



ANNUAL REPORT TO THE CROWN 2008

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Executive Summary

1. Founded in 2002 PGgRc is a partnership between New Zealand pastoral industries and the Foundation for Research Science and Technology (FRST).
2. The Consortium aims to position the Consortium and New Zealand as a global leader in agricultural greenhouse gas mitigation.
3. In the past six years, the Consortium has grown its science team from 12 to 43 and has invested over \$19 million in scientific programmes aimed at reducing agricultural greenhouse gases. It confidently expects its high-quality science programme to gain momentum and make good progress over the next three years.
4. PGgRC has produced leading world research on the production of methane and nitrous oxide from grazing livestock, and is internationally acknowledged for managing the most comprehensive science programme of its type in the world.
5. Non-carbon dioxide emissions from pastoral agriculture account for about 48 of New Zealand's total greenhouse gas emissions. Under the Kyoto Protocol, New Zealand is required to reduce its greenhouse gas emissions to 1990 levels, or to pay or take responsibility for any emissions over this target.
6. There are currently no proven, practical and cost-effective farm practices and technologies to reduce agricultural emissions. However, nitrification inhibitors do show promise for nitrous oxide reduction.
7. PGgRC's key focus goal is to decrease total agricultural emissions of greenhouse gases by 10% per unit of output by 2013 relative to 2004. (This is estimated to be a 4Mt reduction in the agricultural greenhouse gas emissions as identified in the National Inventory).
8. The Consortium also wants to see 33% of farmers implementing at least one greenhouse gas mitigation strategy by 2013.
9. The PGgRC science programme has six key areas of focus and integrates a wide range of science approaches from the microbe to the farm.
10. In the past year the Consortium has progressed all its research goals through:
 - continued progress in the development of a vaccine to reduce methane emissions;
 - development of improved tools for determining rumen population dynamics;
 - further refinement of specific sites for methanogen inhibition through genomic and microbial analysis;
 - the definition of consistent differences in the methane emissions of livestock using respiratory chamber analysis;
 - accurate analysis of plant constituents that influence methane production in ruminant livestock;

- systems analysis of nitrous oxide mitigation options in intensive dairy farm operations.
11. One of our major achievements has been the closure of the *Methanobrevibacter ruminantium* genome – the first rumen methanogen sequence in the world to be completed. We are now working to protect the intellectual property around this work.
 13. We are on track for delivery by 2012, of the concept of a safe and efficient anti-methanogen vaccine.

PGGRC Annual Report – 2007-2008

1.0: The Nature and Purpose of the Programme

- 1.1: PGgRc is a partnership between New Zealand pastoral industries and the Foundation for Research Science and Technology (FRST). It was formed in 2002.
- 1.2: PGgRc is a "centre of excellence" for pastoral-based agricultural greenhouse gas mitigation research both in New Zealand and internationally, and expects to continue its high-quality science programme into the foreseeable future.
- 1.3: Over the past six years the Consortium has invested over \$19 million in scientific programmes aimed at reducing agricultural greenhouse gases. It has produced internationally acknowledged research on the production of methane and nitrous oxide from grazing livestock as part of the most comprehensive programme of its type in the world.
- 1.4: Non-carbon dioxide emissions from pastoral agriculture account for about 48% of New Zealand's total greenhouse gas emissions. Under the Kyoto Protocol, New Zealand is required to reduce its greenhouse gas emissions to 1990 levels, or to pay or take responsibility for any emissions over this target.
- 1.5: There are currently no proven, practical and cost-effective farm practices and technologies to reduce agricultural emissions. However, nitrification inhibitors do show promise for nitrous oxide reduction. There is also a need to improve the accuracy of our estimates of on-farm emissions.
- 1.6: As outlined in the 2004 Memorandum of Understanding between the Crown and the pastoral industries, the government agreed to bear the cost of the agricultural sector's non-carbon dioxide emissions providing the sector contributed to research into ways to reduce greenhouse gas emissions from agricultural activities.
- 1.7: PGgRC has developed, and is now implementing a Research Strategy to reduce greenhouse gas emissions from agricultural activities.

