Manipulating Enteric Methane Emissions and Animal Performance of Late-Lactation Dairy Cows Through Concentrate Supplementation at Pasture

D. K. Lovett,¹ L. J. Stack,¹ S. Lovell,¹ J. Callan,¹ B. Flynn,¹ M. Hawkins,² and F. P. O'Mara¹

¹Department of Animal Science and

²Department of Statistics, University College Dublin, Dublin, Ireland

ABSTRACT

The objective of this study was to determine the potential of increased fiber-based concentrates to reduce methane (CH₄) production in relation to milk yield from late-lactation dairy cows. The effect of 2 levels of concentrate supplementation (0.87 vs. 5.24 kg on a dry matter basis) on herbage voluntary intake, total dry matter intake, milk yield, milk composition, and CH₄ production were determined by way of a randomized block designed grazing trial using lactating Holstein-Friesian cows (231 ± 44 d in milk) grazing a mixed-grass sward with a regrowth aged 36 d.

Increased concentrate supplementation resulted in a significant increase in total dry matter intake, milk yield, fat-corrected milk (FCM) yield, and daily CH₄ production. However, herbage intake and milk composition were unaffected. Although daily CH₄ production increased with fibrous concentrate use the increase was not as great as that observed for milk yield. The decline in CH₄ production per kilogram of milk was nonsignificant; however, when relating CH₄ production to FCM (FCM at 35 g of fat/kg of milk), a declining trend was identified within increasing concentrate supplementation (19.26 and 16.02 g of CH₄/kg of FCM). These results suggest that increased fibrous concentrate use at pasture, even at modest levels, could reduce enteric CH₄ production per kilogram of animal product. However, the effectiveness of such a strategy is dependent on the maintenance of production quotas and a subsequent decline in the number of livestock needed to fulfill the specified production level.

(Key words: enteric fermentation, methane, concentrate supplementation, pasture)

INTRODUCTION

Increased concentrate supplementation has been widely reported to reduce enteric methane (CH₄) pro-

duction when conserved forages formed the basal ration (e.g., Moss and Givens 1995; Ferris et al., 1999). However, in many parts of the world, pasture plays a major role in the provision of dietary energy, and although studies have been conducted in which grazing dairy cows were supplemented with concentrates to increase productivity (Dillon et al., 1997; Kennedy et al., 2003), no studies have been reported to determine the effect on enteric CH₄ production.

Reductions in CH₄ production will be higher when starch-based rather than fiber concentrates are fed to ruminants at a high level of dietary inclusion (Johnson and Johnson, 1995; Moss et al., 2000; Benchaar et al., 2001). However, pastoral based diets, unlike conserved forages, consist of high levels of water-soluble carbohydrates. Comparative studies of starch- vs. fiber-based concentrates fed at pasture have reported that the provision of additional rapidly fermentable carbohydrates into the rumen will decrease ruminal pH (Stakelum and Dillon, 2003b) and result in a greater reduction in herbage intake per increase in concentrate fed and a lower milk response (Meijs, 1986; Stakelum and Dillon, 2003a). This suggests that fiber-based concentrates could be an effective means by which CH₄ production per unit of animal product could be reduced at pasture, as the references indicate that under such conditions, fiber concentrates have a greater milk response than starch-based concentrates.

Greenhouse gases such as CH₄, carbon dioxide (CO₂), and nitrous oxide (N₂O) have the capacity to raise Earth's temperature through the absorption of long-wave radiation. However, for farm-based mitigation strategies to be effective, consideration must be given to the amount of embedded greenhouse gas emissions contained within any imported feed (Lovett et al., accepted). As such, feedstuffs composed primarily of by-products would be expected to have lower embedded greenhouse gas emissions than concentrates composed principally of ingredients specifically cultivated for ruminant feed because prefarm emissions for by-product feeds will be divisible over several usable end products.

This study was designed to assess the potential of a fiber-based concentrate to modify enteric CH₄ emis-

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Corresponding author: F. P. O'Mara; e-mail: frank.omara@ucd.ie.

sions, intake, and animal performance of dairy cows grazing a mixed-species grass sward.

