Review

METHODS OF METHANE MEASUREMENT IN RUMINANTS

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ABSTRACT

This review is devoted to methodology, which can help direct and indirect measurement of methane emissions. This paper will be useful for expanding the knowledge base of researchers, farm planners, and policymakers as they work to develop and maintain sustainable environment conditions for farming systems in Slovakia. The following methods like respiration chamber, SF₆ technique, alternative methods, micrometeorological methods, proxy methods, in vitro gas production technique, and models for predicting methane production are described. Above mentioned methods are compared and their advantages and disadvantages are enlisted.

Key words: methane; emission; method

INTRODUCTION

Animals contribute to global warming by releasing of greenhouse gas emissions. The major greenhouse gas produced from enteric fermentation of ruminants during the normal digestive process is methane (CH₄). Fermentation CH₄ is the sum of enteric CH₄ and manure CH₄ (Veysset et al., 2010; Mihina et al., 2012). Enteric fermentation from livestock is a large source of methane, which has a global warming potential 23 times that of carbon dioxide (Bhatia et al., 2007; Loh et al., 2008). Methane from agriculture arises primarily from enteric fermentation; therefore, ruminants (especially beef and dairy cattle) are mainly responsible for enteric emissions of CH₄ (Kebreab et al., 2006). Enteric CH₄ from ruminant livestock accounts for 17-37 % of anthropogenic CH₄ (Beauchemin et al., 2010; Sejian et al., 2011).

Methodologies for measuring CH₄ emissions range from animal respiration chambers to estimation of model techniques. While chambers provide a simple measurement technique that is ideal for testing treatment differences there are disadvantages, too as only a small area or number of animals may be studied (McGinn et al., 2008; van Haarlem van et al., 2008; Flesch et al. 2007). The latest technology developed to estimate CH₄ more accurately is the micrometeorological mass difference technique (Harper et al., 1999; Sejian et al., 2011).

Emission of CH₄ in ruminants differs depending on factors like animal species, breed, pH of rumen fluid, ratio of acetate: propionate, methanogen population, composition of diet and amount of concentrate fed. Among the ruminant animals, cattle contribute the most towards the greenhouse effect through methane emission followed by sheep, and goats, respectively (Charmley et al., 2008; Bhatia et al., 2008). The purpose of the current study was to describe new methods for direct and indirect measurement of methane emissions.
Respiration chamber

The principle of the chamber is to collect exhaled \( \text{CH}_4 \) emissions from all sources of enteric fermentation (mouth, nostrils, and rectum) from the animal and to measure the concentration. Chambers are divided into two types, the closed-circuit and the open-circuit. The closed-circuit system is almost not used and preferred are open-circuit chambers. An air pump removes all air from the space through a flow meter and gas sensors in the open-circuit system. Each chamber is fitted with internal ventilation fans for efficient mixing of expired gases and incoming air. Air inlet is located at the front and an air outlet at the back. Fresh air to chamber is directly drawn from outside or through an air conditioning system to control humidity and temperature. The chamber is equipped with sensors for measuring relative humidity, temperature and barometric pressure. These allow air flow data to be adjusted for dry, standard temperature and pressure conditions. Outlet gas from each chamber is continuously sampled for analysis. Air flow is ducted via flexible polyurethane hoses. Air circulation is provided throughout the chambers at continuous but adjustable flow rates (usually 100-250 L.min\(^{-1}\)) (Chagunda et al., 2011; Storm et al., 2012).

Methane emission is calculated from flow and gas concentration in inlet and outlet air from the chamber. The difference between the outgoing and incoming amount of methane expresses the methane emission (Muñoz et al., 2012). Outlet gas from each chamber is continuously sampled for analysis. A multigas analyser with capability for measurement of methane and other gasses as carbon dioxide, and oxygen is used for the gas analyses (Pinares-Patino et al., 2008a; Chagunda et al., 2011).