2.0: The Goals of the Strategy

- 2.1: To identify, establish and develop on-farm technologies to improve production efficiency for ruminants
- 2.2: To identify, establish and develop on-farm technologies for sheep, dairy, beef cattle, and deer, which lower methane emissions from New Zealand ruminants and nitrous oxide from grazing animal systems.
- 2.3: To exploit commercial opportunities arising from the science and technologies in a global market.

3.0: Current Targets for the Consortium

- 3.1: To decrease total agricultural emissions of greenhouse gases by 10% per unit of output by 2013 relative to 2004. (This is estimated to be a 4Mt reduction in the agricultural greenhouse gas emissions as identified in the National Inventory).
- 3.2: To have 33% of farmers implementing at least one greenhouse gas mitigation strategy by 2013.
- 3.3: To increase knowledge about climate change and the Kyoto Protocol in the agricultural sector.
- 3.4: To establish New Zealand and the PGgRC as a global leader in agricultural greenhouse gas mitigation.
- 3.5: To ensure national coordination of all greenhouse gas-related investments, while also developing further international collaboration and involvement to increase global capability.
- 3.6: To exploit national and international commercial opportunities arising from the work the Consortium is undertaking.
- 3.7: To help New Zealand farmers adapt to the effects of climate change, and to become competitive in a carbon-constrained global economy beyond 2012.

4.0: PGGRC Science Programme

- 4.1: The PGgRC science programme integrates a wide range of science approaches from the microbe to the farm. It encompasses fundamental research to further understand the processes of methane and nitrous oxide formation through to the design of practical, relevant, on-farm greenhouse gas mitigation systems.
- 4.2: The research programme is strongly focused on developing a pathway for farmer adoption. This is critical if the Consortium goals are to be achieved. There are six research objectives:
 - 4.2.1: **Microbial strategies to reduce methane emissions:** This programme is looking at ways to inhibit methanogenesis by identifying, quantifying and culturing microbes in the rumen. It is also investigating the impacts of these interventions on the long-term functioning of the rumen ecosystem.
 - 4.2.2: **Methanogen genomics:** In this programme we are analysing the genome of rumen methanogens to help us develop new compounds and vaccines that reduce ruminant methane emissions.

- 4.2.3: **The development of an anti-methanogen vaccine:** In this programme we are working to develop, optimise and test an anti-methanogen vaccine that will prevent growth of and methane production by methanogens in the rumen. It is likely that an effective vaccine targeting methanogens in the rumen will require a cocktail of antigens targeting the entire array of methanogen species dwelling in the rumen of livestock. For this reason there are strong links between this work and the work we are doing in our methanogen genome programme.
- 4.2.4: **Animal selection & breeding:** In this programme we are building on work undertaken between 2002 and 2006 when we measured the emissions of 700 dairy cows. To date we have established that there are measurable differences in the carbon emissions of different animals. However, a lack of repeatability of the low- or high-emission trait has hampered progress, and consequently hindered the search for genetic markers to identify high- and low-emitting animals.
- 4.2.5: **Low greenhouse gas emitting farm systems:** This work combines research on the components of farm systems (e.g. dietary manipulation and management of nitrogen inputs). It looks at the development of the newest and the best farm management technologies and the integration of improved technologies into greenhouse gas friendly farm systems. An extension programme is designed to increase awareness and encourage adoption of greenhouse gas reduction measures.
- 4.2.6: **The efficacy of nitrification inhibitors:** This programme is still being developed. In 2006, PGgRC commissioned a review [1] of the current research on the application of nitrification inhibitors in our grazing systems.

To date, our research shows that this technology has tremendous potential to mitigate nitrous oxide. Although nitrification inhibitors are already available on the market, there are important research questions still to be answered before we can maximise their benefits. In particular it is important to ensure any inhibitors meet IPCC requirements and, as such, count towards reducing our emissions.

The Consortium has committed to funding a programme of work in this area, but this has been delayed because of wider issues surrounding the requirement to meet IPCC standards. A lead research group has yet to be engaged.

Working in conjunction with commercial players we expect this will take place in autumn 2009. The Consortium has decided to manage this programme through a science governance group that will ensure involvement and “buy in” by all interested parties.