MATERIALS AND METHODS

Animals and Experimental Treatment

Twenty-four Holstein-Friesian cows with a mean milk yield of 24.5 kg/d (± 5.49 kg) and a BW of 582 kg (± 51.8 kg) were used during the experiment, 18 of which were multiparous. They were all in late lactation (231 ± 44 DIM) at the start of the experiment. Preexperimental milk yields, calving date, and lactation number were used to block the experimental animals into 2 groups. The 2 levels of concentrate supplementation (1 vs. 6 kg/animal daily) were then randomly allocated within blocks, giving 12 animals per treatment (9 multiparous and 3 primiparous). The concentrate, containing a vitamin and mineral supplement (vitamin A, 6000 IU/kg; vitamin D₃, 2000 IU/kg; magnesium, 9 g/kg; copper, 52 mg/kg; selenium, 0.65 mg/kg; and iodine, 10 mg/kg) was distributed over 2 equal feeds by automatic parlor feeders at the time of milking (0530 and 1530 h). The concentrate was composed primarily (720 g/kg) of fibrous by-products, with barley and wheat constituting only 140 g/kg.

Grassland Management and Pretrial Preparation

The composition of the sward used for the experiment was approximately 40% perennial ryegrass (*Lolium perenne*), 40% rough stalk meadow grass (*Poa trivialis*), 10% annual meadow grass (*Poa annua*), and 10% white clover (*Trifolium repens*). The trial required a total of 24 single-day grazing plots consisting of herbage of constant maturity. This was achieved through the use of 2 main paddocks split into 8 subpaddocks of 0.6 ha, with each subpaddock designed to provide a total of 3 d grazing for the 24 experimental animals. Preexperimental pasture management consisted of 2 rounds of rotational grazing by the main milking herd, which was completed on June 25, 2002. The area was then divided into the 8 subpaddocks, and 3 d later, replacement heifers entered subpaddock 1 for 3 d, and then were moved to subpaddock 2 for a further 3 d. This routine continued until each subpaddock was grazed, thereby achieving herbage of the same regrowth age. The stocking rate of the heifers was varied in accordance with subpaddock pasture DM and was designed to achieve a postgrazing residual stubble height of 6 cm. Postgrazing each subpaddock received a total of 50 kg of N/ha; however, because of persistent rainfall and low herbage DM accumulation, an additional 35 kg of N/ha was applied to subpaddocks 4 and above 17 d before trial grazing commenced.

Experimental Animal Grazing Management

The experimental cows, managed as one group, entered subpaddock 1 on July 1, 2002, when the herbage regrowth was 36 d old. Strip-grazing of subpaddocks was achieved by way of temporary electric fencing. Fresh pasture was offered after each milking, with further electric fencing preventing back grazing. Pasture allocation was determined with a rising plate meter (Jenquip, Feilding, New Zealand) and was designed to achieve a constant postgrazing residual stubble height of 6 cm. The daily herbage allowance was split 45 and 55% between the daytime and nighttime allowances, respectively.

Routine Herbage and Concentrate Sampling

Pregrazing herbage mass was sampled at a height of 4 cm above ground for subsequent chemical analysis from each plot immediately prior to access by the experimental animals. Approximately 1.5 kg of herbage fresh weight was taken for each grazing plot. Samples representing grazed grass were taken by following an animal to 2 individual grazing sites within the paddock. At each site, a sample of grass immediately neighboring the grazed grass was taken with the cut height replicating that harvested by the animal. In total, 5 animals/treatment per day were sampled over 4 individual times (0630, 1030, 1630, and 1930 h). Concentrates were sampled directly from the in-line parlor feeders, with 8 feeders sampled at random once weekly. The concentrate was then bulked across feeders and subsampled.

Animal Measurements

Individual intake was determined with the n-alkane procedure of Mayes et al. (1986), with modifications as described by Dillon and Stakelum (1989). The n-alkane dosing lasted for 12 d after commencing on d 14 of the trial. Fecal grab samples were taken twice daily for 6 d commencing on d 19. Enteric CH₄ emissions were determined using the SF₆ tracer gas technique of Johnson and Johnson (1995) for 11 of the 12 animals in each group. Individual CH₄ measurements were made for a total of 5 d commencing on d 20 of the trial.

Milk yield measurements for each animal were taken daily with flow meters (Dairymaster Milk Manager Farming Systems, Co. Kerry, Ireland). Samples of milk were taken twice daily at each milking once a week; samples were then composited for each animal on a pro rata basis.

Animal Management During the Simultaneous Determination of Methane and Intake Measurements

All animals were kept within a large holding pen, from which 4 at a time were transferred to a working

Table 1. Chemical composition of the herbage and concentrate feeds (expressed as g/kg of DM unless otherwise stated) from d 19 to 24 of the trial.

