

## PROOF OF FUNCTION

All potential CH<sub>4</sub> mitigation strategies must be evaluated to prove their efficacy. To achieve wide-spread implementation, strategies must be cost-effective and safe. Several potential mitigation strategies have been trialed with promising results from nitrification inhibitors to lower nitrous oxide emissions and forage species to lower methane from digestion.

In addition to efficacy, strategies must also be shown to be cost effective. At the very least a proven mitigation strategy must be cost neutral. For example agronomic neutrality could be achieved if the cost of the strategy was outweighed by the benefits. Benefits could include; increased dry matter production, animal productivity, improved animal health and Carbon Credits resulting from the reduction in greenhouse gas emissions.

Finally, safety is of paramount importance. Mitigation must not put farm workers, livestock or the environment at risk, and in no way reduce the quality and safety of the produce.

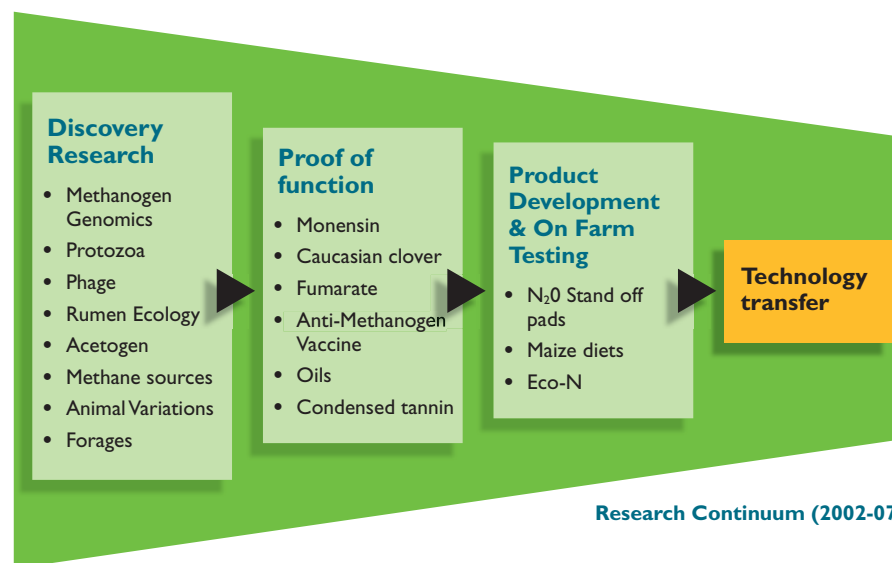
PGgRC has used a series of levels to identify and validate promising technologies. These range from *in vitro* laboratory screenings through to farm scale evaluations. Throughout this process analysis for scientific validations through productivity and economic evaluation are applied depending on the scale of the trial.

The predominant proof-of-function work has been conducted in the mitigation of Nitrous Oxide, on nitrification inhibitors and on the evaluation of whole farm systems. Both of which are described in the Nitrous Oxide section. Since nitrification inhibitors have been commercially released the mitigation strategy has been advanced to the point where proof of function is no longer needed, but now requires widespread field validation.

Current strategies for methane mitigation, developed by the PGgRC are not so far advanced as to warrant farm systems testing but theories and strategies have been developed that use products developed

for other aspects of farming. For example, monensin is an antibiotic that is known to influence rumen microflora and has been tested for its potential to reduce methane emission. Monensin is commercially available in a controlled release capsule that can be easily administered but a literature review shows mixed results for methane abatement, so this technology is ideal for testing at the proof of function stage.

Promising *in vitro* results showing Caucasian clover reduced methane emissions were followed up with an animal trial. Grain and oil supplementation has been trialed, and a patented anti-methanogen vaccine has also been tested.



PGgRC is channeling research from discovery science to proving the efficacy of potential mitigation strategies and developing cost-effective products for integration into existing farm businesses.

Further proof of function trials will be carried out as PGgRC intervention strategies approach that stage. Also PGgRC is establishing cooperative research interests with a range of national and international companies and scientists will be evaluating the efficacy of existing technologies to reduce methane emission.

