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# Development of prediction models for quantification of total methane emission from enteric fermentation of young Holstein cattle at various ages

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ABSTRACT

Methane ($CH_4$) emissions from ruminant animals contribute significantly to the global greenhouse gas budget. The accurate quantification of this source of emissions requires detailed animal and feed information, however there is little information available on systematic measurement of $CH_4$ emissions from young cattle at various ages. The present study was designed to address this gap of knowledge. Data used were derived from a study with 20 Autumn-calved Holstein cattle (10 steers and 10 heifers) with $CH_4$ emissions measured at age of 6, 12, 18 and 22 months, respectively. The cattle were offered a typical diet used on UK commercial farms containing a single grass silage mixed with concentrates. In each period, the cattle were housed as a single group in cubicle accommodation for the first 20 days, individually in metabolism units for the next 3 days, and then in indirect open-circuit respiration calorimeter chambers for the final 5 days with feed intake, feces and urine outputs and gaseous exchange measured during the final 4 days. Within each period, gender had no effect ($P > 0.05$) on nutrient digestibility and any $CH_4$ emission variable in terms of total $CH_4$ emission, $CH_4$ emission as a proportion of live weight or feed intake, or $CH_4$ energy output as a proportion of energy intake. The data from the two groups were therefore pooled to develop prediction equations for daily $CH_4$ emissions ($g\ day^{-1}$). A range of prediction equations have been developed using BW (body weight), feed intake and energy intake. The present data were also used to calculate accumulated $CH_4$ emissions for the two genders. Although gender had no effect ($P > 0.05$) on the results, the accumulated $CH_4$ emissions increased with the growth of cattle (mean 36.2 and 64.3 $kg\ year^{-1}$ for both genders in years 1 and 2, respectively). A number of prediction equations were developed for total $CH_4$ emission factors ($kg\ year^{-1}$) for heifers and steers during the first and second year of the rearing. These factors were very strongly related to ($r^2 = 0.75–0.95$) to BW recorded at the beginning, middle and the end of 1 or 2 year of age. These data can add novel information to the scientific literature and can be used to improve national inventories of $CH_4$ emissions and to develop appropriate mitigation strategies for young Holstein cattle of high genetic merit herds.



## 1. Introduction

Methane ($CH_4$) is a greenhouse gas (GHG) that remains in the atmosphere for approximately 9–15 years. Methane is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide ($CO_2$) over a 100-year period and is emitted from a variety of natural and human-influenced sources (United States Environmental Protection Agency, 2007). Livestock farming is a major contributor to atmospheric $CH_4$ accumulation, with the majority emitted in ruminant husbandry through enteric fermentation which accounts for 89% of total methane emissions, while the rest come from manures (Steinfeld et al., 2006). This is more important in Europe, North America, Australia, and New Zealand, where beef, lamb, and milk are major food sources for humans. Globally, the livestock sector produces 37% of all human-induced $CH_4$ (Steinfeld et al., 2006). At present, there is increasing pressure to reduce GHG from all sectors of the economy. Recent European Union legislation requests that member nations reduce total GHG emissions from 1990 levels by 20% by 2020 (European Union, 2008), and the UK Climate Change Act (UK Office of Public Sector Information, 2008) sets a target of 80% reduction from 1990 levels by 2050. The implementation of

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these targets will have major implications for ruminant livestock systems.

The Intergovernmental Panel on Climate Change (IPCC, 2006) recommends three methodologies to calculate $CH_4$ emission inventories for cattle. The Tier 1 and 2 methods apply for all countries which require limited animal and feed information, while Tier 3 is encouraged to be used for those countries where livestock emissions are particularly important (IPCC, 2006). Application of the Tier 3 method requires the detailed specific animal and feed information for development of sophisticated models, e.g., management regime, animal productivity and feed data. Within the UK, the agricultural sector accounts for approximately 8% of total GHG emission (Thistlethwaite and MacCarthy, 2010). However, in Northern Ireland, this proportion increases to 26%, with the majority derived from $CH_4$ emissions from the livestock sector (41% of total GHG emission from the agriculture industry) (Thistlethwaite and MacCarthy, 2010). Therefore, there is increasing interest in the development of more accurate data to predict total methane emissions from different categories of cattle production systems.

Holstein cattle are a breed of cattle known today as the world's highest and commonest production dairy animals (Oltenacu and Broom, 2010), which have widely and rapidly spread all over the world. In most circumstances, female offspring from Holstein dairy herds routinely starts to milk at age of 24–26 months, while males are due to be slaughtered as beef cattle at a life span of 22–24 months. Such management systems for dairy herds require quantification of total $CH_4$ emissions for a dairy enterprise using two separate calculation models (adult cows vs. young cattle) as they are reared at different feeding and management regimes. In the literature, there has been many models developed for prediction of methane emissions for adult dairy cattle across the world (Ellis et al., 2007; Yan et al., 2010), however there is little information available on prediction of enteric $CH_4$ emissions for young cattle. As adult cattle are in different physiological states and offered different diets, using the prediction models for adult cattle to predict $CH_4$ emissions for young cattle can cause systematic errors. The lack of such information can impact the development of robust $CH_4$ emission inventories and appropriate mitigation strategies for the cattle production systems.