\( \text{SF}_6 \) tracer

The principle is that methane emission can be measured if the emission rate of a tracer (non-toxic, physiologically inert, stable) gas from the rumen is known (Hegarty, 2013). \( \text{SF}_6 \) was selected from many comparisons, because it has an extremely low detection limit (Muñoz et al., 2012). The gas should mix with rumen air in the same way as methane. The \( \text{SF}_6 \) technique involves the use of a \( \text{SF}_6 \) permeation tube dosed into the reticulo-rumen (Lassey et al., 2001). The calculation of daily \( \text{CH}_4 \) emission is based on the \( \text{CH}_4: \text{SF}_6 \) ratio of concentrations (adjusted for background concentrations) and the specific pre-calibrated permeation rate of \( \text{SF}_6 \) from the particular permeation tube deployed in the animal.

\( \text{SF}_6 \) is filled into small permeation tubes. The rate of diffusion of \( \text{SF}_6 \) out of the permeation tubes is measured by placing them in a 39°C water bath and measuring the daily weight loss until it is stable. The permeation tube containing ultra-pure \( \text{SF}_6 \) is placed in the rumen of an animal before the experimental period (Martin et al., 2008). The sampling apparatus consists of a collection canister, a halter and capillary tubing. A representative of breath gas sample, containing respired and eructated gas is collected through a capillary tube placed at the nose of the animal, fitted to a halter, or behind the head and connected with the evacuated canister (approximately 2.5 L); the tubing regulates the sampling rate for 24 hours (Lassey et al., 2001). This strategy requires two suites of canisters (the one removed became free once the collected samples were transferred to the analysis laboratory) (Bárbaro et al., 2008). The concentration of \( \text{SF}_6 \) and \( \text{CH}_4 \) in the canister is determined then by gas chromatography. The methane emission is calculated from the release rate of \( \text{SF}_6 \) and concentration of \( \text{SF}_6 \) and \( \text{CH}_4 \) in the containers in excess of background level (Storm et al., 2012).

Pinares-Patino, Clark (2008) and Laubach et al. (2008) recommended the use of \( \text{SF}_6 \) method in grazing cattle involving large herds. The tracer technique is now widely used in New Zealand and many other countries for \( \text{CH}_4 \) emission measurements on grazing and pen-fed cattle, sheep, deer and alpacas (Pinares-Patino et al., 2008b). \( \text{CH}_4 \) emission estimates \( \text{SF}_6 \) method revealed slightly lower (by 5-10 %) than the respiration chamber measured values. However, other studies with cattle using hoods or respiration chambers (Grainger et al., 2007) reported \( \text{SF}_6 \) tracer estimates slightly higher (by 1-2 %) than calorimetric estimates.

Alternative methods

More applications of alternative methods are combined with milking and feeding. The animals entering in automatic milking or feeding system are recognized and concentrations of \( \text{CH}_4 \) and \( \text{CO}_2 \) are measured. Air is continuously pumped through the equipment to quantify flow and thereby \( \text{CH}_4 \) and \( \text{CO}_2 \) emitted during milking and feeding.

Garnsworthy et al. (2012a) developed a novel technique based on sampling air released by eructation during milking. Methane analyzers are installed in automatic milking stations. Belching frequency and methane released per eructation are used to estimate methane emission rate. Air is sampled continuously from the feed mangers in the milking stations at 1 L.min\(^{-1}\) via an 8-mm diameter polyethylene tube, approximately 3 m in length, connected to the gas inlet port of the infrared methane analyzer with a range of 0 to 10.000 mg.kg\(^{-1}\).

The same authors (Garnsworthy et al., 2012b) recorded methane emissions of cows during milking using methane analyzers installed in automatic milking stations, modified as respiration chamber. Methane concentrations in air released by eructation are measured continuously at each milking and eructation data are used to calculate individual daily means for methane.
emission rate during milking. Air blows through the instrument by the pump between the gas inlet port and analyzer. Air is sampled continuously during the stay in the milking stations via a polyethylene tube, connected to the gas inlet port of analyzer. The port for the exhaust air from the analyzer is vented into the space at least 3 m from any sampling point.

