ON FEEDING LEGUME FORAGES CONTAINING
CONDENSED TANNINS TO DAIRY COWS TO REDUCE
METHANE EMISSIONS

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ABSTRACT
This paper compares the methane emission rates by dairy cattle on two
different diets: perennial ryegrass-based (RG) pasture, the principal diet for
dairy cattle in New Zealand; and forage legumes containing condensed
tannins (CT). Legume diets are expected to lower methane emissions relative
to grasses because of their higher nutritive value, and although legumes
containing CT are not in common usage, substantial benefits have been
attributed to the low concentrations of CT in various legume species including
birdsfoot trefoil (Lotus corniculatus) and sulla (Hedysarum coronarium). These
benefits include improved milk production, increased milk protein content and
prevention of bloat, and in sheep improved live-weight gain, lambing
percentage and resistance to intestinal nematodes. A series of trials have
involved measurement of methane emission from dairy cows, some fed
pasture and some fed birdsfoot trefoil or sulla. Per-animal methane emissions
are determined using the SF$_6$ tracer technique. Methane emissions by cows
fed sulla and RG were similar (254 vs 260 gCH$_4$/d), but, as the consumption of
sulla was higher, emissions expressed as a percent of gross energy intake
were significantly different for the two feeds (6.1 vs 7.2%, P<0.05). A higher
milk yield from the sulla-fed cows resulted in a significantly lower methane
emission per unit milk production (23 vs 32 gCH$_4$/kg milk, P<0.01). While the
contributory roles of higher nutritive value and CT content to the lowered
methane yield have yet to be fully elucidated, such trials indicate that a
strategy of feeding forage legumes containing CT to dairy cows has the
potential both to increase milk productivity and to reduce methane emission
per unit of milk production.

1 INTRODUCTION
Livestock farming, arguably the most methane-productive human activity,
accounts for ~85 out of an estimated 400 Tg of methane emitted annually from
human activities (Prather et al. 2001). Almost all of the livestock emissions are
from ruminant animals, which digest feed through an anaerobic fermentation
in the main compartment of the stomach (rumen), a process commonly
termed “enteric fermentation”. We refer to ruminant-sourced methane
emissions as “ruminant methane”.

1.1 NEW ZEALAND EMISSIONS AND THE KYOTO PROTOCOL
New Zealand (NZ), with 0.2% of the world’s land area, has a temperate
climate and fertile soils that support a disproportionately large number of
farmed livestock compared to a human population of 4 million. Livestock
populations for 2002 include: 39.5 million mature sheep, and a further 32.6
million lambs born mainly for the meat trade; 5.1 million dairy cattle; 4.5 million beef cattle; 1.6 million deer (NZ Ministry of Agriculture and Forestry, 2003). NZ’s per-capita emissions of livestock-sourced gases therefore far exceed the global average. For example, the NZ ruminant methane emission estimated at 1.1 Tg/yr represents about 1.3% of global ruminant methane production. As a result, and uniquely among Annex I countries, agriculture accounts for about half of NZ’s CO₂-equivalent greenhouse gas emissions (51.7% in 1990; 49.5% in 2001: NZ Climate Change Programme, 2003). Ruminant methane accounts for about 65% of the agricultural emissions, with nitrous oxide from agricultural soils dominating the remainder (34%).

Furthermore, because non-CO₂ emission sources are more difficult to quantify than CO₂ sources from fossil-fuel combustion that lead the inventories of other Annex I countries, NZ’s emission inventory is relatively uncertain and more prone to revision. Research aimed at increasing confidence in the inventory will therefore also aid the development of policies to limit greenhouse gas emissions in compliance with the Kyoto Protocol (KP), which NZ has ratified. NZ’s obligations under the KP, once in force, require that annual emissions during the First Commitment Period (2008–2012) do not exceed those for 1990, or that emission rights be purchased at an as-yet undetermined price to cover the excess emission.

