



Reducing CH₄ Emissions from Grazing Ruminants in New Zealand: Challenges and Opportunities*

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ABSTRACT : Almost half of New Zealand's greenhouse gas emissions arise from agriculture and enteric methane (CH₄) emissions arising from ruminant animals constitute 30% of total CO₂-e emissions. Enteric CH₄ emissions have increased by 9% since 1990. Extensive research has been undertaken to develop reliable methods for measuring enteric CH₄ emissions. New Zealand studies using the SF₆ tracer technique suggest that on average this technique yields similar values to the 'gold' standard of calorimetry, but with a larger variance. National inventory estimates based on results obtained using the SF₆ technique will therefore overestimate the uncertainty. Mitigating emissions can be achieved by changing feed type but there are practical and cost barriers to the use of alternative feeds. Forages containing condensed tannins do reduce emissions but are agronomically inferior to the forages currently used. Rumen additives have shown some success *in-vitro* but results from *in-vivo* trials with both monensin and fumaric acid have been disappointing. The development of methods for directly manipulating rumen microorganisms are at an early stage and work to develop vaccines that can inhibit methanogenesis has yielded mixed results. The successful identification of sheep with contrasting CH₄ yields raises the possibility that, in the long term, a breeding approach to CH₄ mitigation is feasible. (**Key Words :** Methane, Rumen, Feed, Monensin, Fumarate, Vaccination, Breeding)

INTRODUCTION

Globally, Steinfeld et al. (2006) estimated that 18% of all anthropogenic GHG emissions arise from livestock farming. This is close to 50% more than those arising from transport. However, this does include 'emissions' from deforestation and actual direct emissions from the rearing of livestock are closer to 12%. Emissions from ruminant animals make up approximately 75% of total livestock emissions (Clark, 2009). In terms of the climate change debate this places livestock agriculture as a major driver of the atmospheric conditions, increased GHG concentrations, which are postulated to be causing climate change. Livestock farmers are therefore under pressure nationally and internationally to adopt practices and technologies that

will reduce their emissions. This has to be done against a background of a growing population with an increasing preference for consuming animal derived protein (Steinfeld et al., 2006).

Although climate change itself may provide the biggest challenge in the long term, the challenge for individual farmers in the short term will be one of managing GHG emissions at the farm scale. This is both in terms of being able to reduce emissions from their farming operations and managing the financial consequences of the cost of mitigation actions and the possibility of there being a price on emissions in the not too distant future.

New Zealand is in a unique situation internationally in that it is the only developed country where agriculture GHG emissions play a major role in the national emissions profile (Figure 1). This means that if New Zealand is to reduce its total emissions of GHG in the future it will have to find ways of reducing agricultural emissions. This problem is made more severe because New Zealand is an agricultural exporting country, is a major supplier internationally of

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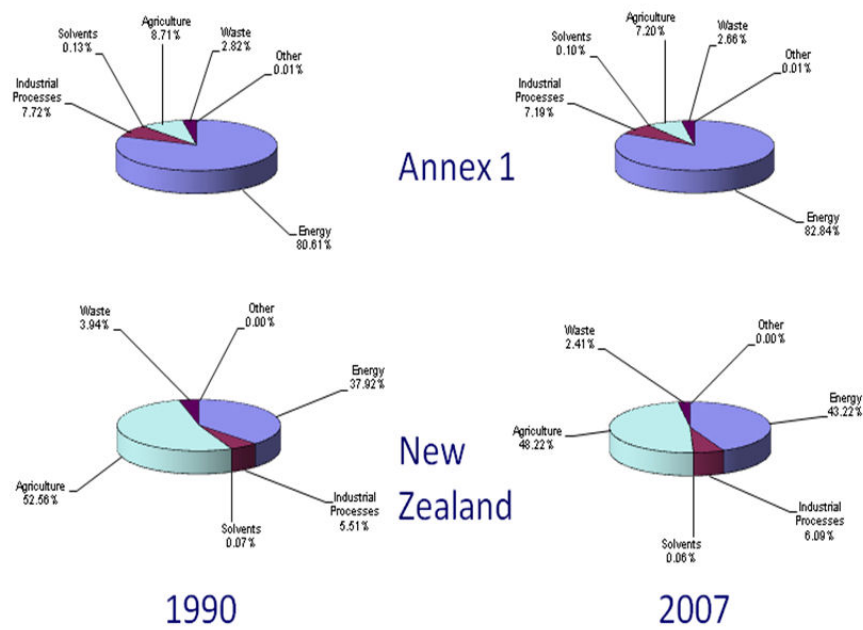


Figure 1. Anthropogenic greenhouse gas emissions by sector from Annex 1 countries of the Kyoto Protocol compared with those of New Zealand. Source IPCC 2007.

