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Estimation of the maintenance energy requirements, methane emissions and nitrogen utilization efficiency of two suckler cow genotypes

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Seventeen non-lactating dairy-bred suckler cows (LF; Limousin × Holstein-Friesian) and 17 non-lactating beef composite breed suckler cows (ST; Stabiliser) were used to study enteric methane emissions and energy and nitrogen (N) utilization from grass silage diets. Cows were housed in cubicle accommodation for 17 days, and then moved to individual tie-stalls for an 8-day digestibility balance including a 2-day adaption followed by immediate transfer to an indirect, open-circuit, respiration calorimeters for 3 days with gaseous exchange recorded over the last two of these days. Grass silage was offered ad libitum *once daily at 0900 h throughout the study. There were no significant differences ($P > 0.05$) between the genotypes for energy intakes, energy outputs or energy use efficiency, or for methane emission rates (methane emissions per unit of dry matter intake or energy intake), or for N metabolism characteristics (N intake or N output in faeces or urine). Accordingly, the data for both cow genotypes were pooled and used to develop relationships between inputs and outputs. Regression of energy retention against ME intake ($r^2 = 0.52$; $P < 0.001$) indicated values for net energy requirements for maintenance of 0.386, 0.392 and 0.375 MJ/kg$^{0.75}$ for LF + ST, LF and ST respectively. Methane energy output was 0.066 of gross energy intake when the intercept was omitted from the linear equation ($r^2 = 0.59$; $P < 0.001$). There were positive linear relationships between N intake and N outputs in manure, and manure N accounted for 0.923 of the N intake. The present results provide approaches to predict maintenance energy requirement, methane emission and manure N output for suckler cows and further information is required to evaluate their application in a wide range of suckler production systems.*

Keywords: energy metabolism, enteric methane emissions, nitrogen output, grass silage, suckler cow

Implications

Suckler cows play an important role in the beef production industry across the world. There is increasing interest in developing mitigation strategies to reduce the environment footprint of beef production systems. Although the present study found no difference in methane emission or utilization of energy or nitrogen between Limousin × Holstein-Friesian and beef composite suckler cows, a range of models were developed for prediction of maintenance energy requirement and excretion of methane and manure nitrogen. The accurate quantification of feed intake and effects on environment footprint is essential for development of sustainable beef production systems.

Introduction

Herds of suckler beef cows constitute a very important sector in the grassland areas of Europe. A total of over 12 million suckler cows are found in all EU countries and the main suckler beef-producing countries are France, Spain, the UK and Ireland (Webster, 2011). Suckler beef production is a sustainable system producing high quality meat with low inputs. However, this industry, like all other livestock production systems, currently is under increasing pressure to reduce manure nitrogen (N) and methane emissions from the meat production. Dry matter intake and N intake have been demonstrated to be the major driver for enteric methane emission (Yan *et al.*, 2000; Mills *et al.*, 2009) and manure N excretion (Kebreab *et al.*, 2001; Yan *et al.*, 2007) from cattle, respectively. Currently, feed intake for beef cattle across the world is calculated from total energy requirements

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for maintenance, production and pregnancy using energy feeding systems adopted locally, for example, systems of Agriculture and Food Research Council (AFRC, 1993) in United Kingdom, National Institute for Agricultural Research (INRA, 1989) in France, and National Research Council (NRC, 1996) in United States). However, there is evidence that high yielding dairy cows have greater metabolic rates (Yan *et al.*, 1997b) and require more energy for maintenance than their lower genetic merit predecessors (Yan *et al.*, 1997a; Bruinenberg *et al.*, 2002; Kebreab *et al.*, 2003). Modern suckler cows may also have a higher energy requirement than that recommended for earlier suckler cow genotypes, as assessed by current energy feeding systems (e.g. INRA, 1989; AFRC, 1993; NRC, 1996) which were developed using data obtained over three decades ago. At the moment, there is little quantitative information available on prediction of methane and manure N emissions and the maintenance energy requirement for modern suckler cows. As diets used for dry suckler cows are normally in a poor quality when compared to those fed to lactating dairy cows and growing beef cattle, the models developed for dairy cows and growing cattle may not be fully applicable to dry suckler cows. Against this background, the objectives of the current study were to evaluate effect of suckler cow genotypes on methane emissions and energy and N utilization efficiencies and use these data to develop models to predict methane emissions, energy requirements and N outputs to address the knowledge gaps that currently exist.