Item	Herbage (n = 6)	Concentrate (n = 1)
DM (g of DM/kg of Fwt) ¹	195 (±10.3)	875
CP	137 (±18.2)	210
NDF	503 (±30.8)	328
ADF	256 (±14.7)	170
ADL	27 (±2.7)	47
Ash	81 (±30.8)	92

¹Fwt = Fresh weight.

chute leading to the head gate. Upon entering the race, the collection canister valves were closed, the collars removed, and the time recorded for each animal. Upon entering the crush, each animal was dosed with the alkane bolus, and a fecal grab sample taken. Then, depending on the time, either a new collection canister was put on the animal, the valve opened, and the time recorded (morning), or the same canister was returned to the animal and the valve opened (evening). The animal was then released into a subsidiary holding pen. This process continued until all animals were processed, at which time the experimental animals were then transferred to the new grazing paddock.

Chemical Analysis

Herbage and concentrate DM and chemical composition was determined by the methodology reported previously by Lovett et al. (2003). The n-alkane concentrations within the herbage and fecal samples used for the determination of individual animal intake values were analyzed in accordance with Mayes et al. (1986).

Statistical Analyses

The statistical effects of differing concentrate supplementation on single-measure parameters (e.g., herbage

intake and milk composition) were determined using the ANOVA procedure in Genstat 6.1 (Lawes Agricultural Trust, 1999) for a randomized block design where the response from the animal in the *j*th block, receiving the *i*th treatment, was as follows:

$$y_{ij} = \mu + T_i + B_j + C_{ij}\beta + \varepsilon_{ij} \quad [1]$$

where μ is the overall constant, or intercept; T_i models the effect of the *i*th treatment on the response; B_j models the effect of the *j*th block on the response; β models the change in the response per unit change in the covariate, C ; and the ε_{ij} are mutually independent residual terms such that $\varepsilon_{ij} \sim N(0, \sigma^2)$ for all *i, j*.

The only response variable not analyzed in this way was CH₄ (g/d). The linear mixed model equation for the response, measured in CH₄ (g/d), from an animal on the *k*th day of the *j*th block receiving the *i*th treatment is as follows:

$$y_{ijk} = \mu + T_i + B_j + \alpha_{ij} + C_{ij}\beta + \varepsilon_{ijk} \quad [2]$$

where μ is the overall constant, or intercept; T_i models the effect of the *i*th treatment on the response; B_j models the effect of the *j*th block on CH₄; β models the change in the response per unit change in the covariate, C ; the α_{ij} are mutually independent random variables such that $\alpha_{ij} \sim N(0, \sigma_u^2)$ for all *i, j*, and they account for the correlation between the repeated measurements made on the same animal; and the ε_{ijk} are mutually independent and normally distributed residual terms such that $\varepsilon_{ijk} \sim N(0, \sigma^2)$ for all *i, j, k*. The α_{ij} and ε_{ijk} random variables are assumed to be independent.

A likelihood ratio test, such that $H_0: \sigma_u^2 = 0$, indicated that the α_{ij} term was required in the model ($P = 0.0014$). The parameters in Model [2] were estimated using the REML procedure in Genstat version 6.1 (Lawes Ag-

Table 2. Effect of concentrate level on intake and animal performance (n = 12) (expressed as kilograms of DM unless otherwise stated).

Item	Low concentrate	High concentrate	SED ¹	Significance
Total DMI	17.74	21.51	0.679	***
Herbage DMI	16.86	16.26	0.679	NS
Concentrate DMI	0.87	5.24	—	—
Milk yield (kg)	17.55	22.72	1.357	**
Milk fat (g/kg)	42.1	42.9	2.34	NS
Milk protein (g/kg)	33.16	34.19	1.033	NS
Fat yield (kg)	0.716	0.926	0.0395	***
Protein yield (kg)	0.636	0.823	0.0414	***
FCM at 35 g/kg	19.20	24.92	1.119	***

¹SED = Standard error of difference.

** $P \leq 0.01$.

*** $P \leq 0.001$.

Figure 1. Crude protein and NDF concentrations (g/kg of DM) in the pregrazed sward over the trial period.

ricultural Trust, 1999). For both methods of analysis, covariates were only included when significant.

RESULTS

Chemical Composition and Pasture Management

The objective of maintaining a consistent sward throughout the grazing trial with a constant regrowth age was successful, and this was reflected in the chemical composition of the sward throughout the trial (Figure 1). However, because of the climate-induced low herbage growth rates (low temperatures and high rainfall), subpaddocks 4 to 8 required an additional 35 kg of N/ha. As such, herbage CP concentrations for the 6 d of measurement proceeding the intake and CH₄ measurement period can be seen in Figure 1 to be on average 20 g/kg of DM higher than for the rest of the trial period. The residual sward stubble height throughout the trial averaged 6.48 cm (± 0.94) for the morning subpaddocks and 6.75 cm (± 0.79) for the evening subpaddocks and demonstrated a consistent herbage allowance throughout the investigation. The mean chemical composition of the herbage grazed and the concentrate feed during the intake and CH₄ measurement period is reported in Table 1.