Table 1. Carbon dioxide equivalent methane and nitrous oxide emissions (million tonnes) from cattle and sheep in New Zealand 1990 and 2006. Data courtesy of Ministry of Agriculture and Forestry, Wellington, New Zealand.

	Dairy cattle		Beef cattle		Sheep		Total	
	2006	1990	2006	1990	2006	1990	2006	1990
Enteric CH ₄	8.62	5.01	5.41	4.89	9.29	11.28	23.31	21.18
Waste CH ₄	0.37	0.21	0.07	0.06	0.09	0.11	0.53	0.38
N ₂ O soils	4.01	2.38	2.23	2.01	4.06	4.89	10.30	9.28
Fertiliser							1.89	0.34

milk and meat products and there are substantial opportunities, particularly in the dairy sector where demand worldwide is growing at 2% per annum, to profitably increase production.

New Zealand’s target under the terms of the Kyoto Protocol is a zero increase in emissions above its 1990 baseline. However, since 1990 CO₂-e emissions of the two principle agricultural GHG, nitrous oxide (N₂O) and methane (CH₄) have increased by 9% and 28% respectively (Table 1). Although changes in land use have offset these increases in emissions in the longer term tackling the issue of agricultural emissions is a high priority for the New Zealand. Enteric CH₄ emissions alone account for close to 30% of New Zealand’s total GHG emissions and a major research focus in New Zealand has been the development of practices and technologies to mitigate these enteric CH₄ emissions. Since New Zealand has a temperate climate devoid of climatic extremes the focus of New Zealand research has been on mitigating CH₄ emissions from grazing animals consuming fresh forage diets.

The following sections summarise some of the key findings arising from the New Zealand research effort.

MEASURING ENTERIC CH₄ EMISSIONS

Estimates of enteric CH₄ emissions from New Zealand



Plate 1. The SF₆ tracer technique for estimating enteric CH₄ emissions in sheep.



Plate 2. Measuring CH₄ from sheep emissions in purpose built CH₄ calorimeters.

ruminants up until 2007 relied on the use of the SF₆ tracer technique developed by Johnson et al. (1994) and adapted for use in grazing animals (Lasey et al., 1997; Plate 1). Although a relatively simple technique to establish, the high variability of the technique in some circumstances is a disadvantage; (Pinares-Patiño and Clark, 2008); Vlaming et al. (2008). A decision was therefore made in 2007 to establish purpose built open circuit CH₄ calorimeters (Plate 2).

An immediate issue was the question of how emissions estimated using the SF₆ technique compare with those obtained using calorimetry. Previous studies from Australia and North America (Johnson and Johnson, 1995; McGinn et al., 2006; Grainger et al., 2007) found that on average there is close agreement between values obtained using the two techniques but this has not always been found to be the case (Pinares-Patino et al., 2007a). Based on a purely statistical comparison of experiments with sheep consuming fresh grass-based diets the mean values obtained from the SF₆ technique do not differ from those obtained using calorimetry (Table 2).

However, although the average value obtained using

these two techniques are the same the variances do differ. This obviously has implications for experimental design but it also has major implications for uncertainty estimates surrounding the New Zealand enteric CH₄ inventory; using the variance associated with calorimetry-based estimates of CH₄ production, rather than SF₆ based estimates, the estimated uncertainty in the national CH₄ inventory (95% confidence interval) falls from over 50% to 16% (Kelliher et al., 2009).

CAN DIET INFLUENCE THE QUANTITY OF CH₄ PRODUCED?

Feed quality

One of the principle aims of grassland management is to increase the quality of the forage ingested by grazing ruminants. Methane production is highly correlated with fibre digestion in the rumen (Kirchgeßner et al., 1995), and so it would be logical to assume that decreasing the fibre content of forages would reduce CH₄ emissions. Since fibre content and digestibility of forages are negatively correlated, and are responsive to management manipulation, at first site it appears that increasing the digestibility of forages could be an effective CH₄ mitigation option for grazing livestock.