Hegarty (2013) describes the device patented in USA called Emission monitoring unit, which measures emissions from individual cattle repeatedly over short timed periods whenever they visit the unit to consume a delivered mixture. Air is continuously drawn into the space where cattle received feed, and CH\textsubscript{4} and CO\textsubscript{2} flux are calculated continuously by multiplying the CH\textsubscript{4} or CO\textsubscript{2} concentration by the flow rate of air.

Other methods under development include the micrometeorological technique, combined feeder and CH\textsubscript{4} analyzer. An additional method for estimating methane emissions from livestock is based on the use of CO\textsubscript{2} as a tracer gas. Instead of using externally some gas, the naturally emitted CO\textsubscript{2} is used to quantify CH\textsubscript{4} emission (Madsen et al., 2010). The exhaled air contains both the gases CO\textsubscript{2} and CH\textsubscript{4} (Laubach et al., 2004).

The calculations are the similar as for the SF\textsubscript{6} tracer technique (just replacing SF\textsubscript{6} with CO\textsubscript{2}). Corrections can be made for growing and lactating animals. The CO\textsubscript{2} method can be used to quantify methane production under different circumstances, for example from a dairy cow’s barn and individual estimates for cows visiting an automated milking system (Storm et al., 2012). Lassen et al. (2012) recorded individual methane (CH\textsubscript{4}) and CO\textsubscript{2} production repeatedly on high number of dairy cows during milking also in an automatic milking system. They used a portable air sampler and analyzer unit based on transform infrared detection. The ratio between CH\textsubscript{4} and CO\textsubscript{2} was used as a derived measure with the idea of using CO\textsubscript{2} in breath as a tracer gas to quantify the production of methane. The repeatability was sufficient. The results of their study suggested that the CH\textsubscript{4} to CO\textsubscript{2} ratio measured using the non-invasive method is suitable and may be useful in both management and genetic evaluations. The instruments combined with automatic milking system may be useful to generate large data for genetic evaluation of CH\textsubscript{4} production in dairy cattle.

Micrometeorological methods

Micrometeorological methods are defined as measuring fluxes of gas in the free atmosphere and relating these fluxes to animal emissions. The methods are based on measurements of wind velocity and methane concentration, but the number of measuring points and the theories used to calculate emission rates differ between methods. The external tracer ratio technique can be used, where a tracer gas is released in the paddock or barn, and the concentrations of tracer and methane are measured in the surroundings (Harper et al., 2011). This category of methods also includes the technique of mass balance in enclosed barns, where ventilation rate and concentrations in inlet and outlet are used to estimate the emission. While it is relatively easy to estimate emission rates from mechanically ventilated closed barns, naturally-ventilated buildings are problematic because of difficulties with measuring air exchange rates (Dermo et al., 2009). These types of buildings are commonly used for cattle since they are not especially susceptible to draughts and temperature changes and no extra heating is required. Air exchange rates in these buildings depend on the temperature gradient, temperature humidity index, and the air velocity. In this case, the release rates of harmful gases may also depend on external and uncontrollable parameters such as wind speed and the other parameters of outside environment. This method is particularly important in the current period; the present trend in milk production in Europe is to change to systems with loose housing in naturally-ventilated buildings (Ngwabie et al., 2009).

Bjorneberg et al. (2009) used an open-path spectrometer operating in the monostatic mode for measuring methane. In this instrument, radiation from an incandescent silicon carbide source is collimated and passed into an interferometer. The exit ray from the interferometer leads onto an external beam splitter, so half the radiation is conducted into a 250 mm telescope that expands the beam due to magnification of its collimation. The diameter of the expanded beam at a distance of 50 m from the telescope is less than 400 mm. A cubic-corner retro reflector is mounted at an appropriate distance from the telescope (usually between 150 and 250 m) and is aligned so that the reflected beam is returned to the telescope. The telescope reduces the beam back to a diameter of about 40 mm. The beam is driven from the telescope to the external beam splitter, which passes the beam to a cooled mercury cadmium telluride detector. Interferograms are measured at 70 s intervals. Quantitative determinations of CH\textsubscript{4} concentrations (also NH\textsubscript{3} and N\textsubscript{2}O) are performed by partial least squares regression of the open-path spectra (Bjorneberg et al., 2009).

