

Using Models to Predict Methane Reduction in Pasture-Fed Dairy Cows

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Abstract: Because New Zealand is a signatory to the Kyoto Protocol Framework Convention on Climate Change (1997), it is required to report national greenhouse gas emissions and maintain them at 1990 levels by 2008-2012. New Zealand has one of the highest per capita levels of the greenhouse gas methane [Woodward et al., 2001] and most of this arises from gut fermentation from ruminants. Not only does this ruminant-produced methane contribute to greenhouse gas emissions, but it is also wasteful in terms of energy loss for the animal. This paper investigates the ability of four methane models within MOLLY [Baldwin, 1995] to model the methane production from a trial conducted at Dexcel, a dairy research company based in Hamilton, New Zealand. In this trial, sixteen Friesian and Jersey dairy cows grazed on either perennial ryegrass (*Lolium perenne*) or sulla - a condensed tannin containing forage legume (*Hedysarum coronarium*). MOLLY was run over 3 days, the period of methane production data collection, and each of the eight ryegrass-fed cows were modelled. (The sulla-fed cows were not modelled due to lack of information on the composition of sulla). MOLLY is one of the cow component models used in the Whole Farm Model (WFM) [Sherlock et al., 1997; Bright et al., 2000] which has been developed at Dexcel. The WFM simulates a pasture-based, rotationally grazed dairy farm and consists of a framework to which are attached four different components – climate, management, pasture and cow. Three of the methane models were empirical – based on regression equations, the remaining model being a mechanistic one. One of the empirical models and the mechanistic model were found to be the best predictors of methane production for the ryegrass-fed cows. The process of modelling methane production at the whole farm level will highlight areas where knowledge of methanogenesis is lacking, and direct research to the most promising feeding strategies to reduce methane emissions.

Keywords: Methane; Cow; Computer model; MOLLY

1. INTRODUCTION

Methane (CH₄) is one of the greenhouse gases whose release into the atmosphere is a major cause of global warming. Almost all of New Zealand's methane is produced by ruminant livestock (enteric methane). Although New Zealand only emits 0.34% of the world's total methane, we have the highest per capita level of 455 kg/year compared with world and OECD averages of 47 and 71 kg/year respectively, [Clark, 1999]. This is mainly because of our high ratio of ruminant livestock to people, Woodward et al. [2002]. On a per hectare basis, dairy cattle produce more than twice that of our other livestock ruminants – sheep and beef cattle, [Clark, 2001]. The New Zealand Government is a signatory to the Kyoto Protocol Framework Convention on Climate Change (1997) and this requires New Zealand to maintain greenhouse

gas emissions at 1990 levels by 2008-2012. If a carbon tax for greenhouse gas emissions is introduced then the New Zealand dairy industry in particular stands to lose a big percentage of its revenue. Hence the need to investigate how we can reduce methane emissions from our livestock ruminants (especially dairy cows).

Farm trials have been done and more are in progress to investigate this matter. For New Zealand trials see, for example, the research described in Ulyatt et al. [1997] and Woodward et al. [2001, 2002]. However, trials are time consuming and expensive, and if computer models can accurately predict methane emissions from ruminant livestock and also investigate the effect of possible diets/treatments on these emissions, then this will save time and money. This paper compares methane emission data from a recent farm trial at Dexcel using lactating dairy cows of different

breeds and ages, with values obtained from four methane models run within MOLLY, an animal submodel of Dexcel's Whole Farm Model (WFM).

2. BACKGROUND

2.1 Whole Farm Model

The WFM has been developed at Dexcel over the last 5 years. It is a complex computer model that can model events that happen on a dairy farm at an individual paddock and cow level on a daily basis. It consists of a framework called the Farm System Simulation Framework (FSSF) to which are attached component models for pasture growth and cow metabolism. Also included in the WFM is climate and management information. Some of the developmental and computing aspects of the WFM have been described previously, see Neil et al. [1997], Sherlock et al. [1997], Sherlock and Bright [1999] and Bright et al. [2000].

There are 3 cow models to choose from when using the WFM, the most complex one being MOLLY, [Baldwin, 1995]. It is a mechanistic dynamic model based on a cow's metabolism that is parameterised for a cow fed high-energy rations. Palliser et al. [2001a, 2001b] described work that had been done with MOLLY and the WFM so that MOLLY more closely resembles a typical New Zealand cow, i.e. one that mainly grazes on pasture.

