Assessment of the GHG footprint of the low and high input dairy systems of the Canterbury P21 farmlet trial

SLMACC Contract 131402

NZAGRC Objective 8.2

May 2016

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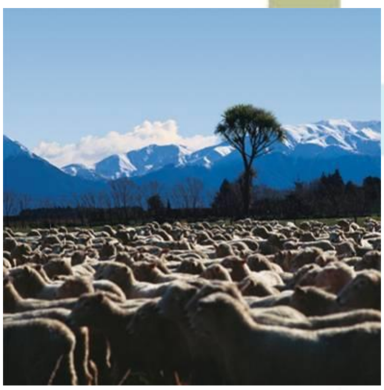

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Executive Summary

Previous farm systems modelling to quantify the role of farm management on greenhouse gas (GHG) emissions has identified promising options for reducing emissions from dairy systems. Some of these options have been included in the design of the Pastoral 21 farmlet studies that ran from 2011 to 2015 in Waikato, Manawatu, Canterbury and South Otago.

The aim of the current study was to verify the modelling assessment of these promising GHG mitigation technologies by estimating the methane (CH_4) and nitrous oxide (N_2O) footprints of the Canterbury P21 systems.

The Canterbury P21 trial examined the effect of Low Stocking Efficient (LSE) and High Stocking Efficient (HSE) dairy farm systems. The key differences between the LSE and HSE systems were, respectively, stocking rate (3.5 vs 5 cows/ha), the pasture base (standard plus diverse pasture vs standard pasture only), N fertiliser use (158 vs 311 kg N/ha/year), grain supplementation (110 vs 475 kg dry matter/cow/year), and winter crop (kale vs fodder beet).

We assessed annual GHG emissions from these systems, averaged for three seasons (2011/12, 2102/13 and 2013/14), through inventory-type calculations based on measurements and estimates of dry matter (DM) intake, CH_4 emission factors, N inputs and N_2O emission factors. These calculations were scaled up to an average size Canterbury dairy farm, with a 232 ha milking platform, and stocking at either 3.5 (LSE) or 5.0 (HSE) cows/ha.

Targeted CH_4 and N_2O measurement campaigns were conducted to measure CH_4 and N_2O emission factors for key components of the milking platform and the wintering support block for each system (CH_4 emissions from animals on ryegrass pasture, kale and fodder beet; N_2O emissions from urine deposited on ryegrass vs diverse pasture, and kale vs fodder beet).

Enteric CH_4 emissions from animals on pasture were the largest source of the GHG emissions from both farm systems. On a per farm basis, these emissions were about 20% higher in the HSE system compared to the LSE system. The HSE system also had much higher enteric methane emissions from other feed sources on the milking platform (pasture silage and grain). The higher CH_4 emissions from HSE were due to the higher DM intake of the different feeds by the HSE herd compared with the LSE herd.

The largest sources of N_2O emissions were urine and dung deposited on pasture and N fertiliser use. The urine and dung emissions were about 60% higher for the HSE system compared with LSE, while the emissions from N fertiliser in HSE were double those of the LSE system. The difference in emissions were driven by differences in N inputs from urine and dung and N fertiliser, as the emission factors were the same or very similar for both systems.

The LSE system resulted in a reduction in total on-farm emissions of about 25% compared with the HSE system. Although these estimates are surrounded by a significant level of uncertainty, they support previous farm systems modelling assessments. Our results are also comparable with previous GHG emission estimates using the nutrient budgeting model OVERSEER®, with both showing the same trend of lower GHG emissions from the LSE system.

The estimated emissions only include on-farm emissions. Yet, the HSE system uses twice as much N fertiliser and uses about 6 times as much grain supplement as the LSE system. We assessed the impact of this on total GHG emissions by estimating the emissions associated with the production of N fertiliser and grain supplement. The results show that although the emissions associated with fertiliser and grain production were 50% and 500% higher for the HSE system compared with the LSE system, these pre-farm emissions made a relatively small contribution (4-7%) to the total GHG emissions of the systems.

Glossary

BW, Breeding Worth
CH_4, methane
DM, dry matter
DMI, dry matter intake
GHG, greenhouse gas
HSE, High stocking rate efficient P21 farm system
LSE, Low stocking rate efficient P21 farm system
MS, Milksolids (milk fat + milk protein)
N_2O, nitrous oxide
P21, Pastoral 21, a collaborative venture between DairyNZ, Fonterra, Dairy Companies Association of New Zealand, Beef + Lamb NZ and the Ministry of Business, Innovation and Employment.

1. Introduction

In a previous SLMACC-funded study, promising greenhouse gas (GHG) mitigation options were identified through farm systems modelling and farmer focus groups (SLMACC project C1OXO902 “Systems analysis to quantify the role of farm management in GHG emissions”). Several of these mitigation options were included in the design of the Pastoral 21 dairy farm systems research trials. These trials investigated the practicality, economic returns and impacts to water of “increased efficiency” systems. In the current project we used data from the P21 dairy farm systems in Canterbury to assess their impacts on methane (CH_4) and nitrous oxide (N_2O) emissions.

The aim of the current project was to verify promising GHG mitigation technologies modelled in the previous SLMACC project by comparing the results of the modelling study with the estimated CH_4 and N_2O footprint of the P21 systems.

2. Methodology

The Canterbury P21-II farmlet trial examined the effect of Low Stocking and High Stocking Efficiency dairy farm systems (LSE and HSE at 3.5 and 5 cows/ha, respectively). The LSE farmlet used dairy cows with higher genetic merit than the HSE farmlet (breeding worth of 140 vs 133, respectively), and also used a combination of ‘Standard’ ryegrass/white clover pasture and ‘Diverse’ pasture (containing chicory, plantain, ryegrass, and clover). The HSE farmlet only used ‘Standard’ ryegrass/white clover pasture. In addition, LSE cows were wintered on forage kale and oats silage, while the HSE cows were wintered on fodder beet and pasture silage. The cow replacement rates for the two systems were the same and is therefore not further considered in the assessment. Table 1 provides additional details of the two farmlets for both the milking platform and the wintering support block.

We assessed annual GHG emissions from these HSE and LSE systems, averaged for three seasons (2011/12, 2102/13 and 2013/14), through inventory-type calculations based on dry matter (DM) intake, CH_4 emission factors, N inputs and N_2O emission factors. These calculations were scaled up to an average size Canterbury dairy farm, with a 232 ha milking platform, and stocking at either 3.5 (LSE) or 5.0 (HSE) cows/ha. Respective herd sizes were 812 and 1160 milking cows.

Targeted CH_4 and N_2O measurement campaigns were conducted to measure CH_4 and N_2O emission factors for key components of the milking platform and the wintering support block for each system.

Table 1. Key management features of the LSE and HSE systems, Canterbury[1]

	Low Stocking Rate Efficient	High Stocking Rate Efficient
	Milking platform	
Stocking rate (cows/ha)	3.5	5.0
Cow genetic merit	Breeding Worth 140	Breeding Worth 133
Pasture base	60% ryegrass/white clover 40% diverse pasture	100% ryegrass/white clover
Days in pasture[#]	282 (237-305)	
Milksolids production* (kg/ha milking platform/yr) (kg/cow/year)	 1662 475	 2210 442
	Winter crop	
Winter feed	Kale + oat silage	Fodder beet + pasture silage
Stocking rate (cows/ha)	15	34
Days on crop[#]	63 (58-69)	

[#] Average of 3 years, with the range given in brackets

* Fat + protein, measured in the P21 study

2.1 Methane emissions

Enteric CH_4 emissions from the HSE and LSE systems were assessed for key components that collectively make up the systems, (e.g. milking platform and winter crop block) based on estimated DM intake for the different feeds used in the farmlets and CH_4 yields (g CH_4/kg DMI) for these feeds. The emissions were converted to CO_2-equivalent emissions using the global warming potential of 25 kg CO_2-equivalent per kg CH_4.

[1] David Chapman, Ina Pinxterhuis, Dawn Dalley, Brenda Lynch, Grant Edwards, Keith Cameron, Hong Di, Pierre Beukes, Alvaro Romera (2013) Boosting the bottom line while also farming within nutrient limits? Yes, we can! SIDE conference 2013.

2.1.1 Estimating DM intake

Dry matter intake of cows grazing pastures was estimated from the difference between pre- and post-grazing pasture DM measurements. Measurements were made using a pasture plate meter, with 'clicks' being converted to DM using the 'all seasons' equation:

DM (kg/ha) = number of clicks x 140 + 500

For the winter crop block, a daily DM intake allowance was set for animals on each crop, and the size of the grazed area determined based on this allowance and the estimated crop biomass. The amount of biomass was determined from weekly cuts of the winter crop to ground level in quadrats (five 1x1m quadrats in the kale crop and three 2x2 m quadrats in the fodder beet crop). After grazing, further quadrat cuts were taken to estimate utilisation of the grazed crop. For the forage kale crop (LSE) an average utilisation of 85% was measured, while the utilisation of the fodder beet crop was 100%. Grain and silage DM intake was estimated from daily allowances and a measured utilisation rate. Average annual DM intake estimates from the different feeds are given in Table 2.

Table 2 Annual average dry matter intake (DMI; kg DM/cow/year) for different feeds in the P21 farmlet systems as estimated from pasture plate meters, or based on daily allowances of supplements and winter forage crops. n/a = not applicable.

	Feed	LSE DMI (kg DM/cow/year)	HSE DMI (kg DM/cow/year)
Milking platform	Pasture	4625	3920
	Pasture silage	370	640
	Grain	110	475
	Total Milking platform	*5105*	*5035*
Winter crop	Fodder beet	n/a	455
	Pasture silage	n/a	380
	Forage kale	515	n/a
	Oat silage	390	n/a
	Total Winter crop	*905*	*835*
	Overall total	***6010***	***5870***

2.1.2 Methane measurements

Targeted CH_4 measurements using GreenFeed emissions measurement units were conducted to estimate CH_4 yields from ryegrass pasture and the two winter forage crops used (kale and fodder beet). Details of these measurements, including the results, have been reported in the progress report for milestone 7 of this project. For completeness, this progress report is included in Appendix 1 of this report. The methane yields for diverse pasture, grain and the two silages were assumed to be the same as for the ryegrass pasture. Although grain can result in a lower methane yield[2], a recent meta-analysis showed that this only occurs when the proportion of grain in the diet is at least 40% of the diet[3]. As the proportions of grain in the diet on the milking platforms of the LSE and HSE systems were 2 and 9%, respectively, we assumed that the methane yield of the grain was the same as for ryegrass pasture (Table 3).

[2] Beauchemin KA, McGinn SM, 2005. Methane emissions from feedlot cattle fed barley or corn diets. Journal of Animal Science 83, 653-661.
[3] Moate PJ, Deighton MH, William SRO, Pryce JE, Hayes BJ, Jacobs JL, Eckard RJ, Hannah MC, Wales WJ (2016) Reducing the carbon footprint of Australian milk production by mitigation of enteric methane emissions. Animal Production Science http://dx.doi.org/10.1071/AN15222

Table 3 Methane yields (g/kg dry matter intake) for different feeds in the P21 farmlet systems. **Bold** = as measured in this project; *italics* = assuming same as value measured for ryegrass pasture; n/a = not applicable; LSE = low stocking efficient; HSE = high stocking efficient.

Feed	LSE Methane (g/kg DMI)	HSE Methane (g/kg DMI)
Ryegrass pasture	**22.3**	**22.3**
Diverse pasture	*22.3*	n/a
Grain	*22.3*	*22.3*
Fodder beet	n/a	**16.5**
Pasture silage	n/a	*22.3*
Kale	**23.3**	n/a
Oat silage	*22.3*	n/a

2.2 Nitrous oxide emissions

The N_2O emissions from the HSE and LSE systems were assessed for key components that collectively contribute to the GHG emissions (e.g. milking platform and winter crop block) through inventory-type calculations based on N input and N_2O emission factors:

Direct N_2O (kg N/year)

= (Nex-urine x EF_3urine) + (Nex-dung x EF_3dung) + (Nfert x EF_1fert) + (Neff x EF_1eff) ***(1)***

Where Nex-urine, Nex-dung, Nfert and Neff are the amounts of urine N, dung N, fertiliser N and effluent N deposited or applied, respectively; and EF_3urine, EF_3dung, EF_1fert and EF_1eff are the N_2O emission factors for urine N, dung N, fertiliser N and effluent N, respectively.

In addition, indirect N_2O emissions from the system were assessed from

Indirect N_2O (kg N/year) = (NH_3 volatilised x EF_4) + (NO_3 leached x EF_5) ***(2)***

with ***NH_3 volatilised = (Nex-urine + Nex-dung + Nfert + Neff) x FracGAS*** ***(3)***

and ***NO_3 leached = as assessed in the P21 programme***

Where, NH_3 volatilised and NO_3 leached are the amounts of ammonia volatilisation and nitrate leaching respectively; EF_4 and EF_5 are the N_2O emission factors for volatilised and leached N, repsectively; and FracGAS is the NZ value for NH_3 volatilisation (i.e. 10% of N applied).