A significant improvement in methane measurement accuracy is contributed by micrometeorological techniques which allow accurate emission estimates from agricultural sources via a dispersion technique (also called inverse dispersion technique) (Flesch et al., 2005). This method has the advantages, which include non-interference, and the ability to incorporate the measurement footprint over larger areas. Inverse-dispersion methods have been used with success in several studies of feedlot gas emissions (Flesch et al., 2007; Loh et al., 2008; McGinn et al., 2011). However, there are several limitations to using...
inverse dispersion methods including wind conditions and the need for source homogeneity (van Haarlem van et al., 2008).

Lagrangian Stochastic (bLS) method, belonging to category of dispersion techniques (but also in the category of micrometeorological techniques), is usually used in conjunction with global positioning system information from individual animals, to evaluate CH$_4$ emissions from pens of cattle (Laubach et al., 2005). CH$_4$ concentration is measured using an open-path laser. Each laser path is located at a height of 1.5 m about 1 to 1.5 m outside the perimeter of the pens (McGinn et al., 2009). The gas dispersion model contains vertical concentration profiles (Laubach et al., 2008).

Methane emissions from grazing cattle are determined in a field experiment using paddock-scale (also belonging to micrometeorological) methods. The paddock-scale methods exploit how the gas, once emitted from the cattle, is transported and dispersed by the wind. Therefore, the emission rate may be calculated from measurements of wind speed, wind direction and turbulence, as well as CH$_4$ concentration upwind and downwind. The paddock-scale methods include a mass-budget approach, flux-gradient method and gas dispersion model. Accuracy is dependent on certain conditions, particularly whether the place is usually windy and free of obstructions that alter the turbulent airflow (Laubach et al., 2008).

Loh et al. (2008) applied open path spectroscopic concentration measurements and a bLS dispersion model for evaluation of methane and total greenhouse gasses in situ from feedlot beef production for the first time. Their results are consistent with other studies using a similar approach to measure emissions on a farm scale.

Proxy methods

Proxy methods were developed with the purpose of examining many animals at a same time without complex and expensive equipment. Close relationship of methane emissions with parameters that can be measured in easily obtainable from samples of milk or feces is used (Dehareng et al., 2012). Usually, the fatty acid profiles of milk are examined for correlations with methane production of the cows. The principle is that some fatty acids or fats in the milk or feces are correlated with either the feed composition or the amount of methanogens in the rumen (Vlaeminck et al., 2006; Chilliard et al., 2009).

The two challenges in using short-term breath measures as a proxy for methane emissions are collecting data for an adequate period to provide a repeatable estimate of emission rate and scaling up from a short-term emission rate to methane production for whole day. These efforts resulting from the fact that the measurement is not entirely reliable and that a short term enteric methane emission measurement is not identical to a measure of daily methane production made in a respiration chamber.

Use of spectrometry to predict the CH$_4$ emission of dairy cows has got high potential, too. (Dehareng et al., 2012) investigated the feasibility to prognosticate CH$_4$ emissions using milk mid infrared spectra. The experiments aimed to induce a large variation in CH$_4$ emission by feeding different diets (fresh grass and sugar beet pulp; maize silage and hay; grass and corn silage with cracked corn, soybean meal and dried pulp). Milk sample of 50 ml was collected from each cow and analyzed by spectrometry. Results suggest the feasibility of direct CH$_4$ prediction from milk mid infrared spectra. This alternative method could be useful to predict the CH$_4$ emissions at farm level or at the regional scale and it also could be used to identify cows with low CH$_4$ emission.