2.2 Previous work

Blaxter and Clapperton [1965] and Moe and Tyrrell [1979] published two empirical models that have been used extensively to predict methane emissions from ruminants. Blaxter and Clapperton's regression equation for methane production was given in MOLLY by Equation (1):

$$\text{BCH4} = 1.30 + 0.112 * \text{appDE} * 100 + \text{mult} (2.37 - 0.050 * \text{appDE} * 100) \quad (1)$$

BCH4 is methane production in Mcal, appDE is the apparent digestible energy of the feed, and mult is the fraction of ME (metabolisable energy) intake relative to maintenance. Their equation was derived from methane measurements from sheep and cattle fed a variety of diets. Moe and Tyrrell [1979] used cattle fed high-quality diets in order to derive their equation and was represented in MOLLY by Equation (2):

$$\text{MCH4E} = [3.406 + 0.510 * \text{FDDMIN} (\text{fdSt} + \text{fdSc} + \text{fdOa} + \text{fdPe}) + 1.736 * \text{FDDMIN} * \text{fdHc} + 2.648 * \text{FDDMIN} * \text{fdCe}] / 4.184 \quad (2)$$

MCH4E is methane production in Mcal, FDDMIN is feed dry matter intake, and fdSt, fdSc, fdOa, fdPe, fdHc and fdCe are the fractions of starch, soluble carbohydrates, organic acids, pectin, hemicellulose and cellulose respectively in the feed. Their data indicated that the production of methane is influenced by the nature of the carbohydrate digested, and that this effect is relatively less important at low levels of feed intake in comparison with high levels of feed intake.

Wilkerson et al. [1995] investigated the accuracy of seven empirical equations, including those of Blaxter and Clapperton [1965] and Moe and Tyrrell [1979], at predicting methane emissions from lactating and non-lactating Holstein cows. They found that Blaxter and Clapperton's and Moe and Tyrrell's equations plus three others were adequate for predicting methane production by non-lactating Holstein cows. However, the prediction rates for lactating cows were less accurate, with Moe and Tyrrell's equation the best. Because measurement of the variables used in the Moe and Tyrrell equation (i.e. soluble residue, hemicellulose and cellulose) is relatively easy, Wilkerson et al. [1995] thought that this made Moe and Tyrrell's regression equation more 'usable'.

Kirchgebner et al. [1995] developed an empirical model for methane emissions from lactating dairy cows and was given in MOLLY by Equation (3):

$$\text{ACH42} = (10.0 + 4.9 * \text{DMILK} + 1.5 * \text{BWPLUSCW}^{0.75}) * 0.0132 \quad (3)$$

ACH42 is methane production in Mcal, DMILK is daily milk yield and BWPLUSCW is live weight.

Johnson and Johnson [1995] discussed the empirical models that Wilkerson et al. [1995] tested. They suggested that Moe and Tyrrell's model was an improvement on that of Blaxter and Clapperton's, since Moe and Tyrrell incorporated feed characteristics in their equation. Johnson and Johnson concluded that it is unlikely that a simple equation based on feed characteristics will accurately predict methane production under all perturbation conditions.

Benchaar et al. [1998] compared the ability of two dynamic, mechanistic models with two empirical ones

at predicting methane production. The dynamic, mechanistic models were those of Baldwin [1995] and Dijkstra et al. [1992]. The empirical models were the regression equations of Blaxter and Clapperton [1965] and Moe and Tyrrell [1979]. In order to test the models, a wide variety of diets (32 diets from 13 publications) were selected and 'fed' to both non-lactating and lactating cows of varying ages. Benchaar et al. [1998] found that the mechanistic models predicted methane production better than the empirical ones. They noted how important it was for the mechanistic models to have accurate values for such input parameters as the chemical composition of the diet, degradation rates of feed components, and passage rates, in order for these models to perform adequately.

Two empirical equations for methane energy output were derived by Yan et al. [2000] using data from dairy and beef cattle fed grass silage-based diets. The equations were functions of digestible energy, feeding level above maintenance and either silage dry matter intake as a proportion of total dry matter intake or silage acid detergent fibre intake as a proportion of total acid detergent fibre intake.

Mills et al. [2001] improved on the earlier representation of methanogenesis in the mechanistic model of Dijkstra et al. [1992] mentioned above. Using the same diets as before, see Benchaar et al. [1998], there was some improvement in the model's prediction of methane production. Like Benchaar et al. [1998], Mills et al. [2001] outlined some likely reasons for the differences between observed and predicted values for methane production. One of these was the error attributable to dietary composition, not only in the analysis, but also in the error associated with variation in nutrient composition between samples of the same feedstuff.

