Animal wise Variation in Enteric Methane Output Traits and its Relationships with Feed Efficiency in Dairy Cattle: A Longitudinal Model Analysis

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ABSTRACT: Data on daily milk yield, feed intake as well as simultaneous measurements of daily methane output of 429 first-lactation Nordic Red cows of the MTT research farm was used. Repeatability of different methane phenotypes as well as relationships between feed efficiency (FE) and methane output traits were estimated at different stages of lactation. Cows were divided into divergent FE (high *vs.* low) groups to ascertain whether cows selected for divergent FE phenotypes also exhibit divergent methane phenotypes. Results showed that relationships between FE and methane output traits varied with stages of lactation. The repeatability of methane phenotypes across lactation stages ranged from 0.1 to 0.7 indicating cow-wise variations suggesting selection for lower methane output could be one mitigation strategy. Divergent FE phenotypes also exhibited divergent methane phenotypes in terms of daily methane output and also per kg of dry matter intake.
Keywords: Animal variation; Methane; Feed efficiency

Introduction

Mitigation of methane emissions from dairy systems could be approached by genetic and nutritional strategies. The use of genetic strategies is particularly attractive as genetic improvement of livestock produces permanent and cumulative changes in performance (Wall et al., 2010). Therefore, any attempt to reduce the ecological foot print of milk production via selection requires a sound understanding of between-animal variation in the trait as well as accurate methods for its measurement on a large scale. However, the lack of reliable techniques for large scale measurement of methane output from individual cows could be a hindrance to this. An alternative strategy for reducing enteric methane emissions from dairy systems could be to improve the efficiency of feed utilization by individual animals (Waghorn and Hegarty, 2011; Basarab et al., 2013). Selection of animals with improved feed efficiency will have a potential to reduce feed costs and also to lower methane output. However, the size and magnitude of the relationships between these traits during lactation is largely unknown.

So far, most studies have reported associations between these traits for specific stages of growth or lactation. But feed intake and production varies with the stages of lactation, and therefore the associations between methane output and feed efficiency traits as well as between-animal variations may also vary during lactation. Hence, understanding of the relationship at different stages of lactation is essential in order to develop alternative tools for the mitigation of methane from dairy production systems. Besides, studies that used direct methane measurements and data covering the whole lactation period are scarce. The objectives of this study were to estimate between-animal variations and associations between methane output and FE traits during the different stages lactation fitting a longitudinal model.

Materials and Methods

Data. Records from first-lactation Nordic Red cows of the MTT Agrifood Research Finland experimental dairy herd were used in this study. The dataset contained records on milk yield, dry matter (DM) intake, body weight and other production variables from a total of 429 cows from 1998 onwards. In addition about 107 cows had part to whole lactation measurements of daily methane output. The cows were managed similarly and fed on similar diet composed of grass silage and concentrate. From the data, FE traits were defined as energy conversion efficiency (ECE, ECM/ME), residual energy intake (REI, actual energy intake minus the predicted energy requirements) and details of these traits have already been given in Mäntysaari et al. (2012).

Methane measurement. Methane output of each individual cow was monitored continuously in the barn using F10 equipment. F10 is a multi-gas analyzer (GASERA Ltd. Turku, Finland) that is based on Photoacoustic Infrared Spectroscopy technique (Negussie *et al.* 2013). It is portable and suitable for the measurement of difficult gases e.g., such as those with high humidity and is ideal for use in dairy barns. A two-point sampling method was used to measure individual cow methane (CH_4), carbon dioxide (CO_2) and acetone outputs from the breath sample of cows via sampling tubes fitted to two separate individual concentrate feeding kiosks. The feeding kiosks are visited by cows several times during the day. During each visit the breath of a cow was sampled several times and analyzed for the contents of the different gases and the ID, date, time and its measurements were recorded automatically. Repeated daily F10 measurements of the gases were used to calculate the daily mean CH_4:CO_2 ratio for each cow. The CH_4:CO_2 ratios were then used to estimate the daily CH_4 output of cows using the method by Madsen et al. (2010). Methane output per day was described as total output in gram/day (CH_4g) or per unit of product or intake as: CH_4g/kg milk (CH_4mk), CH_4g/kg DM intake (CH_4dm) or feed energy lost as CH_4 as percentage of gross energy intake (CH_4GE). For each animal, these variables were merged with the corresponding records of feed intake, production and energy efficiency traits such as ECE and REI for statistical analysis. In addition, divergent FE phenotypes were selected by ranking cows into high REI (REI > SD above the mean), medium (REI±SD from the mean) and low (REI < SD below the mean) and their relationship with CH_4 output phenotypes were assessed.