In Vitro gas method

The gas measuring technique has been widely used for evaluation of nutritive value of feeds. More recently, the increased interest in the efficient utilization of roughage diets has led to an increase in the use of this technique due to the advantage in studying fermentation kinetics. Gas measurement provides a useful data on digestion kinetics of both soluble and insoluble fractions of feedstuffs (France et al., 2000). This method has been modified for methane creation (Navarro-Villa et al., 2011; Storm et al., 2012).

The principle is to ferment feed under controlled laboratory conditions by natural rumen microbes. Feedstuffs are incubated at 39°C with a mixture of rumen fluid, buffer and minerals for a certain time period. The amount of total gas produced during incubation is measured and its composition analyzed, to obtain data on the in vitro production of methane. The method requires access to fresh rumen fluid, which is typically obtained from fistulated cows or other ruminants. The calculations are the same as for the CO$_2$ tracer technique.

Pellikaan et al. (2011) showed the gas production equipment which offers the possibility to determine total gas production, as a measure of organic mater fermentation, and methane synthesis simultaneously. With this system the maximum level of total gas production and methane synthesis can be determined, as well as the kinetics of synthesis. A fast screening of feedstuffs and additives for methane synthesis and total gas production is possible.

Models for predicting methane production

In many cases of scientific trials using the total national emissions calculation is not possible. Therefore there is an interest in being able to predict methane production using models based on existing data, such
as animal characteristics (weight, age, breed), feed characteristics (nutrient and energy content), intake data (dry matter or nutrients) or digested nutrients. Such models often use data derived from experiments conducted with cattle in respiration chambers, but not techniques for measuring methane which were applied in recent years. Tremendous progress has been made in the field of designing simulation models for predicting CH$_4$ emissions, and the latest integrated farm system models offer greater scope to accurately predict greenhouse gas emissions with the incorporation of climatic and management information (Ellis et al., 2009; Sejian et al., 2011). Dry matter intake (DMI), metabolizable energy intake, neutral detergent fibre, acid detergent fibre, ether extract, lignin, and forage proportions were considered in the development of models to predict CH$_4$ emissions (Ellis et al., 2007).

Majority of methane models were developed from measurements obtained in respiration chambers. Some models require the proportion of roughage in the ration, while the other models require digested amounts of different nutrients. Total CH$_4$ production (L/d) in the cattle data set has been closely related to dry matter intake. Ramin and Huhtanen (2013) concluded that feed intake is the main determinant of total CH$_4$ production and that gross energy intake is negatively related to feeding level and dietary fat concentration and positively related to diet digestibility, whereas dietary carbohydrate composition has only minor effects. CH$_4$ production was positively related to diet digestibility and negatively related to dietary fat concentration, whereas dietary carbohydrate composition had only minor effects. When authors expressed as a proportion of gross energy intake, CH$_4$ production was negatively related to feeding level and dietary fat concentration and positively related to diet digestibility and dietary concentrations of non-fibre carbohydrate and neutral detergent fibre.

A comparison of the above mentioned models leads to large differences in the estimates of methane emission. The model estimates are also associated with errors. The best equations developed by Ellis et al. (2007) for beef cattle, dairy cattle, and cattle in general had prediction errors of 14.4, 20.6 and 28.2 %, respectively. When models were evaluated with independent datasets, the prediction errors were increased.

The results of Ramin and Huhtanen (2013) indicate that CH$_4$ production can be predicted accurately from a set of variables that are available at the time of prediction. Equations predicting CH$_4$ production per unit of feed intake (gross energy or dry matter) are biologically more valid, and therefore it is recommended that CH$_4$ production is predicted as intake of gross energy (GE) or dry matter (DM) $\times$ production per unit (MJ of GE or kg of DM) of intake.

Methods of choice for estimating enteric methane emission depend on aim, equipment, knowledge, time and money available, but interpretation of results obtained with a given method can be improved if knowledge about the disadvantages and advantages are used in the planning of experiments (Ramin and Huhtanen, 2013). The prediction models should use to predict emissions for each strategy (Legesse et al., 2011; Aljaloud et al., 2011; Kebreab et al., 2006, 2008).