New Zealand studies using animals fed fresh, as opposed to dried, forage diets suggests that in C3 grasses at least the percentage of GE lost as CH₄ may be relatively insensitive to forage quality over the range of qualities found in temperate grazing systems. Molano et al. (2003) working with *Lolium perenne* L. (perennial ryegrass) at two stages of growth and four levels of feeding, found no relationship between CH₄ emissions per unit of DM intake and digestibility when emissions were measured using the SF₆ technique (Table 3). These findings are supported by a recently completed series of comprehensive trials in New Zealand undertaken with cattle and sheep fed fresh pasture

Table 2. Sample sizes and sample arithmetic mean yields (g CH₄/kg DMI) for the animal groups on grass based diets by experiment class. Coefficients of variation (%) of the sampling distributions of the arithmetic means are in parentheses. From Kelliher et al. (2009). Data courtesy of the New Zealand Ministry of Agriculture and Forestry.

Species group	SF ₆ indoors		Chambers	
	n	Arith. mean	n	Arith. mean
Sheep <1 yr	102	23.87 (2.8)	49	24.07 (1.5)
Sheep >1 yr	153	23.67 (2.2)	182	22.91 (1.0)

Table 3. Apparent digestibility, dry matter intake and enteric CH₄ emissions from sheep consuming perennial ryegrass based diets at four levels of voluntary feed intake and two contrasting digestibilities. Source Molano et al. (2003)

	Low digestibility				High digestibility				
	61.5	62.5	61.1	65.1	74.5	76.9	74.1	75.9	
Apparent digestibility	61.5	62.5	61.1	65.1	74.5	76.9	74.1	75.9	p<0.001
DMI kg/d	0.57	0.73	0.91	1.37	0.78	0.95	1.15	1.54	p<0.001
CH ₄ g/d	11.5	17.7	24.3	31.9	15.6	22.7	27.4	35.9	p<0.001
CH ₄ g/kg DMI	20.5	24.2	26.6	23.3	20.1	24.1	24.0	23.5	NS

diets (Muetzel, unpublished data), and a detailed analysis of the influence of chemical characteristics on CH₄ emissions in New Zealand experiments undertaken between 1997 and 2009 (Hammond et al., 2009). They are also consistent with the work of Pinares-Patiño et al. (2003a) who, working with *Phleum pratense* L. (timothy grass) at four stages of maturity spanning an organic matter digestibility of 56-78% and a neutral detergent fibre (NDF) content of 52-76%, could find no relationship between digestibility or NDF and the percentage of GE intake lost as CH₄ in cattle fed at 1-1.5 above maintenance. These New Zealand data fully support the views of Pinares-Patino et al. (2007b) that there is only a weak correlation between forage quality and CH₄ emissions under the range of pasture qualities found in well managed temperate pastures.

Forage type

There is ample evidence from the literature that feed type influences CH₄ production (see reviews by Waghorn, 2007; Beauchemin et al., 2008; Martin et al., 2009). Briefly, diets high in concentrates, diets with increased proportions of legumes, diets containing tannin-rich species and diets with enhanced lipid concentrations have all been found to decrease CH₄ emissions when expressed as a proportion of GE intake or as CH₄ emitted per kg DMI. However, in grazing ruminants there are practical and economic constraints on the ability to reduce emissions at the farm level by changing feeding practices.

Increasing the proportion of legume in the diet while at the same time maintaining dry matter production per hectare is not a simple management issue and white clover, the dominant legume in New Zealand pastures, has been found to have little impact on CH₄ emissions from cattle (Beever et al., 1985; van Dorland et al., 2007). New Zealand studies support this view. Lee et al. (2004), working with cattle found that enteric CH₄ emissions can be substantially reduced when the white clover content of the diet is high but that at the levels of white clover found in

practice (<20%) there is no significant effect (Figure 2).

New Zealand studies with forage species containing condensed tannins (CT) can reduce CH₄ emissions in cattle (Woodward et al., 2001) and sheep (Waghorn et al., 2002; Pinares-Patiño et al., 2003b). In theory this makes them an ideal mitigation option since they have also been found to increase liveweight gains and decrease the severity of gastrointestinal worm infestations (Min et al., 2003). The disadvantage of CT containing plants in temperate pastures is that they do not compete well with other temperate species and so have substantial disadvantages when considered within a farm systems context. As pointed out by O'Hara et al. (2003), the benefits of CT containing plants have been recognised for over 30 years but to date we still do not have a competitive CT containing pasture plant. The recent announcement that scientists working at AgResearch have produced a genetically modified high tannin content white clover may perhaps in the long run provide a solution to this conundrum. Similarly, although supplementing diets with lipids may not be viable in grazing ruminants at present, plant breeders may be successful in their attempts to breed forage cultivars with enhanced lipid content in the future.

