
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Strategic feeding management to mitigate enteric methane emissions and urinary nitrogen excretion.

K Garrett [ab*], MR Beck[b], and P Gregorini[b]

[a]*The University of Waikato, current affiliation is* [b]*Lincoln University. Faculty of Agriculture and Life Sciences, PO Box 85084, Lincoln University, Lincoln 7647, Christchurch*

[*]*Corresponding Author*: E-mail: Konagh.Garrett@lincolnuni.ac.nz

Abstract

MINDY, a mechanistic and dynamic dairy cow model was used to explore strategic feeding managements in early (EL) and late lactation (LL), with the aim of reducing enteric methane (CH_4 g d^{-1}) emissions and urinary N (UN g d^{-1}) excretion, while maintaining milk production. Strategies explored were a factorial arrangement of (1) herbage allowances (20, 30, 40, or 50 kg d^{-1}), (2) times of herbage allocation (AM or PM), (3) supplement types (barley grain, maize grain and silage) and (4) times of supplement allocation (AM, PM, or both). A Pareto front analysis was conducted to identify 'best compromise' treatments. Increasing herbage allowance increased consumption of fermentable carbohydrates and N, resulting in greater CH_4 and UN emissions per cow. Allocating herbage in the PM rather than the AM increased dry matter intake by 1.9 and 1.7% and milk solids (MS) by 2.3 and 0.7% in EL and LL, respectively. Afternoon forage allocation produced more CH_4 (5.1 and 3.6%) and less UN (4.7 and 7.8%) in EL and LL, respectively. Morning supplement allocation on average yielded the lowest CH_4 and UN emissions. Results indicate that feeding management can mitigate both UN and CH_4 however, MS production can be compromised depending on stage of lactation.

Introduction

New Zealand dairy cattle production systems are under increasing societal pressure to reduce environmental impact in terms of emissions of urinary nitrogen (UN) and methane (CH_4) (Foote et al. 2015). Amid these pressures, farmers must make management decisions to maintain or increase milk production to maintain farm profitability. Suitable feeding management is one of these decisions. Strategic feeding management has emerged as a potential tool to alter grazing events and rumen-fermentation patterns, and thereby intake, milk production, and UN and CH_4 emissions (Gregorini et al. 2016). Herbage composition fluctuates throughout the day, as photosynthates accumulate and water evaporates, resulting in greater DM, and total non-structural carbohydrates content, which dilutes crude protein (CP), and fibre contents (Delagarde et al. 2000; Gregorini et al. 2008). Changes in herbage composition increase herbage palatability and enhance ease of comminution and ingestion as well as rumen fermentability (Vibart et al. 2011). Consequently, matching herbage allocation to afternoon periods can alter rumen function, leading to less rumen-NH_3 production and thereby UN excretion (Gregorini 2012; Orr et al. 2001). Starch-based concentrate supplementation has been shown to reduce UN as N intake is lowered. Increasing the proportion of starch within the diet has also been shown to reduce production of CH_4 (Hassanat et al. 2012). Whilst existing literature examined the effect of timing of herbage and supplement allocation on grazing behaviours, nutrient intake and rumen function individually, reports including the impacts of management alterations on both UN excretion and CH_4 emissions are lacking.

Measurements of UN and CH_4 emission (g d^{-1}), pose considerable experimental, and technical challenges. Integrating these processes with feeding strategies is an even greater challenge. Modelling allows quick and relatively inexpensive evaluations that can accelerate efforts in a field of endeavour (Provenza et al. 2015). Therefore, using the model MINDY, our objective was to simulate UN excretion and CH_4 emissions of grazing dairy cows as effected by strategic feeding management during early (EL) and late lactation (LL) combining: herbage allowance, time of herbage allocation, supplement type and time of supplement allocation.

Methods

The model

The latest version of the model MINDY (Gregorini et al. 2018) was used. MINDY is a mechanistic and dynamic model of a grazing ruminant representing diurnal patterns of ingestion, digestion and metabolism, and production (Gregorini et al. 2018). For further information regarding MINDY the reader is directed to Gregorini et al. 2013. MINDY also represents urine excretion patterns, therefore is a suitable model to analyse the impact of strategic feeding management on UN and CH_4 emissions.

