvement of forage quality and addition of grain also increases the voluntary intake and decreases the ruminal retention time, providing energetically more efficient post-ruminal digestion and mitigating the proportion methane energy loss (Blaxter and Clapperton, 1965). The effect of feed intake and concentrate proportion in the diet on Ym has been analyzed (Hristov et al., 2013). In the other hand, the addition of oilseeds to diet increases fatty acids and energy intake, prohibiting the methanogenesis in the rumen (Hristov et al., 2013; Patra, 2016). High-oil content by-product feedstuffs are also the source of free lipids and are widely used as feeds supplements at cost-effective (Eckard et al., 2010). Each percentage increase in dietary fat mitigates methane emission by 3.8% (Patra, 2014). In many cases, the addition of oilseeds may decreases the voluntary intake and decreases the fiber digestibility in the rumen (Chuntrakorn et al., 2014). Overall, feedstuff selection can both enhance animal performance and decrease methane intensity.

Feed supplements: Plant secondary compounds, enzymes, yeast, and electron receptors can mitigate enteric methane emissions when supplementing in diets (Anantasook et al., 2013; Eckard et al., 2010; Norrapoke et al., 2014; Patra, 2016; Tomkins et al., 2015). Among plant secondary compounds (saponins and condensed tannins) and oils have been shown as the most promising feed supplements with up to 52% for their mitigation degree (Eckard et al., 2010). Martin et al. (2010) concluded that the effect of the supplemental fat could largely depend on fatty acids profile, with the stronger to weaker is in the order of medium chain fatty acids, linoleic acid, linolenic acid, oleic acid and saturated fats. Further, eicosapentaenoic acid, omega-3 fatty acids, and docosahexaenoic acid are also giving a strong methane mitigating effects when tested in vitro (Martin et al., 2010). In addition to this, linoleic acid sourced by soybean has less unexpected effect on feed intake and fiber digestibility (Hess et al., 2008; Hristov et al., 2013; Fiorentini et al., 2014). Possibly, 5 mechanisms in the rumen that mitigate methane due to fat supplementation: (i) long-chain fatty acids reducing fiber degradation, (ii) total dietary fat exceeds 6% to 7% stimulating a lower feed intake, (iii) medium-chain fatty acids restrain methanogens, (iv) fats inhibit protozoa, and (v) hydrogen is sinked through rumen biohydrogenation process (Johnson and Johnson, 1995; McGinn et al., 2004; Beauchemin et al., 2008). Plant saponins also potentially enteric methane mitigation. It was suggested that the saponins are giving anti-protozoal properties, lowering hydrogen production by protozoa and, thus reducing the abundance of protozoa-associated methanogens (Beauchemin et al., 2008). In condensed tannins option, methane abetment at 13% to 16% have been concluded, with mainly through a direct poisonous cause on methanogens (Eckard et al., 2010). Here, further study is still needed concerning the feedstuffs sources, oil types, long-term feeding, and dose rates require to mitigate methane and enhance ruminant productivity (Eckard et al., 2010).

Chitosan: an effort has been made to screen natural materials that playing alternative antibiotic role, mitigating methane energy loss through decreasing acetate to propionate ratio in a similar way to that of an ionophores. In this regard, the chitosan, has been well established, comparing to monensin (Goiri et al., 2009a). Chitosan is a linear polysaccharide composed of randomly distributed β-(1-4)-linked D-glucosamine (deacetylated unit) and N-acetyl-D-glucosamine (acylated unit) (Kong et al., 2010). It is extracted by treating shrimp and other crustacean shells with the alkali, sodium hydroxide (Toan et al., 2006). In human medicine, it may be useful as an antibacterial agent (Kong et al., 2010). In ruminant, there has been evidenced that chitosan reduce methane emission (Goiri et al., 2009a; Goiri et al., 2009b), and improve acetate to propionate ratio, though the effects can be specified to diets, chitosan
characteristics, and chitosan dose rates (Goiri et al., 2009c; Kaewpila, 2016). Presently, another mode of action of chitosan has been suggested, which it can directly inhibit methanogen growth (Goiri et al., 2009a; Henry et al., 2015) through agglutination between its molecule (positive charge) and cell membrane surfaces (negative charge) (Chung et al., 2004).

CONCLUSIONS

Enteric methane emission from cattle is an important source of greenhouse gas, which contributes to climate change impact and is strongly associated to animal productivity. Here, we have outlined and discussed the methods recently established and its use for enteric methane emissions measurement of zebu cattle. Based on a meta-analysis recently, we suggested the specific \( Y_m \) models for Zebu beef cattle fed low quality crop residues and by-products in tropical developing countries. There are many feeding technology and practical option exit for direct enteric methane mitigation in concurrent with improve beef cattle productivity. More research in long term work is needed to develop practical and economical beef farming practice to improve animal productivity and environmental sustainability.

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