Subsequent to such trials, economic analysis will be conducted to consider the productivity potential. Some treatments appear to be effective but are prohibitively expensive, even if accepted as a mitigation technology by the UNFCCC. Fumarate is one such potential technology that can lower methane but is too expensive to be considered for farmers.

Ultimately there are several hurdles that need to be overcome before a technology is viable for adoption. The mitigation

must be effective, easy to integrate into a farming system, not affect the quality of product or market access (not contravene import rules for animal health treatments to major trading partners), and provide at least economic neutrality. Ideally it should increase productivity and profitability to ensure industry uptake and adoption, so that an economic reward is achieved by reducing greenhouse gas emissions.



## The effect of monensin on methane production, milk yield, feed intake and other indices of cow fed pasture from September–December 2005

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### Background

Monensin (Rumensin) is an ionophore that can modify the rumen microflora and in some situations, reduce methane production as well as increase the efficiency of feed utilization. Monensin is an antibiotic which is approved for use in New Zealand and other countries, for promoting ruminant health.

Monensin can be administered via intra-ruminal controlled release capsules (CRC) that last for approximately 100 days. Although the efficacy of monensin for increasing the efficiency of feed utilization has been proven for animals fed grain based diets, the benefits for animals fed forages (pasture) are less well defined.

The effects on methane production are less well studied, especially for forage based diets, but on average monensin has reduced methane production in short term trials, although the effects seem to be variable.

### Objectives

To measure the effects of monensin delivered by CRC on methanogenesis, milk production and digestion over an 80 day period. The duration of the trial will indicate the persistency of any reduction in methanogenesis.

### Materials and Methods

Sixty cows in early lactation were grazed as a single herd, except during four indoor measurement periods. After the initial measurement period required for covari-

ate analyses, half of the cows were given a monensin CRC.

Only 32 cows were used for measuring methane production and intakes during the four ad libitum feeding periods (16 with and 16 without intra-ruminal monensin CRCs). Milk production and liveweight were determined for all 60 animals over the duration of the experiment.

Indoor feeding and grazing was exclusively pasture, typical of standard dairying practice. Grazing allowance was about 40 kg DM/cow/day to achieve *ad libitum* intakes. Milk production was determined daily from all cows, with weekly liveweights, condition scores, milksolids and somatic cell counts weekly.

The 32 cows used for the methane measurements included 10 that had been previously fitted with rumen fistulae, so that samples of rumen contents were able to be taken during the methane measurement periods. Samples were taken to measure ruminal metabolites, including ammonia and volatile fatty acid (VFA) concentrations, and samples were taken for enumeration of the microflora, should a need arise. Rumen fistulae also enabled retrieval of the CRCs from 5 cows to measure rates of monensin release.

The data obtained from this experiment were analysed by covariance; milk production and composition, methane production and intakes were measured prior to monensin CRC administration. The design provided optimal sensitivity for statistical

analyses of the main effects and enabled the two objectives to be addressed *viz.* effect of monensin on methanogenesis and production over time.

### Results

The administration of monensin did not significantly affect dry matter intake (DMI), methane production or milk yields. Monensin did not affect fat:protein ratios, cow liveweight change, milk somatic cell counts or rumen parameters (pH, NH<sub>3</sub>). Methane emissions averaged 19.2 g/kg dry matter intake, a value that is approximately 10% lower than values used in the current National Inventory calculations.

These results demonstrate no significant benefits for greenhouse gas mitigation or animal productivity. However measurement of residual monensin in the CRC from the 5 rumen fistulated cows showed the release rate was about 54% of the

anticipated value. The poor performance of the controlled release technology will have impacted on the efficacy of the monensin evaluation.

### Related Publications

Clark, H. (2003) Estimating the impact of monensin sodium on methane and nitrous oxide emissions from the dairy sector between 1990 and 2002. A report prepared for MAF Policy.

Clark, D.A., Waugh, C.D., Van Vugt, S. & Clark, H. (2003) The effect of monensin on methane emission from identical twin dairy cows fed pasture. Australia-New Zealand Non-CO<sub>2</sub> Greenhouse Gas Conference, Victoria, October 2003.