Effect of Concentrate Feeding Level on Dry Matter Intake

Concentrate feeding level had a significant ($P < 0.001$) effect on total DMI (Table 2), with cows in the high-concentrate treatment ingesting on average 3.77 kg/d additional DM. This increase was driven by the higher

level of concentrate supplementation, as concentrate level had no significant effect on herbage DMI.

Effect of Concentrate Feeding Level on Milk Production

Milk production and the yield of both milk fat and protein were elevated ($P < 0.01$, $P < 0.001$, and $P < 0.001$, respectively) by the level of concentrate supplementation (Table 2). With regard to milk yield, differences between the dietary treatments increased further from 5.17 to 5.72 kg when corrected for a fat content of 35 g/kg.

Effect of Concentrate Feeding Level on Methane Production

Methane emissions in terms of grams of CH₄ per cow daily increased with increased concentrate supplementation ($P < 0.05$) (Table 3). However, with increasing concentrate supplementation, methane production per unit of milk declined. Although this was not significant when expressed per kilogram of milk, when expressed at an equal fat content, the decline approached significance ($P < 0.1$), and a trend was established.

DISCUSSION

Effect of Concentrate on Voluntary Intake

The very low substitution rate identified within this study (0.14 kg of herbage DM/kg concentrate DM) is at the lower range of values published (e.g., Dillon et al., 1997; Stakelum et al., 1988; Stakelum and Dillon,

Table 3. The effect of concentrate level on methane emissions and their relationship to animal productivity.

Item	Low concentrate	High concentrate	SED ¹	Significance
CH ₄ (g/d)	346	399	25.3	*
CH ₄ (g/kg of DMI)	19.60	17.83	1.820	NS
CH ₄ (g/kg of milk)	21.0	17.7	2.01	NS
CH ₄ (g/kg of FCM)	19.26	16.02	1.731	†
CH ₄ (g/kg of milk protein)	555	509	38.1	NS
CH ₄ (g/kg of milk fat)	525	428	50.7	†

¹SED = Standard error of difference.

† $P \leq 0.10$

* $P \leq 0.05$

2003a), and may be attributed in part to the concentrate used within this study. Meijs (1986) reported that the substitution rate was reduced from 0.45 to 0.21 kg of pasture/kg of concentrate when the concentrate type was changed from a high-starch to a fiber-based concentrate. This response to differing concentrate types can be attributed to the effect high levels of starch supplementation have on ruminal pH and fiber digestion, and this presumably accounts for the much higher substitution rates within the literature when starch-based concentrates are fed. However, it also is likely that the low substitution rate identified arose from the tight grazing patterns used in this study to replicate national grazing practices, for as herbage allowance increases, the substitution rate also increases (e.g., Stockdale and Trigg, 1985; Stakelum, 1986a,b), thereby restricting the potential for the low-supplement animals to actively select their diet.

Effect of Concentrate on Milk Yield and Milk Constituent Yield

No significant effect on milk fat content was observed, which agrees with the earlier work of both Dillon et al. (1997) and Wilkins et al. (1994), although the significant increase in milk protein content observed by Wilkins et al. (1994) contrasts with the nonsignificant increase identified both in this study and in that of Dillon et al. (1997). Increased concentrate use is typically associated with a reduction in milk fat content (Sutton and Morant, 1989); however, the response at pasture is less well-characterized, with both significant and nonsignificant increases and decreases being reported (as reviewed by Bargo et al., 2003). Although milk fat content increased slightly, overall milk fat and protein yield increased significantly, demonstrating that the decrease in milk fat content arises from a dilution effect rather than a reduction in milk fat synthesis.

Increased concentrate supplementation resulted in increased milk yield within this study, with such a response at pasture widely reported (e.g., Dillon et al.,

1997; Kennedy et al., 2003; Stakelum and Dillon, 2003a). This increase in milk yield is directly attributable to the increased DMI reported here. The milk response was 1.18 and 1.31 kg of milk/kg of concentrate DM for actual and FCM milk yields, respectively. This is higher than the mean rate of 1 kg of milk/kg of concentrate DM following the review of Bargo et al. (2003); however, the substitution rate within this study was lower than average; hence, a higher than average response rate is to be expected.