The systems' direct and indirect emissions were then assessed by:

Total system N_2O (kg N/year) = [$\sum_i$ (direct $N_2O)_i$ + (indirect $N_2O)_i$] ***(4)***

Where *i* represents the different components of the farm system (i.e. milking platform or winter crop),

The emissions were converted to CO_2-equivalent emissions using the global warming potential of 298 kg CO_2-equivalent per kg N_2O.

2.2.1 Estimating N input

N input data

Nitrate (NO_3) leaching, Nfert and Neff data were provided by members of the P21 project. As there was no effluent applied in the farmlets, the Neff term was excluded from equation (1). However, as we did not reduce the estimated total amount of urine and dung excreted by the herds by 5% (which is the proportion that the inventory uses to estimate N in effluent), most of the N_2O emissions that would have been associated with effluent application are accounted for in our calculations.

A detailed methodology of estimating N inputs in urine and dung was provided in Milestone report 4 of this SLMACC project. For completeness, the methodology has also been included in the current report in Appendix 2. This methodology uses monthly measurements of the N content and creatinine content in the urine and the animal body weight to estimate urine N excretion, from which dung N excretion is then inferred (see *Approach 1* below). In this current report we have added a second approach for estimating Nex-urine and Nex-dung based on monthly measurements of N content in faeces, total DM intake, N content of the diet, milk yield and milk protein content (see *Approach 2* below). Both methodologies use different measurements as the main parameters and Approach 2 thus provides an independent verification of the amounts of urine and dung N estimated using Approach 1 (Table 4).

Approach 1: the monthly measurements of the N content and creatinine content in the urine and the animal body weight were used in an equation provided by (Pacheco et al 2007)[4] that assumes a constant creatinine clearance factor of 21.9 mg/per kg body weight. This enables the estimation of the total amount of urine-N excreted per unit of body weight. Based on monthly measurement of animal live weight, total N excretion per cow could be estimated. Total Nex-dung was then estimated from Nex-urine and the N content of the dry matter based on the equation used in the NZ inventory methodology (Pickering and Wear 2013)[5]:

The proportion of N excreted as urine (%) = 10.5 x N content in diet (%) + 34.4 ***(5)***

The proportion of N excreted as dung (%) = 100 - the proportion of N excreted as urine ***(6)***

Approach 2: total Nex-dung was estimated from the monthly measurements of the N content in faeces, monthly measurements of DM intake and by assuming an average digestibility of the diet of 70%, i.e. 30% of the DMI is excreted in dung[6]:

Nex-dung (kg N/cow/year) = 30% x DM intake (kg DMI/cow/year) x N in faeces (kg N/kg DM) ***(7)***

Total Nex was then estimated from total DMI, the N content of the diet and the N exported in milk as follows:

Total Nex (kg N/cow/year) = DM intake (kg DMI/cow/year) x N in diet (kg N/kg DMI) – Milk yield (kg/cow) x protein content (kg protein/kg milk) x 0.16 (kg N/kg protein) ***(8)***

Nex-urine was then estimated from: ***Total Nex – Nex-dung*** ***(9)***

[4] Pacheco D, Burke JL, Death AF, Cosgrove GP (2007) Comparison of models for estimation of urinary nitrogen excretion from dairy cows fed fresh forages. Proceeding of the Australasian Dairy Science Symposium Sep 2007.
[5] Pickering and Wear (2013) Detailed methodologies for agricultural greenhouse gas emission calculation Version 2. MPI Technical Paper No: 2013/27. Wellington: Ministry for Primary Industries
[6] Waghorn, G.C., Burke, J.L., Kolver, E.S. 2007. Principals of feeding value. In: P.V. Rattray, I.M Brookes and A.M Nicol. eds. Pasture and Supplements for Grazing Animals. New Zealand Society of Animal Production Occasional Publication 14. Pp35-59

Inputs of N fertiliser were the actual N fertiliser rates applied to the farmlets, while the N leaching losses were estimated using the nutrient budgeting model OVERSEER®[7]. Estimates of average annual N inputs and losses are provided in Table 4.

Table 4 Annual average urine and dung N excretion (estimated using approach *1* or *2*), N fertiliser applications and estimated N leaching losses (all in kg N/ha/year) for the milking platform and winter crop blocks of each P21 farm system.

	Low Stocking Rate Efficient				**High Stocking Rate Efficient**			
	Milking platform		Winter crop		Milking platform		Winter crop	
	1	*2*	*1*	*2*	*1*	*2*	*1*	*2*
N_{urine}*	245	275	158	191	362	384	307	314
N_{dung}	110	174	129	88	166	246	204	196
N_{fert}	158		307		311		200	
$N_{leached}$	35		175		53		125	

* The estimates from Approach 1 were used to estimate the N_2O emission results presented in section 3.2

2.2.2 N_2O emission factors and fractions

New Zealand default emission factors and fractions were used for all calculations, except for EF_3-urine for the milking platform, i.e. for cows on 'Standard' pasture (HSE system) vs cows on a combination of 'Standard' and 'Diverse' pasture (LSE system); and for EF_3-urine for the wintering crop, i.e. cows on fodder beet (HSE) vs cows on kale (LSE). The values for these emission factors were obtained from targeted N_2O emission measurements in two field trials (Table 5):

- Autumn trial: N_2O emission factor for standard fresh cow urine deposited in autumn to lysimeters containing either standard-ryegrass pasture (HSE) or diverse pasture (LSE) (See Appendix 3 for more details)
- Winter trial: N_2O emission factor for species-specific fersh cow urine deposited in winter to winter crop field plots containing either fodder beet (HSE) or kale (LSE)

In the Autumn trial, two rates of urine-N were included as it has been shown that 'diverse' pasture (containing plantain and chicory) will reduce the N content of animal urine (Totty *et al.* 2013)[8] and thus the N-excretion rate in individual urine patches.

For the final calculations of total N_2O emissions per farm system, the emission factors for ryegrass pasture receiving 700 kg urine-N/ha and diverse pasture receiving 500 kg urine-N/ha were used. Table 6 provides an overview of all the emission factors and fractions used for estimating the N_2O footprint of the two systems.

[7] Data provided by P21 research team.
[8] Totty VK, SL Greenwood, RH Bryant, GR Edwards (2013) Nitrogen partitioning and milk production of dairy cows grazing simple and diverse pastures. J. Dairy Sci. 96: 141-149

Table 5 N_2O emission factors for urine deposited on pasture and winter crops of the HSE and LSE Canterbury P21 farm systems.

Season	**Farm system**	**Plant species in lysimeter or field plots**	**Urine N rate*** (kg N/ha)	**EF_3 urine** (% of urine N excreted on pasture)
Autumn	HSE	'Standard' ryegrass/white clover pasture	500 700	0.69 1.12
	LSE	'Diverse' pasture (ryegrass, white clover, chicory, plantain)	500 700	0.84 1.03
Winter	HSE	Fodder beet	300	0.85
	LSE	Kale	300	1.10

* For the autumn trial, fresh cow urine collected from animals on 'standard' ryegrass/white clover pasture was used for both plants species. For the winter trial, species-specific fresh cow urine was used (i.e. urine from animals on kale for the kale treatment and urine from animals on fodder beet for the fodder beet treatment). For both trials, the N content of the fresh urine was adjusted to the same concentration, by adding either urea or water, to avoid any differences in N application rate. These concentrations reflected typical urine N concentrations of cows grazing standard or diverse pasture[9], and cows on winter crops[10].

Table 6 The N_2O emission factor and fractions used for estimating the N_2O footprint of the P21 Canterbury systems. The $EF_{3\text{-urine}}$ values (in bold and italics) are as measured in two field trials (see table 5); all other values are the default factors used in the NZ GHG inventory.

	Low Stocking Rate Efficient		**High Stocking Rate Efficient**	
	Milking platform	Winter crop	Milking platform	Winter crop
$EF_{3\text{-urine}}$	***1.12*** (ryegrass) ***0.84*** (diverse)	***1.1***	***1.12***	***0.85***
$EF_{3\text{-dung}}$	0.25	0.25	0.25	0.25
$EF_{1\text{-fert}}$	0.48	0.48	0.48	0.48
$EF_{5\text{-leach}}$	0.75	0.75	0.75	0.75
$Frac_{NH3}$	10	10	10	10
$EF_{4\text{-NH3}}$	1.0	1.0	1.0	1.0

[9] Totty VK, Greenwood SL, Bryant RH, Edwards GR, 2013. Nitrogen partitioning and milk production of dairy cows grazing simple and diverse pastures. J. Dairy Sci. 96, 141-9.
[10] Edwards, G.R., de Ruiter, J. M., Dalley, D.E., Pinxterhuis, J.B., Cameron, K.C. Bryant, R.H., Di, H.J., Malcolm, B.J., Chapman, D.F. 2014b. Urinary nitrogen concentration of cows grazing fodder beet, kale and kale-oat forage systems in winter. Australasian Dairy Science Symposium. Waikato, Nov 19-21. 2014. Pp 144-147.

3. Results

3.1 CH_4 emissions

Average annual CH_4 emissions from the P21 farmlets with 29 and 34 cows were about 3700 and 4000 kg CH_4/year for LSE and HSE, respectively. When scaled to an average size Canterbury dairy farm of 232 ha (milking platform), the emissions were about 110 and 150 t CH_4/year for the LSE and HSE systems, respectively (Fig 1). Animals on grazed pasture were the largest source of CH_4 emissions, contributing c. 75% and 70% of the total emissions for the LSE and HSE systems, respectively. The other feed sources each contributed between 2 and 11% of the emissions.

Total CH_4 emissions from the HSE system were 35% higher than from the LSE system. This was largely due to higher emissions from the HSE milking platform, as CH_4 emissions from the HSE winter crop were only 10% higher than from the LSE winter crop. When expressed per unit of milk solids produced emissions were similar for both farm systems.

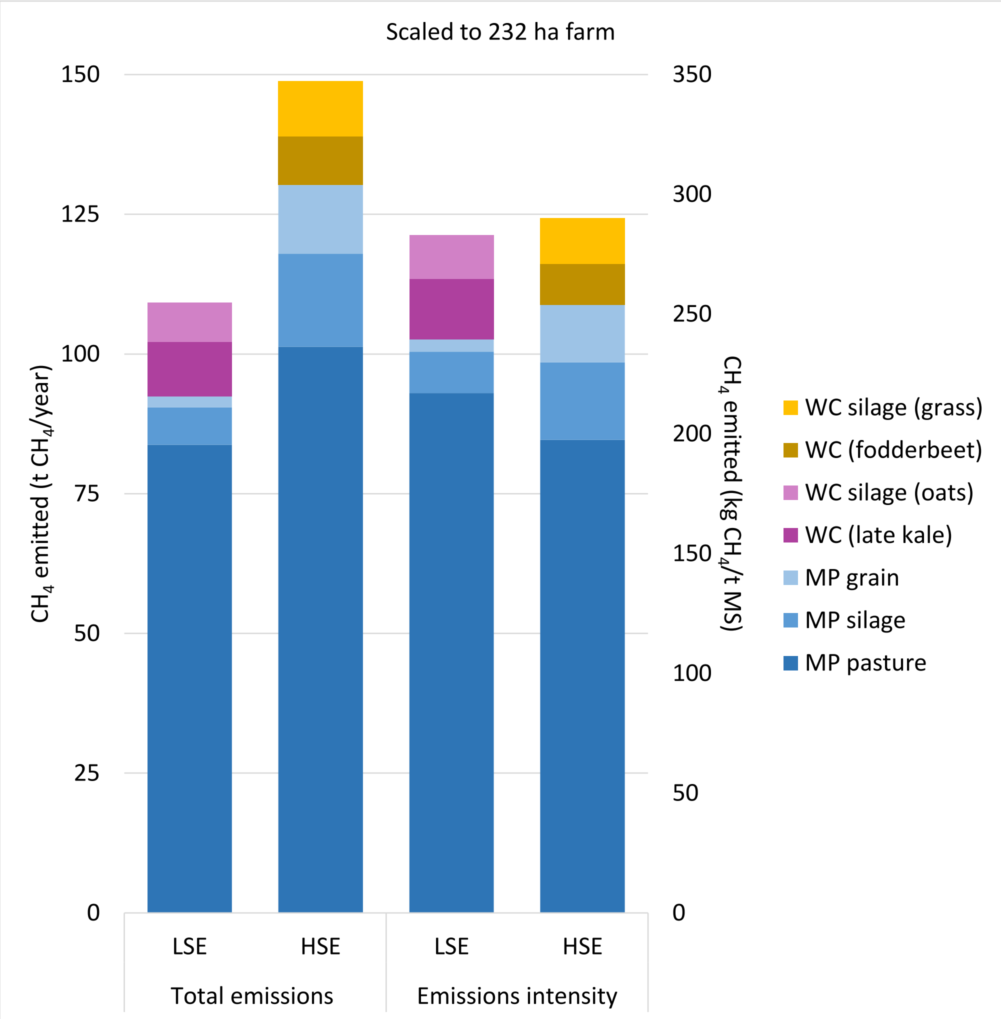

Figure 1 Average annual total CH_4 emissions (t CH_4/year) and CH_4 emissions intensity (kg CH_4/t milksolids) for the different feed sources of two 232 ha Canterbury farms based on the low stocking efficiency (LSE) and the high stocking efficiency (HSE) P21 systems. MP=milking platform, WC=winter crop.