Material and methods

All animal procedures used in this study were conducted with the approval of the AFBI Hillsborough Ethical Review Committee and in accordance with the UK Animal Scientific Procedures Act (1986).

Animals, experimental design and diets

Seventeen dairy-bred suckler cows (LF; Limousin × Holstein-Friesian) and 17 beef composite suckler cows (ST; Stabiliser) were selected from the AFBI suckler herd. The ST breed is a composite breed of cattle developed in America by Lee Leachman of Colorado (www.leachman.com). The aim of the breed was to harness the hybrid vigour of a number of different breeds to produce a beef animal that calves easily, matures early, with good fertility, good and consistent conformation and lower feed costs. The breeds used to make up the ST are a mix of traditional British breeds and maternal Continental breeds.

All cows in the study were used during their respective dry (non-lactating) periods. The experiment was conducted over two periods: November 2010 to January 2011 (6 LF, 6 ST) and January 2012 to March 2012 (11 LF, 11 ST). All the suckler cows were pregnant during the calorimetric measurements and digestibility balance and mean stage of pregnancy was 196 days (SD, 48.0). Before commencement of the study, animals were paired according to age, BW and body condition score (BCS) within each breed. In each period, cows were housed in cubicle accommodation for 17 days, and then transferred to individual tie-stalls for a 8-day digestibility balance including a 2-day adaption. After the balance, animals were transferred to indirect, open-circuit, respiration calorimeters for 3 days with gas exchanges recorded for the last 2 days.

The animals were fed grass silages *ad libitum* from the same silo (three silo silages used) once daily, at 0900 h, throughout the entire experimental period. The amount of feed offered was adjusted based on the intake of the previous day, so as to try to ensure a refusal equal to ~10% of the previous day's intake. The chemical compositions of the three silo grass silages offered are presented in Table 1.

Table 1 *Chemical composition of the experimental grass silage*

	Silo 1	Silo 2	Silo 3
DM (g/kg)	208	242	404
Gross energy (MJ/kg DM)	18.4	19.3	18.6
CP (g/kg DM)	113	140	95
ADF (g/kg DM)	308	247	289
NDF (g/kg DM)	480	369	437
Ash (g/kg DM)	83	94	93

Measurements

The BW and BCS of the cattle were recorded on the first day of the study and then immediately before entry to the digestibility balance and then, again, after exiting the respiration chamber. The BCS of each animal was assessed before entry to the study on a scale from 1 (very thin) to 5 (very fat), according to Mulvany (1977).

The quantities of feed (silage) offered and feed refused were recorded daily for each animal during digestibility balance and chamber measurement periods. The silage offered to cattle was sampled daily for the determination of gross energy (GE), N content, pH, volatile fatty acids (VFA), alcohol (ethanol and propanol) and ammonia-N (NH_3-N) (all on a fresh weight basis). The DM contents of the silage and all silage refusals were determined after oven drying at 85°C for 24 h. The 6 days silage samples during the balance period were then bulked together and a representation sample was taken for analysis of ash, ADF, NDF concentrations. Silage DM concentrations used in the present study were calculated from oven DM concentrations corrected for the loss of VFAs, lactic acid, alcohol and ammonia (Porter and Murray, 2001).

Faeces and urine outputs were recorded on each day of the balance and representative sub-samples (~10% of total weight and volume respectively) taken for proximate chemical analysis. Sulfuric acid (35% aqueous vol/vol) was added to urine collection bins to reduce the pH of the collected urine to <pH 3 and prevent loss of N as ammonia. The pH values of urine were checked on the first and last day of balance collection. Faeces or urine samples taken during

the 6-day digestibility balance were pooled for each animal and thoroughly mixed before a representative sub-sample was taken and frozen for subsequent analysis. The urine samples were analysed for GE and N contents. After defrosting, faeces samples were divided into two portions. One portion (200 g) was used for determination of N content (fresh weight basis) and the other portion was dried at 85°C for 72 h for calculation of DM content before milling to pass an 0.8 mm screen prior to storage for analysis of ash, GE, ADF and NDF concentrations.