Effect of Concentrate on Methane Production

Increased concentrate usage is a widely acknowledged means by which national enteric CH₄ emissions can be reduced (e.g., Moss et al., 2000). However, this experiment recorded a significant ($P = 0.05$) daily increase in CH₄ production per animal with increasing concentrate usage from 346 to 399 g of CH₄/d at the low and high level of supplementation, respectively. Although daily CH₄ emissions per animal can be reduced through concentrate supplementation, this response is quadratic, as demonstrated by the experimental work of Moss and Givens (1995) and Lovett et al. (2003). In addition, concentrate choice when implementing a possible mitigation strategy is important as the carbohydrate composition and starch source will affect enteric CH₄ emissions (Johnson and Johnson, 1995; Moss et al., 2000; Benchaar et al., 2001). The concentrate used in this study would have a lower capacity to reduce CH₄ production relative to starch-based concentrates due to its high fiber content, and in addition, even at the highest level of supplementation, the proportion of concentrate within the overall diet was only 0.24. Consequently, reductions in daily CH₄ emissions per animal were unlikely to be achieved due to the low level of dietary inclusion for 2 reasons. Firstly, the reduction in ruminal pH, assuming a response similar to that found in the study of Stakelum and Dillon, (2003b), is unlikely to be reduced to the level of 5.8 when it could be expected to have an influencing role

(Russell, 1998). Secondly, the low starch component within the concentrate would be unlikely to sufficiently stimulate the production of glucogenic volatile fatty acids to a level at which they would provide a viable alternative H^+ sink (in the form of propionate) as opposed to CH_4 within the rumen.

The Effect of Concentrate on the Relationship Between Animal Productivity and Methane Emissions

Both daily CH_4 emissions and milk production increased with increased concentrate supplementation. The rate of increase in CH_4 production for each additional kilogram of concentrate fed was 12 g of CH_4 ; this was less than the recorded increase in milk production (1.31 kg of FCM for each kg of supplementary concentrate). Consequently, emissions per kilogram of milk decreased, with a declining trend ($P = 0.1$) identified when milk yield was expressed on a FCM basis; as such, this finding merits further discussion. The ratio between CH_4 emissions and animal productivity has previously been reported to be negatively curvilinear for both beef (Kurihara et al., 1998) and milk (Kirchgesner et al., 1995) production. Reductions in CH_4 emissions per unit of animal product through increased animal productivity are achieved through the interaction of a variety of factors. Firstly, CH_4 production associated with the dietary intake required to maintain the animal is distributed over a greater amount of animal product, leading to reduction in CH_4 production per kg of animal product. Secondly, higher voluntary intakes have been reported to decrease the proportion of energy intake being lost as methane (Blaxter and Clapperton, 1965; Moss and Givens, 1995; Johnson and Johnson, 1995) due to a restriction in the extent of ruminal fermentation arising from a decrease in the mean ruminal residence time (Okine et al., 1989; Pinares-Patino et al., 2003). Ruminal fermentation patterns thus shift toward a reduced acetate-to-propionate ratio and CH_4 production because the relative strength of ruminal H^+ sources declines whereas that of H^+ sinks increases.

The carbohydrate source within a diet as reviewed by Johnson and Johnson (1995) and Moss et al. (2000) will affect the methanogenic potential of the diet. Diets containing high levels of starch will emit less CH_4 than those composed principally of structural carbohydrates, whereas high soluble carbohydrate concentrations are reported to be intermediate. As such, the potential of starch-based concentrates to reduce enteric CH_4 is widely recognized. However, comparative studies have reported a greater substitution rate and a reduced milk response when dairy cows at pasture are fed starch-rather than fiber-based concentrates (Meijs, 1986;

Stakelum and Dillon, 2003a), although other studies have reported no effect (Valk et al., 1990; Delahoy et al., 2003). Consequently, the potential of starch-based concentrates to reduce enteric CH_4 production at pasture may be reduced as the maintenance burden of CH_4 production can be associated with a reduction in animal performance. In addition, concentrate feeds are themselves associated with the emission of greenhouse gases (Lovett et al., accepted), and it is probable that when taking a systems approach, concentrates comprising fibrous by-products will have lower embedded emissions than supplementary feeds composed of specifically cultivated feedstuff crops. This study has demonstrated that the use of fiber-based concentrate feeds to supplement free-ranging dairy cows may form an effective CH_4 mitigation strategy for increased supplementation, resulting in a significant increase in milk yield, a nonsignificant decrease in CH_4 production per kilogram of DMI, and, more importantly, a declining trend in CH_4 per kilogram of FCM.

CONCLUSIONS

Although increasing the level of dietary supplementation with a fiber-based concentrate increased daily CH_4 production in free-ranging dairy cows, the low substitution rate and high milk response rate resulted in a trend of decreasing CH_4 production per kilogram of milk. This finding suggests that the use of fiber-based concentrates at pasture could form part of an effective CH_4 mitigation strategy within the dairying industry.

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