3.2 N_2O emissions

Average annual N_2O emissions (up-scaled to an average size for a Canterbury dairy farm of 232 ha milking platform) were about 1300 and 1900 kg N_2O/year for the LSE and HSE systems, respectively (Fig 2). The largest sources of N_2O were urine+dung deposited in the milking platform, which contributed 49% and 55% in the LSE and HSE systems, respectively. Nitrogen fertiliser use in the milking platform was the second largest source, contributing 14% and 19% respectively. The other N sources each contributed between 1 and 10% of the emissions.

Total N_2O emissions from the HSE system were 45% higher than those from the LSE system. This was due to higher emissions on the HSE milking platform, as emissions from the HSE winter crop were about 35% lower than from the LSE winter crop. When expressed per unit of milk solids produced total N_2O emissions from the HSE system were only 9% higher than from the LSE system.

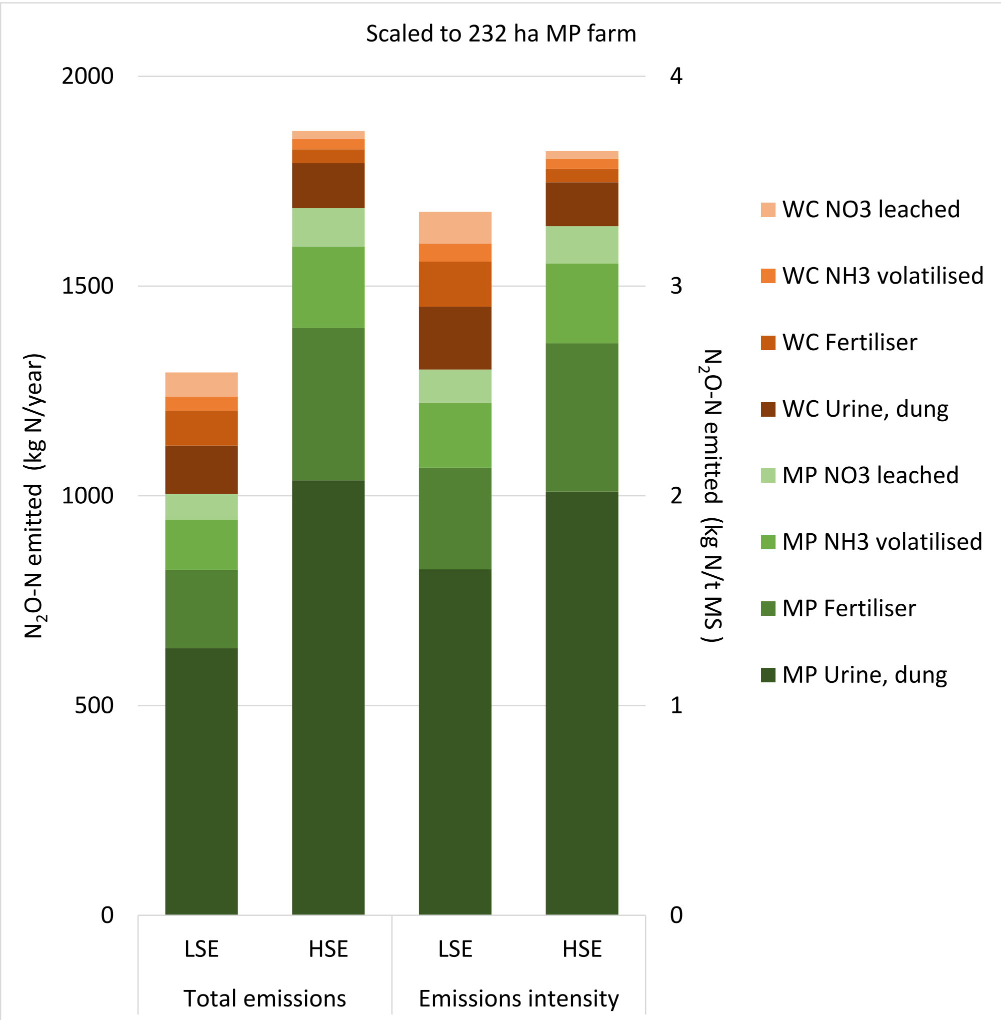

Figure 2 Average annual total N_2O emissions (kg N_2O/year) and N_2O emissions intensity (kg N_2O/t milk solids) for different nitrogen flows in two 232 ha Canterbury farms based on the low stocking efficiency (LSE) and the high stocking efficiency (HSE) P21 systems. MP=milking platform, WC=winter crop.

3.3 Total emissions

Total (CH_4 and N_2O) average annual emissions (up-scaled to an average size for a Canterbury dairy farm of 232 ha milking platform) were about 3300 and 4600 t CO_2-equivalent for the LSE and HSE systems, respectively (Fig 3). The largest source of emissions was enteric fermentation on the milking platform (69% (LSE) and 71% (HSE) of total emissions), with the enteric CH_4 from animals on the winter crop contributing another 12% and 10% for LSE and HSE, respectively. The N_2O emissions contributed 18-19% of total emissions.

Total emissions from the HSE system were 38% higher compared with the LSE system. This was due to higher emissions on the milking platform, as the emissions from the winter crop were very similar for both systems (550 vs 556 t CO_2-eq/year). When expressed per unit of milk solids produced, total emissions were also similar for both systems (8.6 vs 9.0 t CO_2-eq/t MS)

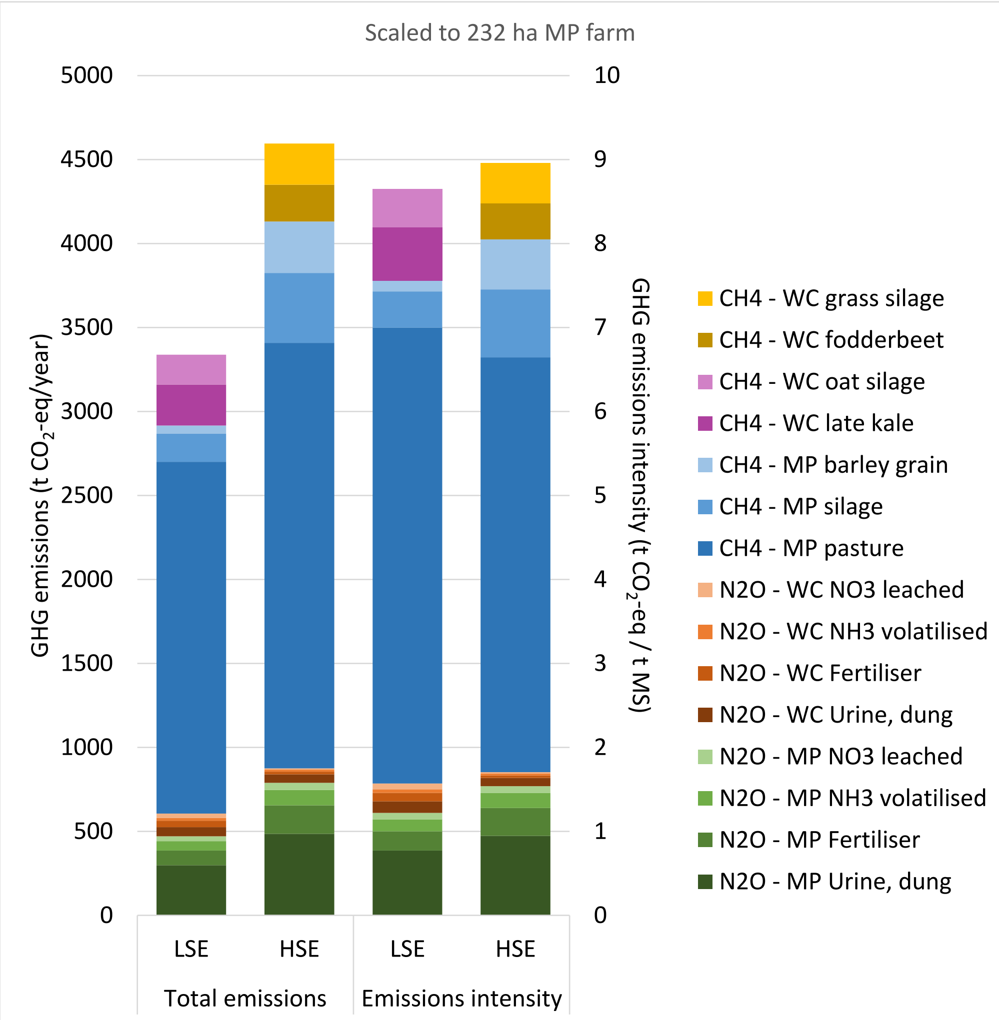

Figure 3 Average annual GHG emissions (CH_4 + N_2O in t CO_2-eq/year) and GHG emissions intensity (t CO_2-eq/t milksolids) for the different feed sources and nitrogen flows in two 232 ha Canterbury farms based on the low stocking efficiency (LSE) and the high stocking efficiency (HSE) P21 systems. MP=milking platform, WC=winter crop.

3.4 Comparison with previous modelling

The estimates in this study were compared with a previous modelling study conducted for the P21 Canterbury farmlets[11]. This showed that the estimates from the current study were comparable to previous estimates using the nutrient budgeting model OVERSEER® (Fig 4).

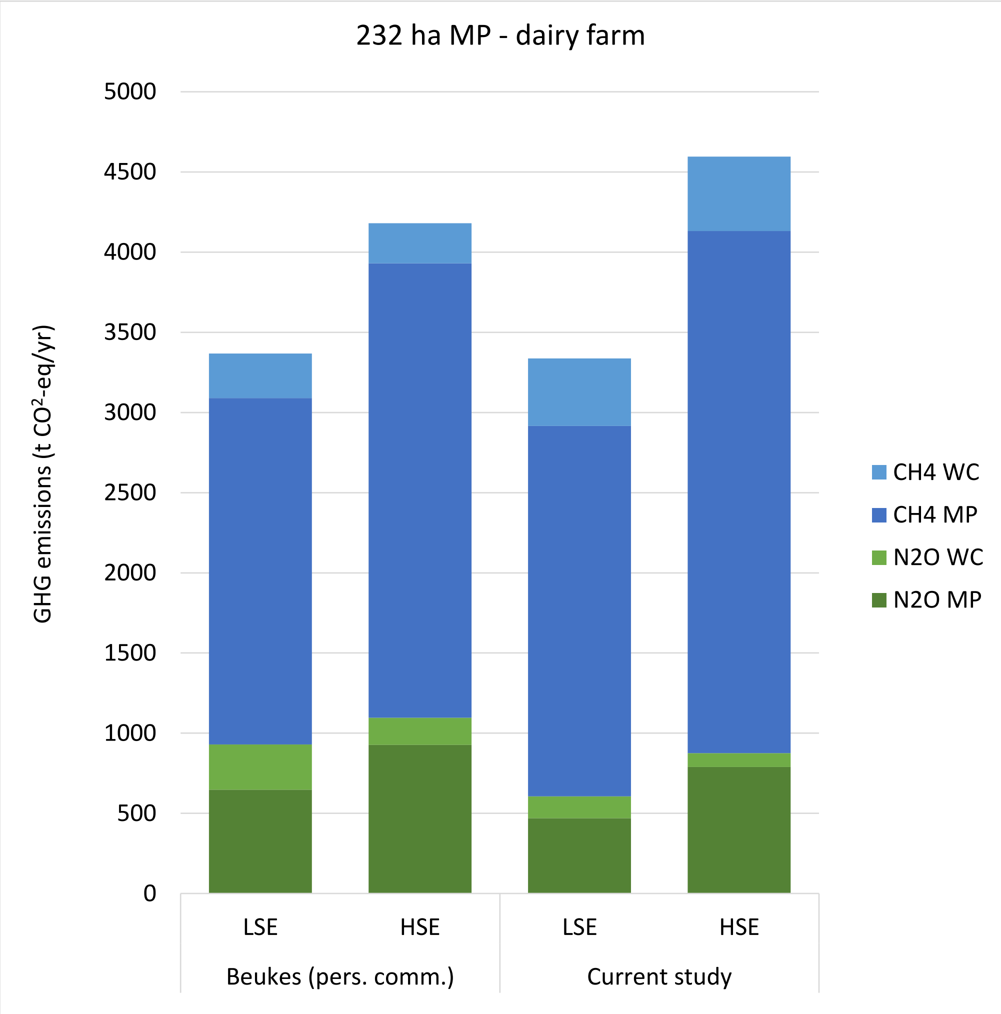

Figure 4 Comparison of average annual GHG emissions (CH_4 + N_2O in t CO_2-eq/year) for the different components of two 232 ha Canterbury farms based on the low stocking efficient (LSE) and high stocking efficient (HSE) P21 systems as estimated in the current study and based on OVERSEER® modelling (Beukes et al. 2011[11] and Beukes pers. comm.).

[11] Beukes PC, Romera AJ, Gregorini P, Clark DA, Chapman DF (2011) Using a whole farm model linked to the APSIM suite to predict production, profit and N leaching for next generation dairy systems in the Canterbury region of New Zealand. 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011 http://mssanz.org.au/modsim2011. PC Beukes pers. comm.