Gross energy concentrations were determined using an isoperibol bomb calorimeter (Parr Instruments Co., Moline, IL, USA) according to Porter (1992). NH_3-N concentrations of silages were determined as described by Steen (1989). Total N concentrations in silage, faeces and urine samples were analysed on a fresh weight basis using a Tecator Kjeldahl Auto 1030 Analyzer (Foss Tecaor AB, Höganäs, Sweden). Concentrations of VFA in silage were determined as described by Porter and Murray (2001). Silage pH was determined on aqueous extracts using a Metrohm 670 Titroprocessor (Metrohm Ltd., Herisau, Switzerland) fitted with an Orion Ross combination electrode (Metrohm Ltd., Herisau, Switzerland). The concentrations of NDF, ADF and ash in silage were determined using methods described by Cushnahan and Gordon (1995).

Calorimeters

The two calorimeters used in the current study were indirect, open-circuit, respiration chambers. Animals were placed in one of the two calorimeters for 3 days upon completion of their respective digestibility balance. The respiration chambers incorporate airlocks to provide staff access for feeding and sampling. The total chamber volume of 22 m^3 was ventilated by suction pumps set at a rate of 75 m^3/h. Temperature and humidity control was achieved with air conditioning units set at 12 ± 1°C and 60 ± 10% relative humidity, respectively. The chambers were operated under negative pressure (−5 Pa) with exhaust air removed at three positions for volume measurement and gas analysis. The chambers were calibrated at the beginning, middle and end of each of the two periods (i.e. November 2010 to January 2011 and January 2012 to March 2012), by releasing known quantities of standard CO_2, CH_4 and N_2 (used to reduce O_2 concentration) into the chambers. All equipment, procedures, analytical methods, and calculations used in the calorimetric study were as reported by Gordon *et al.* (1995).

Statistical analysis

Digestible energy (DE) was calculated as the difference between GE intake and faecal energy output. Metabolizable energy (ME) was derived as the difference between GE intake and the sum of faeces energy, urine energy and methane energy (CH_4-E). Energy retention (ER) was calculated as the difference between GE intake and the sum of faeces energy, urine energy, CH_4-E and heat production (HP). Heat production was determined from measurements of oxygen consumption, CO_2 and CH_4 production, and urine N output using the equation of Brouwer (1965).

The effect of suckler cow genotype on animal performance, enteric methane emissions and energy and N utilization were analysed by the restrict maximum likelihood variance components analysis and linear mixed models with removal of period and silage silo factors, using the Wald test with the model's adequacy assessed by means of residual plots and a pseudo R^2 value. The statistical program used in the present study was Genstat 14.2 (14th edition; Lawes Agricultural Trust, Rothamsted, UK). Effects of the factors were declared significant at $P < 0.05$ unless otherwise noted and trends were discussed at $P < 0.10$.

Results

Effects of genotype on energy and nitrogen metabolism and methane emissions

Data for BW, BCS, grass silage intakes and DM digestibility are presented in Table 2. The ST cows had greater BW ($P = 0.002$) and BCS ($P < 0.001$) than LF cows but there were no significant differences between LF and ST for DMI expressed either as kg/d or as g/kg$^{0.75}$. There was also no significant difference in the digestibility of DM between the LF and ST breeds.

Data for energy intake, energy output and efficiency of energy utilization are presented in Table 3. Although ST cows had numerically higher GE intake and EB than LF cows, none of the differences were significant. There were no significant differences in energy outputs (faecal energy, urinary energy, CH_4-E, or HP), or the efficiency of energy use (DE : GE, ME : GE, HP : ME intake or EB : ME intake) between LF and ST.