Feed additives

There are a large number of products on the market or products being tested that claim to have methane reducing properties. These range from garlic extracts, spices and essential oils through to enzymes, yeasts and antimicrobials such as ionophores (Beauchemin et al., 2008; McAlister and Newbold, 2008). The evidence supporting these claims tends to come from *in-vitro* studies and, with the exception of the ionophore monensin, more research is needed before any of these approaches can be recommended. Ionophores, particularly monensin, have been used routinely in animal production systems for many years as growth promoters. There is evidence to suggest that they can reduce CH₄ through a combination of reduced voluntary intake, reduced acetate production and the inhibition of H₂ release from formate (Goodrich et al., 1984; van Nevel and Demeyer, 1996; Tedeschi et al., 2003; Beauchemin et al., 2008). Slow release delivery devices are available and used widely to control bloat in grazing cattle making monensin a highly

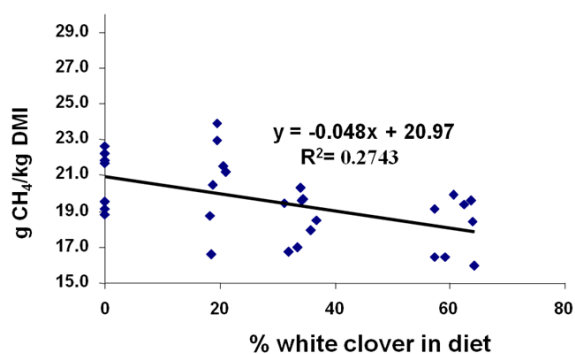


Figure 2. The influence of clover content of the diet on enteric CH₄ emissions from dairy cattle. Source Lee et al. (2004).

Table 4. Methane emissions from dairy cows (g/kg DMI) dosed with monensin controlled release capsules and consuming a pasture based diet. From Waghorn et al. (2008). Data courtesy of the Pastoral Greenhouse Gas Research Consortium.

	Days after administration of controlled release capsule			Probability treatment
	5	40	70	
Control	17.7	21.2	19.6	0.604
Monensin CRC	19.5	21.0	19.1	

Table 5. Effects of fumaric acid supplements on mean (\pm sd) liveweight (LW) at the start and end of the trial and on the mean (\pm sd) dry matter intake (DMI) of wethers, apparent digestibility, CH₄ emissions/day and CH₄ emissions/kg DNI, and rumen pH, averaged over two periods of measurement. From Molano et al. (2008).

	Fumaric acid supplements in diet (%)				
	0	4	6	8	10
CH ₄ emissions	18.5 \pm 2.68	17.8 \pm 4.60	14.1 \pm 5.72	14.8 \pm 4.45	12.6 \pm 2.64
g/kg DMI	17.6 \pm 2.54	17.8 \pm 5.54	18.5 \pm 6.18	17.9 \pm 1.89	15.9 \pm 3.53
g/d	6.01 \pm 0.16	6.46 \pm 0.31	6.76 \pm 0.15	6.58 \pm 0.11	6.75 \pm 0.24

attractive mitigation agent. However, studies in Australia and New Zealand with forage fed dairy cows have been disappointing (Grainger et al., 2008; Waghorn et al., 2008) and at present, based on the evidence available (Table 4), it is not possible to make any firm claims as to the CH₄ reducing potential of monensin in forage fed dairy cattle in Australia and New Zealand. A further issue is that ionophores are classed as antibiotics and there is a strong move to phase out the routine use of antibiotics in livestock production systems. Hence even if the efficacy of monensin as a long-term CH₄ inhibitor could be conclusively demonstrated, its routine use may not be readily acceptable to both consumers and regulatory authorities.

IS IT POSSIBLE TO DIRECTLY INFLUENCE THE PROCESSES CONTROLLING ENTERIC CH₄ PRODUCTION?