Statistical analysis. The data was analyzed fitting mixed linear model. Fixed effects in the model included age, production year month, stages of lactation and random effects were animal and residual. To estimate across lactation stages repeatability and assess the associations between FE and CH_4 output traits univariate and bivariate random regression models were used. The models fitted quadratic Legendre polynomial plus Wilmink term to model the fixed lactation curve and the individual animal effects in the data. Variance estimates of the regression coefficients were then used to estimate within and between-animal variations and calculate phenotypic association between traits, $r_{p_{(t_i,t_j)}}$ at day t_i and t_j and repeatability for a trait, r_{t_i} as a ratio of between animal to total variation as follows:

$$r_{p_{(t_i,t_j)}} = \frac{\phi'_{(t_i)} P \phi_{(t_j)}}{\sqrt{\phi'_{(t_i)} P \phi_{(t_i)} \cdot \phi'_{(t_j)} P \phi_{(t_j)}}}$$

$$r_{ti} = \frac{\phi'_{(t_i)} G \phi_{(t_j)}}{\phi'_{(t_i)} P \phi_{(t_j)}}$$

Where **G** is the genotypic variance plus the general environmental variance (V_G+V_{EG}) and **P** is the phenotypic variance (V_P) (Falconer, 1981). Statistical analyses were made using DMU package (Madsen and Jensen, 2010).

Results and Discussion

Sources of variation. Table 1 shows the mean and SD of the different enteric CH_4 output traits as well as dairy cow energy efficiency traits. For CH_4 phenotypes, among others the stage of lactation was the main sources of variation. Particularly with the progression of lactation and with the increase in the level of DM intake corresponding increases in CH_4 output was observed. During lactation, the highest daily CH_4 output was observed around mid lactation when the animals start to gain weight and condition. Working on 665 Holstein-Friesian heifers, de Haas et al. (2011) also reported a similar trend for predicted CH_4 output that followed a standard feed intake curve during lactation.

Associations between traits: Across lactation, correlations between ECE and REI with the CH_4 output traits ranged from (-0.52 to -0.62) and (0.38 to 0.60), respectively (Table 1). De Haas et al. (2011) also reported a correlation of 0.72 between Residual feed intake (RFI) and predicted CH_4 output. For instance in Table 1, the high and positive correlation between CH_4g and REI indicates that cows with lower REI (high FE) also tend to have lower CH_4 output. This could be because animals with improved feed utilization efficiency (lower REI) tend to have lower DM intake and have improved feed conversion ratio and hence lower enteric CH_4 emission than their high REI counterparts at a relatively similar levels of production. This is in line with the results of Nkrumah et al. (2006) who also reported similar results working on beef cattle. This suggests that selection for FE traits could be an alternative strategy for lowering CH_4 output of cows.

Table 1. Across lactation mean and standard deviations and correlations between enteric methane output traits CH_4g (g/day), CH_4mk (g/kg), CH_4dm (g/kg), CH_4GE (%) and feed efficiency traits REI (MJ of ME/d), ECE (kg ECM/MJ of ME) traits in Nordic Red cattle.

Traits	Mean	SD	Correlation (r_p) with ECE	Correlation (r_p) with REI
CH_4g	330.0	58.0	-0.62	0.60
CH_4mk	13.5	3.8	-0.68	0.47
CH_4dm	17.0	3.7	-0.52	0.38
CH_4GE	5.70	0.9	-0.52	0.38
ECE	0.13	0.01	1.00	-0.70
REI	0.95	14.2	-0.70	1.00

[§] ECM=Energy corrected milk; ME= Metabolizable energy, MJ= Mega joule.

During lactation daily feed intake and milk production vary in dairy cows. Methane output in cows is a function of these variables and hence understanding the variation in CH_4 output at different stages of lactation is important. Our estimates (result not shown) of within trait phenotypic correlations for CH_4g varied during lactation. Correlations between DIM 30 and 60, between DIM 30 and 150 were 0.62 and 0.10, respectively whilst that between DIM 30 and 240 was 0.35. These correlations of less than unity indicate CH_4g in early lactation is different than in mid lactation and also different than CH_4g in late lactation underscoring the need for daily or frequent monitoring and recording. On the other hand, across-traits phenotypic correlations between CH_4g-REI and CH_4mk-REI during lactation are in Table 2. Here the associations between the FE and CH_4 phenotypes were relatively lower in early lactation than mid to late lactation. The reason for this may be related to the lower feed intake in early lactation and hence relatively lower CH_4 output despite the relatively more milk production due partly to body reserve mobilization. However, the correlation started to rise after peak lactation at a time when feed intake also begins to rise slightly and cows start to gain weight and condition. This trend follows the DM intake curve during lactation which rises shortly after the beginning and increases towards peak lactation until it starts to decline gradually in late lactation. A similar trend of intake has been reported by Mäntysaari et al. (2012) for Nordic Red cows.