Van Vugt, S.J., Waghorn, G.C., Clark, D.A. & Woodward, S.L. (2005) Impact of monensin on methane production and performance of cows fed forage diets. *Proceedings of the New Zealand Society of Animal Production* 65: 362-366

	Control	Monensin	P
DMI (kg/day)	16.42	16.44	0.937
Methane (g/day)	322.5	323.0	0.961
Methane (g/kg DMI)	19.52	19.88	0.604
Milk yield (kg/day)	21.18	21.44	0.669
Milk solids (kg/day)	1.65	1.63	0.721



## The effect of coconut oil and monensin on methane mitigation agents for forage fed sheep

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### Background

New Zealand's pastoral livestock production systems place severe constraints on the type of measures available to farmers for the abatement of enteric methane emissions.

Research has shown that some legumes and herbs can reduce methane emissions in sheep, deer and cattle. Similarly, research has also shown that mitigation agents, such as oils (e.g. coconut oil), and monensin supplements can reduce methane emissions per unit of intake.

However, much of this work has been based on grain and/or conserved forage as the main dietary constituents and it is not known if the same effects can be achieved with fresh forage diets.

### Objectives

The aim of this study was to investigate and compare the effect of different potential methane mitigation technologies, singly or in combination, on methane emissions from sheep fed fresh forage diets.

### Materials and Methods

The experimental design was a two-factorial design with two measurements two weeks apart, with animals receiving the experimental diet and mitigation agent(s) for 10 days prior to the first methane measurement.

There were four main treatment groups;

- (1) no agent (n = 8),
- (2) monensin (n = 8),
- (3) coconut oil (n = 12) and
- (4) coconut oil + monensin (n = 12)

Within each main treatment group animals were further split into sub-groups and fed either perennial ryegrass (*Lolium perenne*)-based pasture or chicory (*Cichorium intybus*) cut fresh daily and fed 1.5 times estimated energy requirements for maintenance on a per animal basis.

Animals receiving either mitigation agent were dosed twice daily. Monensin was dosed via a drench gun at a rate of 15 mg/day and coconut oil was dosed at a rate of 3% dry matter intake (DMI)/day on an individual animal basis. The coconut oil was administered by a 20 ml syringe. Methane production was measured using the sulphur hexafluoride (SF<sub>6</sub>) technique when sheep were housed individually in metabolism cages.

### Results

Preliminary results found:

- Sheep fed chicory were producing 37% and 22% less methane per day and per kilogram of DMI, respectively than sheep fed pasture ( $P < 0.001$ ).
- Monensin alone and monensin + coconut oil treatments reduced methane production per day and per kg DMI by up to 33% ( $P < 0.01$ ) compared with the control and coconut oil groups.

There were no significant interactions

between the types of forage fed and administered mitigation agents ( $P > 0.7$ ).

	g CH <sub>4</sub> /day	g CH <sub>4</sub> / kg DMI
Chicory	17.0	24.3
Pasture	26.9	31.0
Monensin	20.2	25.7
Coconut oil	24.5	29.8
Monensin + Coconut oil	18.1	22.1
Control	25.1	33.2

These results show that significant reductions in both methane production and yield can be achieved with fresh forage feeding. Based on these results, monensin appears to be able to reduce methane emissions from animals fed fresh pasture or chicory, although results from other New Zealand experiments using monensin are less encouraging.

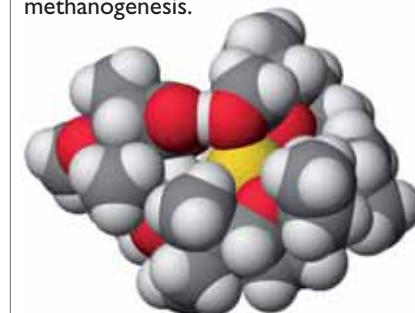
Supplementing pasture based diets with coconut oil alone does not appear to be an effective mitigation approach, although there was some benefit from supplementing with coconut oil and monensin.

### Future Developments

To determine the effectiveness of other forage herbs and legumes at reducing ruminant methane emissions, the mechanisms of action of alternative forages such as chicory, and whether inclusion of alternative forages in pasture mixes or as a proportion of the total diet will impact on methane emissions.