4. Discussion

Enteric CH_4 emissions from animals on pasture were the largest source of GHG emissions from both farm systems. These emissions were about 20% higher in the HSE system compared to the LSE systems. The HSE system also had much higher enteric methane emissions from other feed sources on the milking platform (pasture silage and grain). As we used the same CH_4 yield (g CH_4/kg DMI) for the different feed source fed on the milking platform, the higher CH_4 emissions from HSE were due to the higher DM intakes by the HSE herd compared with the LSE herd. Although grain can result in a lower methane yield[12], a recent meta-analysis showed that this only occurs when the proportion of grain in the diet is at least 40% of the diet[13]. As the proportions of grain in the diet on the milking platforms of the LSE and HSE systems were 2 and 9%, respectively, we assumed that the methane yield of the grain was the same as for ryegrass pasture. The methane emissions from the winter crop were slightly higher for the LSE herd on kale vs the HSE herd on fodder beet, partly due to the lower CH_4 yield measured for fodder beet. However, the HSE herd was fed more silage in addition to the winter crop and, as a result, total CH_4 emissions from the winter period were very similar for the two systems.

The largest sources of N_2O emissions were urine and dung deposited on pasture and N fertiliser use. The urine and dung emissions were about 60% higher for the HSE system compared with LSE, while the N fertiliser emissions in the HSE system were double those of the LSE system. The difference in emissions were driven by differences in N inputs from urine and dung, and N fertiliser as the emission factors were the same for both systems. The exception was the factor used for the diverse pastures of the LSE milking platform area. Here we used a lower EF_3 of 0.84%, compared with 1.12% the standard pasture. However, as only 40% of the pasture base of the LSE system was diverse pasture, the effect of the lower EF_3 on total emissions was relatively small as it resulted in a weighted average emission factor for the LSE system of 1.01% (=0.4*0.84% + 0.6*1.12%) compared with 1.12% for the HSE system.

Estimations of the amounts of urine and dung N excreted in the systems therefore had a significant effect on the N_2O emission estimates. As N excretion rates are notoriously difficult to determine, we used two independent approaches to estimate them. One approach was based on monthly measurements of animal live weight and N and creatinine concentrations in the urine, and assuming a constant creatinine clearance rate per unit of live weight[14]. The measured N content of the diet was then used to partition N excretion between urine and dung, using the equation from the national N_2O inventory[15]. The other approach was based on measurements of dry matter intake, the N content in the diet and the N content in faeces and assuming an average digestibility of the diet of 70%[16]. Despite being based on different measurements and using different assumptions, the two methods resulted in very comparable N excretion rates, thus providing confidence in the estimates.

If should be noted that the GHG emission estimates are surrounded by a significant level of uncertainty due to the inherent variability in both the CH_4 and N_2O emission factor measurements

[12] Beauchemin KA, McGinn SM, 2005. Methane emissions from feedlot cattle fed barley or corn diets. Journal of Animal Science 83, 653-661.

[13] Moate PJ, Deighton MH, William SRO, Pryce JE, Hayes BJ, Jacobs JL, Eckard RJ, Hannah MC, Wales WJ (2016) Reducing the carbon footprint of Australian milk production by mitigation of enteric methane emissions. Animal Production Science http://dx.doi.org/10.1071/AN15222

[14] Pacheco D, Burke JL, Death AF, Cosgrove GP (2007) Comparison of models for estimation of urinary nitrogen excretion from dairy cows fed fresh forages. Proceeding of the Australasian Dairy Science Symposium Sep 2007.

[15] Pickering and Wear (2013) Detailed methodologies for agricultural greenhouse gas emission calculation Version 2. MPI Technical Paper No: 2013/27. Wellington: Ministry for Primary Industries

[16] Waghorn, G.C., Burke, J.L., Kolver, E.S. 2007. Principals of feeding value. In: P.V. Rattray, I.M Brookes and A.M Nicol. eds. Pasture and Supplements for Grazing Animals. New Zealand Society of Animal Production Occasional Publication 14. Pp35-59

and the estimates of the input data (in particular, the annual DM intakes of the LSE and HSE herds and the annual N excretion levels). As indicated in Appendix 1, the DM intake estimates that were used to estimate the CH_4 emission factors, have an estimated uncertainty of 10-15%. Similarly, the measured N_2O emissions have a standard error of about 15% (Appendix 3). There was also a 10-20% difference in the urine Nex values of the LSE herd as estimated using the two different methods (see Table 4). For the HSE herd this difference was smaller at 2-6%. The difference in dung Nex values was greater than for urine (up to 50%), but as the dung emission factor is only a quarter of the urine emission factor, the impact of this variability on N_2O emissions will have been lower. We could not conduct a full uncertainty analysis of the total GHG emission estimates as this was outside the scope if the current project.

The design of the P21 farmlet systems was based on systems and nutrient budget modelling. This modelling suggested that the GHG emissions from systems with fewer cows with a higher per-cow production could be lower[17]. Our results support this modelling assessment, with the LSE system indeed resulting in a reduction in on-farm emissions of about 25% compared with the HSE system. The modelling also suggested that systems with fewer cows with a higher per-cow production could reduce GHG emissions intensity (i.e. emission per unit of product). However, in our study the estimated GHG emission intensities were similar for the two systems. This could be due to the fact that the two systems did not only differ in terms of the stocking rate and per-cow production; other differences included, the pasture base, fertiliser and grain use, and the wintering crop. Furthermore, total MS production of the LSE system was lower than for the HSE system. The latter may explain why the LSE system did only show a lower not show a lower GHG intensity than the HSE system, as was suggested by the earlier modelling where production levels between systems were very similar.

The reduction in emissions from the LSE system was due to reduced emissions from milking platform, as the emissions from the LSE winter crop (kale) were higher than those of the HSE winter crop (fodder beet). Thus, even at the higher stocking rate of the HSE system, wintering on fodder beet resulted in lower emissions. Therefore, if fodder beet was used as the winter crop in the LSE system this may result in even lower total GHG emissions than the current LSE system.

Our results are also comparable with previous GHG emission estimates using OVERSEER®, although our CH_4 emissions were higher, and N_2O emissions lower, than the OVERSEER® estimates (Figure 4). The higher CH_4 emissions could be due to differences in both the DM intake estimates as well as the CH_4 yields used. Our DM intake estimates and some of the CH_4 yield estimates are based on actual measurements, while OVERSEER® uses the NZ default CH_4 yield for all feeds (21.6 g CH_4/kg DMI). The lower N_2O emissions are probably a combination of differences in urine and dung input estimates as well as a difference in the $EF_{3\text{-dung}}$ OVERSEER® still using the previous NZ default value of 1%, instead of the current default value of 0.25%. Nevertheless, our results and the OVERSEER® estimates show the same trend of lower GHG emissions from the LSE system.

The estimated emissions only include on-farm emissions. Yet, the HSE system uses twice as much N fertiliser and about 6 times as much grain supplement as the LSE system. We assessed the impact of this on total GHG emissions by estimating the emissions associated with the production of N fertiliser and grain supplement. The GHG emissions associated with the production of N fertiliser were estimated using a 'manufacturing emission factor' for urea of 1.056 kg CO_2-eq/kg

[17] Beukes PC, Gregorini P, Romera AJ, Levy G, Waghorn GC (2010) Improving production efficiency as a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand. Agriculture, Ecosystems and Environment 136: 358–365

urea[18]. The GHG emissions associated with grain production were estimated using an emission factor of 0.344 kg CO_2-eq/kg grain (S.F. Ledgard and S. Falconer, pers. comm.). The results show that the emissions associated with fertiliser were 50% higher for the HSE system compared with the LSE system, while imbedded emissions from grain production were about 5 times higher for HSE (Figure 5). However, in both systems these pre-farm emissions only made a small contribution to the total GHG emissions, contributing 4% and 7% of total pre-and on-farm emissions for the LSE and HSE system, respectively.

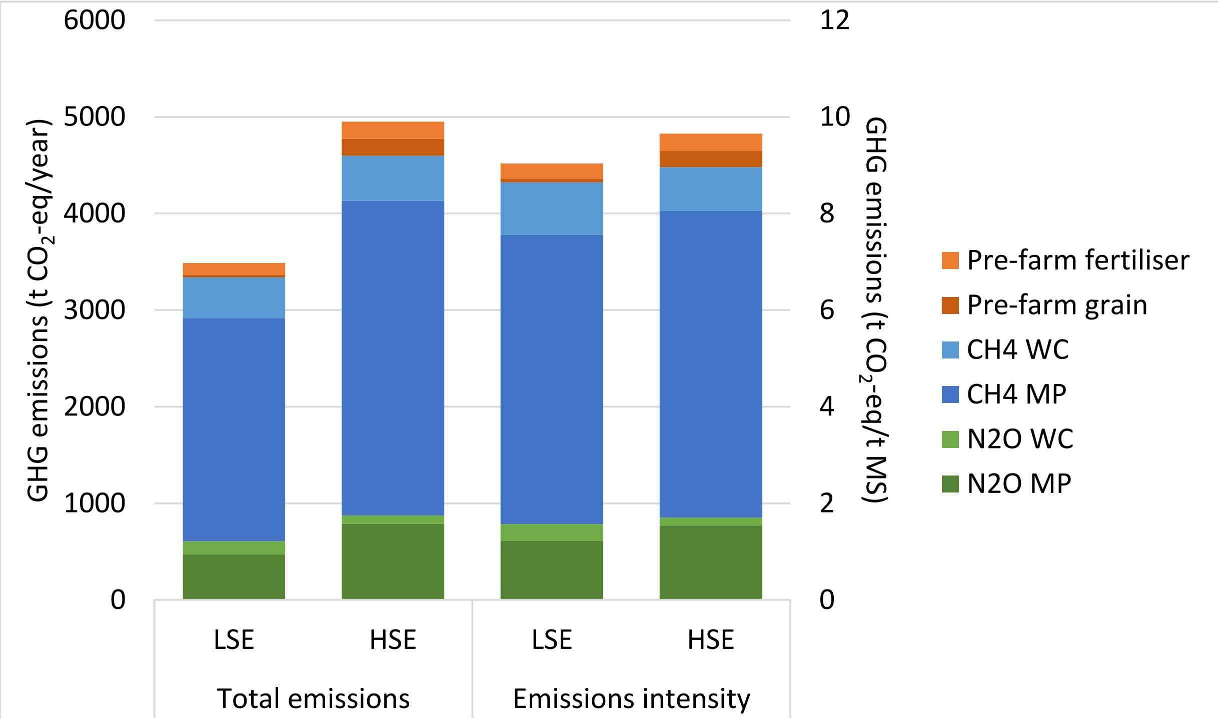

Figure 5 Total GHG emissions and GHG emissions intensity of on-farm emissions and emissions associated with pre-farm N fertiliser and grain production for two 232 ha Canterbury farms based on the low stocking efficiency (LSE) and the high stocking efficiency (HSE) P21 systems. MP=milking platform, WC=winter crop.

[18] Ledgard, S.F., Boyes, M., Brentrup, F., 2011. Life cycle assessment of local and imported fertilisers used on New Zealand farms. In: 'Adding to the knowledge base for the nutrient manager'. Eds. Currie L D, Christensen C L. http://flrc.massey.ac.nz/publications.html. Occasional Report No. 24, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 13p.

5. Conclusions

The estimates of the GHG footprint of the Canterbury P21 dairy systems suggests that the HSE milking platform had higher total emissions than the LSE milking platform. In contrast, the estimated GHG emissions from the wintering support block were lower for the HSE compared to the LSE system. For the milking platform and winter crop combined, total GHG emissions were higher for the HSE system. However, the GHG intensities were very similar for the two systems.

Using fodder beet as the winter crop in the LSE system, may result in even lower total GHG emissions than the current LSE system.

Although our estimates are surrounded by a significant level of uncertainty inherent to assessing GHG emissions from livestock systems, they compare reasonably well with previous modelling estimates of GHG emissions of the P21 Canterbury farmlets. Total emissions were slightly higher when estimated using OVERSEER®, but our results showed the same trend of lower GHG emissions from the LSE system.

Pre-farm gate emissions from fertiliser and grain production contributed only 4 and 7% of the total GHG emissions for the LSE and HSE systems, respectively.

6. Acknowledgements

Many thanks to the P21 Canterbury research team for access to the data of the P21 farmlet trail, Anna Clement from DairyNZ and Rachael Bryant from Lincoln University for collating and providing advice on the data, and to Pierre Beukes from DairyNZ for the OVERSEER modelling data.

7. Appendix 1 – Methane emissions from dry and lactation dairy cows grazing winter forage crops and pastures used in the P21 Canterbury farmlets

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[1]DairyNZ, Hamilton; [2]AgResearch Grasslands, Palmerston North

BACKGROUND

This document relates to:

- SLMACC project "Testing of Mitigation Options Through Modelling Dairy Farm Systems" (Agreement number AGR131402) – Milestone 7

No.	Milestone Description	Milestone completion date	Evidence of milestone completion
7	A series of field measurements of methane emissions has been completed analysed and reported	31 January 2016	A report on results submitted

- NZAGRC Integrated Farm Systems Project milestone 8.2.3c Report on CH_4 emissions from LSE cows on kale winter forage with HSE cows on fodder beet winter forage.

