Annual Report 2016

NEW ZEALAND
AGRICULTURAL GREENHOUSE GAS
Research Centre

Leading Partners in Science

CONTENTS

PROGRESS TOWARDS SOLUTIONS

Identifying mitigation solutions is a key component of the New Zealand Agricultural Greenhouse Gas Research Centre's (NZAGRC) Vision and Mission. The complexity of the problem means that identifying solutions is a long term goal. Successfully reducing greenhouse gas (GHG) emissions below a 1990 baseline within the New Zealand context of an expanding agricultural sector will require progress in both direct and indirect mitigation options. Direct mitigations are those solutions that reduce absolute emissions per unit of substrate (e.g. feed, nitrogen). Indirect mitigations are those that arise as a result of general improvements in the efficiency of production (e.g. by improved animal genetics and feeding practices which will reduce emissions per unit of product but can increase absolute emissions per animal).

It is important that the new knowledge developed in NZAGRC funded/co-funded research programmes is used to have a practical impact on the greenhouse gas emissions emitted from New Zealand agriculture. The table below highlights key some key outputs from 2015/16 and their envisaged impacts.

NZAGRC/PGgRc output	*Expected impact*
The breeding work has found: • Differences in methane emissions between sheep selection lines (~10%) persist and are repeatable on fresh pasture. • Methane measurements made in PAC chambers have been validated and are heritable and repeatable. • Preliminary analysis indicates economic benefits for the sheep from the lower methane line.	These results give important confirmation that methane differences are maintained under grazing conditions. Portable accumulation chambers (PAC) can be used as a low cost, rapid method for more cost-effective identification and testing of the large numbers of animals needed for the successful commercial breeding of low emitting phenotypes. Proven economic benefits of selecting for the low methane trait will encourage uptake of this work.
Feeding fodder beet (FB) at high levels of inclusion (>75%) results in repeatable reductions in CH_4 emissions. Provision of FB in the diet is an effective way to reduce the total amount of N excreted in the urine.	This work indicates that FB, which is an increasingly popular crop, has potential to reduce both CH_4 and N excretion to the environment when fed to sheep. However, attention needs to be given to ensure that nutrient supply from FB:pasture diets is sufficient and balanced to support animal productivity and health.
Results from animal trials show that prototype vaccinations can produce high levels of methanogen-specific antibody in the saliva and rumen. Two methanogen antigens have been identified as leads for further development. A refined list of prioritised vaccine targets has been produced.	The confirmed antigens and new ones identified in the prioritised list will be investigated in further trials of prototype vaccines in 2016/17.
Four inhibitors reduced methane from sheep over two days. Two of these were effective in short-term cattle trials. Three of these were considered to have potential as commercial products. Over 40 new inhibitors have been identified and confirmed to conclude the screening programme for inhibitor development, and these will be ranked for effectiveness along with previous "hits" in up-coming research in this objective.	Further testing and development of the three successfully identified inhibitors will continue in 2016/17. New potential inhibitors will continue to enter the development pipeline and be tested *in-vitro* and *in-vivo*.