An inverse dispersion model was utilized to calculate CH$_4$ emissions from a commercial cattle feedlot and an adjacent runoff retention pond. The feedlot measurements were collected within the interior of the feedlot enabling a near continuous emissions record over the 12 d of the study period (van Haarlem et al., 2008).

There have been several attempts to formulate mathematical models to predict CH$_4$ emissions from cattle. The models can be classified into 2 principal groups: empirical (statistical) models that relate nutrient intake to CH$_4$ output directly and dynamic mechanistic models that attempt to simulate CH$_4$ emissions based on a mathematical description of ruminal fermentation biochemistry (Kebreab et al., 2008; Alemu et al., 2011). A synthesis of the available literature suggests that the mechanistic models are superior to empirical models in accurately predicting the CH$_4$ emission from dairy farms. The latest development in prediction model is the integrated farm system model which is a process-based whole-farm simulation technique (Sejian et al., 2011).

The model proposed by Moe and Tyrrell (cit. Kebreab et al., 2006) is an empirical one developed using data from cattle, and the model relates intake of carbohydrate fractions to CH$_4$ production as follows: Methane (MJ/d) = 3.41 + 0.51 NFC + 1.74 HC + 2.65 C, where NFC = non-fibre carbohydrate (kg/d); HC = hemicellulose (kg/d); and C = cellulose (kg/d). In cases in which NFC values were not available, it was calculated as NFC = 100 − (CP + ether extract + ash + NDF), where CP = crude protein and NDF = neutral detergent fibre.

MOLLY model is a dynamic mechanistic model of nutrient utilization in cattle. Ruminal CH$_4$ production was predicted based on hydrogen balance. Excess hydrogen produced during fermentation of carbohydrates and protein to lipogenic volatile fatty acids (acetate and butyrate) is partitioned between use for microbial growth, bihydrogenation of unsaturated fatty acids, and production of glucogenic volatile fatty acids (propionate and valerate). The assumption is made that the remaining hydrogen is used solely and completely for methanogenesis (Kebreab et al., 2004).

The rumen model of Dijkstra et al. (cit. Kebreab et al., 2006) is the basis for the mechanistic model used in the present evaluation. The model is based on a series of dynamic, deterministic, and nonlinear differential equations. Kebreab et al. (2004) incorporated the rumen
model to a whole animal model that included nitrogen and phosphorus utilization. Bannink et al. (2011) developed a new stoichiometry for fermentation within the rumen based entirely on experimental observations with lactating dairy cows; therefore, model COWPOLL was modified to accommodate these stoichiometric coefficients. One of the fundamental differences in estimating CH₄ emissions between MOLLY and COWPOLL is the representation of microbes in the rumen and the coefficients of fermentation for transformation of substrate to volatile fatty acids. The MOLLY model uses 1 group of microbes, whereas COWPOLL separates the microbial community into 3 groups: amylolytic, cellulolytic bacteria, and protozoa (Kebrab et al., 2008).

Charmley et al. (2008) described a modelling approach that estimates cattle methane emissions for various bioregions. The approach incorporates a metabolizable energy based model of animal production linked to a property herd economic model. This provides a flexible tool to evaluate animal and property herd dynamics on regional methane yields and live weight productivity, as well as to assess financial impacts. The model predicts that an important determinant of methane output per unit of product is reduced days to market. Reduced days to market may be achieved through a range of energy supplementation and marketing strategies. The modelling framework can be applied to a wide range of production, management and marketing scenarios to generate information on possible changes in methane emissions and financial gross margins. While these changes can be quantified, the output should be considered in light of the data deficiencies (Charmley et al., 2008).

Many governments have implemented policies to reduce greenhouse gas emissions from agriculture and significant efforts are now being directed towards developing animal husbandry methods that lower enteric CH₄ emissions (Beauchemin et al., 2010). To adequately assess greenhouse gas mitigation strategies, it is necessary to use a whole system modelling approach (Beauchemin et al., 2010).