To determine the effectiveness of methane mitigation agents in the long-term grazing situation.

**Monensin** is a naturally occurring ionophore, isolated from *Streptomyces cinnamonensis*, and is used extensively in US beef and dairy cattle farming to improve growth rates. Monensin can form complexes with metal ions and transport them across cellular and subcellular membranes. This cation transporting ability, confers monensin with antibiotic and other biological activities, possibly including inhibiting methanogenesis.





## Effect of fumaric acid supplementation on the enteric methane production of wether lambs consuming a ground lucerne diet

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### Background

Organic acids, such as fumarate also called fumaric acid (FA) and malate, are key ingredients of the citric acid cycle and occur naturally in plants with concentrations ranging from 2-8% of dry matter. Some strictly anaerobic bacteria synthesise succinate or propionate from fumarate or malate, utilising a reductive or reverse citric acid cycle, also called the succinate-propionate pathway.

Propionate synthesis from malate and fumarate requires either two or three major reactions: conversion of malate to fumarate, the reduction of fumarate to succinate, followed by the decarboxylation of succinate to yield propionate.

Reducing equivalents are needed in the reduction of fumarate to succinate and, therefore, fumarate may provide an alternative electron sink for hydrogen. As hydrogen is used to reduce fumarate, there is a decline in the availability of hydrogen for methanogenesis in the rumen.

Empirical evidence supports this theory and CH<sub>4</sub> production has been decreased *in vitro* by adding fumaric acid. The decrease in methane produced corresponded well with the fraction of fumarate converted to propionate.

There are 17 reported studies that have evaluated this mitigation option *in vitro*. Review of these publications show varied results, 7 showed decreased methane production, 9 observed no change and 1 reported an increase, suggesting that fu-

marate and malate does reduce methane emission *in vitro* and that the effect is dose dependent.

Few *in vivo* studies have been conducted, these report a wide range of often confounding results of varying levels of supplementation. Theoretical calculations suggest that FA included at 10% of the diet (150 g/d) will reduce CH<sub>4</sub> by approximately 2.7 g/d suggesting some of the reported reductions of 13 and 8.4 g/d difficult to explain based on current knowledge.

### Objectives

To evaluate the potential of supplementary feeding of organic acids (fumaric acid) to reduce enteric methane emissions from ruminants.

### Materials and Methods

Methane emissions were measured from twenty 18-month old wether sheep during two 4 day periods. The animals were fed a basal diet of Lucerne chaff and FA was added to the diet at five different levels; 0, 4, 6, 8 and 10 g FA/100g dry matter feed.

Individual daily methane emissions were estimated using sulphur hexafluoride (SF<sub>6</sub>) tracer gas technique and daily dry matter intake, weekly liveweight change and total faecal output recorded.

Rumen samples were collected before and using the treatment periods in order to evaluate the effect of FA on ruminal pH, volatile fatty acids (VFA) and ammonia concentrations.



Trial sheep in Metabolism crates

### Results

The addition of FA did not significantly affect methane emissions per kg dry matter intake. Daily dry matter intake was, however, significantly reduced at high levels of FA supplementation. There was no consistent effect of FA on ruminal parameters (pH, VFA, ammonia concentration).

There was a strong trend for CH<sub>4</sub> inhibition (g/d) as the FA% in the diet increased. This reduction appeared not to be due to the FA itself but as a consequence of reducing the voluntary feed intake induced in animals on the higher FA% diet treatments (FA% >4%).

The higher FA treatments reduced both DMI and CH<sub>4</sub> (on a per day basis) but there is no discernible effect of FA alone on CH<sub>4</sub> per day because DMI reduced during experimentation. There was not significant change to the ratio of CH<sub>4</sub> to DMI, both decreased proportionally and the ratio of emission/DMI remained similar.

### Future Developments

Although the treatment is effective the economics are not. PGgRc economic analysis suggests that carbon would need to be over NZ\$3000 per tonne to cover the treatment costs assuming 25% methane abatement.