MINDY also represents urine excretion patterns, therefore is a suitable model to analyse the impact of strategic feeding management on UN and CH_4 emissions.

Virtual experiments

A factorial arrangement of treatments was designed to simulate the interaction among herbage allowance, time of herbage allocation, type of supplement, and timing of supplement allocation. Eighty instances of MINDY were initialized as multiparous Friesian dairy cows, and strip-grazed four different herbage allowances, 20, 30, 40, and 50 kg DM d^{-1}, allocating herbage after either the morning (AM) or afternoon (PM) milking. No supplement (NS), barley grain (BG), maize grain (MG) or maize silage (MZ) was also allocated in full prior to the AM or PM milking, or in two equal proportions fed prior to each milking. To maintain the same level of metabolisable energy (ME), MG (9.2% CP, 13.6 MJ kgDM^{-1} ME), MZ (9.3% CP, 10.3 MJ kgDM^{-1}), and BG (11.5% CP, 12.4 ME) were fed at 1.37, 1.81, or 1.50 kg DM, respectively. The simulated sward was perennial ryegrass-based with 200 kg N/ha per year applied, extrapolated from (Minneé et al. 2018). The simulated pre-grazing sward herbage mass was 3000 kg DM ha^{-1}.

Virtual experiments were run for 30 days in September, during EL (31 DIM), and in April, during LL (180 DIM), with the last four days taken as the 'measurement' period. The outputs required from MINDY were: dry matter intake (DMI), milk solids production (MS = Fat + CP), milk yield, UN excretion, CH_4 emissions, CH_4 yield, and emission intensity.

Data analysis

As there are likely a number of optimal dietary solutions due to the correlation between UN and CH_4, we identified the combination of treatments that best at achieved both low UN and CH4 values and maintained MS production using the multi-objective optimization technique described by Gregorini et al. (2016). In brief, a Pareto front analysis was conducted using R (R Core Team, 2019).

Interpretation of this analysis: without additional subjective or objective information the frontier "set of treatments representing the best compromise between the two constraints ie CH4 and UN" can be considered equally good. The Pareto Front values are herein described as the frontier. For example, any alteration to a frontier solution to further reduce UN will increase CH_4 production or lower MS production.