[1] “A review of Nitrification Inhibitors and Other Nitrogen Cycle Modifiers in New Zealand Pastoral Agriculture.”

5.0: Consortium Funding

5.1: PGgRC is funded by:

- Fonterra Co-operative Ltd
- Meat & Wool New Zealand Ltd (MWNZ)
- DairyNZ Inc
- PGG Wrightson Ltd
- The New Zealand Fertiliser Manufacturers' Research Association Inc (NZFMRA)
- DEEResearch Ltd
- AgResearch Ltd
- Landcorp Farming Ltd.

5.2: FRST provides matched industry funding to the Consortium.

5.3: Associate members are:

- The National Institute for Water and Atmosphere (NIWA)
- The Ministry of Agriculture and Forestry (MAF).

5.4: Research providers and contributors include:

- AgResearch Ltd
- DairyNZ Inc
- Via Lactia Biosciences
- Lincoln University.

5.5: Table of Funding 2007/08

AgResearch	350,000.00
FRST (government)	2,250,000.00
DairyNZ	450,000.00
DEEResearch	35,000.00
NZFMRA	94,500.00
Fonterra	500,000.00
MWNZ	390,000.00
PGG Wrightson	125,000.00
Landcorp Farming	100,000.00

6.0: Research Progress and Success

- 6.1: The programme has built on five years of achievement from both the industry and FRST, and is now well established and progressing well.
- 6.2: One of our major achievements has been the closure of the *Methanobrevibacter ruminantium* genome – the first rumen methanogen sequence in the world to be completed.
- 6.3: The completion of the methanogen genome sequence is a significant scientific achievement. We are now working to protect the intellectual property around this work, and once this is completed a report on the work will be published. We are approaching this matter with some urgency and see publication of the report as an important measure of the science team's achievements.
- 6.4: Building on this knowledge, we are well advanced with a programme to sequence other rumen methanogens, identifying common methanogen-specific elements. The significance of this work is that we will then be able to target as many groups of methanogens as possible without affecting other rumen microbes responsible for fibre degradation.
- 6.5: We have also made good progress in measuring and monitoring assays for the rumen population. The application of these tools will be essential to ensure that rumen function and livestock productivity is enhanced when interventions are introduced.
- 6.6: We are on track for delivery by 2012, of the concept of a safe and efficient anti-methanogen vaccine. Several targets have been identified in rumen methanogen's. Crucially, *in vitro* growth/methane production assays have provided proof-of-concept for the viability of an anti-methanogen vaccine. These assays have shown that high-quality antisera work against critical structures of methanogens to impair growth or methane output.
- 6.7: Animal selection is seen as a long-term strategy for farmers, and as such it has been an important focus for the Consortium since its inception. This year we have demonstrated that the use of respiratory chambers to identify low-emitting livestock is a feasible option and this now presents us with a mechanism to select them. Although widespread screening of livestock using this technique is unlikely, the use of this approach with highly recorded animals may enable us to find more cost-effective selection tools, such as gene or bio-markers, that can be cheaply applied to the nation's herds and flocks.
- 6.8: Using additional funding from the MAF Climate Change Plan of Action, we have expanded our work on *in vitro* and *in vivo* testing of mitigation technologies at AgResearch's Palmerston North facility. The facilities have eight sheep and two

cattle respiratory chambers, along with a continuous flow fermentor that enables improved product evaluation as mitigation solutions are developed.

- 6.9: In summary, we have progressed all our research programme goals through:
- development of improved tools for determining rumen population dynamics;
 - further refinement of specific sites for methanogen inhibition through genomic and microbial analysis;
 - continued progress in the development of a vaccine to reduce methane emissions;
 - the definition of consistent differences in the methane emissions of livestock using respiratory chamber analysis;
 - accurate analysis of plant constituents that influence methane production in ruminant livestock;
 - systems analysis of nitrous oxide mitigation options in intensive dairy farm operations.