Table 2 *Effects of suckler cow genotypes on BW, feed intake and digestibility*

	Limousin × Holstein-Friesian	Stabiliser	SE	*P*-value
Animal data				
BW (kg)	589	679	26.2	0.002
Body condition score	2.66	3.68	0.163	<0.001
Feed intake				
DM intake (kg/day)	8.1	8.9	0.43	0.07
DM intake : BW (g/kg$^{0.75}$)	68.2	67.2	3.5	0.77
DM digestibility (kg/kg)	0.742	0.754	0.0131	0.39

Table 3 *Effects of suckler cow genotypes on energy intake, excretion and energetic efficiency*

	Limousin × Holstein-Friesian	Stabiliser	SE	*P*-value
Energy intake and outputs (MJ/day)				
GE intake	152.6	168.0	8.17	0.07
Faecal energy	41.9	43.5	2.49	0.51
Urinary energy	7.4	7.6	0.67	0.75
Methane energy	10.0	11.1	0.76	0.14
Heat production	90.2	98.8	5.40	0.11
Energy retention	3.2	6.9	5.29	0.49
Energy utilization efficiency (MJ/MJ)				
DE : GE	0.725	0.737	0.0143	0.39
ME : GE	0.611	0.625	0.0163	0.38
Heat production : ME intake	0.981	0.952	0.055	0.70
Energy retention : ME intake	0.019	0.048	0.0553	0.70

Table 4 *Effects of suckler cow genotypes on enteric methane emissions*[1]

	Limousin × Holstein-Friesian	Stabiliser	SE	*P*-value
CH_4 (g/day)	180	200	13.7	0.14
CH_4 : DM intake (g/kg)	22.3	22.4	1.08	0.86
CH_4 : digestible DM intake (g/kg)	30.1	29.8	1.51	0.87
CH_4-E : GE intake (MJ/MJ)	0.065	0.066	0.0031	0.84
CH_4-E : DE intake (MJ/MJ)	0.091	0.090	0.0046	0.85

[1] CH_4-E–methane energy.

Table 5 *Effects of suckler cow genotypes on nitrogen (N) intake, output and utilization efficiency*

	Limousin × Holstein-Friesian	Stabiliser	SE	*P*-value
N intake and output (g/day)				
N intake	161	179	8.8	0.051
Faecal N	69	75	4.7	0.23
Urinary N	82	85	8.6	0.70
N retention	10	19	10.7	0.42
N utilization (g/g)				
Faecal N : N intake	0.439	0.437	0.0270	0.93
Urinary N : N intake	0.494	0.477	0.0447	0.70
N retention : N intake	0.067	0.087	0.0613	0.75

Data for enteric methane emission are presented in Table 4. There was no significant difference between LF and ST in respect of methane emissions expressed as g/day, per kg DM intake or per kg digestible DM intake. There was no significant difference either, between LF and ST cows, for losses of CH_4-E expressed as a percentage of GE intake or DE intake.

Data for N balance and N utilization are presented in Table 5. There were no significant differences between ST and LF in N intake, faecal N output, urinary N output, N retention or N utilization measures (faecal N : N intake, urinary N : N intake or N retention : N intake) between ST and LF.

Regression analysis for maintenance energy requirement and methane and nitrogen excretion

Because suckler cow genotypes (LF *v.* ST) had no significant effects on energy metabolism, methane emission rates or N utilization, the data from the two breeds were pooled to develop a range of relationships between inputs and outputs. The relationships between energy intake and retention are presented in Table 6 and Figure 1. All relationships between ME intake (MJ/kg$^{0.75}$) and EB (MJ/kg$^{0.75}$) were significant ($P < 0.001$; $r^2 = 0.52$; SE $= 0.091$). The equation (1), using data from both breeds, produced a net energy requirement for maintenance (NE_m) of 0.386 (MJ/kg$^{0.75}$) which was taken as the intercept. Because genotype had no significant effect on energetic efficiency, a common slope was used to produce equations (2) and (3) for LF and ST, respectively. The NE_m values derived from equations (2) and (3) were 0.392 and 0.375 (MJ/kg$^{0.75}$) for ST and LF cows, respectively, but the difference was not significant.

The relationships developed for prediction of methane and manure N are presented in Table 7. There was a positive linear relationship between methane emission with DM intake (equation (4): $r^2 = 0.59$, SE = 28.1) and the r^2 value was slightly decreased and SE value increased when relating methane emission to digestible DMI (equation (5): $r^2 = 0.57$, SE = 29.0). These relationships produced a methane emission rate of 22.3 or 30.0 g associated with 1 kg intake of DM or digestible DM when the constant was omitted from the relationship. Similar relationships were also obtained when CH_4-E was related to GE intake, DE intake, and ME intake (equations (6), (7), (8), respectively). The CH_4-E was respectively 0.066, 0.091 and 0.107 of GE intake, DE intake, and ME intake, respectively, when the constants were omitted from the above equations.