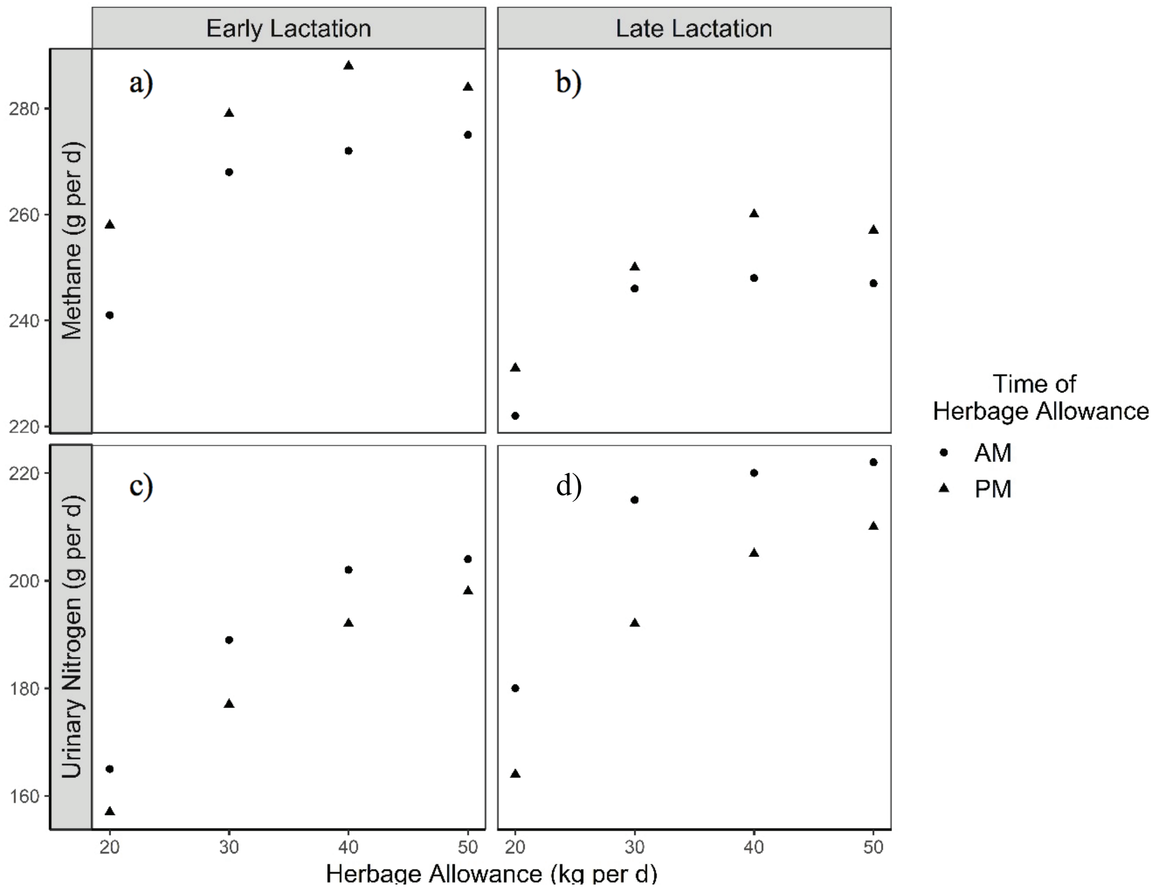
Results

Effect of herbage allowance and timing of allocation

The predicted DMI, post-grazing herbage mass (residual covers), milk yield, and MS production per cow increased with herbage allowance. The 50 kg herbage allowance DMI, milk yield, and MS were respectively 25, 5, 14, and 24 % greater than the 20 kg herbage allowance in EL. However, the predicted DMI, MS, UN excretion, CH_4 emission, and CH_4 yield increased in diminishing increments with increasing herbage allowance.

Compared to the AM herbage allocation, treatments allocated the same allowance in the PM consumed more DM (0.7-3.2%). The predicted MS production was on average 2.3% and 0.7% greater for the treatments allocated the same herbage allowance in the PM rather than the AM in EL and LL, respectively. The time of herbage allocation had the largest effect on MS production at the lowest herbage allowance. The AM treatments on average excreted more UN and less CH_4 than the treatments allocated herbage in the PM (Fig. 1).

Figure 1 Predicted effect of timing of herbage allocation either after the morning (AM) or afternoon (PM) milking at increasing herbage allowances on urinary nitrogen (a and c for early and late lactation cows) and methane emissions (b and d for early and late lactation cows).



Effect of supplement type and time of supplement allocation

The predicted DMI, herbage and supplement intake, MS production, UN excretion and CH_4 emissions for each supplement type: NS, BG, MG, and MZ are reported in Table 1. In EL, DMI increased by 3, 8 and 22% for MG, BG and MZ, respectively, compared to NS treatments. While in LL, MG, BG, and MZ treatments, respectively, consumed 4, 6, and 24% more than the NS treatments. The MS production was greatest for the MZ treatments.

In EL the mean enteric CH_4 emissions of MZ, MG, and BG were 9, 8 and 5% greater than those in the NS treatments. The NS treatment excreted the most UN in both EL and LL. The LL CH_4 emissions were 11, 0.4 and 0.4% greater for the MZ, MG, and BG treatments than for the NS treatment.

Supplement allocation in the AM, regardless of the time herbage was allocated, had on average, the lowest CH_4 emissions and UN excretion, whilst maintaining MS production (2.4 kg d^{-1}), in EL. The average CH_4 production was 1% less than that in the other treatments and UN excretion was 3% less than that in the treatments allocated supplement twice a day did. In LL, the AM treatments on average excreted 4-7% less UN and 2% less CH_4 than the other allocations of supplement.