The formation of CH₄ in the rumen is an essential component of the digestion system in a ruminant animal and any attempt to modify the process must not adversely affect digestion. During the formation of CH₄ a group of microbes, methanogenic archaea, predominantly use CO₂ and H₂ to produce CH₄ according to the following equation: CO₂+4H₂→CH₄+2H₂O. The removal of hydrogen by methanogens helps maintain a low partial pressure of hydrogen in the rumen without which microbial growth and forage digestion are inhibited (Wolin et al., 1997). Any attempts to modify the processes leading to the formation of CH₄ must therefore take into account how to reduce CH₄ production and how to deal with the removal of hydrogen so that the efficiency of the digestive system is not impaired.

Organic acids, such as malic acid and fumarate, are precursors of propionate production in the rumen and can, in theory, act as alternative sinks for hydrogen thereby reducing the substrate available for CH₄ formation. *In-vitro* results have often been strongly positive (e.g., Kolver et al., 2004) but the results from the single animal trial carried out in New Zealand was disappointing (Table 5). Our studies therefore support the views of McAllister and Newbold (2008) who concluded that supplementing diets with organic acids at the levels required to-suppress CH₄ emissions is uneconomical.

Two complementary alternative approaches to the problem of reducing CH₄ production without compromising digestive efficiency are being researched in New Zealand.

First, utilising genomic information obtained from the principle methanogens found in the rumen (Leahy et al., 2010), researchers are looking to 'design' inhibitory compounds that will disrupt the metabolic processes essential to the formation of CH₄ (Attwood and McSweeney 2008). This task is made particularly difficult since the rumen contains many different types of microbes and any inhibitor needs to be specific in its mode of action; the inhibitor should only target methanogens and, since there are many different types of rumen methanogen, for successful methane inhibition it must target as wide a range of methanogens as possible.

Second, the hydrogen issue is being addressed by studying whether it is possible to promote acetogenesis, a pathway which converts CO₂ and H₂ into acetate in the rumen as an alternative to methanogenesis. Acetogens are found in the rumen (e.g., Olesen et al., 2006) and it is likely that they are normal flora in all ruminants (Attwood and McSweeney, 2008) although the conditions in the rumen strongly favour methanogenesis over acetogenesis (Thauer et al., 1977; Cord-Ruwisch et al., 1988). If acetogenesis could be promoted at the expense of methanogenesis this could result in a greater supply of acetic acid and an improved energy supply to the animal.

A further novel approach which has been tried in both Australia and New Zealand is vaccinating animals so that they produce antibodies against the methanogens present in the rumen and suppress methanogen growth and CH₄ production. Wright et al. (2004), working in Australia, had mixed results using vaccine based on whole killed cells and follow up work in New Zealand using vaccines prepared from New Zealand and Australian methanogen strains proved unsuccessful (Clark et al., 2005) (Table 6).

A new approach, based on using cell fractions as opposed to whole cells, is now being tested. Early results from *in-vitro* studies have clearly demonstrated that it is possible to stimulate the production of antibodies in sheep that can suppress both methanogen growth and CH₄ production (Wedlock et al., 2010) (Figure 3).

Table 6. Percentage changes in the quantity of methane emitted per unit feed intake compared to adjuvant only controls following vaccination with anti-methanogenic vaccine preparations. Data courtesy of the Pastoral Greenhouse Gas Research Consortium.

Vaccine	Post-primary vaccination			Post-booster vaccination		
	A	B	C	A	B	C
Australia ¹	-6	Not used	-1	-7.7*	Not used	+0.8
New Zealand ²	-4	+2	Not used	+2	+9	Not used

All data non-significant except for *, where $p = 0.51$.

Source ¹ Wright et al., 2004; ² Clark et al., 2004.

Breeding animals with low CH₄ emissions

Work in New Zealand by Pinares-Patino et al. (2003c) established that there are differences between individual animals in the quantity of CH₄ they emit per unit of dry matter intake. This finding has resulted in the establishment of research programmes aimed at exploiting these differences.

Initial studies aimed at identifying sheep with contrasting emission were hampered by the variability inherent in the SF₆ tracer technique (Pinares-Patino, 2007a;

Vlaming et al., 2008) but the change to using calorimeters to measure emissions has enabled New Zealand scientists to identify individual high and low emitting animals (Pinares-Patino, personal communication). A new enlarged research programme will concentrate on i) establishing, by 2012, two flocks of sheep that differ by 20% in their average emissions and ii) discovering the genetic and physiological basis for these differences in emissions.