A comprehensive lab study using glycosinolate hydrolysis products that can be found in brassica crops, has shown that some compounds can reduce nitrification and lower N_2O emissions. A lab study using aucubin, a key compound in plantain, showed that aucubin could also lower N_2O emissions.	These promising inhibitory compounds will be further tested to confirm these initial results. These data will be provided to the New Zealand GRA funded GPLER3 programme on the development of new nitrification inhibitors.
Development work has shown that it is practical to use Spikey®, an array of electrodes and associated hardware and software to locate and treat urine patches on a 'follow the cows' basis.	The Spikey® technology will be used to test the efficacy of targeted application of different nitrogen transformation inhibitors and gibberellic acid in reducing ammonia, nitrous oxide and N leaching losses from cattle urine. The ability to target applications to urine patches will help farmers to better target their use of mitigation technologies and to hence reduce costs and minimise concerns over residues.
A model for predicting soil C stabilisation capacity has been improved by studying more samples and using better handling techniques. Using the improved model, it is estimated that a relatively high proportion of NZ's pastoral soils can potentially store more C.	Provides improved confidence that there is potential to increase the amount of C stored in New Zealand's agricultural soils and that continued investment in soil C research is warranted.
Measurement and monitoring of performance on the S+B monitor farms has demonstrated an alignment with modelling results. The modelling of practical and adoptable scenarios, selected in partnership with farmers and their rural professionals, suggests further win-win opportunities (improved profit, reduced GHG emissions per unit of product), even with high performing farming systems.	Monitor farms now have some identified practices that they can introduce and evaluate on farm. The new information will be promoted in future field days and farmer discussion groups.
The Maori project has found: • Many of the changes in farm systems resulted in relatively marginal changes in GHG emissions & profitability. Often if GHG emissions decreased so did profitability, and vice versa. • Systems changes which gave a win-win, in that GHG emissions decreased and profitability increased included: (i) lowering stocking rates on dairy farms; (ii) increasing sheep:cattle ratios; (iii) increasing farm efficiency; and (iv) planting marginal areas in forestry.	Win-win scenarios identified that could potentially be introduced and evaluated on the focus farms. This new information will be discussed with the focus farm Trustees to evaluate whether these identified scenarios can be introduced on-farm. The information will be promoted to the wider Maori and non-Maori sector to encourage further uptake of these win-win approaches.

CHAIR'S REPORT

History was made on 12 December 2015, when the gavel went down on a new global climate change agreement at the 21st UN climate change conference (COP 21) in Paris. For the first time in the UN Framework Convention on Climate Change (UNFCCC) two-decade history, all governments at the meeting agreed to act on climate change, and all will transition to a lower carbon economy over the course of this century.

The new agreement represents a shift from imposed legally binding burden-sharing to a vision combining generalised global rules with specific actions determined by each country in line with its national circumstances. This combination sets up a kind of bounded flexibility. Everyone is to take action on emissions, plan for adaptation, apply agreed methodologies and accounting approaches, report and be reviewed on their progress alongside a commitment to set increasingly ambitious targets. The agreement calls for zero net anthropogenic greenhouse gas emissions to be reached during the second half of the 21st century. The parties will also "pursue efforts to" limit the global warming to 1.5 °C above pre-industrial levels.

Agriculture is neither treated differently from other sectors, nor excluded from the Paris Agreement. There are explicit references to the importance of food security and the need to ensure food production isn't compromised. It is now important to develop strategies, both short and long term, to achieve the duel objectives of reducing GHG emissions and maintaining food production levels. New mitigation tools will make a valuable contribution to these strategies and the subsequent action plans.

The New Zealand government has set a target to reduce greenhouse gas emissions to 30 per cent below 2005 levels by 2030. It has also demonstrated its commitment to agricultural research in this area by announcing an additional $20m in support of the Global Research Alliance on Agricultural Greenhouse Gases (GRA). This reflects the importance of developing domestic solutions as well as fostering international collaboration to address a globally significant problem.

In the case of New Zealand, the agriculture sector contributes 49% to the country's GHG emissions. Therefore, the sector will need to play its part to help New Zealand meet its emissions reduction target. The emissions intensity of New Zealand agriculture, that is the gases generated per unit of meat or milk produced on farms, has declined on average by about 1% since at least 1990. However, the reduced emissions intensity has been more than offset by the increased overall product generated by the sector. As a result, New Zealand's total agricultural emissions have risen by 14%. Without the efficiency gains on farms, emissions would have grown much more, by almost 40%. So, while New Zealand farmers are already making a contribution and their efficiency gains are addressing a large portion of the problem, they are not enough to counter the extra GHGs being produced overall.

By continuing to improve on-farm efficiency and productivity, there is the opportunity to further reduce the intensity of emissions per unit product. However, this is unlikely to stop the country's total agricultural emissions from rising in the future given the growing global demand for high-value protein-rich food. Practical and cost-effective new and enhanced approaches to reducing agricultural GHG emissions are required to help meet environmental, social and international aspirations and obligations, as well as economic growth targets. This is the role of the NZAGRC alongside the jointly industry/government-backed PGgRc. Our efforts are a prime example of Government, industry and researchers working together, combining resources to identify and develop additional interventions that will provide effective and practical results by 2020 and beyond.