Treatment comparison:

Enteric CH_4, UN, and MS production from all feeding strategies are presented in Fig. 2. Feeding strategies on the frontier, provide the best compromise for reducing both UN and CH_4 (Table 2). These treatments illustrate how much UN and CH_4 emissions can be reduced before reaching a compromise (i.e., the frontier), where reductions in one (CH_4 or UN) using strategic feeding management result in increased production of the other (pollution swapping) (Gregorini et al. 2016).

Discussion

Herbage allowance

MINDY predicted that increasing the herbage allowance by increasing the area available would result in greater DMI, MS production, and UN excretion and CH_4 emissions per cow. The results showed that DMI and

Table 1 Predicted effect of supplement type on intake, milk production, methane emissions and urinary nitrogen excretion. Presented data is the mean of each treatment comprising different supplement types with the standard deviation. (μ±SD).

		Early Lactation[1]				Late Lactation[1]			
Item[1]	Unit	NS	BG	MZ	MG	NS	BG	MZ	MG
DMI[2]	kg d^{-1}	14.5 ± 1.4	15.7 ± 2.1	17.7 ± 1.8	14.9 ± 1.7	12.0 ± 1.1	12.7 ± 1.8	14.8 ± 1.8	12.5 ± 1.5
Herbage intake	kg d^{-1}	14.5 ± 1.4	14.2 ± 2.1	16.3 ± 2.2	13.6 ± 1.7	12.0 ± 1.1	11.2 ± 2.1	13.6 ± 2.2	11.1 ± 1.7
Supp. intake[3]	kg d^{-1}	--	1.5 ± 0.2	1.4 ± 0.6	1.4 ± 0.0	--	1.5 ± 0.0	1.3 ± 0.6	1.4 ± 0.3
MY[4]	kg d^{-1}	24.0 ± 1	25.6 ± 1.9	27.9 ± 1.6	24.5 ± 1.3	14.1 ± 1.1	14.5 ± 0.8	19.1 ± 1.1	14.4 ± 1.2
MS[5]	kg d^{-1}	2.1 ± 0.1	2.2 ± 0.2	2.8 ± 0.1	2.1 ± 0.1	1.20 ± 0.0	1.2 ± 0.2	1.7 ± 0.1	1.2 ± 0.2
UN[6]	g d^{-1}	190 ± 17	167 ± 17	168 ± 18	172 ± 17	201 ± 24	184 ± 17	184 ± 18	182 ± 21
CH_4[7]	g d^{-1}	264 ± 15	277 ± 31	288 ± 15	284 ± 21	245 ± 12	246 ± 31	272 ± 15	246 ± 18
CH_4 yield[8]	g $kgDM^{-1}$	18.6 ± 1.4	18.2 ± 0.8	17.6 ± 1.1	18.5 ± 1.1	20.5 ± 0.5	20.2 ± 1.9	19.4 ± 1.6	20.5 ± 1.9
Emission intensity	g $kgMS^{-1}$	127 ± 4	128 ± 7	112 ± 3.5	132 ± 5.1	204 ± 4.4	210 ± 7.4	169 ± 3.5	212 ± 14.9