Between-animal variation: Marked variability was observed in the size of between-animal variation of the different CH_4 output phenotypes during lactation (Table 3). Repeatability, as a ratio of between-animal to total variation indicates the potentially available animal variation which will predict the scope of improvement in these traits via selection. Our estimates of repeatability for the three different CH_4 phenotypes are in Table 3. The result shows that between-animal variations for these traits are higher in early lactation and moderate in mid and started to rise again towards late lactation. Of all the three CH_4 phenotypes, the repeatability was higher for CH_4GE ranging from 0.2 to 0.74 during lactation. Repeatabilities of these traits from dairy cows and across the different stages of lactation are rarely reported.

Table 2. Across lactation phenotypic correlation between CH_4g and REI (below diagonal) and between CH_4mk and REI (above diagonal) for selected days in milk.

DIM	Days in Milk					
	30	60	90	120	180	240[&]
30		0.14	0.14	0.12	0.05	0.01
60	0.29		0.13	0.18	0.17	0.05
90	0.26	0.41		0.21	0.24	0.09
120	0.21	0.42	0.52		0.28	0.13
180	0.14	0.38	0.50	0.56		0.22
[‡]240	0.10	0.19	0.28	0.35	0.51	

[&]Above diagonal is phenotypic correlation between CH_4mk and REI at selected days in milk. Standard errors of estimates ranged from 0.01-0.06.
[‡]Below diagonal is phenotypic correlation between CH_4g and REI at selected days in milk. Standard errors of estimates ranged from 0.04-0.11.

Divergent FE phenotypes: There is limited data showing the relationship between feed efficiency and CH_4 output in dairy cows. Particularly results from long-term data covering the whole lactation and including a relatively larger number of dairy cows are lacking. The divergent REI phenotypes identified in this study had overall average milk production of 28.9kg/day and DM was 19.2 kg/day (SD=2.2). The high REI group of cows consumed about 11.3% and 18.6% more DM than medium and low REI group of cows, respectively. Hegarty et al. (2007) and Mäntysaari et al. (2012) also reported that cattle selected for low RFI or REI had a lower total feed intake. In addition, the low REI group produced less CH_4 per kg DM intake (15.9g/kgDM) than the high REI group (18g/kgDM). The difference in the output of CH_4 as a fraction of DM intake between the high and low selected lines may suggest that the difference may not only be a function of reduction in feed intake. There could also be some part that is due in part to the innate difference in CH_4 producing abilities of the divergent lines selected. Nkrumah et al. (2006) also reported similar differences between high and low FE lines working on beef cattle data.

Table 3. Daily repeatability (between-animal variation /total variation) estimates of methane output traits for selected days in milk.

Traits	Days in Milk				
	30	60	120	180	240[†]
CH_4g	0.65	0.39	0.35	0.27	0.38
CH_4mk	0.73	0.28	0.11	0.08	0.04
CH_4GE	0.74	0.40	0.30	0.19	0.30

[†]Standard error of estimates ranged from 0.02-0.10.

Conclusion

Available between-animal genetic variation determines the scope of lowering CH_4 output via selection strategies. For the three different CH_4 phenotypes, our estimates of repeatability ranged from 0.2 to 0.7 during lactation. This indicates that there is potential genetic variation suggesting selection for lower CH_4 output should be considered as one mitigation strategy. Relationships between FE and CH_4 output traits varied during lactation. The analysis of divergent FE groups showed the high FE group had relatively lower feed intake and hence lower daily CH_4 output at relatively similar production level. They also have lower fraction of energy lost as CH_4 per kg DM suggesting underlying innate differences in CH_4 output between the divergent FE groups. Our results indicate a potential of selection for feed efficiency traits as an alternative to reduce the carbon foot print of milk production systems particularly when large scale measurements of CH_4 phenotypes are difficult or impossible. However the superiority of the high FE group should be validated at different stages of lactation and the consequences of selection on energy efficiency traits on other production and functional traits needs to be validated.

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