Three primary areas require refinement and relate to a better understanding of the forage base that makes up the major component of the diet. They include estimation of diet quality under selective grazing conditions; estimation of dry matter intake under heterogeneous grazing conditions; and precision of predicting methane yield from cattle grazing forages (Charmley et al., 2008).

Mathematical models allow us to predict CH₄ production from cattle without undertaking extensive and costly experiments. The models used can be classified as either statistical models, which relate nutrient intake to CH₄ production directly, or dynamic mechanistic models, which estimate CH₄ production using mathematical descriptions of rumen fermentation biochemistry (Kebrab et al., 2004, 2006). Although many statistical models have been fairly successful in predicting CH₄ production, many have inputs that are not commonly measured and some may have difficulty predicting CH₄ production outside the range of values on which they were developed. These problems may be addressed by using commonly measured equation input variables and by developing models on expansive data sets compiled from multiple sources (Ellis et al., 2007).

Advantages and inefficiencies of methods

Respiration chambers are regarded as the standard method for estimation of CH₄ methane emission from ruminants, because the environment can be controlled and the reliability and stability of instruments can be measured. However, results obtained in chambers cannot be extrapolated to loose housing animals, nor on pasture. This method is extremely slow and expensive (Hegarty, 2012), requires trained animals, restricted animal movement, causes stress, and have a high labour input (Pinares-Patiño, Clark, 2008). Respiration chambers are not used for determining methane production on farm.

The SF₆ method can be used to investigate nearly all aspects of feeding and nutrition, effect of chemical and physical composition, restricted or ad libitum feeding, different additives and grazing. However, using the method for investigation of dynamics of methane emission may be problematic. The following cons are maintaining a constant release rate from permeation tubes, effect of release rate upon emission rate of methane, background level determination, inconsistency between CH₄ measurements determined in chambers and with SF₆ method gives more variable results of methane emission than chamber measurements. The method is the only available method for measuring individual free ranging animals on pasture (Muñoz et al., 2012). The number of animals is limited to 30 (Laubach et al., 2008). The CO₂ technique is a newly developed approach for estimation of methane emissions from ruminants. It can be used under different conditions on large numbers of animals or for the overall estimation of herd emissions. However, this method is less precise than the respiration chamber methods.

The micrometeorological methods are still new and further development and documentation on reliability is needed, but the methods are valuable in evaluating whole dairy systems and interactions between animals and landscape. Unfortunately, all these methods are influenced by instabilities like non-steady state wind or movement of point-emission sources (McGinn et al., 2008). It is also difficult to relate the CH₄ production to feed intake for grazing animals.

A disadvantage of In Vitro gas production
technique is that it only simulates the ruminal fermentation of feed, not emissions and digestibility by the entire animal. Furthermore, under normal conditions it does not include long-term adaptation of the ruminal microorganisms to the tested feedstuffs. During live animal experiments it is usually a practice to have adaptation periods to new feeds of at least 14 days and animals’ output is not considered stable in this method (Pellikaan et al., 2011). Results should therefore always be interpreted with care (Storm et al., 2012). Fortunately, the method can easily be applied to many animals making it possible to reduce the standard error of means from experiments. It is possible to determine in vitro degradation of the feedstuffs and find if the reduction in methane production is at the cost of total feed degradation. Screening large amounts of feeds and additives is the best application of the in vitro method. This method has a large capacity, making it possible to test many different combinations of feedstuffs.

The mathematical models are essential for estimating national or global emissions. They are easy to apply and will give estimates of the average emission of the unit in question. The models are based on experimental data and as such are limited in their application. However, a model based on respiration chamber experiments can therefore not be directly applied to free ranging cattle. Also, our understanding of ruminal digestion is not yet complete. Therefore a continuous need exists for more data to increase our knowledge of this complex system.

CONCLUSION

Many suitable methods for CH₄ measuring are already in use and new ones are being developed. Some, however, are only useful for a particular environment. It is extremely important to compare several methods for accurate assessment. Further research is needed to better understand the CH₄ measurement and evaluation in progressed managements.

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