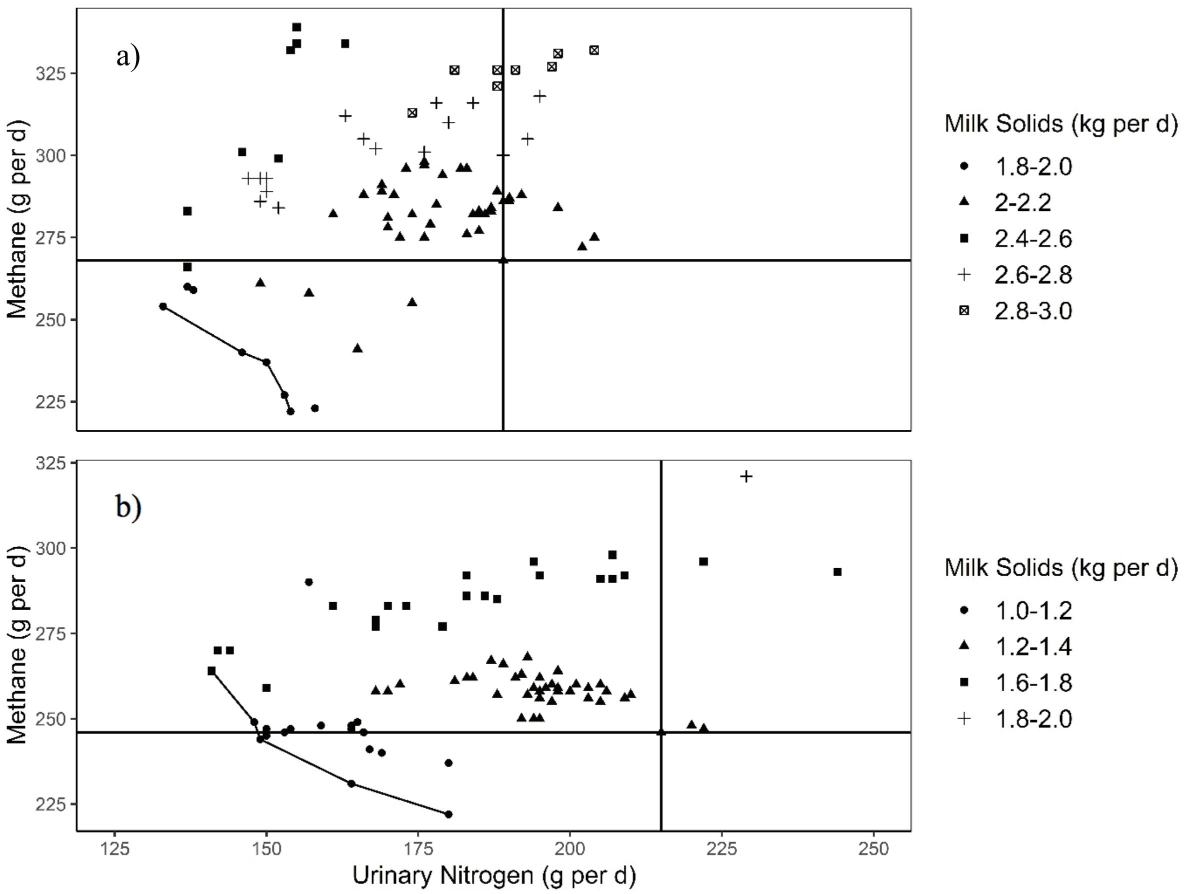
[1] NS= Non-supplemented; BG= Barley grain; MZ= Maize silage; MG = Maize grain
[2] DMI = Dry matter intake; [3]Supp. intake = Supplement intake; [4]MY= Milk yield; [5]MS = Milk solids; [6]UN = Urinary nitrogen excretion; [7]CH_4 = Methane emissions; [8]CH_4 yield = Methane yield

Table 2 Treatments appearing on the frontier during early and late lactation

Stage of lact.[1]	HA[2] ($kgDMd^{-1}$)	Time of herbage alloc.[3]	Supp. type[4]	Time of supp. alloc.[5]	DMI[6]	MY[7]	MS[8]	CH_4[9]	UN[10]
					kg d^{-1}	kg d^{-1}	kg d^{-1}	g d^{-1}	g d^{-1}
EL	20	AM	BG	AM	12.3	22.9	2.0	237	150
EL	20	AM	BG	Both	11.8	22.5	1.9	227	153
EL	20	AM	MG	AM	12.3	22.7	1.9	240	146
EL	20	AM	MG	PM	11.5	22.0	1.9	222	154
EL	20	AM	MG	Both	11.6	22.4	1.9	227	153
EL	20	PM	MG	AM	12.1	22.3	2.0	254	133
LL	20	AM	NS	--	10.2	13.3	1.1	222	180
LL	20	PM	NS	--	10.4	13.5	1.2	231	164
LL	20	PM	MS	Both	12.0	17.8	1.7	264	141
LL	20	PM	MG	AM	11.0	13.7	1.2	244	149
LL	20	PM	MG	Both	11.1	13.8	1.2	249	148