Milestone 8.2.3	Effect of forage species and low stocking (LSE: 3.5cows/ha) or high stocking rate (HSE: 5.0 cows/ha) efficient systems on GHG emissions-Canterbury
Deliverables	b. Report on CH_4 emissions from LSE cows on kale winter forage with HSE cows on fodder beet winter forage by 30 Dec 2015.

The SLMACC project aims to assess GHG emissions (methane (CH_4) plus nitrous oxide (N_2O)), from the Canterbury P21 farmlet systems through inventory-type calculations based on dry matter (DM) intake, CH_4 emissions, N input and N_2O emission factors. The NZAGRC-IFS project will measure GHG emissions across multiple P21 farmlet systems, assess these emissions and combine these with farm systems modelling to provide an integrated assessment.

This report provides the details on the CH_4 emissions from cows on different feeds that are used in the P21 Canterbury farmlet studies. Two CH_4 studies were conducted, one comparing CH_4 emissions from pregnant dry dairy cows on the winter crops, kale and fodder beet (Part 1 of this report; funded by NZAGRC); and one comparing CH_4 emissions from lactating dairy cows on pasture and pasture plus 3 kg fodder beet (Part 2 of this report funded by SLMACC).

Part 1 Methane emissions from the winter feeding kale and fodder beet trials
METHODS

These trials were the first undertaken using the new GreenFeed (GF) units, 76 and 77. Unit 76 was commissioned first and was placed with about 25 pre-calving cows grazing kale with barley straw supplementation. The second unit (77) was delivered 3 weeks later and placed with cattle grazing fodder beet supplemented with pasture silage (FBS) in early August 2015. As part of these trials, an experimental protocol for cow experimentation has been developed and the GreenFeed standard operating procedure (SOP) has been refined.

The implementation of GF with pregnant dry cows grazing the winter feeds was intended but opportunistic, rather than a planned trial. Animals were added and removed from the kale crops as determined by farm management. Removal of some animals was related to imminent calving and other feed options available, but numbers were maintained through addition of heifers. As a consequence, animals, and animal numbers varied over the 8 week period during which measurements were undertaken. There were fewer animal movements on the 3 week fodder beet/silage treatment. Both GF units were removed from cows/crops on 17th September, 2015.

This first use of GF has enabled robust measurements of methane and carbon dioxide emissions, as well as circadian patterns of emission, rates and frequency of cow visitation. Variation in animal numbers and the absence of RFID tags in some individuals has precluded assessment of the numbers of animals using GF, especially in kale treatment. Another limitation concerns the calculation of methane yields, which is reliant on estimating liveweight gain as well as liveweight (SCA 1990) to estimate intakes based on metabolisable energy (ME) requirements. Insufficient measurements of liveweight were available to accurately determine individual daily gain (and individual intakes), so mean values for daily gain have been assumed for the two diets, enabling estimations of intake and methane yield (g CH_4/kg DMI).

RESULTS

Feeds

The diets were: kale plus 3kg of barley straw DM/cow/day and fodder beet with 6kg DM/cow/day of grass silage (replaced by 6kg/cow/day of oat silage in the last 2 weeks). Feed analyses were not available when intake calculations were made, so other data were used as follows:

1. In recent DairyNZ metabolism stall trials, the DM digestibility of a diet comprising 34% silage plus fodder beet was 79% and will be used in the estimates of intake for the FBS treatment, with a dietary ME of 12.0 MJ/kg DM. The ME of fodder beet will be near 13 MJ ME/kg DM, but silage ME may be about 10.0 MJ/kg DM.
2. A lower ME was used for kale and straw, because straw ME will be about 8 MJ/kg DM and kale stalks will be a bit gnarly. It is likely that intakes of barley straw would have been 1-2 kg DM/cow/day, despite 3 kg DM/cow offered, and a substantial amount of kale stalk was not eaten, so a DM digestibility of 74% and an ME of 11.5 MJ/kg DM was assumed for this diet.

Chemical analyses require further assessment and have not been presented here.

Estimation of intakes

As the GF measurements were not part of the winter management plan, some of the data required for the estimation of DM intake were unavailable. Calculation of individual intakes require cow breed, live weight, BCS, daily gain, age and days pregnant, as well as estimated DM digestibility and ME content of the diet eaten. The cows were Holstein-Friesian and calculations were based on the following:

1. Their body condition score (BCS) was that closest to the date when measurements were made; mostly 5.0-5.5.
2. Daily gain in animals fed kale was derived from a weight on 23rd July and another on 17th September. Ideally there needs to be three weights pre and post measurement period (because of 20-40 kg fluctuations in weights of adults). The average gain for cows that had

not calved by 17th September was 0.35 kg/day, so this value was applied to all cows fed kale.

3. With fodder beet (FBS), estimated weights were determined from 20th May - 23rd July and averaged 0.75 kg/d. The average daily gain was determined from a few cows from 23rd July to 17th September and although it was 0.83, it was biased by one value, so estimated weights were set at 0.75 kg/day for all cows.
4. Mean liveweight was determined for the mid-point of the measurement period, and all were in the last trimester of pregnancy.

Uncertainty of intake estimates

Total dry matter intake was difficult to estimate and it was impossible to know how much silage or straw were eaten with fodder beet and kale, respectively. Although individual live weights, and especially live weight gains, will differ from those used in the estimates, it is not possible to improve on accuracy of these estimates as the required measurements are unavailable. As a result, it is anticipated that there is a 10-15% variation around the mean values for intakes (and methane yield).

Table 1.1 Age, liveweight (± st.dev) and estimated intakes of cows used for Greenfeed measurements. The three categories of kale relate to time periods associated with its maturity and movement of groups of cattle onto and from the crop.

	cows	Age (y)	BCS	Liveweight	Estimated intakes; cow/day	
				Mean ± st.dev.	MJ ME	kg DM
Early kale	14	3.1	5.4	554 ± 83.1	111	9.7
Kale	13	5.2	5.1	633 ± 61.8	118	10.3
Late kale	9	3.8	5.3	525 ±78.4	109	9.5
Fodder beet	22	4.5	5.1	603 ± 78.9	132	11.0

BCS, body condition score; MJ ME, megajoules of metabolisable energy

GreenFeed visits

The numbers of cows visiting GreenFeed are presented in Table 1.2, along with frequency of visits and a coefficient of variation. We have not attempted to determine the percentages of cows that visited GF because cows entered and were removed from the paddock where GF was located and because some did not have RFID tags, which are essential for a reward of pellets and gas measurements.

The distribution of visits over 24 h was similar for the cows on both treatments, with lowest visitation between 03.00-07.00 h and to a lesser extent between 19.00 – 22.00h (Figure 1.1).

Table 1.2 Number of cows visiting GreenFeed when fed kale (with a straw supplement) and fodder beet (with a silage supplement), total number of measurement days and frequency of daily visits

	Cows (n)	Measurement days	Average number of daily visits/cow# Mean ± st. dev)	CV (%)
Early kale	14	~ 24	2.0 ± 1.10	54
Kale	13	~ 26	1.3 ± 0.63	47
Late kale	9	~ 20	2.0 ± 1.52	77
Fodder beet	22	~ 24	1.6 ± 0.94	59

CV, coefficient of variation; #relates to cows that visited GF only

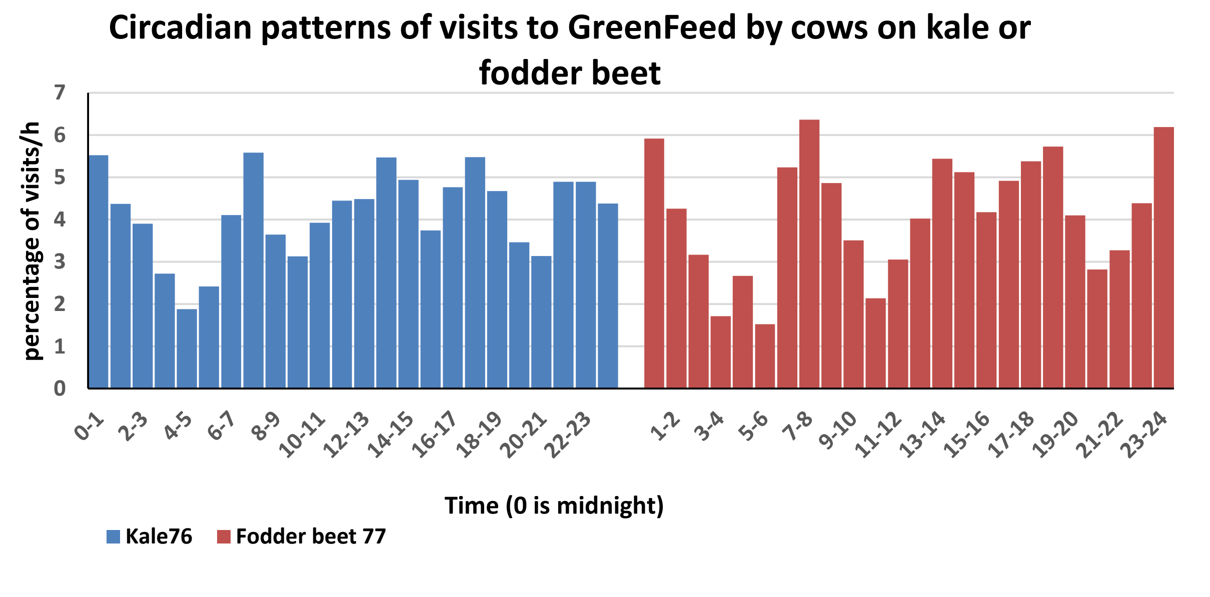

Figure 1.1 Distribution of cow visits to GreenFeed over 24h (percentage of daily visits in each hour).

Gas emissions

Mean daily emissions for methane and carbon dioxide are summarised in Table 1.3, and show lowest values for both gases for cows fed in the FBS treatment, despite highest intakes (Table 1.1).

Table 1.3 Gas emissions (mean ± st.dev.) estimated by GreenFeed from dry cows fed either kale with a straw supplement or fodder beet with silage supplement

	CH_4 (g/d)	CO_2 (g/d)	CH_4/CO_2 molar ratio
Early kale (n=14)	213 ± 18.0	9005 ± 1141	0.066 ± 0.0070
Kale (n=13)	244 57.5	9550 ± 1070	0.070 ± 0.0145
Late kale (n=9)	221 ± 32.2	9156 ± 1347	0.067 ± 0.0058
Fodder beet (n=22)	180 ± 27.1	7890 ± 731	0.063 ± 0.0088

NB, the high variance in the Kale group is probably a consequence of a rumen fistulated cow.
The pattern of methane emissions (Figure 1.2) showed a marked decline in methane emission rate from cows fed kale from about 04.00 to 09.00h, and a lesser decline with the fodder beet diet from 07.00 – 10.00h. Overall emissions were higher from cows fed kale than fodder beet (Table 1.3, Figure 1.2).

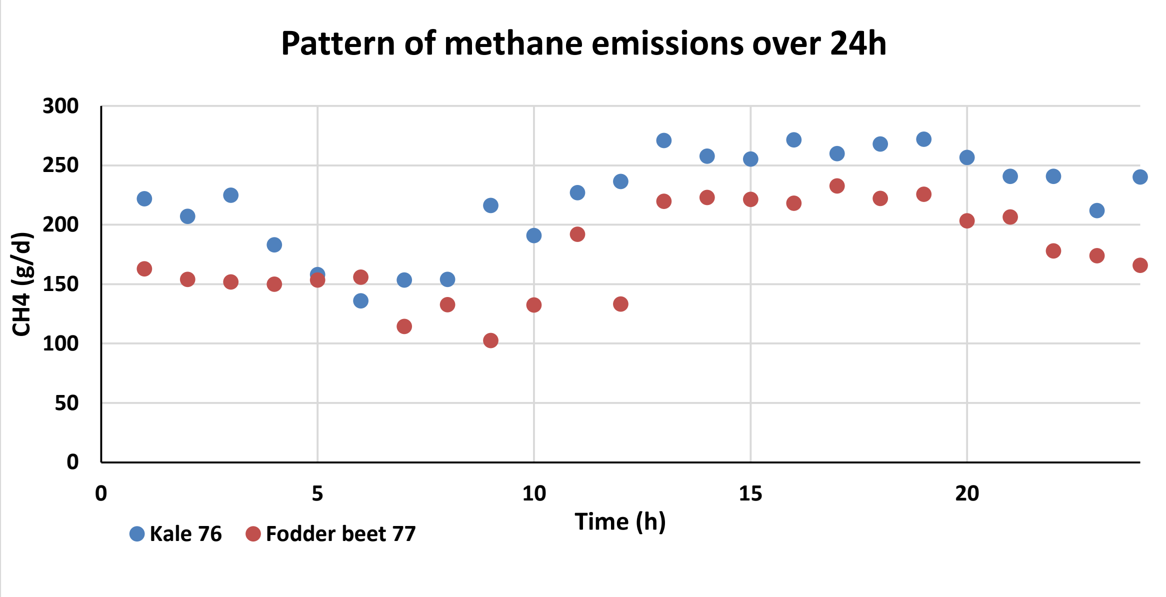

Figure 1.2 Circadian pattern of methane emissions from 36 cows grazing kale with a straw supplement and 22 cows fed fodder beet with a silage supplement.

