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Equations to predict methane emissions from cows fed at maintenance energy level in pasture-based systems

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A B S T R A C T

Ruminant production is a vital part of food industry but it raises environmental concerns, partly due to the associated methane outputs. Efficient methane mitigation and estimation of emissions from ruminants requires accurate prediction tools. Equations recommended by international organizations or scientific studies have been developed with animals fed conserved forages and concentrates and may be used with caution for grazing cattle. The aim of the current study was to develop prediction equations with animals fed fresh grass in order to be more suitable to pasture-based systems and for animals at lower feeding levels. A study with 25 nonpregnant nonlactating cows fed solely fresh-cut grass at maintenance energy level was performed over two consecutive grazing seasons. Grass of broad feeding quality, due to contrasting harvest dates, maturity, fertilisation and grass varieties, from eight swards was offered. Cows were offered the experimental diets for at least 2 weeks before housed in calorimetric chambers over 3 consecutive days with feed intake measurements and total urine and faeces collections performed daily. Methane emissions were measured over the last 2 days. Prediction models were developed from 100 3-day averaged records. Internal validation of these equations, and those recommended in literature, was performed. The existing in greenhouse gas inventories models underestimated methane emissions from animals fed fresh-cut grass at maintenance while the new models, using the same predictors, improved prediction accuracy. Error in methane outputs prediction was decreased when grass nutrient, metabolisable energy and digestible organic matter concentrations were added as predictors to equations already containing dry matter or energy intakes, possibly because they explain feed digestibility and the type of energy-supplying nutrients more efficiently. Predictions based on readily available farm-level data, such as liveweight and grass nutrient concentrations were also generated and performed satisfactorily. New models may be recommended for predictions of methane emissions from grazing cattle at maintenance or low feeding levels.

Abbreviations: A, actual value; ADF, acid-detergent fibre; ADFI, acid-detergent fibre intake; CH_4, methane emissions; CH_4-E, methane energy output; DDMI, digestible dry matter intake; DEI, digestible energy intake; DM, dry matter; DMd, dry matter digestibility; DMI, dry matter intake; DOMD, digestible organic matter in dry matter; DOMI, digestible organic matter intake; EE, ether extract; Eq., equation; FAO, Food and Agriculture Organization of the United Nations; FL, feeding level; GE, gross energy; GEd, gross energy digestibility; GEI, gross energy intake; GHG, greenhouse gases; IPCC, Intergovernmental Panel on Climate Change; LW, animal liveweight; Max, maximum value observed; ME, metabolisable energy; MEI, metabolisable energy intake; Min, minimum value observed; MPE, mean prediction error; MSPE, mean-square prediction error; N, nitrogen; *n*, number of samples; NDF, neutral-detergent fibre; NDFI, neutral-detergent fibre intake; OM, organic matter; OMI, organic matter intake; P, predicted value; R^2, pseudo correlation coefficient; SD, standard deviation; UK, United Kingdom; WSC, water-soluble carbohydrates.

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1. Introduction

Ruminants have a special role in food production industry because of their exclusive ability to transform non-edible material (e.g. cellulose in grass) to foods of unique nutritional quality that provide a range of beneficial nutrients to humans, such as proteins of high biological value, fatty acids, vitamins, antioxidants and minerals (Cottle et al., 2011; MacRae et al., 2005). In addition, ruminants fed at pasture do not directly compete with humans for food (Buddle et al., 2011). However, in previous publications from Food and Agriculture Organization of the United Nations (FAO) and Intergovernmental Panel on Climate Change (IPCC) livestock production, and in particular ruminants, have been associated with an undesirable increase of greenhouse gases (GHG), such as carbon dioxide, methane and nitrous oxide (FAO, 2010; IPCC, 2006). At global scale, milk production contributes 2.7% of total anthropogenic GHG emissions while total emissions attributed to dairy herds including transport activities, meat production from old or young fattened stock and draught power are estimated to about 4.0% of total anthropogenic GHG (FAO, 2010). Methane and nitrous oxide are the main GHG emitted from the dairy sector, representing over 50% and about 30–40% of total emissions respectively (FAO, 2010). In the United Kingdom (UK), emissions from agriculture sector represented 9.6% of total GHG emissions in 2011, thus showing a slightly higher contribution when compared with 1990 (8.4%), although emissions from agriculture were overall decreased by 19.7% during the same period (Salisbury et al., 2013). A recent report showed that 30% of UK agricultural emissions (or 2.7% of total GHG emissions in UK) may be attributed to rumen enteric fermentation (Webb et al., 2014). Methane is a by-product of fermentation of organic matter (OM; starch, cellulose, hemicelluloses, protein and other minor materials) by anaerobic bacteria, protozoa and fungi in the rumen, and secondarily in hindgut, while methanogenesis results on a 2–12% loss of gross energy intake (GEI) (Johnson and Johnson, 1995). The latter highlights methanogenesis' relevance not only to the environmental impact of dairy herds, but also to cow feeding efficiency and farm profitability.