[1]Stage of lact. = Stage of lactation, EL= Early lactation, LL=Late lactation; [2]HA = Herbage allowance, [3] Time of herbage alloc. = Time of herbage allocation, AM= Morning, PM= Afternoon; [5] Supp. type = Supplement type, NS= No supplement, BG = Barley grain, MZ = Maize grain; [6] Time of supp. alloc. = Time of supplement allocation, AM= Morning, PM= Afternoon; Both= Morning and afternoon; [6]DMI= Dry matter intake; [7] MY = Milk yield; [8]MS= Milk solids; [9]CH_4= Methane emissions; [10]UN= Urinary N excretion

Figure 2 Relationship between urinary nitrogen, methane emissions and milk solids (kgd^{-1}) production during (a), early lactation (r=0.37) and (b) late lactation. (r=0.31). Points of the frontier are identified by the non-linear lines in the bottom left of each graph. The vertical and horizontal lines intersect at treatments allocated 30 kg DM in the AM as per a 'standard practice'.



MS production increased with herbage allowance with a 'diminishing return' response as metabolic requirements are satisfied, which was in agreement with Pérez-Prieto and Delagarde (2013) findings. Increases in herbage allowance resulted in greater total CH_4 emissions and UN excretion per cow, as a product of increased DMI.

Time of herbage allocation

Predicted DMI for the NS treatments allocated herbage in the PM was greater compared to the same herbage allowance allocated in the AM. Similar empirical research by Orr et al. (2001) found that the mean DMI was 1.1% greater for cows allocated herbage in the PM, although the response seen by Orr et al. (2001) may have been depressed as animals were supplemented with concentrate. The greater DMI of the cows allocated herbage in the PM expectedly resulted in a greater MS yield.

Animal's allocated herbage in the AM produced more UN and emitted less enteric CH_4 than the PM treatment did. A potential consequence of animals eating a greater portion of their daily intake immediately after herbage allocation. Throughout the day the chemical composition of herbage fluctuates, these changes are associated with water loss during transpiration and the accumulation of photosynthates (Gregorini et al. 2008). Herbages have a greater DM and water-soluble carbohydrate (WSC) content and lower CP content in the evening than in the morning (Orr et al. 2001; Gregorini 2012). MINDY's ability to simulate diurnal fluctuations of herbage chemical composition and related grazing patterns, as effected by grazing management result in differences in UN and CH_4 output between AM and PM allocated breaks. In addition, the biomechanical properties of herbages changes throughout the day, namely toughness is reduced from AM and PM (Vibart et al. 2011). Reduced toughness allows herbage consumed in the PM to be more easily comminuted (Gregorini et al. 2008), all of which cause greater fermentability (Gregorini et al. 2008), and as a result greater CH_4 emissions. Vibart et al. (2017) reported greater N use efficiency for cows allocated herbage in the PM than in the AM, as more N is partitioned into the milk. Therefore, it seems advantageous to allocate herbage in the PM when the goal is reduced UN excretion and greater milk production.

Supplement type

The addition of supplements to herbage-based diets can mitigate CH_4 production by altering the ratio of fibre to starch and protein (Dijkstra et al. 2011). However, within the present study the supplemented treatments consumed more DM than did the NS treatments, resulting in greater