A similar circadian pattern was evident for carbon dioxide emissions (Figure 1.3) from cows fed both diets, but emissions from those in the kale treatment always higher than from the fodder beet with silage cows. Higher carbon dioxide emissions may indicate a higher intake (assuming most is of a metabolic origin).

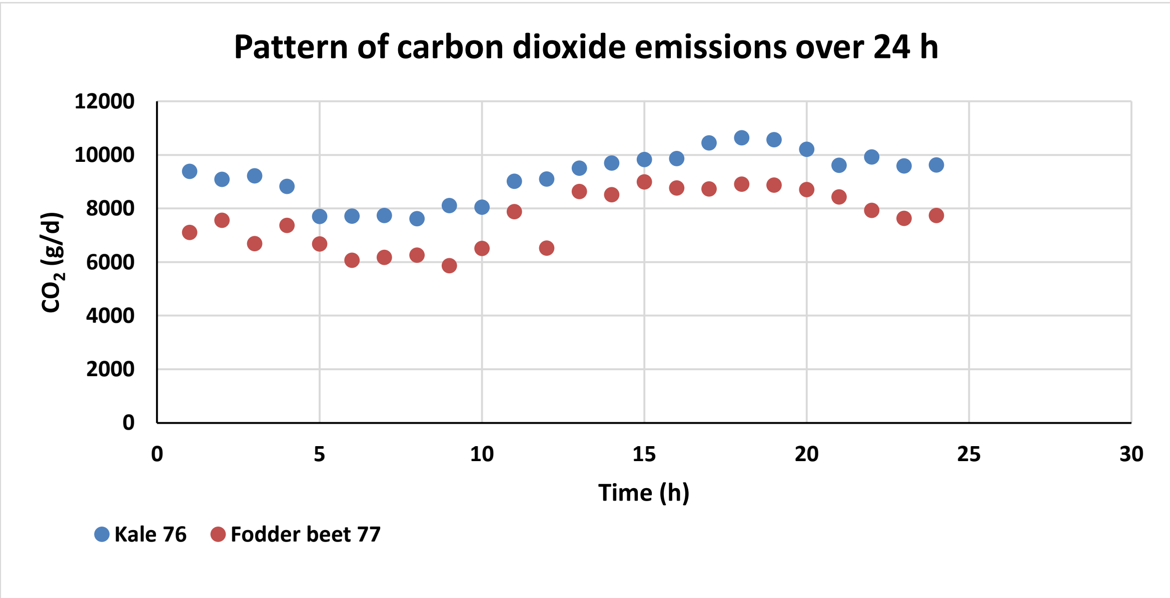

Figure 1.3 Circadian pattern of carbon dioxide emissions from 36 cows grazing kale with a straw supplement and 22 cows fed fodder beet with a silage supplement.

Methane yield has been estimated and values for cows fed kale with silage were similar for each group, and values were not dissimilar to those used for the New Zealand inventory (Clark, 2003; Jonker et al., 2016). Most notable was the lower value determined from cows fed fodder beet with grass silage, 16.5 vs. 23.2 g/kg DM intake. Potential weaknesses in the accuracy of intake estimates have been documented, nevertheless values are consistent between the three groups of cattle fed kale with straw, and those eating fodder beet have a substantially lower emission rate than all groups fed the kale diet. Consistent with these results, molar CH_4/CO_2 ratio, a potential proxy of CH_4 yield, was lower in cows grazing fodder beet than in cows grazing forage kale.

Table 1.4 Effect of diet on methane yield (g/kg dry matter intake) based on emissions and estimated dry matter intake (DMI) of individual cows.

	Est. DMI (kg/d)	Methane (g/kg DMI)
Early kale (n=14)	9.7	22.3
Kale (n=13)	10.3	23.9
Late kale (n=9)	9.5	23.3
Fodder beet (n=22)	11.0	16.5

SUMMARY

The information summarised here was derived from the first trials with the new GreenFeed units, and were the first experience of operation for both AgResearch staff at Lincoln, and those at Lincoln University. In addition to learning their operation, a large amount of information concerning methane and carbon dioxide emissions has been obtained.

The nature of the trials resulted in three groups of dry cattle being fed kale with straw, with intakes estimated at about 10 kg DM/day and 226 g methane/day, compared with 180 g/day from cows fed on fodder beet with silage. The consistent emissions and yields from the three groups fed kale, and similarities with the New Zealand value for cattle, provides reasonable confidence in the estimates of feed intake, but does not suggest a kale diet is likely to mitigate emissions.

In contrast, the 29% reduction in methane yield from cows fed fodder beet with pasture silage, vs. kale with straw, or pasture, suggests an opportunity for mitigation. We recommend proportions of fodder beet be evaluated with silage or pasture to confirm these findings under more rigorous conditions and to define relationships between the proportion of fodder beet in the diet and methane yield, as well as elucidating the mode of action.

Part 2: Methane emissions from lactating cows fed pasture vs. pasture + fodder beet

METHODS

Twenty cows were placed in each experimental group, and GF unit No. 76 was placed with those grazing pasture and unit 77 with those grazing pasture with FB. The GreenFeeds were placed with cows at 13.00 h on 12th November and removed 07.00 h on 4th Dec 2015, but data analysis was restricted to 19 days from 14 November to 3 December, 2015. Analyses were undertaken with all but one cow that visited the GF, and the exclusion (from the pasture + FB treatment) visited less than 20 times over the experiment. All cows that visited GF in the pasture (P) treatment visited more than once/day, and all but one that visited GF in the PFB treatment visited more than once/day. However, some cows never visited GF.

GreenFeed operation was undertaken in line with recommendations in the SOP (Waghorn et al., 2015) and data indicating timing of visits and estimates of emissions for methane and CO2 were downloaded from the GF website as is standard practice. Data were interpreted to show the circadian pattern of cow visits, frequency of visits and the gas emission rate over 24 h as well as mean values for individual cows.

Pasture was sampled pre and post grazing to determine composition, and the cows given a new break after each milking, according to standard operation for rotational grazing. The FB bulbs had been lifted several months previously, stored and were fed onto the new pasture break in the morning of each day. Milk production was measured daily, with milk analysis every 2-3 days. Cow liveweight was determined pre-trial and on several occasions during the latter part of the trial.

Methane and CO_2 are expressed as means for individuals, treatments and in terms of milksolids (fat+protein) production. Methane yield (g/kg DMI) is more challenging because intakes are not measured, and the calculated values presented here are affected by assumptions and data available for the calculation. There was only one measure of liveweight made prior to the measurements (10/11/15) and this has affected the accuracy of intake estimates. Cow liveweight can vary 40kg over/between days, mainly in association with rumen fil, and some estimates of daily liveweight change were unrealistic. Unrealistic liveweight changes (in excess of 0.8 kg/day; increase or decrease) were substituted with smaller changes based on weights determined on 5 occasions during the latter part of the trial (0.2, 0.5, 0.7kg and often zero change). Calculations of intake (and yield) were made using 'likely' change, and zero weight change. The poor estimates of liveweight change do compromise the value of methane yield estimates, but to a lesser extent than in non-lactating cows, because a high proportion of feed intake is directed to milk energy.

RESULTS

Feeds

The composition of pasture on offer is summarised in Table 2.1, with the fodder beets offered at about 3 kg DM/head/day. Pastures had similar composition of the DM, with about 18.4% crude protein, 40.5% fibre (NDF) and the organic matter content suggesting about 8% ash. The predicted DM digestibility averaged 79.3% and ME of 11.1 MJ/kg DM. In contrast, the FB contained very little fibre and crude protein, but 62.5% readily fermentable carbohydrates in the bulb.

Table 2.1 Composition (% of dry matter; DM) and predicted DM digestibility (pred dig) and metabolisable energy (ME; MJ/kg DM) content of pasture on offer to cows in the pasture and pasture + FB treatments, and fodder beet (FB) bulbs.

Row Labels	NDF	ADF	OM	CP	N%	Pred dig	ME
FB treat	41.67	23.35	91.61	17.89	2.86	78.49	10.92
Past treat	39.26	21.63	92.25	18.91	3.03	80.21	11.19
FB bulbs	11.22	7.25	94.08	8.20	1.31		13.43

ME estimates based on CSIRO estimates (SCA, 1990)

The pasture composition was similar for both trials comprising (DM basis) 81% grass, 7% white clover, 5% weeds and 7% dead material. The pasture DM pre grazing was 15-28%, and 17% for FB bulbs.

Estimation of intakes

The similarity of pasture chemical and botanical composition enables the impact of FB supplementation on methanogenesis to be evaluated without confounding effects of divergent pasture composition. Although the predicted DM digestibility is only slightly higher than measured values from cows fed fresh ryegrass pastures of a similar composition, the predicted ME content of pastures on offer seems unrealistically low (SCA, 1990; Waghorn 2007).

Dry matter digestibility measured by Kolver and Aspin (2006) in lactating cows fed pasture containing 19.8 % CP and 41.0% NDF was 78.8%, and Rius et al., (2012) reported 78.0% DM digestibility with fresh pasture containing 23.1% CP and 36.4% NDF in the DM. These values are similar to those in Table 2.1, and if the OM digestibility was assumed to be 80%, then the ME will be: 18.4 (gross energy of pasture) × 0.80 (OMD) × 0.82 (proportion of ME in digestible energy for forages; CSIRO, 1990) = 12.1 MJME/kg DM.

The mean predicted ME by NIRS was 11.05 (Table 2.1). For the purposes of intake estimation, the pastures are assumed to have an ME content of 11.8 MJ ME/ kg DM and the diet containing FB with pasture (about 0.2 FB in the DMI) will be ((0.8 x 11.8) + (0.2 x 13.4)) = 12.1 MJ ME/kg DM. DM apparent digestibilities are assumed to be 78% for pasture and 80% for pasture + fodder beet.

Table 2.2 Liveweight (Lwt), production and estimated dry matter (DM) intakes of cows visiting GreenFeed and grazed on pasture and pasture with supplements of about 3 kg fodder beet (FB) DM/day.

	Lwt	BCS	Milk	Milk (%)		Lwt gain	Estimated DMI#	
	kg		Kg/d	Fat	Protein	Kg/d	measured	No gain
Pasture	517	4.5	23.29	5.12	3.74	0.36	19.15	17.93
Pasture + FB	492	4.3	22.93	5.59	3.86	-0.02	17.52	17.49

BCS body condition score. #Dry matter intakes (kg) were estimated based on measured (including estimates of) daily live weight change and assuming no change in live weight.

Characteristics of cows visiting GF (at least 1/day), including estimated intakes are presented in Table 2.2. Cows were aged about 5 years in both treatment groups, with similar milk production, but those receiving a FB supplement produced milk with a higher fat and protein %, than pasture alone (Table 2.2). Daily milksolids (Fat+protein; MS) averaged 2.06 and 2.17 kg/d during the measurement period for cows in the pasture and pasture + FB groups, respectively. Most were 80-90 days in milk at the time of measurement.

GreenFeed visits

Of the 20 cows in each treatment, data were analysed from 14 in the P treatment and 17 in the PFB treatment (Table 2.3). On pasture, 6 cows never visited GF, and 3 never visited GF in the PFB treatment. One cow in the PFB treatment visited less than 20 times and was excluded from the analysis, and another was rumen fistulated, so her visits were included in the analysis, but emissions excluded.

Table 2.3. Mean number of visits per day to GreenFeed (during 19 measurement days) of lactating dairy cows grazing either pasture or grazing pasture + supplementation of 3 kg fodder beet bulbs.

	Mean (StDev)	CV (%)	<1.0 visits/d[1]	>3.0 visits/d[1]
Pasture (n=14)	3.4 (1.65)	48	0	8
Pasture + fodder Beet (n=17)	3.3 (1.03)	31	1	10

[1]of cows visiting GreenFeed less than 1.0 or more than 3.0 times a day.

Data used in the analyses presented here are based on 906 visits by the 14 cows in the pasture treatment and 996 by the 16 cows fed pasture + FB treatment. The pattern of visits (Figure 2.1) were similar for both treatments, and the low/absent visitation between 07.00 -09.00 h and 16.00-18.00h coincided with milking.