### Related Publications

Newbold CJ, Ouda JO, Lopez S, Nelson N, Omed H, Wallace RJ, and Moss AR. 2002. Propionate precursors as possible alternative electron acceptors to methane in ruminal fermentation. In *Greenhouse Gases and Animal Agriculture*, ed. Takashi J. and Young BA. Amsterdam, Elsevier  
Kolver ES, and Aspin PW. 2006. Supplemental fumarate did not influence milksolids or methane production from dairy cows fed high quality pasture. *Proceeding of the New Zealand Society of Animal Production*, Vol 66: 409-515



## The effect of oil or cereal grain supplements on methane production from cows grazing pasture

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### Background

Studies have shown that oils derived from plant or animal sources are able to reduce ruminant methane production by up to about 25%. Although the degree of methane suppression is variable, unsaturated oils or fats *should* always reduce methane production because the process of rumen bio-hydrogenation (creating harder fats) provides a sink for hydrogen ions derived from fermentation. Less hydrogen will be available for methane production.

Most trials involving oils have resulted in some reduction in methanogenesis, but this does not always occur and the extent of inhibition is affected by their structure. Although the mechanisms of inhibition are not well defined, greatest reductions have resulted from oils which inhibit microbial activity. However excess oil (over about 6% of dietary dry matter) will lower feed intakes and animal production. It is also important to be aware that laboratory (*in vitro*) trials evaluating oils always seem to achieve a greater inhibition than occurs in animals.

A 10-day trial conducted previously by Dexcel in 2003 showed 22-35% reduction in methane emissions (g/kg DMI) when cows were given a 500 ml supplement of sunflower or sunflower and fish oil. Cow DM intake and milk production (22-24 kg/day) were not affected but milk solid yields tended to be lower ( $P = 0.08$ ).

### Objectives

To measure methane production from cows fed pasture as a sole diet (Pasture treatment) or pasture with either grain (Grain treatment) or oil (with a protein meal) supplements. The grain and oil treatments supplied about 15% of metabolisable energy (ME) intake.

### Materials and Methods

The trial involved 3 groups of 10 cows, grazed as a single herd on pasture. Treatments commenced immediately after calving and continued for 12 weeks. Methane production was measured over a 4 day period after 11 weeks of supplementation.

Pasture allowance provided about 40 kg DM/cow/day and facilities enabled individual cows to consume grain or protein meal supplements immediately after morning milking. The oils were given as a drench after morning and afternoon milking.

The grain supplement (2.5 kg DM/day) comprised equal weights of maize and barley. The oil comprised 100 ml fish oil and 200 ml linseed oil and this treatment group was also given 1.5 kg (DM) of soybean and linseed meal (equal weights).

Methane emissions were estimated using the SF<sub>6</sub> tracer gas technique and yokes were changed daily after morning milking.

### Results

Daily methane production from cows in the Pasture, Grain and Oil treatment groups (g/day) averaged 354, 360 and 328, respectively ( $P = 0.218$ ). Intakes (kg DM/day) were higher for cows in the Pasture (15.50) and Grain (17.17) treatments than the Oil group (14.90); ( $P = 0.039$ ). However methane production expressed as g/kg DM intake, was similar ( $P = 0.340$ ) for cows in the Pasture (23.0), Grain (21.1) and Oil (21.7) treatments and are similar to values used in New Zealand inventory calculations (21.6 g/kg DM intake).

Although milk production (kg/day) was not significantly different across treatments, there was more variation between cows fed grain (25.8, SD 4.5) and oil (23.8, SD 3.9) supplements than pasture alone (23.1, SD 2.2). Similar results were evident for milk solids, although there were no significant effects of treatments ( $P = 0.33$ ), daily yields (kg) were lower and more variable for cows on the Oil treatment (1.73, SD 0.37) compared to the Grain (1.91, SD 0.24) or Pasture (1.81, SD 0.14) treatments.

It is concluded that daily supplementation with grain or fish and linseed oil for an extended period does not necessarily lower methane emissions, expressed in absolute terms or relative to feed DM intake. Oil supplements may lower voluntary feed intake and this will be detrimental to production.

### Future developments

Future evaluation of oil or other dietary compounds for methane mitigation should be accompanied by measurements of rumen digestive physiology and microbiology to enable the bases for variable responses to be better understood.