3. METHOD

Woodward et al. [2002] described a trial that was conducted during autumn in Hamilton, New Zealand, at Dexcel. There were 16 lactating dairy cows (8 Friesian and 8 Jersey breed) of varying ages used in the trial. The cows were approximately 128 days pregnant and were in late lactation. Eight animals (4 Friesian and 4 Jersey) grazed perennial ryegrass (the main component of typical New Zealand dairy pastures) and the other half of the herd grazed sulla (*Hedysarum coronarium*), a condensed tannin-containing legume. The purpose

of the trial was to see if dairy cows grazing sulla had lower methane production than those grazing the more usual perennial ryegrass. Various daily measurements were taken on each cow during the 11 day trial including intake data (kg of dry matter), forage composition, live weights (kg), milk yields (kg), milk protein, fat and lactose yields (kg), with methane measurements (Mcal) occurring in the final 3 days of the trial.

MOLLY required as input a detailed breakdown of the dietary composition as follows: soluble carbohydrate, hemicellulose, cellulose, non protein nitrogen, lignin, soluble and insoluble protein, organic acids, starch, pectin, lipid, urea, soluble and insoluble ash, lactate, butyrate, acetate and added fat. The forage composition data from the above trial was not detailed enough to enable these dietary components for sulla or ryegrass to be known. However we have seasonal estimates for these components for ryegrass and we used this in order to estimate the dietary components for the ryegrass-fed animals. We ran MOLLY over 3 days for each of the eight ryegrass-fed cows, and their methane outputs were compared with those obtained in the trial described above. Within the version of MOLLY which we used, there were already three methane production models: the empirical models of Blaxter and Clapperton [1965], Moe and Tyrrell [1979] and MOLLY's own mechanistic one [Baldwin, 1995]. We also inserted into MOLLY, Kirchgebner et al's. [1995] empirical model for methane emissions from lactating dairy cows, giving a total of four methane models. See Section 2.2 for a brief description of the three empirical models and their equations.

Methane is produced in the rumen where methanogenic bacteria utilise excess hydrogen to reduce carbon dioxide to methane [Wilkerson et al., 1995]. MOLLY's own mechanistic model calculated methane production (CH₄E, Mcal) based on hydrogen balance and was given in MOLLY by Equation (4):

$$\text{CH}_4\text{E} = 0.211 * (\text{DCsHy} + \text{DRAaHy} - \text{DHymI} - \text{DHyFIF} + 2\text{RLaAc} - \text{RLaPr}) / 4 \quad (4)$$

DCsHy is the hydrogen formation from soluble carbohydrate fermentation, DRAaHy is the hydrogen released due to amino acid fermentation in the rumen, DHymI is the use of hydrogen to support rumen microbial growth, DHyFIF is the use of hydrogen to saturate unsaturated fatty acids, RLaAc is the rate of acetate formation from lactate, and RLaPr is the rate of propionate formation from lactate.

MOLLY, [Baldwin, 1995], had to be initialised to a 'late lactation' cow and various parameters were initialised in MOLLY so that its outputs of live weights and milk production for each cow matched those of the data. This 'matching' was important so that we could be confident that the methane models being run in MOLLY were obtaining the correct input parameters or values. The MOLLY-input parameters that needed to be initialised included initial and mature live weights – IBW and MatBW respectively. Various milk parameters also required initialisation. These were mature peak daily milk (MPDM) which sets the number of udder cells - a parameter used to measure a cow's genetic merit (ability to produce milk). The initial number of udder enzymes (iUENZ) and the hormone which controls the synthesis of these enzymes (iLHOR) were also adjusted. Setting these five parameters appropriately for each cow resulted in a close match between predicted and observed live weights and daily total milk production, see Table 1. Adjusting the dietary components enabled us to closely match the data for milk protein and lactose yields, see Table 1. However, we were unable to match the milk fat yields with the same accuracy, see Table 1.

Table 1. Mean predicted (P) and observed (O) live weights and milk production values and the standard deviations for the eight ryegrass-fed cows.

	Live weight (kg)	Total milk (kg/d)	Milk protein (kg/d)	Milk lactose (kg/d)	Milk fat (kg/d)
O	425 ± 74	8.36 ± 1.00	0.32 ± 0.03	0.41 ± 0.05	0.48 ± 0.06
P	425 ± 74	8.35 ± 1.00	0.35 ± 0.05	0.40 ± 0.05	0.35 ± 0.04

4. RESULTS

Table 2 shows the mean observed (O) and predicted (P) methane outputs for all 8 cows in Mcal/day and the standard deviations. It also gives an error, as a percentage, which is defined as the residual (P – O) divided by O. Tables 3 and 4 show the same information for the four Friesian and four Jersey cows respectively.