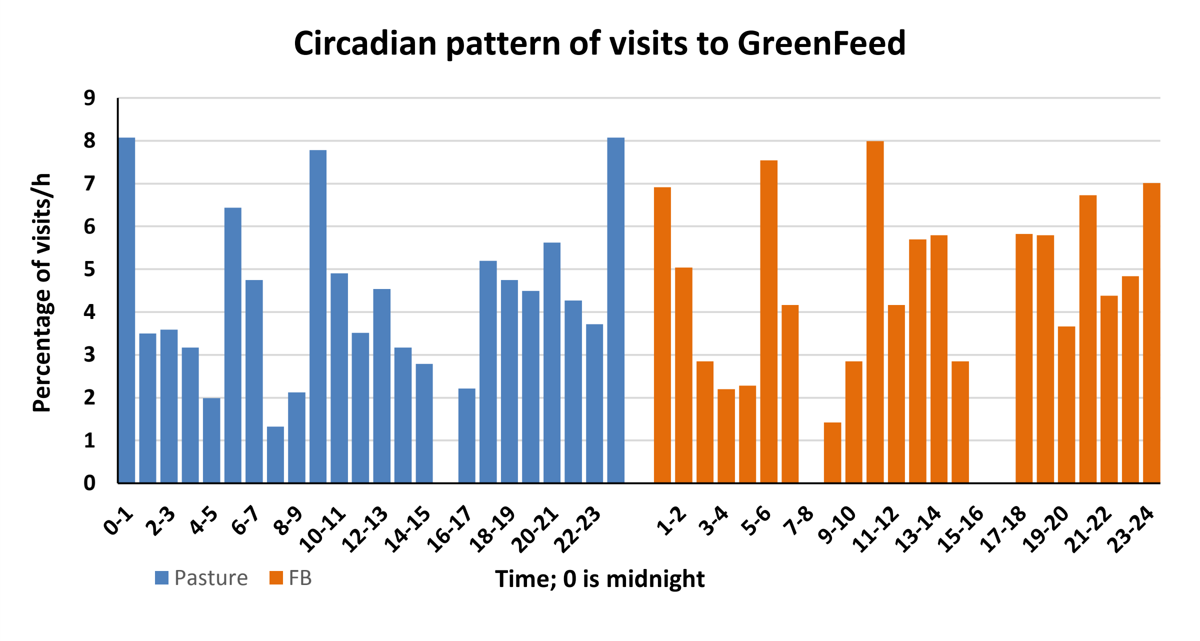

Figure 2.1 Distribution of cows visits to GreenFeed over 24h (percentage of daily visits in each hour)

Gas emissions

Mean daily emissions are summarised in Table 2.4, with an average of 397g CH_4/cow/day (range 364-449) from cows fed pasture and 350g CH_4/cow/day (range 311-418). Data from a cow with a rumen fistula that was included in the herd were removed because the methane emissions (estimated at 121 g/d suggest about 60% of methane (but only 10% of carbon dioxide) was lost from the fistula.

Table 2.4 Gas emissions (mean ± std) estimated by GreenFeed from lactating dairy cows grazing either pasture or grazing pasture + supplementation of 3 kg fodder beet (FB) bulbs.

	Methane		Carbon dioxide		CH_4/CO_2 molar ratio	
	g/d ± std	CV	g/d ± std	CV	Mean ± std	CV
Pasture (n=14)	397 ± 28.6	7.2	11540 ± 726	6.3	0.095 ± 0.0064	6.8
Pasture + FB (n=15#)	350 ± 30.5	8.7	11224 ± 864	7.9	0.085 ± 0.0044	5.1

#Data from 15 cows in the pasture + FB treatment; one user had a rumen fistulae that resulted in a substantial methane loss.

The pattern of methane emissions (Figure 2.2) shows a consistent rate of emissions over 24 h, and lower rates from cows fed pasture with fodder beet, except during the day, presumably in associated with FB digestion. A similar pattern was evident with carbon dioxide emissions (Fig. 2.3).

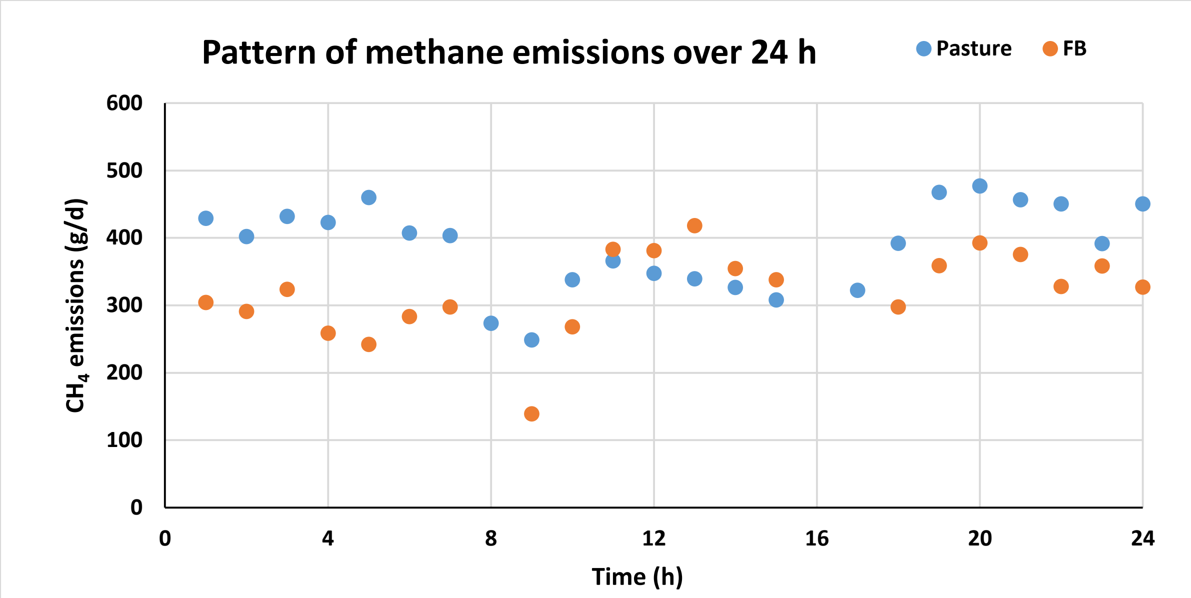

Figure 2.2 Circadian pattern or methane emissions from 14 cows grazing pasture and 15 cows grazing pasture with 3 kg/day fodder beet supplementation

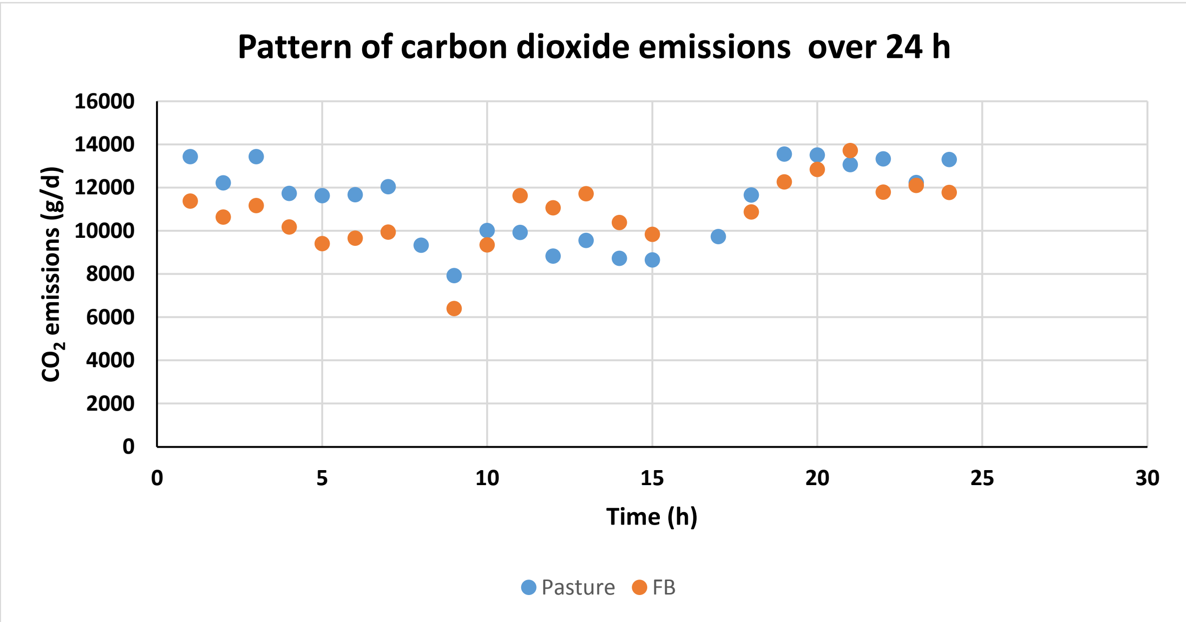

Figure 2.3 Circadian pattern or carbon dioxide emissions from 14 cows grazing pasture and 15 cows grazing pasture with 3 kg/day Fodder beet supplementation.

Table 2.5 Methane production expressed in relation to estimated dry matter (DM) intake based on adjusted measure daily live weight gain, or zero live weight gain, and milksolids (fat + protein; MS) by cows grazing either pasture or pasture with fodder beet (FB) supplements.

	Methane yield measured	g/kg DM intake zero	Methane g/kg MS
Pasture (n=14)	21.03	22.33	195
Pasture + FB (n=15[#])	20.42	20.42	168

[#]Data from 15 cows in the pasture + FB treatment; one user had a rumen fistulae that resulted in a substantial methane loss.

The methane yield (g/kg DMI) appeared to be lower from cows fed pasture supplemented with fodder beet (Table 2.5), but the difference was small and affected by daily gains, which could not be estimated with certainty. Nevertheless, the values derived for pasture fed cows (21.0-22.3 g/kg DM intake) were in line with expectations detailed in the New Zealand inventory (Clark et al., 2003; Jonker et al., 2016) and including fodder beet in the diet resulted in a lower methane yield.

More important was the substantially lower methane/kg MS production when FB were included in the diet (168 vs. 195 g/kg), and these values are defensible. The impact of FB is evident in the circadian patterns of methane and carbon dioxide emissions, both of which are higher than for cows fed pasture in the hours after FB were fed, in contrast to other times (18.00-09.00 h).

SUMMARY

This 3-week trial was undertaken with two groups of 20 mature Holstein/Friesian dairy cows at 90-100 days of lactation. The cows were grazed either on ryegrass based pasture, or pasture with fodder beet bulbs fed at about 3 kg DM/head. 14-16 of the 20 cows visited the GreenFeed unit regularly, on average 3.3 times/cow/day and visits were distributed throughout the day, except during milking, and were lower in the early hours of the morning than other times.

Average methane emissions were 397 g/day from cows grazing pasture and 350 g/day when pasture was supplemented with fodder beet. The rate of methane production appeared to have been affected (reduced) after fodder beet were fed. Cow dry matter intakes were estimated from cow ME requirements and ME content of the diets, and expression of methane in terms of DM intake suggested a lower value when fodder beet was fed with pasture. Supplementing pasture with fodder beet reduced methane from 195 to 168 g/kg milksolids.

Carbon dioxide emissions were similar for cows fed both diets (11.4 kg/day), and fodder beet supplementation reduced the CH_4/CO_2 ratio from 0.095 to 0.085. These results suggest supplementing pasture with about 15-20% fodder beet can reduce methane emissions with no detrimental effects on production.

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8. Appendix 2 – Nitrous oxide detailed methodology

The N_2O emissions from the HSE and LSE systems were assessed for key components that collectively make up the systems, (e.g. milking platform and winter crop block) though inventory-type calculations based on N input and N_2O emission factors:

Direct N_2O (kg N/year)

= (Nex-urine x EF_3urine) + (Nex-dung x EF_3dung) + (Nfert x EF_1fert) + (Neff x EF_1eff) ***(1)***

Where Nex-urine, Nex-dung, Nfert and Neff are the amounts of urine N, dung N, fertiliser N and effluent N deposited or applied, respectively; and EF_3urine, EF_3dung, EF_1fert and EF_1eff are the N_2O emission factors for urine N, dung N, fertiliser N and effluent N, respectively.

In addition, indirect N_2O emissions from the system were assessed from

Indirect N_2O (kg N/year) =(NH_3 volatilised x EF_4) + (NO_3 leached x EF_5) ***(2)***

with ***NH_3 volatilised = (Nex-urine + Nex-dung + Nfert + Neff) x FracGAS*** ***(3)***

and ***NO_3 leached = as assessed in the P21 programme***

Where, NH_3 volatilised and NO_3 leached are the amounts of ammonia volatilisation and nitrate leaching respectively; EF_4 and EF_5 are the N_2O emission factors for volatilised and leached N, repsectively; and FracGAS is the NZ value for NH_3 volatilisation (i.e. 10% of N applied).

The systems' direct and indirect emissions were then be assessed by:

Total system N_2O (kg N/year) = [$\sum_i$ (direct N_2O)$_i$ + indirect N_2O] ***(4)***

Where *i* represents the different components of the farm system (i.e. milking platform or winter crop block),

N input data

NO3 leaching, Nfert and Neff data were provided by members of the P21 project. As there was no effluent applied in the farmlets, the Neff term was excluded from equation (1).