NZ sells milk, meat and other farm products to an open international marketplace without restriction from production quotas. Thus, a unilateral imposition of an emission tax or similar on NZ farmers would erode international competitiveness. Agricultural and non-agricultural emissions in 2001 are estimated to be 12% and 22% higher than those in 1990, and both are projected to rise further without intervention. Dairying supplies the largest contribution to that rise in agricultural emissions, due mainly to growth in the dairy industry over the last decade and conversion of other land-uses to dairy farms. A key strategy aimed at reducing ruminant methane emissions is to investigate new feedstock and animal-management options, and to explore the potential for intervention in rumen microbiology. Improved feeding offers good opportunities for mitigation in the short to medium term.

1.2 MITIGATING RUMINANT METHANE EMISSIONS

The production of ruminant methane represents an energy loss to the ruminant herbivore equivalent to 3–10% of the gross energy (GE) value of its dietary intake (GEI, MJ/d). We refer to this proportion of GEI as the “methane yield” after Crutzen et al. (1986). The methane yield is known to depend upon diet quality, characterised by an inverse relationship with the metabolisable energy (ME) content of the diet, which measures energy per kg DM available for absorption by the animal (Blaxter & Clapperton 1965).

The ratio of methane to milk (or milksolids) production rates, which we term the “methane co-productivity” of milk production, is a useful input to economic-impact modelling of greenhouse gas mitigation. It has the merit of being expressed in terms of directly measured quantities. However, it must be used with caution as a comparative measure between distinct animals, especially at different stages of lactation. This is because the
partitioning of dietary energy between maintenance of body condition and milk production depends upon more than diet quality and animal characteristics such as liveweight: in early lactation the cow lactates at the expense of body tissue while in late lactation she gains weight while lactating.

Methane co-productivity can be reduced through increasing both feed quantity and feed quality.

- For a given diet, feed demand increases with milk yield but at a proportionately lower rate because of the greater proportion of energy that supports lactation. Thus, while high milk producers generate more methane than low producers, their methane co-productivity is lower.
- For a given feed intake (fixed GEI), methane co-productivity varies inversely with feed quality, both through an elevated milk production (more of the GEI is metabolised) and due to a lower methane yield and reduced daily emission.

Increasing feed quality will stimulate increased feed consumption (higher GEI) and production so that the reduced methane co-productivity may or may not be accompanied by a lower methane emission rate. Thus, while a rise in feed quality across the national herd will reduce methane co-productivity, it will not assure a lower ruminant methane inventory.

In this work, we examine the effect of feeding lactating dairy cows with legume forages that contain condensed tannins (CT), compared with control cows fed perennial ryegrass (Lolium perenne, RG), which with white clover (Trifolium repens, WC), is the principal diet for pasture-fed livestock in NZ. Dietary CT enhance nutritional performance (Waghorn et al. 1999), resulting in higher milk production in dairy cows (Harris et al. 1998; Woodward et al. 2000), and credited with reduced methane from both sheep (Waghorn et al. 2002) and dairy cows (Woodward et al. 2001). The study of Waghorn et al. (2002) in particular compared methane yields from sheep fed a range of diets, including a study which attributed to CT a 16% reduction in methane yield. Thus, we examine the hypothesis that feeding CT-containing legumes to dairy cows has potential as a methane mitigation strategy.

2 METHODS

2.1 EXPERIMENTAL DESIGN

The experiment was conducted at a research farm at Dexcel Ltd, Hamilton, NZ (37°48´S, 175°20´E), with 16 mixed-age dairy cows (8 Friesian + 8 Jersey breeds; lactation length 211±15 days) in March 2001. The Friesian cows were heavier (473±63 kg) than the Jerseys (377±26 kg). Two sub-herds each of four Friesians and four Jerseys were matched for liveweight and milk production when grazing the same pasture. One sub-herd was allocated RG pasture and the other CT-containing sulla (Hedysarum coronarium), for 12 days in March 2001. Methane, milk and intake measurements were averaged over the last 3 days, the "measurement period".
A generous fresh pasture allowance of 40 kg dry matter (DM) per cow was made available daily, and the herbage was sampled daily over the measurement period down to grazing depth. The herbage samples were pooled by sub-herd and analysed for DM, CT and chemical composition using near infrared reflectance spectrophotometry, as reported in detail by Woodward et al. (2002).