7.0: Other Consortium Achievements

- 7.1: Landcorp Farming Ltd has recently joined the Consortium as a new partner, contributing both cash and resources through its extensive farming operations.
- 7.2: The Consortium has appointed a commercial manager to further develop the strategies to commercialise the outputs of the research programme.
- 7.3 We have appointed two independent advisory groups to provide advice for the Board on science and commercial strategies. The science group includes seven research experts, five of whom are from outside of New Zealand. The commercialisation advisory group includes four New Zealand-based experts with international experience in the commercialisation of science.
- 7.4: We have developed comprehensive tools for commercialisation and assessment that will act as a guide as we move our research through to solutions for the sector.
- 7.4: The science advisory group has now evaluated our complete programme of work and will continue to meet every six months for the rest of the contract period.
- 7.5: The Consortium was a principal sponsor and co-host with Australia of the Greenhouse Gas & Animal Agriculture (GGAA) Conference, held in Christchurch in November 2007. We released our five-year review (2002–07) detailing the outputs from research investment at the Conference.
- 7.6: Our website (www.pggrc.co.nz) was re-launched in November 2007, and it has taken on a hosting and management role for the Livestock Emission Abatement Research Network (LEARN) (www.livestockemissions.net). This is an initiative

championed by MAF, AgResearch and the Consortium to draw global greenhouse gas researchers together using the internet. The network has attracted over 370 researchers and interested parties from over 40 countries, and continues to gain momentum through workshops and other activities.

- 7.7: The second year of our current contract will see further development of the Consortium's activities, with a major review early in 2009 to refine the science plan for the remaining three years through to 2012.
- 7.8: Both the Consortium Manager and the Chairman have written and presented a significant number of briefing reports and presentations for stakeholder and sector-interest groups.

8.0: Partnership Initiatives

- 8.1: Landcorp Farming will provide funding and in-kind support, along with on-farm facilities, that will enhance the Consortium's opportunity to demonstrate mitigation solutions as they are advanced.
- 8.2: Collaboration with the Australian Beef CRC will enable the research teams on both sides of the Tasman to work together to sequence and annotate three more methanogens, using the knowledge developed previously by both Beef CRC and PGgRC.
- 8.3: During the year, (2007-2008) the Consortium has initiated negotiations with several organisations about potential solutions for the abatement of methane. The development of the proof of concept facilities utilising SLMACC funding will further enhance our ability to evaluate these opportunities.

9.0: Human Capital Building

- 9.1: Since its formation in 2002 the Consortium has increased the number of researchers it contracts from 12 to a team of 43 currently working across our programmes.
- 9.2: This year Ben Vlaming completed and was awarded his PhD, the first to come from the PGgRC programme. Another PhD candidate, Natasha Swainson, is also expected to be conferred with her doctorate in the near future.

10.0: Future Plans and Challenges 2009–12

- 10.1: We expect the Consortium research programme to gain momentum and make good progress over the next three years.
- 10.2: We plan to accelerate our most promising research on inhibitory compounds and vaccines through the MAF Sustainable Land Management & Climate Change fund. In tandem with this, we will complete the development and commissioning

of our greenhouse gas evaluation process to demonstrate the tangible application of investment in the area to date.

A challenge for the Consortium in this contestable process is the Crown policy of expecting the costs of any acceleration to be met by a 50% cash contribution from the industry participants. Other entities are not restricted to these provisions.

- 10.3: Research on both animal variation and forage will reach critical milestones in the 2008–09 year, and with expert input the next steps in these programmes will be identified and incorporated into the work programme for 2012–15.
- 10.4: The Consortium will continue to develop and manage a programme of work that will more clearly demonstrate opportunities for cost effective use of nitrogen inhibitors to farmers. It will show how mitigation solutions can enhance productivity through pasture growth and contribute to reducing their own on-farm greenhouse gas inventories. We believe these will be the two key drivers for future uptake.
- 10.5: We will continue to utilise and draw on independent advice from our Science and Commercial advisory groups. The Science advisory group will meet in early March 2009 to review progress and work with the PGgRC team to review the next three years of research through to the end of the FRST contract in June 2012.
- 10.5: As the research programme progresses, the Consortium expects an increasing emphasis on commercialisation. We are moving rapidly to appraise our identified “mitigation products” and evaluate them against the market requirements so we can develop effective commercialisation plans for them.
- 10.6: The Consortium is confident that its continued investment in pastoral greenhouse gas research will place New Zealand in a better position to counter the effects of climate change. We believe we are excellently placed to achieve our goal of providing cost-effective solutions to greenhouse gas emissions the pastoral livestock sector.
- 10.7: The development of the solutions needed to achieve this goal will require broad knowledge and integration across many disciplines. These will seldom be found at any one institution, so the PGgRC will be actively looking for, and supporting, collaboration nationally and internationally. With this will come other challenges in harnessing the combined resources and focusing them to deliver cost-effective solutions that allow our pastoral industries to continue to grow and prosper.