Nex-urine was estimated for each farmlet from monthly measurements of the N content and creatinine content in the urine and the animal body weight. These parameters were used in an equation provided by (Pacheco et al 2007)[19] that assumes a constant creatinine clearance factor of 21.9 mg/per kg body weight:

$$\textit{Urine N excretion (g N/cow/day)} = \frac{\textit{21.9 x Body weight (kg)}}{\textit{creatinine (mg/kg urine)}} \textit{ x urine N (g/kg)} \qquad (5)$$

Nex-urine (kg N/ha)
= Urine N excretion/1000 x stocking rate (cows/ha) x days on pasture or crop ***(6)***

Total Nex-dung was estimated from Nex-urine and the N content of the dry matter using the following equation (Pickering and Wear, 2013)[20]:

[19] Pacheco D, Burke JL, Death AF, Cosgrove GP (2007) Comparison of models for estimation of urinary nitrogen excretion from dairy cows fed fresh forages. Proceeding of the Australasian Dairy Science Symposium Sep 2007.
[20] Pickering and Wear (2013) Detailed methodologies for agricultural greenhouse gas emission calculation

$$\textit{\%N in urine} = (10.5 \times \textit{\%N in diet}) + 34.4 \quad (7)$$

$$\textit{N ex-dung (kg N)} = (100 - \textit{\%N in urine}) \times \frac{\textit{Nex-urine (kg)}}{\textit{\%N in urine}} \quad (8)$$

N_2O emission factors and fractions

New Zealand default emission factors and fractions were used for all calculations (Table 2), except for EF_3-urine for the milking platform, i.e. for cows on 'Standard' pasture (HSE farmlet) vs cows on a combination of 'Standard' and 'Diverse' pasture (LSE farmlet). The values for these emission factors were obtained from targeted N_2O emission measurements as provided in the Milestone 2 report for this SLMACC project[21] (Table 3).

Table 2 The NZ default N_2O emission factor and fractions used for estimating the N_2O footprint of the P21 Canterbury farmlets

Factor/fraction	Value
EF_3-urine pasture	See Table 3
EF_3-urine winter crop	1 % of urine-N excreted on winter crop
EF_3-dung pasture	0.25 % of dung-N excreted on pasture
EF_3-dung winter crop	0.25 % of dung-N excreted on winter crop
EF_1 fertiliser	1 % of fertiliser N applied
EF_1 effluent	n/a as no effluent was applied in the P21 farmlets
FracGASF	10 % of fertiliser N applied
FracGASM	10 % of urine- and dung-N excreted on pasture and winter crop
EF_4	1 % of NH_3-N volatilised
EF_5	2.5 % of NO_3-N leached

Table 3 The N_2O emission factor for urine N (EF3 urine) as measured for this SLMACC project

System	Plant species	Urine N rate*	**EF_3 urine** (% of urine N excreted on pasture)
HSE	'Standard' ryegrass/white clover pasture	500	0.69
		700	1.12
LSE	'Diverse' pasture (ryegrass, white clover, chicory, plantain)	500	0.84
		700	1.03

* Two rates of urine-N were included as it now known that 'diverse' pasture (containing plantain and chicory) will reduce the N content of animal urine (Totty *et al.* 2013)[22] and thus the N-excretion rate in individual urine patches.

Version 2. MPI Technical Paper No: 2013/27. Wellington: Ministry for Primary Industries

[21] de Klein CAM, Dynes R, Cameron KC, Di HJ (2014) Testing of Mitigation Options Through Modelling Dairy Farm Systems – Milestone 3 Progress report: N_2O emission measurements associated with the Canterbury P21 farmlet system. Report for MPI August 2014

[22] Totty VK, SL Greenwood, RH Bryant, GR Edwards (2013) Nitrogen partitioning and milk production of dairy cows grazing simple and diverse pastures. J. Dairy Sci. 96: 141-149

9. Appendix 3 - N_2O emission measurements associated with the Canterbury P21 farmlet system (Milestone 3 progress report)

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Introduction

This document relates to milestone 3 of the SLMACC project "Testing of Mitigation Options Through Modelling Dairy Farm Systems" (Agreement number AGR131402):

No.	Milestone Description	Milestone completion date	Evidence of milestone completion
3	Treatments in place and data collection commenced.	31 August 2014	Progress report submitted

The report describes the progress to-date on the N_2O emission measurements in association with the Canterbury P21-II farmlet trial. This trial is examining the effect of Low Stocking and High Stocking Efficiency dairy farm systems (LSE, HSE), including a comparison of 'standard' ryegrass/white clover pasture versus 'Diverse' pasture (containing chicory, plantain, ryegrass, and clover) on farm productivity and water quality.

The SLMACC project aims to assess GHG emissions from these HSE and LSE systems though inventory-type calculations based on DM intake, CH_4 yield, N input and N_2O emission factors. This report describes progress to-date on targeted N_2O measurements that are being made to provide system specific N_2O emission factors for the following treatments:

System	Plant species	Urine-N rates		
HSE	'Standard' ryegrass/white clover pasture	0	500	700
LSE	'Diverse' pasture (ryegrass, white clover, chicory, plantain)	0	500	700

Two rates of urine-N are included as it now known that 'diverse' pasture (containing plantain and chicory) will reduce the N content of animal urine[23] and thus the N-excretion rate in individual urine patches. The results will be combined with existing NZ specific values to assess the N_2O emissions from key farm systems components parts of the P21 systems (Table 1).

[23] Totty VK, SL Greenwood, RH Bryant, GR Edwards (2013) Nitrogen partitioning and milk production of dairy cows grazing simple and diverse pastures. J. Dairy Sci. 96: 141-149

Table 1: Source of parameters used for assessing direct N_2O emissions

	Parameter							
Farm system component	**Nex-urine**	**Nex-dung**	**Nfert**	**Neff**	**EF3urine**	**EF3dung**	**EF1fert**	**EF1eff**
Milking platform non-effluent	from P21 data	from P21 data	from P21 data	from P21 data	This SLMACC programme	NZ default	NZ default	N/A
Milking platform effluent	from P21 data	from P21 data	from P21 data	from P21 data	This SLMACC programme	NZ default	NZ default	NZ default
Winter crop	from P21 data	from P21 data	from P21 data	from P21 data	Existing data or proposed NZAGRC Integrated systems (tbc)	NZ default	NZ default	N/A
Young stock area	from P21 data	from P21 data	from P21 data	from P21 data	NZ default	NZ default	NZ default	N/A
Other blocks?								

Approach

The measurements are conducted by applying a standardised chamber methodology to existing lysimeters (set up under the P21-II programme to measure N leaching losses).

Soil monolith lysimeters (500 mm diameter x 700 mm deep) were collected from the Templeton sandy loam soil in the P2-II farmlet grazing trial areas on the Lincoln University Research Dairy Farm. The lysimeters were installed in a purpose built lysimeter trench facility close to the P21 grazing trial. Each lysimeter was equipped with an individual irrigation nozzle to ensure that accurate application of irrigation water occurred in line with on-farm practice. Pasture on the lysimeters was cut at approximately 2,800 kg DM ha^{-1} pasture mass to simulate a typical grazing rotation, and clippings were removed from the lysimeters.

Fresh urine was collected from Friesian xJersey cross cows and was analysed before application to the lysimeters. Urine was applied on 2nd May 2014 to simulate autumn urine deposition by grazing dairy cows. Each urine treatment had four replicates and these were allocated to the lysimeters in a completely randomised design.

Determination of N_2O emissions

Nitrous oxide emissions were determined using a closed chamber method similar to that described by Hutchinson & Mosier (1981). The enclosure was constructed of a metal cylinder and was insulated with 2.5 mm thick polystyrene foam to avoid heating of the atmosphere in the chamber during sampling. During periods of N_2O measurements, the chamber was fitted inside a water trough which was mounted around the top of the lysimeter casing for gas sampling. At each sampling time, the chamber was placed on top of the lysimeters for a total of 40 minutes, and 3 samples, 20 minutes apart, were taken using a syringe through a rubber septum fitted on top of the gas collection chamber. The samples allowed the calculation of the rate of N_2O increase in the enclosure during the sampling period. Each sampling was carried out during the middle of the day between 12:00 h to 14:00 h. Nitrous oxide was analysed using gas chromatography (SRI 8610 gas chromatograph, SRI Instruments, California, USA) equipped with a ^{63}Ni electron capture detector. N_2O emissions were calculated based on the increases of N_2O from the three samples collected on each occasion (Hutchinson & Mosier 1981). Daily emissions were then calculated based on the hourly fluxes. Cumulative emissions were calculated by integrating the measured daily fluxes.

Plate 1. Collecting gas samples from the lysimeters on the Lincoln University Research Dairy Farm

Results to-date

Draft initial results show some separation of the daily fluxes between the treatments (Fig 1). The measurements will continue until background concentrations are reached.

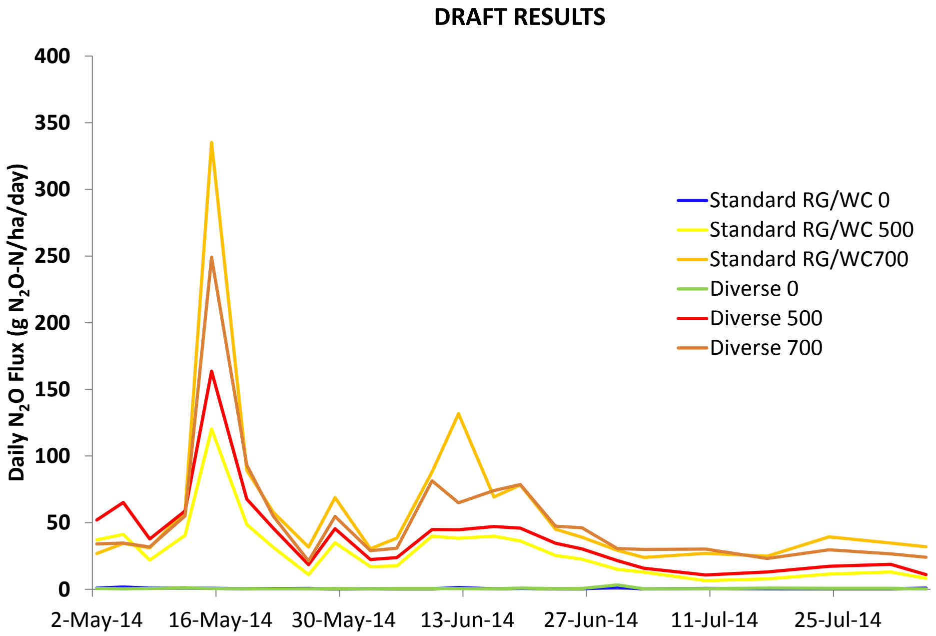

Figure 1. Daily nitrous oxide flux.

The interim results for the cumulative nitrous oxide emissions to date show differences emerging between the rates of urine-N applied; with higher emissions occurring at the 700 kg N/ha application rate compared to the 500 kg N/ha application rate (Fig 2).

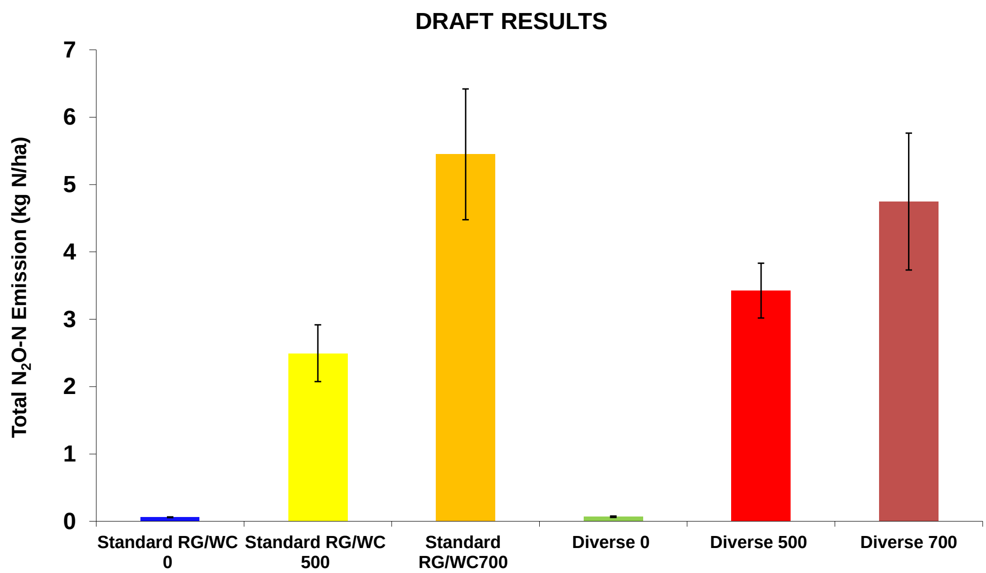

Fig 2. Cumulative nitrous oxide emissions to date.

Because the plantain and chicory in the ‘Diverse’ pasture will reduce the urinary N excretion rate from cows grazing these pastures (Totty *et al.* 2013), it is important to compare the lower urine application rate for the ‘Diverse’ pasture system (i.e. 500 kg N/ha) against the higher urine rate which is typical for the ‘standard’ ryegrass/white clover pasture (i.e. 700 kg N/ha). This comparison indicates that the N_2O emission from the 500 kg N/ha rate in the Diverse pasture appears, at this stage, to be less than the emissions from the 700 kg N/ha rate in the standard perennial ryegrass/white clover pasture.

However, these are interim results and definitive conclusions cannot be drawn until the emissions envelop is complete and a proper statistical analysis is carried out.

References

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Totty VK, SL Greenwood, RH Bryant, GR Edwards (2013) Nitrogen partitioning and milk production of dairy cows grazing simple and diverse pastures. J. Dairy Sci. 96: 141-149