2.2 METHANE MEASUREMENTS

Daily methane production from individual cows employs the sulfur hexafluoride (SF$_6$) tracer technique of Johnson et al. (1994), as described by Lassey et al. (1997). Briefly, respired breath is sampled over 24 hours using a lightweight collection system mounted on each cow. A similar system collects “background” samples upwind of the grazing area. Sub-samples of each collection are analysed by gas chromatography (Hewlett-Packard 5890 Series II) for methane and for the purposeful tracer SF$_6$ using flame-ionisation and electron-capture detection, respectively. The SF$_6$ tracer is introduced via a “permeation tube”, a controlled release device with an individual pre-calibrated SF$_6$ permeation rate, Q$_{SF6}$ (range 3.8–5.2 mg SF$_6$/d), that is inserted into the rumen of each animal one week prior to the experiment (Lassey et al. 2001). Daily methane emission from each cow is calculated as $Q_{CH4} = Q_{SF6} \times [CH_4]/[SF_6]$, where $[CH_4]$ and $[SF_6]$ are the gas concentrations in excess of background in the respired sample. The average daily emission over the measurement period is reported.

2.3 INTAKE MEASUREMENTS

Individual DM intakes (DMI) were estimated indirectly using C$_{32}$ alkane markers administered twice daily starting five days prior to the measurement period, together with faecal sampling during the day following methane measurement to acknowledge a 24-hour digestion period. DMI estimates follow from the C$_{32}$ content of faecal samples, pooled for each animal, in conjunction with the DM digestibility of the herbage (Dove & Mayes 1991). This indirect estimate of DMI, inevitable for grazing animals, carries an undetermined level of uncertainty.

2.4 MILK ANALYSES

Daily milk production was measured from each cow over the measurement period. Sub-samples were analysed for milk fat (MF), milk protein (MP), and total milksolids (MS = MF + MP).

3 RESULTS AND DISCUSSION

The sulla pasture was both purer than the RG-based pasture (98±1% versus 73±7%) and of higher quality (ME content 12.6 versus 9.8 MJ/kg DM; crude protein 266 versus 212 g/kg DM; soluble carbohydrates 192 versus 57 g/kg DM; total fibre content 147 versus 483 g/kg DM). Summer grasses and weeds dominated impurities in the RG-based pasture. The CT content of the sulla was 27.2 g/kg DM.

As reported in Table 1, the mean DMI of sulla-fed cows significantly exceeded that of RG-fed cows (P<0.001), probably as a result of the lower fibre content. The higher levels of nutrient intake allowed the sulla-fed cows to achieve
significantly greater milk and milksolids production (P<0.001). It is notable that
daily emissions were insignificantly different between the two treatments.

<table>
<thead>
<tr>
<th>Milk &amp; Methane production</th>
<th>sulla</th>
<th>RG</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter intake (kg DM/cow/d)</td>
<td>13.1</td>
<td>10.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Milk yield (kg/cow/d)</td>
<td>11.24</td>
<td>8.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Milk fat concentration (%)</td>
<td>5.51</td>
<td>5.80</td>
<td>0.14</td>
</tr>
<tr>
<td>Milk protein concentration (%)</td>
<td>4.05</td>
<td>3.76</td>
<td>0.06</td>
</tr>
<tr>
<td>Milksolids yield (kg MS/cow/d)</td>
<td>1.07</td>
<td>0.81</td>
<td>0.04</td>
</tr>
<tr>
<td>Methane emission rate (g CH₄/cow/d)</td>
<td>254</td>
<td>260</td>
<td>25</td>
</tr>
<tr>
<td>Methane yield (CH₄ as % of GEI)</td>
<td>6.1</td>
<td>7.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Methane co-productivity (g CH₄/kg milk)</td>
<td>23.2</td>
<td>31.8</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Table 2 presents some comparative methane and milk production measurements for three NZ trials performed by our research team in late summer. All are for grazed pastures covering a variety of pasture types, including RG/WC mixtures (Lassey et al. 1997) and two distinct sub-tropical C4 grasses, perennial kikuyu grass (*Pennisetum clandestinum*) and annual summer grass (*Digitaria sanguinalis*, SG) (Ulyatt et al. 2002). The different herd characteristics, especially liveweights, in the different trials hinder cross-trial comparison. In particular, the predominantly-Friesian cows in trials A–C were considerably heavier on average than the mixed-breed herd in the present trial (mean 425 kg). It should also be noted that in trials A–C feed intakes were estimated via an energy requirements model rather than based on faecal output measurements.