The Consortium will be striving to deliver solutions that support this change, be they products targeting livestock, microbes, changes to the farm environment, or knowledge that needs to be adopted. The approaches taken will be based on sound science, and will build on the knowledge and skills developed so far.

Appendices

PGgRC Management

Consortium Manager – Mark Aspin
Commercial Manager – James Li
Media Advisor – Allison Webber

Principal Investigator – Dr Harry Clark

PGgRC Board

Mark Leslie – Chairman
Max Kennedy – MWNZ
Rick Pridmore – DairyNZ
Peter Benfell – AgResearch
Hilton Furness – Fert Research (NZFMRA)
Damian Lynch – PGG Wrightson

Observers

Mark O'Connor – DeeResearch Ltd
Collier Isaacs – Landcorp Farming Ltd
Mike Jebson – MAF
Murray Poulter – NIWA

Science Programme Leaders & Key Publications

1) Microbial strategies to reduce methane emissions

Team Leader – Dr Peter Jansen

Presentations

Debjit Dey and Ron S. Ronimus (2007). *Application of a Denaturing Gradient Gel Electrophoresis (DGGE) Technique for Monitoring Methanogen Populations in the Rumen*. Abstract and Oral, Greenhouse Gases in Animal Agriculture (GGAA) Conference, Christchurch, 26–29 November 2007.

Marek Kirs, Debjit Dey, Catherine Tootill, Matt Nicholson and Ron S. Ronimus (2007). *Development of a Fluorescent In Situ Hybridisation (FISH) Technique for the Enumeration and Identification of Ruminant Methanogens*. Abstract and Poster presentation, Greenhouse Gases in Animal Agriculture (GGAA) Conference, Christchurch, 26–29 November 2007.

Catherine Tootill, Debjit Dey, Matt Nicholson and Ron S. Ronimus (2007). *Protozoa from New Zealand Ruminants*. Abstract and Poster presentation, Greenhouse Gases in Animal Agriculture (GGAA) Conference, Christchurch, 26–29 November 2007.

Published Reports

Hoskin S.O., Nicolson M.J., Swainson N.M. and Joblin K.N. (2007). *Lowering Ruminant Methane: Deer, Diet and Protozoa*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 22–23. Pastoral Greenhouse Gas Research Ltd, Wellington, New Zealand [ISBN 978-0-473-13021-3].

Janssen P.H. (2007). *Techniques for Monitoring Changes in the Rumen*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 16–17. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

Kleive A. and Joblin K. (2007). *Comparison in Hydrogen Utilisation of Ruminant and Marsupial Reductive Acetogens*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 34–35. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

Nicholson M.J., Janssen P.H., Evans P.N. and Joblin K.N. (2007). *Analysis of Methanogen Diversity in the Rumen Using Temporal Temperature Gradient Gel Electrophoresis*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 18–19. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

Ronimus R., Tootill C., Dey D. and Kirs M. (2007). *Methanogen-Protozoal Interactions*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 20–21. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

Olson K. and Ronimus R (2007). *Applications of Phage Therapy to Reduce Ruminant Methane Emissions*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 24–25. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

2) Methanogen Genomics

Team Leader: Dr Graeme Attwood

Key Meetings/Presentations/Reports

Attwood, G. T. and McSweeney, C. S. (2007). *Methanogen Genomics to Discover Targets for Methane Mitigation Technologies and Options for Alternative H₂ Utilisation in the Rumen*. Austral. J. Exp. Agric. 48:28–37. Presented at the Greenhouse Gases in Animal Agriculture Conference, Christchurch, 26–29 November 2007.