Previous reviews (Cottle et al., 2011; Moss et al., 2000; Pacheco et al., 2014; Ulyatt and Lassey, 2001) reported that ruminant enteric methane production depends on dry matter intake (DMI), forage type, diet composition, individual feed components, animal physiological differences, genetic parameters and grazing and herd management. The accurate assessment of methane emissions from cattle is challenging because these are highly dependent not only on DMI and GEI but also on the type of energy-supplying nutrients. For example, grain supplementation or offering highly digestible grass may result on lower methane emissions per unit of GEI than a more fibrous forage-based diet (Cottle et al., 2011). This implies accuracy of predicting methane emissions may be improved if different equations were developed for each production level (e.g. maintenance, growth, lactation) and type of diet (e.g. total mixed ration, pasture-based diets with high concentrate allowance, low-input grazing diets). The latter practice may also serve for the development of Tier 3 predictions, which is recommended by IPCC to substitute Tier 2 currently using GEI, which is calculated from standard models, and a standard methane conversion factor (methane energy output:GEI) (IPCC, 2006). For these modifications, any future proposed equations should be internationally peer-reviewed and shown to improve prediction accuracy (IPCC, 2006).

A number of studies have presented prediction equations for methane emissions from beef and dairy cattle using DMI, GEI, grass nutrient concentrations and digestibility, dietary components, physiological state, rumen volatile fatty acid concentrations, animal liveweight (LW) and milk composition as predictors (Blaxter and Clapperton, 1965; Ellis et al., 2009; Moraes et al., 2014; Ramin and Huhtanen, 2013; Yan et al., 2000, 2009). However, these models, as well as the equations recommended by IPCC (2006) and FAO (2010), have been developed using data collected with animals fed mainly conserved forage and concentrates and, given the influence of the nature of feed ingredients on methane emissions, may be used with caution for grazing cattle. Pasture-based ruminant production is the most common management system in some cool and moist areas of the world capable of long grazing seasons, such as New Zealand, Ireland and parts of UK, United States of America and Australia, and the contribution of grazing animals to methane emissions from the agricultural section in these countries is distinctively important (Ferris, 2007; Pacheco et al., 2014). Therefore, there is a necessity for additional prediction tools which may be more suitable for grazing cattle, and within the different production levels, than the existing models.

The main objectives of this study were therefore to (i) to examine relationships of methane emissions with grass nutrient content and digestibility parameters, energy concentrations and LW, using a broad range of fresh-cut grass quality, (ii) develop prediction equations for methane emissions from nonpregnant nonlactating dairy cows fed solely fresh-cut grass at maintenance energy level, using feed, nutrient and energy intakes, LW and grass nutrient/energy concentrations and digestibility parameters as predictors either in single or multiple linear relationships, and (iii) to validate the existing and new equations using data from animals fed solely fresh-cut grass diets at maintenance feeding level.

2. Materials and methods

The present study was performed under the regulations of Department of Health, Social Services, and Public Safety of Northern Ireland, in line with the Animal (Scientific Procedures) Act 1986 (Home Office, 1986).

2.1. Experimental design

The current study presents results from two metabolism experiments of 300 daily measurements of dry matter (DM) and nutrient intakes and output in faeces and urine, and 200 daily measurements of gas emissions, which were carried out in two consecutive grazing seasons (2007 and 2008) and included 25 nonpregnant nonlactating Holstein cows fed solely fresh-cut grass at maintenance energy level. All experiments were carried out in the calorimetric chambers of Agri-Food and Biosciences Institute, Hillsborough, UK, which are designed for accurate recording of gas exchanges (methane and carbon dioxide emissions and oxygen consumption) as well as total daily feed intake and faeces and urine outputs. Animals were between 5 and 8 years old and their LW and body condition score are presented in Table 1. Maintenance ME requirements were estimated as 0.65 MJ per kg of metabolic body size (Agnew et al., 2004). Grass feeding quality for accurately feeding animals at maintenance energy requirements was assessed daily by (i) measuring grass DM contents by microwaving at full power for 3–5 min and (ii) predicting grass ME contents by near-infrared spectroscopy (Agnew et al., 2000), using a NIRS™ 5000/6500 Feed and Forage Analyser (FOSS, Hillerød, Denmark). Daily grass ME concentrations were estimated as the average value of the samples collected over the previous two consecutive days. For each individual cow, data on DM and nutrient intakes and outputs in faeces and urine were average values of a 3-day (continuous) period and data on gas emissions were average values of the last two days of the same period; thus, a total of 100 records were used to develop prediction equations for methane emissions. A broad range of fresh-cut grass quality was offered to cows, as a result of harvesting eight perennial ryegrass swards of contrasting