Table 2. The mean observed (O) and predicted (P) methane outputs for all 8 cows, the residual (P-O)

divided by O as a percentage, and the standard deviations.

Observed methane output = 3.35 ± 0.62 (Mcal/d)	Predicted methane output (Mcal/d)	Error = 100(P-O)/O (%)
Blaxter and Clapperton [1965]	5.26 ± 0.51	60 ± 22
Moe and Tyrrell [1979]	3.13 ± 0.19	-4 ± 14
Baldwin [1995]	2.96 ± 0.27	-10 ± 12
Kirchgebner et al. [1995]	2.52 ± 0.26	-24 ± 9

Tables 2-4 show that of the four models, those of Moe and Tyrrell [1979] and Baldwin [1995] are the best predictors of methane production. Baldwin's [1995] and Kirchgebner et al's. [1995] models consistently underpredict methane outputs, Moe and Tyrrell's [1979] model underpredicts for all 8 cows and 4 Friesians, but overpredicts for the four Jersey cows – see Tables 2, 3 and 4. The model of Blaxter and Clapperton [1965] consistently overpredicts by a big margin, errors range from 45 to 74 %.

Table 3. The mean observed (O) and predicted (P) methane outputs for the 4 Friesian cows, the residual (P-O) divided by O as a percentage, and the standard deviations.

Observed methane output = 3.82 ± 0.54 (Mcal/d)	Predicted methane output (Mcal/d)	Error = 100(P-O)/O (%)
Blaxter and Clapperton [1965]	5.52 ± 0.31	47 ± 24
Moe and Tyrrell [1979]	3.24 ± 0.18	-14 ± 9
Baldwin [1995]	3.14 ± 0.26	-17 ± 10
Kirchgebner et al. [1995]	2.72 ± 0.15	-28 ± 11

Table 4. The mean observed (O) and predicted (P) methane outputs for the 4 Jersey cows, the residual (P-O) divided by O as a percentage, and the standard deviations.

Observed methane output = 2.88 ± 0.16 (Mcal/d)	Predicted methane output (Mcal/d)	Error = 100(P-O)/O (%)
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Blaxter and Clapperton [1965]	5.00 ± 0.57	73 ± 11
Moe and Tyrrell [1979]	3.03 ± 0.14	6 ± 11
Baldwin [1995]	2.78 ± 0.13	-3 ± 10
Kirchgebner et al. [1995]	2.33 ± 0.16	-19 ± 5

5. DISCUSSION

Benchaar et al. [1998] found that the two mechanistic models of Baldwin [1995] and Dijkstra et al. [1992] were better predictors of methane output than the two empirical models of Blaxter and Clapperton [1965] and Moe and Tyrrell [1979]. In fact, Benchaar et al. described the performance of the empirical models as 'poor'. Our results from a small data set do not support their findings - Moe and Tyrrell's model was similar to Baldwin's model. It may be that our input parameters to Baldwin's model or even some other parameters within MOLLY could be improved. The mismatch between the observed and predicted milk fat yields (Table 1) would tend to support this argument.

An interesting feature of our results is that two out of the four models tested, were considerably better at predicting the methane outputs from Jersey cows than that of Friesians. This applies particularly to one of the two models, namely that of Baldwin [1995]. However, caution should be used in the interpretation of this result, given the small number of cows representing each breed.

6. CONCLUSION

Currently, MOLLY [Baldwin, 1995] is the only cow submodel in the WFM or Whole Farm Model, that can calculate methane production. This paper has shown us which of the four methane models within MOLLY give the closest match to the data, namely the models of Moe and Tyrrell [1979] and Baldwin [1995]. We acknowledge that the methane production fits between data and model can still be improved, and believe the next stage is to further test these two models using a larger data set, again from grazing dairy cows so that we are modelling the eating habits of New Zealand cows. Better knowledge of the dietary components as required by MOLLY for not only ryegrass, but also for feeds like sulla, will enable the methane models to be

more accurate. This knowledge of the dietary components of not only typical New Zealand feeds, but also alternative feeds that are under consideration for methane emission reduction purposes, is a prerequisite for successful use of the models to compare the effect of different feeds on methane production. As MOLLY becomes better at predicting methane outputs from New Zealand pasture-fed cows it will, as part of the WFM, become a powerful research tool, enabling scientists to design the most appropriate on-farm trials. The WFM will also highlight areas where there is a lack of knowledge of methanogenesis and direct research into those areas that look to be the most promising in reducing methane emissions in dairy cattle.

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