Attwood, G. T., W. J. Kelly, E. H. Altermann and S.C. Leahy (2007). *Analysis of the Methanobrevibacter Ruminantium Draft Genome: Understanding Methanogen Biology to Inhibit their Action in the Rumen*. Austral. J. Exp. Agric. 48:83–88. Presented at the Greenhouse Gases in Animal Agriculture Conference, Christchurch, 26–29 November 2007.

Attwood, G. T., Kelly W. J., Altermann E. H., Moon C. D., Leahy S. and Cookson A. L. (2008). *Application of Rumen Microbial Genome Information to Livestock Systems in the Postgenomic Era*. Austral. J. Exp. Agric., 2008, 48:695–700. Presented as the Underwood lecture to the combined Australia-New Zealand Society of Animal Production Conference, Brisbane, Australia, 23–27 June 2008.

Attwood G. T., Kelly W. J., Altermann E. H. and S.C. Leahy (2007). *Methanobrevibacter Ruminantium Genome Sequencing*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 38–39. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

Attwood G. T., Kelly W. J., Altermann E. H. and Leahy S.C. (2007). *Future Directions for Methanogen Genomics*. In: Kennedy R. (ed.) Pastoral Greenhouse Gas Research Consortium (PGgRc) 5 Year Science Progress Report, pp. 40–41. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

Patents submitted

- Cell-permeabilising peptides and polypeptides for microbial cells
- Phage ϕ mru polynucleotides and polypeptides
- Vaccines and vaccine components for inhibition of microbial cells

3) Development of an Anti-methanogen Vaccine

Team Leader: Dr Bryce Buddle

Publications

Buddle B.M., Denis M., Janssen P., Pedersen G. and Wedlock D.N.(2008). *Immunological Tools to Reduce Greenhouse Gas Emissions*. NZ Branch Australasian Society for Immunology meeting, Wellington, 5–6 June 2008.

Wedlock D.N., Denis M., Pedersen G., Janssen P. and Buddle B.M. (2008). *A Vaccine to Reduce Greenhouse Gas Emissions*. Presentation for the World Environment Day, Palmerston North, 5 June 2008.

Buddle B.M., Denis M., Pedersen, G. and Wedlock, D.N. (2008). *Towards a Vaccine Against Methanogens*. Presentation to the Pastoral Greenhouse Gas Research Consortium Board of Directors, 6 June 2008.

Buddle B.M., Wedlock D.N. and Denis M. (2008). *Vaccine Against Methanogens*. Climate Change Summit. Palmerston North, 13–14 February 2008.

Buddle B.M., Wedlock D.N. and Denis M. (2007). *Towards a Vaccine Against Methanogens*. Greenhouse Gases and Animal Agriculture Conference, Christchurch, 27–29 November 2007.

Popular articles

Lee A. (2008). *Greenhouse Gas Conference: Simple Jab May Beat Methane*. Dairy Exporter, February 2008 (based on an interview with Bryce Buddle).

Radio interview

Buddle B.M. *Vaccine to Reduce Methane Emissions*. National Radio, 29 November 2007.

4) Animal Selection & Breeding

Team Leader: Dr Cesar Pinares

Publications

Pinares-Patino C.S., Rochette Y., Koolaard J.P., Jouany J.P., Clark H. and Martin C. (2007). *Effect of SF6 Tracer Permeation Rate Upon Calculated Ruminant Methane Production Rates Using Rumen Head Space Gas Composition*. Proceedings of the 3rd International Greenhouse Gases and Animal Agriculture Conference (GGAA2007), Christchurch, New Zealand, 26–29 November 2007.

Pinares C.S., Holmes C.W., Lassey K.R. and Ulyatt M.J. (2007). *Measurement of Methane Emission from Sheep by the Sulphur Hexafluoride Tracer Technique and by the Calorimetric Chamber: Failure and Success*. Animal (replaces Animal Science & Animal Research), Cambridge University Press.