Table 6 *The relationship between ME intake and energy retention using data of Stabiliser (ST) and Limousin × Holstein-Friesian (LF)*

Equation no.	Breed	Equation[1,2,3]	R^2	SE
1	LF + ST	$ER = 0.541_{(0.1191)}$ ME intake $- 0.386_{(0.1000)}$	0.52	0.091
2	LF	$ER = 0.538_{(0.1207)}$ ME intake $- 0.392_{(0.1036)}$	0.52	0.091
3	ST	$ER = 0.538_{(0.1207)}$ ME intake $- 0.375_{(0.1043)}$		

[1] Unit–MJ/kg$^{0.75}$ for ER (energy retention) and ME intake.
[2] Data in brackets are SE values.
[3] Equations (2) and (3) were developed for LF and ST, respectively, using a common slope, as genotype had no significant effect on energetic efficiency.

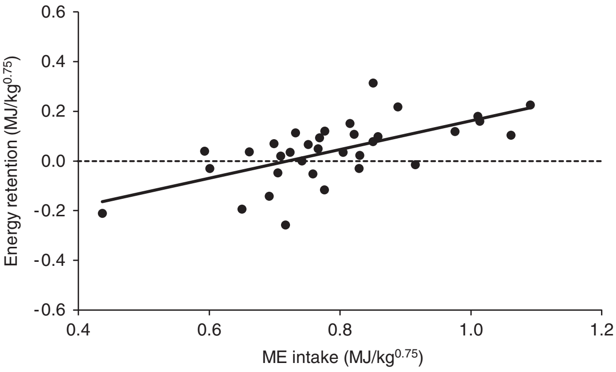

Figure 1 The relationship between EM intake and energy retention using data of both Stabiliser and Limousin × Holstein-Friesian.

There was a positive linear relationship between N intake and N outputs from faeces (equation (9a): $r^2 = 0.30$, SE = 12.4), urine (equation (10a): $r^2 = 0.45$, SE = 23.1) and manure (equation (11): $r^2 = 0.46$, SE = 30.5). These relationships show that N output from faeces, urine and manure were 0.438, 0.486 and 0.923 g for each 1 g of N intake when the constant was omitted from the relationship. Adding DM intake as a supporting predictor to equation (9a) and equation (10a) marginally increased r^2 values from 0.30 to 0.31 (equation (9a) *v.* (9b)) and 0.45 to 0.49 (equation (10a) *v.* (10b)), while reduced SE values from 12.4 to 12.0 (equation (9a) *v.* (9b)) and from 23.1 to 23.0 (equation (10a) *v.* (10b)).

Discussion

Energy requirement

As there is little comparable information for the energy requirement of suckler cow breeds used in the present study (i.e. ST), we have compared our results to beef cattle or dairy cows of similar BW. In the current study, the estimated NE_m values varied from 0.375 to 0.392 (mean 0.386 MJ/kg$^{0.75}$). When assuming a live weight of 600 kg for a suckler cow, the calculated NE_m using AFRC (1993) is 0.337 MJ/kg$^{0.75}$ which is 87% of that obtained in the present study. There are several possible explanations for the greater NE_m value obtained in the current study with dry suckler cows. The use of grass silage as sole diet in the current work may have been an important factor. Yan *et al.* (1997a) collated a calorimeter data set ($n = 221$) of lactating cows offered diets contained grass silage from 0.18 to 1.00 of total diet (mean 0.58; SD 0.217) and found that when the overall data set was divided into three sub-sets, according to silage-GE : total-GE ratio, the derived NE_m values were significantly greater as the proportion of silage in the total diet increased. Forage-based diets are associated with a larger gastro-intestinal tract mass

Table 7 *Prediction equations for methane emission and nitrogen output of suckler cows using data of both Stabiliser and Limousin × Holstein-Friesian*