### Related Publications

Machmuller, A., Ossowski, D.A. & Kreuzer, M. (2000) Comparative evaluation of the effects of coconut oil, oil seeds and crystalline fat on methane release, digestion and energy balance in lambs. *Animal Feed Science and Technology* 85: 41-60

Woodward, S.L., Waghorn, G.C. & Laboyrie, P.G. (2004) Condensed tannins in birdsfoot trefoil (*Lotus corniculatus*) reduce methane emissions from dairy cows. *Proceedings of the New Zealand Society of Animal Production* 64: 160-164

	Pasture	Grain	Oil	Treat Sig. (P)
DM Intake (kg/day)	15.5	17.2	14.9	0.039
Milk (kg/day)	23.1	25.8	23.8	0.250
Methane (g/day)	354	360	328	0.218
Methane/DMI (g/kg)	23.0	21.1	21.7	0.340



## Field testing an anti-methanogen vaccine in growing ewe lambs

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### Background

In the mid 1990s CSIRO advocated a novel approach to methane mitigation which involved vaccinating ruminants so that they produced antibodies against their own rumen methanogen populations. Because of its ease of use and potential universal applicability this approach is highly attractive. By 2003 the CSIRO research programme had reached the stage where prototype vaccines were available for field testing.

### Materials and Methods

Fifteen ewe lambs aged approx. 9 months were assigned to each of three treatments:

- 1) Adjuvant only
- 2) Vaccine A
- 3) Vaccine B (Vac. A+ additional methanogenic material isolated from New Zealand sheep).

The vaccination procedure had two stages, primary vaccination 20/06/03 and booster vaccination 31/07/03. Measurements were conducted of herbage intake, total methane production (using SF<sub>6</sub> tracer technique) pre-vaccination and 4 weeks post-primary and secondary vaccination, and blood plasma antibody titres pre & post vaccination. Animals were confined to metabolism crates during methane measurements and fed chaffed ad lib Lucerne hay. Animals were allocated treatments based on previous methane emissions.

### Results

Herbage dry matter intake, liveweight gain and total methane output did not differ significantly between the control and vaccine treated groups in either of the post vaccination measurement periods.

Concentrations of IgG in blood did not differ between the three treatment groups pre or post vaccination.

There was no evidence of raised antibody response to either primary or secondary vaccinations.

In addition to the vaccine having no effect on CH<sub>4</sub> production sheep in the Vaccine A and B groups suffered adverse local reactions at the injection site.

### Future Developments

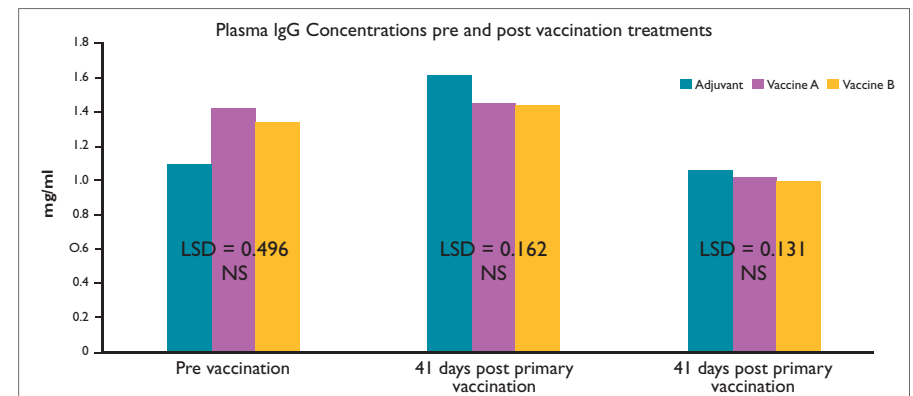
Although the vaccines tested here did not successfully reduce CH<sub>4</sub> emissions the approach is still highly attractive. The knowledge gained in this trial has provided direction for further attempts to develop a successful anti-methanogen vaccine.