CH_4 emissions. The supplements have lower CP contents than pasture, contributing to the reduced UN excreted by the supplemented treatments. The MZ treatments were less effective at mitigating total CH_4, however they decreased CH_4 yield, the later can be related to the lower degradability of the maize silage fibre (Dijkstra et al. 2011). Some of the supplemented treatments including MZ lead to greater herbage intake than non-supplemented treatments, which results in a greater mean for the former. Empirical research has shown that when feeding supplement, two types of herbage: supplement relationships could happen. One, and the most known is substitution and in rare cases, addition. Addition could explain the increased herbage intake for some of the treatments including MZ. As the readily available energy coming from soluble and undegradable starch of low MZ levels compared to the other supplements would reduce the rapid increments of concentration of rumen ammonia creating, and thereby its negative (anorexic) effect on herbage intake (Gregorini 2012). Energy supplementation is expected to increase N output and microbial CP to the small intestine. However, the microbial uptake of N to synthesis proteins can be increased if dietary energy level is increased (Lu et al. 2019). Excess of high levels of ammonia is explained by the greater N excretion in the non-supplemented cows. Although the MZ treatment, on average, consumed more pasture than the NS treatments, they excreted less UN, potentially due to the slower fermentation of the fibre-rich feed increasing the capture of N (Dijkstra et al. 2013).

Time of supplement allocation

The time supplement is allocated can alter the supply of nutrients and energy entering the rumen, in turn altering subsequent grazing events and behaviours (Gregorini 2012). The AM supplement allocation was on average the most effective at achieving our goal of reduced UN and CH_4 production while maintaining MS production. As MINDY simulates the diurnal patterns of ingestion, digestion and metabolism, differences in feeding management can alter subsequent intake patterns. If supplemented in the morning, MINDY substitutes morning herbage (higher in CP and NPN than afternoon herbage) will supplement (with lower CP and NPN) as supported by a large body of literature (Al-Marashdeh et al. 2016; Scaglia et al. 2009). This premise supports MINDY's prediction, that allocating supplement in the AM is more effective at mitigating UN and CH_4 emissions.

Treatment comparison: reducing environmental impact while maintaining or increasing MS

Each of the treatments of the frontier were treatments allocated 20 kg d^{-1}; as a result MINDY simulations grazed the swards to lower residuals than other allowances, consuming the stem-rich lower strata, high in fibre and low in protein. These treatments also consumed less DM, thereby reducing total UN and CH_4 excretions per cow. Supplementation allowed maintenance of milk production. In EL, four treatments maintained MS production whilst emitting less CH_4 and UN compared to a 'standard practice' of allocating 30 kg DM in the AM. The treatment allocated 20 kg DM herbage allowance in the PM and supplemented with BG in the AM improved MS production to 2.4 kg MS and emitted less UN and CH_4 than the 'standard' treatment. In LL, any reduction in UN and CH_4 emissions compromised MS production compared to a 'standard practice'. Reaching the frontier means making a trade-off decision, where further reduction in UN implies an increase in CH_4 or *vice versa*. The feeding management strategies investigated within this study can mitigate both UN and CH_4 when applied to a herd, stable in size; however, MS production can be compromised depending on stage of lactation.

Conclusions

Simple inexpensive alterations to feeding management can help mitigate environmental footprint avoiding pollution swapping. In the context of this study, PM herbage allocation and AM supplement allocation were more effective at mitigating UN and CH_4, while maintaining a high MS production. Although strategic feeding management can mitigate CH_4 and UN, milk production can be compromised, depending on the stage of lactation.

References

Al-Marshadeh O, Gregorini P, Edwards GR 2016. Effect of time of maize silage supplementation on herbage intake, milk production, and nitrogen excretion of grazing dairy cows. Journal of Dairy Science 99: 7213-7132.

Beukes PC, Gregorini P, Romera A 2011. Estimating greenhouse gas emissions from New Zealand dairy systems using a mechanistic whole farm model and inventory methodology. Animal Feed Science and Technology 166: 708-720.

Dijkstra J, Oenema O, Bannink A 2011. Dietary strategies to reducing N excretion from cattle: implications for methane emissions. Current Opinion in Environmental Sustainability 3: 414-422.