Pinares C.S., Machmuller A., Vlaming B., Molano G., Cavanagh A. and Clark H. (2008). *The SF6 Tracer Technique for Measurement of Methane Emissions from Ruminants - Effect of Tracer Permeation Rate on Estimates Precision in Cattle*. Canadian Journal of Animal Science.

Vlaming B., Lopez-Villalobos N., Brookes I.M., Hoskin S. and Clark H. (2008). *Within and Between – Animal Variance in Methane Emissions in Non-Lactating Dairy Cows* Australian Journal of Experimental Agriculture. [Volume 48 Issue 1-2.]

Pinares-Patino C.S. and Clark H. (2008). *Reliability of the Sulphur Hexafluoride Tracer Technique for Methane Emission Measurement From Individual Animals: An Overview*. Australian Journal of Experimental Agriculture.[Volume 48 Issue 1-2].

Patino C.S., Lovejoy P.J., Hunt C., Martin R., Molano G., Waghorn G. and Clark H. (2008). *A Versatile Sheep Respiration Chamber System for Measurement of Methane Emission*. New Zealand Society of Animal Production Annual Conference. [Brisbane, Australia, June 2008].

5) Low Greenhouse Gas Emitting Farm Systems

Team Leader – Nitrous Oxide: Dr Jiafa Luo

Team Leader – Methane: Harry Clark

Refereed international publications

Luo J., Ledgard S.F., de Klein C.A.M., Lindsey S.B. and Kear M. (2008). *Effects of Dairy Farming Intensification on Nitrous Oxide Emissions*. Plant and Soil 309: 227–237.

Luo J., Ledgard S.F. and Lindsey S.B. (2008). *A Test of a Winter Farm Management Option for Mitigating Nitrous Oxide Emissions From a Dairy Farm*. Soil Use and Management 24: 121–130.

Luo J., Lindsey S.B. and Ledgard S.F. (2008). *Nitrous Oxide Emissions from Animal Urine Application on a New Zealand Pasture*. Biology and Fertility of Soils 44: 463–470.

Luo J. and Saggar S. (2008). *Nitrous Oxide and Methane Emissions from a Dairy Farm Stand-off Pad*. Australian Journal of Experimental Agriculture 48: 179–182.

Conference presentations

Luo J., Lindsey S.B., Ledgard S.F., Sun W. and Kear M. (2007). *Nitrous Oxide Emissions from Prototype Farms for Dairy Farming's Future*. A poster presentation at the International Greenhouse Gases & Animal Agriculture Conference, Christchurch, 26–29 November 2007.

Luo J., Lindsey S., Ledgard S., Sun W. and Kear M. (2008). *Nitrous Oxide Emissions from Dairy Farmlets, as Affected by Use of a Winter Restricted Grazing Strategy and a Nitrification Inhibitor: Year 1*. A poster presentation at the Massey FLRC Workshop. February 2008.

Luo J. and Saggar S. (2007). *Nitrous Oxide and Methane Emissions from a Dairy Farm Stand-off Pad*. A poster presentation at the International Greenhouse Gases & Animal Agriculture Conference, Christchurch, 26–29 November 2007.

Project progress reports

Luo J., Lindsey S. and Ledgard S. (2008). *Nitrous Oxide Emissions from DairyNZ's Prototype Dairy Farms (2006–2007) – Progress Report*. Report prepared for PGgRC.

Luo J., Ledgard S.F. and Lindsey S.B. (2007). *Nitrous Oxide Emissions from Dairy Farms: Sources and Management Options to Reduce Emissions*. In: PGgRC (Pastoral Greenhouse Gas Research Consortium) 5 Year Progress Report 2002–2007, pp. 72–73. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].

Luo J., Lindsey S. and Ledgard S. (2008) Nitrous Oxide emissions as Affected by the Use of Dairy Effluent. Report prepared for PGgRC.

Luo J., Saggar S. and Ledgard S.F. (2007). *Nitrous Oxide and Methane Emissions from a Livestock Stand-off Pad*. In: PGgRC (Pastoral Greenhouse Gas Research Consortium) 5 Year Progress Report 2002–2007, pp. 76–77. Pastoral Greenhouse Gas Research Ltd, Wellington [ISBN 978-0-473-13021-3].