Feed Intake (g/day)	Pre-Vaccination	PostPrimary	PostBooster
Control	1180	1137	1310
Vaccine A	1202	1151	1307
Vaccine B	1216	1184	1265
SED	71.6	55.3	31.3
P	NS	NS	NS

Animal liveweight (kg)	Pre-Vaccination	Post Primary	Post Booster
Control	33.7	33.8	36.8
Vaccine A	33.9	33	37.3
Vaccine B	33.5	34.2	36.3
SED	0.82	0.45	0.47
P	NS	< 0.05	NS

Methane emissions (g/day)	Pre-Vaccination	Post Primary	Post Booster
Control	22.4	21.7	21.2
Vaccine A	21.5	21.2	21.9
Vaccine B	24.4	23.1	22.4
SED	2.01	1.61	1.19
P	NS	NS	NS

### Blood antibody concentration (mg/ml)





## Identification of an anti-methanogen component in a commercial batch of indole-acetonitrile

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### Background

In a previous study, 4 sheep were treated twice daily with a bolus of indole-acetonitrile, with the indole-acetonitrile coming from two separate batches. During that trial (Fig. 1.), measurement of methane showed that indole-acetonitrile batch B (ICN-b) but not indole-acetonitrile batch A (ICN-a) inhibited methane strongly.

This was an unexpected and surprising result that needed further investigation.

### Objectives

Identify the active components in a batch of indole-acetonitrile displaying anti-methanogen activity.

### Materials and Methods

The strategy for identifying the bioactive component of ICN-b comprised of several steps.

The first step was to demonstrate the *in vivo* results could be repeated *in vitro*.

Methane and hydrogen production were measured in an assay containing minced ryegrass (0.5g DM), 12 ml anaerobic buffer and 3ml rumen fluid in the presence of ICN-a or ICN-b.

An <sup>1</sup>H-NMR analysis showed the presence of a range of components in ICN-b which were absent from ICN-a. The contaminants were separated from ICN by chromatography and characterised by mass spectrometry. The presence of indole-acetamide (IAM) was identified to be present in ICN-b but not in ICN-a.

### Daily Methane Emissions from Sheep on White Cover

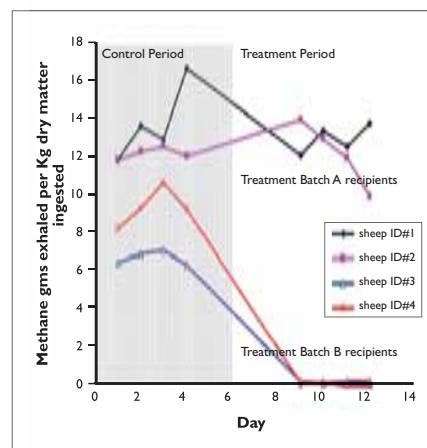


Fig. 1. Methane emissions for sheep receiving indoleacetonitrile.

Given the above step did not reveal the identity of a known antimethanogenic compound, the next step was to use a bioassay guided fractionation to obtain a bulk purified active fraction. Prior to the fractionation process, assays were performed to decipher the active compounds physically characteristics and stability.

ICN was freeze-dried and air-dried to remove volatiles, and the anti-methanogenic activities of ICN-a, ICN-a + IAM, ICN-b, freeze-dried ICN-b and air-dried ICN-b were measured. The activity of ICN-b was shown to be volatile.

Analytic techniques specifically designed to characterise volatile compounds were performed and assays performed on identified contaminants to ascertain their associated anti-methanogenic activity.

### Accumulated Methane

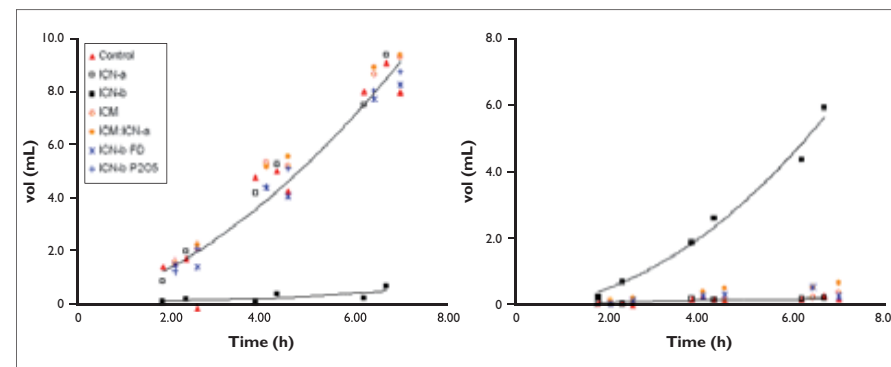


Fig. 2. Accumulated methane and hydrogen in presence of test compounds.