Dijkstra J, Reynolds C, Kebreab E, Bannink A, Ellis J, France J, Van Vuuren A 2013. Challenges in ruminant nutrition: Towards minimal nitrogen losses in cattle. In WJ Oltjen, E Kebreab, H Lapierre eds. Energy and Protein Metabolism and Nutrition in Sustainable Animal Production. The Netherlands: Wageningen Academic Publishers. Pg 47-58.

Foote KJ, Joy MK, Death RG 2015. New Zealand dairy farming: milking our environment for all its worth. Environmental management 56: 709-720.

Gregorini P 2012. Diurnal grazing pattern: its physiological basis and strategic management. Animal Production Science 52: 416-430.

Gregorini P, Beukes PC, Romera AJ, Levy G, Hanigan MD 2013. A model of diurnal grazing patterns and herbage intake of a dairy cow, MINDY: Model description. Ecological Modelling 270, 11-29.

Gregorini P, Beukes PC, Dalley D, Romera AJ 2016. Screening for diets that reduce urinary nitrogen excretion and methane emissions while maintaining or increasing production by dairy cows. Science of The Total Environment 551: 32-41.

Gregorini P, Gunter S, Beck P 2008. Matching plant and animal processes to alter nutrient supply in strip-grazed cattle: timing of herbage and fasting allocation. Journal of Animal Science 86: 1006-1020.

Gregorini P, Provenza FD, Villalba JJ, Beukes PC, Forbes MJ 2018. Diurnal patterns of urination and drinking by grazing ruminants: a development in a mechanistic model of a grazing ruminant, MINDY. Journal of Agricultural Science 156: 71-81.

Gregorini P, Soder K, Sanderson M, Ziegler G 2009. Toughness, particle size and chemical composition of meadow fescue (Festuca pratensis Hud.) herbage as affected by time of day. Animal Feed Science and Technology 151: 330-336.

Hassat F, Gervais R, Julien C, Massé DI, Lettat A, Chouinard PY, Petit HV and Benchaar C 2013. Replacind alfalfa silage with corn silage in dairy cow diets: Effects on enteric methane production, ruminal fermentation, digestion, N balance, and milk production. Journal of Dairy Science 96, 4553-4567.

Lu Z, Xu Z, Shen Z, Tian Y, Shen H 2019. Dietary energy level promotes rumen microbial protein synthesis by improving the energy productivity of the ruminal microbiome. Frontiers in Microbiology 10: 847.

Minneé E, Bryant RF, Chapman D, Gregorini P 2018. Simulating the intake and nitrogen excretion from cows grazing forages fertilised with increasing rates of nitrogen. New Zealand Journal of Animal Science and Production 78: 21-25.

Orr R, Rutter S, Penning P, Rook A 2001. Matching grass supply to grazing patterns for dairy cows. Grass and Forage Science 56: 352-361.

Pérez-Prieto LA, Delagarde R 2013. Meta-analysis of the effect of pasture allowance on pasture intake, milk production, and grazing behavior of dairy cows grazing temperate grasslands. Journal of Dairy Science 96: 6671-6689.

Provenza FD, Gregorini P, Carvalho PCF 2015. Synthesis: foraging decisions link plants, herbivores and human beings. Animal Production Science 55: 411-425.

Scaglia G, Boland HT, Wyatt WE 2009. Effects of time of supplementation on beef stocker calves grazing ryegrass. II. Grazing Behavior and Dry Matter Intake. The Professional Animal Scientist 25: 749-756.

Vibart R, Pacheco D, Lowe K, Barrett B 2011. Performance, nitrogen utilization, and grazing behaviour from late-lactation dairy cows offered a fress allocation of a ryegrass-based pasture either in the morning or in the afternoon. In ‘Adding to the knowledge base for the nutrient manager’. In The Fertilizer and Lime Research Centre 24th Annual Workshop, Massey University, New Zealand.

Vibart R, Tavendale M, Otter D, Schwendel B, Lowe K, Gregorini P, Pacheco D 2017. Milk production and composition, nitrogen utilization, and grazing behavior of late-lactation dairy cows as affected by time of allocation of a fresh strip of pasture. Journal of Dairy Science 100: 5305-5318.