Equation no.	Equation[1,2]	R^2	SE
4	CH_4 (g/day) $= 23.27_{(3.73)}$ DM intake $- 7.7_{(32.0)}$	0.59	28.1
5	$26.20_{(4.29)}$ DDM intake $+ 24.8_{(28.34)}$	0.57	29
6	CH_4 energy (MJ/day) $= 0.067_{(0.0106)}$ GE intake $- 0.111_{(1.7589)}$	0.59	1.59
7	$0.075_{(0.0124)}$ DE intake $+ 1.820_{(1.5840)}$	0.56	1.67
8	$0.076_{(0.0154)}$ ME intake $+ 3.131_{(1.6405)}$	0.49	1.82
9a	Faecal N (g/day) $= 0.205_{(0.0585)}$ N intake $+ 38_{(10.5)}$	0.30	12.4
9b	Faecal N (g/day) $= 0.054_{(0.0922)}$ N intake $+ 4.66_{(2.670)}$ DM intake $+ 24_{(14.0)}$	0.31	12.0
10a	Urinary N (g/day) $= 0.550_{(0.1076)}$ N intake $- 10_{(18.7)}$	0.45	23.1
10b	Urinary N (g/day) $= 0.691_{(0.1780)}$ N intake $- 5.13_{(5.150)}$ DM intake $+ 9_{(27.1)}$	0.49	23.0
11	Manure N (g/day) $= 0.735_{(0.1424)}$ N intake $+ 31_{(24.8)}$	0.46	30.5

[1] Unit–kg/day for DM intake and DDM (digestible DM) intake; MJ/day for GE intake, DE intake and ME intake; g/day for N intake.
[2] Data in brackets are SE values.

(Reynolds *et al.*, 1991), resulting in greater oxygen consumption by the animal. The lower NE_m of AFRC (1993) may also be because the model used by AFRC (1993) was developed using fasting data of cattle after a prolonged period of restricted feeding (usually at the maintenance level). However, in the current study, cows were fed *ad libitum* and had normal metabolic activity. Fasting after a lengthy period of restricted nutrition can result in deamination of amino acids released from tissue proteins, to provide a supply of glucose for metabolism (Chowdhury and Ørskov, 1994). Deamination can induce some metabolic disorders in animals (e.g. hypoglycaemia, hyperlipidaemia, hyperketonaemia and hypoinsulinaemia; Chowdhury and Orskov, 1994) and such effects can affect the FHP of cattle (Agnew and Yan, 2000) resulting in a lower metabolic rate. These disorders may not occur in cattle fed at maintenance levels for a certain period, although a long term of maintenance feeding may force cattle to adjust their body metabolism with a lower basal metabolic rate (Agnew and Yan, 2000).

The findings from the present study suggest that the use of AFRC (1993) to estimate the maintenance energy requirement for sucklers cow could underestimate their energy requirement. However, further information is required to validate the present results for these suckler breeds managed under a wide range of feeding regimes.

Methane emissions

Meta-analysis of methane emission data found that the CH_4-E : GE intake ratio ranged from 0.016 to 0.099 in 404 experimental trials with Holstein cows in the United States (Moe and Tyrrell, 1979) and from 0.037 to 0.101 in 247 Holstein-Friesian cows in the United Kingdom (Yan *et al.*, 2000). The CH_4-E : GE intake ratio values obtained in the present study (0.066 to 0.067) fall within the mid-range of each of the two previously quoted studies while the mean value from the current study (0.066) is greater than that of 0.056 (0.038 to 0.074) reported by Kebreab *et al.* (2008) for dairy cows but similar to that of 0.065 ± 0.01 reported by the Intergovernmental Panel on Climate Change (IPCC, 2006) for use in cattle. The mean methane emission per kilogram DM intake in the present study was 22.3 g/kg, which is similar to those (20.4–22.9 g/kg) calculated from the average data of methane emission and feed intake reported for lactating dairy cows (Moe and Tyrrell, 1979; Mills *et al.*, 2003; Ellis *et al.*, 2007).