### Results

Methane (0.8 ml/h) was produced in the presence of ICN-a, but not in the presence of ICN-b.

Hydrogen accumulation was observed in the presence of ICN-b, the only extract not to produce methane.

The volatile compounds in active ICN-b and in inactive air-dried ICN-b were measured by GC-MS after absorption to a microextraction fibre.

Twelve volatile contaminants were detected in ICN-b that were absent from ICN-a, and markedly reduced in air-dried ICN-b. Of the 12 volatile contaminants identified, only the chloroform assay arrested methane production. Methane inhibition was accompanied with accumulation of hydrogen.

It was concluded that the anti-methanogen activity observed in sheep receiving indole-acetonitrile batch B was due to the

### Accumulated Hydrogen

presence of contaminating chloroform.

The quantity of chloroform present in ICN-b was estimated to be 47mg/g. At the level of dosage in the previous sheep trial, 47mg/day of chloroform would have unwittingly been administered in the ICN-b treatment. This quantity would have been sufficient to arrest methane production.

## Carbon Conscious Agriculture in the 21st Century

With the commencement of a second consortium contract, which will carry us through to 2012, the PGgRc is faced with a rapidly changing industry striving to adapt to new business signals from a world starting to think consciously about the environment.

The programme of work carried out through the PGgRc in the last five years was against a background of enhancing productivity while reducing emissions. While this is still a key goal, as we advance our understanding across the broad programme of research, it is clear that the effects of climate change are becoming more obvious globally. The pressure to significantly reduce the carbon footprint of our free grazing agriculture will increase. This can be seen by the calls to have an understanding of total carbon costs through analysis such as life cycle analysis (LCA) and report these alongside product. This is fundamentally a different way of thinking about the industry.

The research investment to date will help the PGgRc to support the advance of the industry in responding to these emerging pressures, remaining internationally competitive, while reducing carbon inputs.

With the government signalling the incorporation of agriculture in an Emissions Trading scheme in 2013, the challenge is upon farmers to think differently about their businesses in the future.

We will have to ensure the project outputs work within an agricultural business that progressively has a price for carbon built in to it. This will present significant challenges in communicating results to farmers in a manner that allows them to determine whether the application of that research knowledge will enhance their business. The incorporation of adoption research in the programme will address some of these issues.

Our pastoral industry, so important to the economy of New Zealand, is going to need to adapt to farming practices that reduce the carbon footprint while continuing to enhance productivity. The ability to understand the effects of these changes will be crucial to the sector achieving high levels of adoption and enhance flexibility in its ability to change.

Each of the research objectives in the consortium's programme of work will contribute to this. Better understanding may allow us to manipulate rumen microbial populations and develop technologies that move hydrogen capture away from methane to other substrates better utilized by the ruminants, thus reducing carbon emissions. Selecting livestock that produce low emissions will further enhance this reduction, but will need to be done with consideration for the selection of other traits.

Similarly, the manipulation of the nitrogen cycle to mitigate nitrous oxide poses the same challenges of balancing productivity enhancements with environmental considerations contributing to the drive to adopt improved practices.

### PGgRc and the Next Five Years

The development of solutions to achieve mitigation and abatement will require broad knowledge and integration across many disciplines. This integration will seldom be found in any one institution, so the PGgRc will be actively looking for and supporting collaboration nationally and internationally. With this will come other challenges of harnessing combined resources and focusing them in order to deliver cost effective solutions that allow our pastoral industry to continue to grow and prosper.

The consortium will be striving to deliver solutions that support this change in business drivers, be they products targeting livestock, microbes or the farm environment, or knowledge that needs to be adopted. The approaches taken will be built on sound science and the knowledge and skills gained so far. It is sure to be an interesting and exciting journey.