Woodward et al. (2002) discuss some possible explanations in terms of rumen function and digestive performance for differences in methane production between cows and between diets. Waghorn et al. (1999, 2002) discuss in more detail herbivore nutrition for different diets. The present trial is not definitive in elucidating the role of CT, though it confirms the importance of legumes as determinants of milk yield and suggests a concomitant reduction in methane generation per unit milk production or per unit intake. We were not able to make useful inter-comparisons between the Jersey and Friesian groups within the sub-herds because of low animal numbers and incomplete data for some individuals.
TABLE 2. Average milk and methane production for dairy cows grazing different pastures, reported by Lassey et al. (1997) (A) and by Ulyatt et al. (2002) (B, C).

<table>
<thead>
<tr>
<th>Milk &amp; Methane production</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture type</td>
<td>RG/WC</td>
<td>Kikuyu</td>
<td>SG</td>
</tr>
<tr>
<td>Trial date</td>
<td>Mar 1996</td>
<td>Feb 1997</td>
<td>Mar 2000</td>
</tr>
<tr>
<td>Cow liveweight (kg)</td>
<td>483±44</td>
<td>440±46</td>
<td>585±59</td>
</tr>
<tr>
<td>Lactation length (d)</td>
<td>210</td>
<td>207±25</td>
<td>220±23</td>
</tr>
<tr>
<td>Est. dry matter intake (kg DM/cow/d)</td>
<td>12.9</td>
<td>15.6</td>
<td>18.9</td>
</tr>
<tr>
<td>Milk yield (kg/cow/d)</td>
<td>14.1</td>
<td>11.15</td>
<td>14.5</td>
</tr>
<tr>
<td>Methane emission rate (g CH₄/cow/d)</td>
<td>263</td>
<td>363</td>
<td>422</td>
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<tr>
<td>Methane yield (CH₄ as % of GEI)</td>
<td>6.2</td>
<td>7.1</td>
<td>6.7</td>
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<tr>
<td>Methane co-productivity (g CH₄/kg milk)</td>
<td>18.6</td>
<td>32.6</td>
<td>29.1</td>
</tr>
</tbody>
</table>

4 CONCLUSIONS
While NZ pastures are of high quality by world standards (typical DM digestibility is 70–75%) there are opportunities to improve nutritive value through developing new crops and new agronomic and animal-husbandry practices. Such an approach should be mindful of collateral emissions from crop cultivation: of nitrous oxide from fertiliser applications, and of carbon dioxide from both intensive mechanisation and soil tillage (van der Nagel et al. 2003). Separate studies of the nutritive value of CT-containing legumes suggest the potential of such crops to promote increased productivity in both dairy cows and sheep (eg, Waghorn et al. 1999; Woodward et al. 2000). The present work examines whether a reduction in methane emission also accompanies the increased productivity by dairy cows, at least in the short term, as has been observed for sheep (Waghorn et al. 2002). While promising, the results of this small trial fall within the range of variability of other comparable trials, and so are not definitive. Consequently, it remains unproven whether the CTs themselves incrementally reduce “methane co-productivity” (the ratio of methane to milk production) or whether the leguminous properties alone of sulla account for the reduction observed for sulla-fed cows when compared to RG-fed cows.

Subsequent ongoing research is addressing this issue through the use of polyethylene glycol (PEG) as a suppressant of CT biochemistry: cows fed CT-containing legumes with and without PEG treatment can be directly compared and differences attributed to the role of CT. Waghorn et al. (2002) conducted a similar experiment with sheep and attributed to CT a 16% reduction in methane yield. Preliminary analysis of the cow experiments confirms a specific role for CT in reducing methane yield.
ACKNOWLEDGMENTS

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REFERENCES