In recognition of this and other knowledge gaps, a large scale project was established in UK in 2011 to obtain information which was not available for development of accurate $CH_4$ emission inventories and mitigation strategies for ruminant production systems. The present study was funded by this project and designed to: (i) evaluate effects of gender (steers vs. heifers) of young Holstein cattle at various ages on enteric $CH_4$ emissions; (ii) use these data to develop prediction models for enteric $CH_4$ emissions from young Holstein cattle; and (iii) quantify yearly accumulated $CH_4$ emissions from young Holstein cattle.

## 2. Materials and methods

The present study was conducted under the regulations of Department of Health, Social Services and Public Safety of Northern Ireland in accordance with the Animals Scientific Procedures Act (1986). The data on BW, feed intake and energy metabolism used to calculate enteric $CH_4$ emission data for the present study, were published by Jiao et al. (2013).

### 2.1. Animals, experimental design, and diet

Twenty Autumn-calved Holstein cattle (10 steers and 10 heifers; birth weight = 44.3 ± 4.4 kg) at age of 5 months were used in a four-periods study (28 days period$^{-1}$) with measurements taken at age of 6 (185 ± 5.3 days), 12 (368 ± 7.4 days), 18 (548 ± 8.9 days) and 22 (674 ± 15.3 days) months, respectively. Five days after birth, calves were offered a milk replacement and a concentrate supplement in a straw bedded house and weaned at age of 50 ± 6.2 days (weaning weight = 67.2 ± 5.2 kg). All steers were castrated at age of 4–5 months (134 ± 14.3 days) and heifers bred by artificial insemination between 14 and 16 months of age (450 ± 23.7 days). Before the commencement of the study, the cattle were blocked into 10 pairs for similar conditions in terms of age, BW, BW gain, and body condition score.

In each measurement period, all cattle were housed as a single group in a cubicle accommodation for the first 20 days, and then transferred to metabolism units where cattle were tied individually in stalls for 3 days, before being housed in indirect open-circuit respiration calorimeter chambers for 5 days. All data on feed intake, nutrient digestibility and energy metabolism including the $CH_4$ emission were measured during the final 4 days in chambers. The cattle were fed a single mixed diet based on concentrates and grass silage for ad libitum intake once daily at 0900 h during the 4 periods. The diet offered was a typical ration of concentrate and grass silage used on UK commercial farms and prepared daily using a Belle Premier 200XT feed mixer (Belle Engineering Ltd., Sheen, Derbyshire, UK). A single grass silage was used for all 4 experimental periods, and the silage used for the last 8 days of each period were boxed in evacuated condition at the beginning of each period. In the first period, the concentrate supplement was offered at a ratio of 550 g kg$^{-1}$ of dry matter (DM), while it was given at a fixed rate of 2 kg DM daily in other 3 periods. The concentrate supplement was formulated from rolled barley, sugar beet pulp, full-fat soybeans, ground corn grain, molasses and a mineral–vitamin mix at 49.5, 15.0, 20.0, 10.0, 2.5, 2.0 and 3.0% on a DM basis, respectively. The grass silage had a pH of 4.18 and contained DM, GE, crude protein, NDF, ADF and ash of 18.8%, 19.5 MJ kg$^{-1}$ of DM, 12.5, 62.5, 38.9 and 8.1% of DM, respectively.

During the winter interval between the 2nd and 3rd period, both heifers and steers were housed as a single group fed concentrates at 2 kg DM daily and a grass silage ad libitum. During the summer intervals between the 1st and 2nd period, and between the 3rd and 4th period, heifers and steers were managed as a single group and grazed on a single pasture. Given that heifers were due to calve between 23 and 25 months age (730 ± 23.7 days), all chamber measurements for heifers and steers in the final period were undertaken at approximately 22 months (674 ± 15.3 days).

### 2.2. Respiration calorimeter chambers

The $CH_4$ emissions and energy metabolism data used in the present study were measured in indirect open-circuit respiration calorimeter chambers. The calorimeter chambers were made of double glassed sides and insulated fenestrated panels mounted on a profiled floor, incorporating airlocks for entry and feeding. Each chamber had a volume of 22 m$^3$ and was ventilated by suction pumps set at 75 m$^3$ h$^{-1}$, with temperature and humidity control achieved by air conditioning units set at 12 ± 1 °C and 60 ± 10% relative humidity, respectively. The chambers were operated under a negative pressure (5 Pa) and exhaust air removed at three positions for volume measurement and gas analysis. At the beginning, mid, and end of each period, the chambers were calibrated by releasing a known quantity of pure $CO_2$ into the chambers using the calibration procedure reported by Yan et al. (2000). The purpose of the calibration was to ensure a recovery rate of released $CO_2$ at a range of 97–103%. All equipment, procedures, analytical methods and calculations used in the calorimetric experiments were as reported by Gordon et al. (1995).