A number of previous studies have demonstrated that methane emissions (g/day) from enteric fermentation are highly correlated with feed intake and a range of prediction equations for methane emissions or CH_4-E emission from lactating dairy and beef cattle, using DM intake (kg/day) and ME or GE intake (MJ/day) values as the primary predictor, have been published (Yan *et al.*, 2000; Mills *et al*, 2003; Ellis *et al.*, 2007). Ellis *et al.* (2007) developed a range of prediction equations from a combined database in beef and dairy cattle using DM intake or ME intake as primary predictors for methane emission and found that the r^2 values for DM intake were greater than for ME intake (0.68 *v.* 0.60). The results obtained in the present study agree with several previous publications which have shown DM intake (kg/day) and GE intake (MJ/day) are better predictors for enteric methane emissions than ME intake ($r^2 = 0.59$ and 0.59 *v.* 0.49, respectively; SE $= 1.59$ *v.* 1.82 for prediction using GE intake *v.* ME intake).

There is little information in the literature on methane emissions for non-lactating suckler cows, and less still for the two genotypes (LF and ST) used in the current study. The results from the present study provide an approach for estimating methane emissions on the basis of DM intake, GE intake, DE intake and ME intake. However, more information is still required to cover the effects of different feeding regimes and management systems.

Nitrogen output

Preventing pollution of groundwater and surface water by nitrates from agricultural sources is an increasingly important issue for livestock producers and, inevitably, interest in growing in developing approaches to estimate N outputs from livestock. Yan *et al.* (2007) reported that N intake is an accurate predictor of N excretion in growing beef cattle. The current data confirmed previous reports of a linear relationship between N intake and N excretion, for example by Kebreab *et al.* (2001) and Yan *et al.* (2006 and 2007) who reported positive linear relationships between N intake and manure N output. One of the objectives of the current study was to develop similarly equations for prediction of N outputs from modern suckler cows. Nitrogen outputs were not different between the LF and ST suckler cows in the current study. However, the study established that positive linear relationships existed between N intake and N output and suggested that prediction equations developed in the present study could be used to monitor N outputs for suckler cow feeding systems. However, further information is required to validate these relationships for suckler cows managed under a wide range of production sustems.

Conclusions

This study generated a range of calorimetry data for non-lactating suckler cows offered only grass silage diets. There was no significant effect of suckler cow genotype (LF *v.* ST) on the efficiency of energy use, enteric methane emissions or N outputs. The relationship between EB and ME intake indicated that the NE_m for a non-lactating suckler cow is $0.386\ MJ/kg^{0.75}$. Linear regression analysis on pooled data found that CH_4-E was 0.066 of GE intake. There were positive linear relationships between N intake and N outputs in manure, and manure N accounted for approximately 0.923 of the N intake. The present results provide information to predict maintenance energy requirement, methane emission and manure N output for suckler cows, however, further studies are required to evaluate these results for application to a wide range of suckler cow feeding regimes.

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References

Agnew RE and Yan T 2000. Impact of recent research on energy feeding systems for dairy cattle. Livestock Production Science 66, 197–215.

Agricultural and Food Research Council (AFRC) 1993. Energy and protein requirements of ruminants. CAB International, Wallingford, UK.

Brouwer E 1965. Report of sub-committee on constants and factors. Pages 411 in Energy metabolism. EAAP Pub. No. 11. European Association for Animal Production (EAAP), Troon, UK.

Bruinenberg MH, Van Der Honing Y, Agnew RE, Yan T, Van Vuuren AM and Valk H 2002. Energy metabolism of dairy cows fed on grass. Livestock Production Science 75, 117–128.

Chowdhury SA and Ørskov ER 1994. Implications of fasting on the energy metabolism and feed evaluation in ruminants. Journal of Animal and Feed Sciences 3, 161–169.

Cushnahan A and Gordon FJ 1995. The effects of grass preservation on intake, apparent digestibility and rumen degradation characteristics. Animal Science 60, 429–438.

Ellis JL, Kebreab E, Odongo NE, McBride BW, Okine EK and France J 2007. Prediction of methane emission from dairy and beef cattle. Journal of Dairy Science 90, 3456–3467.

Gordon FJ, Porter MG, Mayne CS, Unsworth EF and Kilpatrick DJ 1995. The effect of forage digestibility and type of concentrate on nutrient utilisation for lactating dairy cattle. Journal of Dairy Research 62, 15–27.