In dairy cattle a slightly different approach has been taken, that of selecting animals with a reduced residual feed

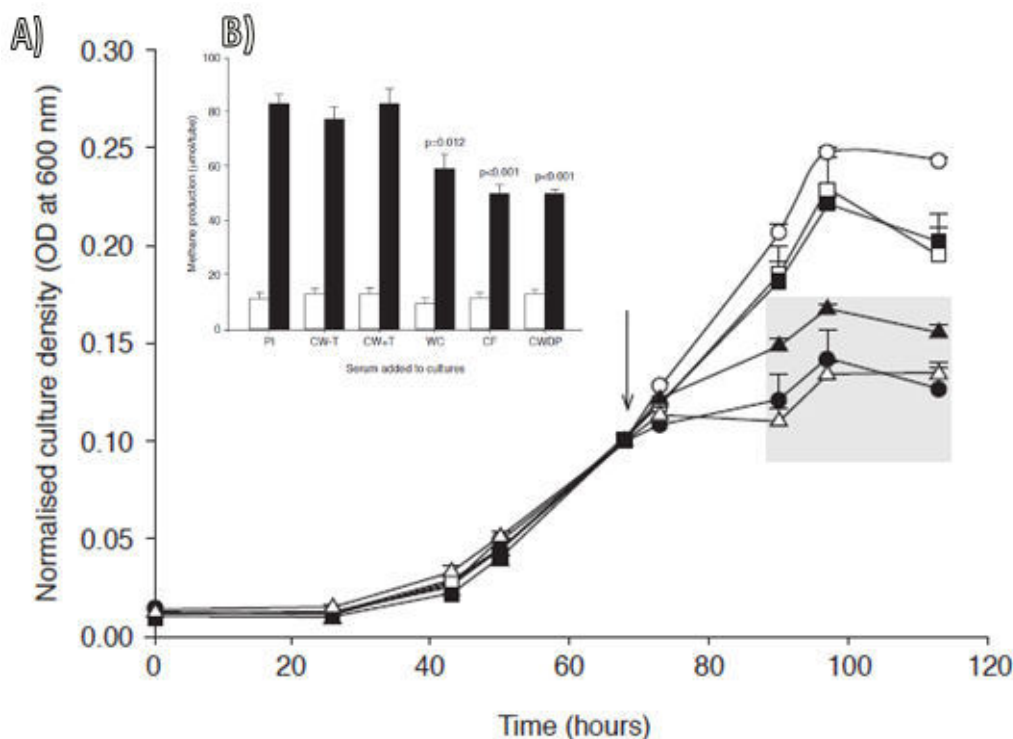


Figure 3. (A) Mean (\pm SE) optical density (OD) at 600 nm of culture of *Methanobrevibacter ruminantium* M1 treated with pooled antisera from ($n = 4$) vaccinated with whole cells of *M. Reuminantium* M1 (\bullet), cytoplasmic fraction (Δ), cell-wall fraction (treated with trypsin) (\blacksquare), cell-wall fraction (without trypsin treatment) (\square), or cell wall-derived proteins (\blacktriangle); or treated with pooled ($n = 20$) pre-immune sera (\circ). Sera were added 68 h after inoculation of the cultures (denoted by the arrow). The densities in the cultures at the points bounded by the grey square were lower than in the cultures that received pooled pre-immune sera ($p > 0.001$). (B) Mean (\pm SE) production of methane by *in-vitro* cultures of *Methanobrevibacter ruminantium* M1 just before addition of sera at 68 h (\square) and during the growth phase at 90 h (\blacksquare). Antisera to whole cells or fractions were pooled from four sheep, while pre-immune sera were pooled from 20 animals. (PI = pre-immune; CW-T = cell wall without trypsin treatment; CW+T = cell wall plus trypsin treatment; WC = whole cells); CP = cytoplasmic fraction; CWDP = cell wall-derived proteins). p-values are the significance of the difference compared with cultures treated with pre-immune sera. Bars without p-values were not significantly different ($p > 0.05$). Data courtesy of the Pastoral Greenhouse Gas Research Consortium.

intake. Animals with reduced feed intake should have lower emissions simply because enteric CH₄ emissions are directly correlated with feed intake. Initial studies in Canada found that animals selected for low residual feed intake had up to 28% lower CH₄ emissions than their high residual feed intake counterparts (Nkrumah et al., 2006). No results are yet available from New Zealand studies.

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