Trends in Biotechnology

Review

Measuring Methane Production from Ruminants

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Radiative forcing of methane (CH_4) is significantly higher than carbon dioxide (CO_2) and its enteric production by ruminant livestock is one of the major sources of greenhouse gas emissions. CH_4 is also an important marker of farming productivity, because it is associated with the conversion of feed to product in livestock. Consequently, measurement of enteric CH_4 is emerging as an important research topic. In this review, we briefly describe the conversion of carbohydrate to CH_4 by the bacterial community within gut, and highlight some of the key host–microbiome interactions. We then provide a picture of current progress in techniques for measuring enteric CH_4, the context in which these technologies are used, and the challenges faced. We also discuss solutions to existing problems and new approaches currently in development.

Trends

Enteric CH_4 emissions from ruminants are a significant source of greenhouse gas.

Enteric CH_4 is also associated with farming productivity.

Various enteric CH_4 measurement methods have been developed, ranging from tracers and capsules, for individual ruminants, to whole farm systems.

Further development of enteric CH_4 measurement technologies is required to enable reliable, feasible, and low-cost assessments.

Significance of Enteric Methane Production by Ruminants

CH_4 is the most abundant organic trace gas in the atmosphere, which has a significant impact on the global heat budget and national greenhouse inventories [1,2]. Biogenic methanogenesis is a major contributor to global atmospheric CH_4 stocks (estimated at 1–3% of net primary production) [3]. Global anthropogenic CH_4 sources are estimated to account for 50–55% of the total emissions since the year 2000 (approximately 331 Tg/year of a total of 678 Tg/year with livestock production contributing between 87 and 94 Tg/year) [4,5].

It is estimated that the half-life of CH_4 in the atmosphere is 12.4 years, making this an important factor when considering radiative forcing and global warming potential (GWP_{100}) [5–7]. CH_4 reacts with the hydroxyl radical in the troposphere. Oxidation of CH_4 by hydroxyl (OH-) leads to the formation of formaldehyde (CH_2O: 90% of sink), carbon monoxide (CO), and, with sufficient nitrogen oxides (NOx), ozone (O_3) [8]. These processes also affect water vapor and O_3 concentrations in the stratosphere, augmenting the radiative forcing of CH_4 and, hence, its GWP_{100}. Oxidation of CH_4 in the stratosphere results in the formation of water vapor and, hence, increased radiative forcing. It has been estimated that 25% of the increase in stratospheric water vapor observed between 1980 and 2010 resulted from an increased CH_4 concentration [9]. The current estimate of the GWP_{100} of CH_4 with carbon-climate feedback is 34 (without feedback calculations, 28), whereas the global temperature potential of the gas (GTP_{100}) is 11 [10].

Methanogenesis is an important part of the energy metabolism in ruminants and measuring its production is critical in understanding ruminant livestock productivity. CH_4 emissions data can be combined with information relating to the rumen microbiome, metabolic processes, and digestion to provide invaluable insights into the efficiency of livestock systems. However, to date, improvements in livestock efficiency have mostly been made through advances in gut microbiology, nutrition, genetics, and health of the host animal and not through the inclusion of CH_4 emission information. Through a better understanding of enteric methanogenesis and the fate of microbial products yielded during the fermentation processes, further productivity gains may be possible

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[11–16]. For instance, increase in productivity can be achieved by reducing CH_4 through an increase capture of metabolic hydrogen (H_2) into volatile fatty acids (VFA) or through a change in biochemical processes that result in alternate biochemical pathways becoming thermodynamically more favorable [17].

Primary enteric fermentation yields VFAs (acetate, propionate, and butyrate), fermentation acids (lactate), alcohols (e.g., ethanol), succinate, and other branched chain VFAs. In addition, CH_4, CO_2, H_2, and ammonia (NH_3) gases are produced. CH_4 production is the major route for H_2 clearance from fermentation [18]. Most CH_4 is directly eructed from the rumen head space. However, approximately 10–15% is emitted through the respiration pathway and via flatus as a result of hindgut fermentation of digesta [19]. If the CH_4 emitted from the animal is estimated as digestible energy, between 2% and 12% of such metabolizable energy is voided [20].

Reductions in greenhouse gas emissions through CH_4 mitigation strategies and more efficient production systems via CH_4 assessment techniques have influenced anthropogenic climate change and farming. For instance, it has been demonstrated that reductions in enteric CH_4 production can be achieved through the genetic selection of more feed-efficient beef cattle with low residual feed intake (RFI, which is the difference between the actual feed intake of an animal and its expected feed requirements) [21]. This approach is attractive because it reduces the costs of production through lowered feed intake, reducing CH_4 emissions (and potentially lower nitrous oxide emissions) without compromising the growth rate. In this regard, the expected reduction in CH_4 emissions from the Australian beef herd, based on animals of lower RFI, has been modeled in a single herd configuration in southern Australia [22]. In the process, a gene flow model was used to simulate the spread of improved RFI genes through a breeding herd over 25 years (2002–2026). The data suggest that, for an individual adopting herd, the annual CH_4 abatement in year 25 of selection would be 15.9% lower than in year 1. A similar example has recently been adopted by the Government of the province of Alberta, Canada [23] for an emissions reduction protocol based on the selection of low RFI beef cattle.

Altogether, if we fail to accurately measure enteric CH_4, the strategies to reduce greenhouse gas emissions and increase farming productivity are likely to remain vague, random, and consequently inefficient [24–27]. In this review, we provide an overview of current methods to measure livestock CH_4 production. We include a critique of current approaches and provide an opinion on where the new advances in measurement technologies may emerge.

Fundamentals of Ruminant Methanogenesis

Ruminants have evolved a symbiotic association with their gut microbiome that can synthesize a range of cellulose- and hemicellose-digesting enzymes [28]. This association allows the animal to obtain nutrients through herbivory. In ruminants, digestion of feed is a two-stage process [26,29,30]: (i) enzymatic degradation of feed sources in the rumen with the release of a range of monomers (sugars, amino acids, glycerol, and fatty acids); and (ii) the fermentation of those compounds by rumen microbiota (bacteria, methanogenic Archaea, Protozoa, and fungi).

The pregastric fermentation of cellulose-rich feeds in the reticulo-rumen-omasal complex (forestomach) environment is intrinsically tightly regulated (redox potential of –300 to –350 mV; 38–42°C and pH 6–7). These conditions maintain ruminal microbial system functionality but clearance of VFAs, H_2, and CO_2 must occur. VFAs are transported across the rumen and omasal walls and utilized by the animal, whereas CO_2 is released to the head space of the rumen and lost through eructation or transported via circulation to the lungs and respired. Clearance of metabolic H_2 is either through VFA production or, predominantly, conversion to CH_4. This latter process is facilitated by methanogenic Archaea. Three major (*Methanobrevibacter*, *Methanomicrobium*, and *Methanosphaera*) and three minor (*Methanosarcina*, *Methanobacterium*, and rumen cluster C) genera of