Intergovernmental Panel on Climate Change (IPCC) 2006. 2006 Guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies (IGES), Hayama, Kanagawa, Japan. Retrieved January 20, 2008, from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4_10Ch10_Livestock.pdf

Kebreab E, France J, Agnew RE, Yan T, Dhanoa MS, Dijkstra J, Beever DE and Reynolds CK 2003. Alternative to linear analysis of retained energy data from lactating dairy cows. Journal of Dairy Science 86, 2904–2913.

Kebreab E, France J, Beever DE and Castillo AR 2001. Nitrogen pollution by dairy cows and its mitigation by dietary manipulation. Nutrient Cycling in Agroecosystems 60, 275–285.

Kebreab E, Johnson KA, Archibeque SL, Pape D and Wirth T 2008. Model for estimating enteric methane emissions from United States dairy and feedlot cattle. Journal of Animal Science 86, 2738–2748.

Mills JAN, Crompton LA, Bannink A, Tamminga S, Moorby JM and Reynolds CK 2009. Predicting methane emissions and nitrogen excretion from cattle. In: Crompton LA and Wheeler TR (editors), Proceedings of the forty-first meeting of the agricultural research modellers' group, The Journal of Agricultural Science 147, 741.

Mills JAN, Kebreab E, Yates CM, Crompton LA, Cammell SB, Dhanoa MS, Agnew RE and France J 2003. Alternative approaches to predicting methane emissions from dairy cows. Journal of Animal Science 81, 3141–3150.

Moe PW and Tyrrell HF 1979. Methane production in dairy cows. Journal of Dairy Science 62, 1583–1586.

Mulvany PM 1977. Dairy cows condition scoring. Paper No. 4468. National Institute for Research in Dairying, Shinfield, Reading, UK.

National Institute for Agricultural Research (INRA) 1989. Ruminant Nutrition. Recommended Allowances and Feed Tables. R. Jarrige, edited. INRA, Paris, France.

National Research Council (NRC) 1996. Nutrient requirements of beef cattle, 7th revised edition. National Academy Press, Washington, DC.

Porter MG 1992. Comparison of sample preparation methods for the determination of the gross energy concentration of fresh silage. Animal Feed Science and Technology 37, 201–208.

Porter MG and Murray RS 2001. The volatility of components of grass silage on oven drying and the inter-relationship between dry matter content estimated by different analytical methods. Grass Forages Science 56, 405–411.

Reynolds CK, Tyrell HF and Reynolds PJ 1991. Effects of diet forage-to-concentrate ratio and intake on energy metabolism in growing beef heifers: whole body energy and nitrogen balance and visceral heat production. Journal of Nutrition 121, 994–1003.

Steen RWJ 1989. A comparison of soyabean, sunflower, and fish meals as protein supplements for yearling cattle offered grass silage based diets. Animal Production 48, 127–132.

Webster J 2011. Management and Welfare of Farm Animal: The UFAW Farm Handbook, 5th edition. Retrieved July 29, 2015, from https://books.google.co.uk/books?isbn=1405181745

Yan T, Agnew RE, Gordon FJ and Porter MG 2000. Prediction of methane energy output in dairy and beef cattle offered grass silage-based diets. Livestock Production Science 64, 253–263.

Yan T, Frost JP, Agnew RE, Binnie RC and Mayne CS 2006. Relationships among manure nitrogen output and dietary and animal factors in lactating dairy cows. Journal of Dairy Science 89, 3981–3991.

Yan T, Frost JP, Keady TWJ, Agnew RE and Mayne CS 2007. Prediction of nitrogen excretion in faeces and urine of beef cattle offered diets containing grass silage. Journal of Animal Science 85, 1982–1989.

Yan T, Gordon FJ, Agnew RE, Porter MG and Patterson DC 1997a. The metabolizable energy requirement for maintenance and the efficiency of utilization of metabolizable energy for lactation by dairy cows offered grass silage based diets. Livestock Production Science 51, 141–150.

Yan T, Gordon FJ, Ferris CP, Agnew RE, Porter MG and Patterson DC 1997b. The fasting heat production and effect of lactation on energy utilization by dairy cows offered forage-based diets. Livestock Production Science 52, 177–186.