A number of key science results in 2015/16 demonstrate that the science teams are getting closer to viable solutions to reduce agricultural GHGs. In particular, the joint NZAGRC-PGgRc methane programme has made significant progress. Differences between high and low emitting sheep have been demonstrated under field conditions, and compounds which inhibit methane in the short term have been successfully trialled in animals. There is now a strong drive towards engaging commercial partners for new methane mitigation technologies, which the PGgRc is leading.

Through its national and international roles and responsibilities, particularly through its active involvement in the GRA, the Centre continues to build on its reputation as an important source of clear and unbiased advice on the science behind agricultural greenhouse gases and their mitigation options.

Professor Warren McNabb
Chair of NZAGRC Steering Group
August 2016

NZAGRC DIRECTOR'S REPORT

Over the past year, the Paris agreement has led to increased momentum and growing interest in the climate change space. There is mounting political and public pressure to develop practical tools and strategies to achieve ambitious emissions reductions targets. It is an exciting time to be involved in this area and the NZAGRC is working hard to contribute to what we envisage will be globally applicable mitigation solutions.

Working alongside MPI and the PGgRc, usable results, outputs and publications continue to emerge from our research. We keep a close eye on ensuring that the outcomes of our funding can be translated into practical solutions; in some areas, notably the animal breeding and inhibitor space, discussions with potential commercial partners are underway. These are being led by the PGgRc in line with agreed commercialisation strategies.

In addition to experimental work, NZAGRC-funded scientists have increased their engagement with farmers over the past year. In the Integrated Farm Systems and Māori programmes, a number of meetings and huis have been held. These have involved scientists and farmers working together to understand the impact of specific farms current management practices on GHG emissions and then developing practical alternative scenarios which could reduce each farm's environmental impact. A goal of this work is to identify and quantify current good practices to reduce agricultural GHGs and to work with others to encourage their widespread adoption.

Capability building has been a feature of the NZAGRC since its inception in 2009 and we are continuing to invest in this area. Our on-going scholarship programme with Massey, Lincoln and Waikato Universities has provided opportunities for undergraduates to gain experience in a research environment and provide stipends for post-graduates. In addition, we currently provide direct support to 10 PhD students linked to NZAGRC research programmes.

We continue to work collaboratively with the PGgRc, MPI and a wide range of national and international organisations. The Centre's role in administering GRA funding on behalf of MPI ensures excellent coordination of the New Zealand research programme with international efforts.

Highlights for the Centre staff this year include the coordination of a collaborative project with the Food and Agricultural Organisation of the United Nations (FAO). Our international work also involved working with FAO and CCAFS (the CGIAR Research Program on Climate Change, Agriculture and Food Security) and S.E. Asian countries involved in the GRA to help them develop more rigorous GHG accounting methodologies. At an operational level, we recruited Tania Brown as the Centre Administrator. Victoria Hatton, the Operations Manager (International) split her time between Rome and Palmerston North, working as the project coordinator of the joint project we have with the FAO.

I would like to express my thanks to all of our Advisory Groups. The Steering Group continue to be exceptionally dedicated to the Centre and have provided valuable and knowledgeable advice throughout the last year.

Dr Harry Clark
NZAGRC Director
August 2016

THE NEW ZEALAND AGRICULTURAL GREENHOUSE GAS RESEARCH CENTRE

The NZAGRC is 100% government-funded by the Ministry for Primary Industries through its Primary Growth Partnership Fund. It is a core component of the New Zealand Government's approach for addressing the reduction of greenhouse gas emissions from agriculture. This includes New Zealand becoming: (a) a major investor in agricultural GHG mitigation research; (b) a world leader in finding solutions to agricultural GHG emissions via its domestic investment programme; and (c) a leader in international initiatives to advance the search for mitigation solutions and help ensure international treaties address agricultural GHG emissions in an appropriate manner. The Centre is a science funder, has additional responsibilities for strategic research coordination, capacity building and leads New Zealand science input into international activities and policy processes in the agricultural GHG area.

The NZAGRC is a partnership between the leading New Zealand research providers working in the agricultural GHG area and the PGgRc. About NZ$48.5 million is being invested by the NZAGRC into research and development activities over ten years. The NZAGRC is a "virtual" Centre and the research that it funds is carried out by researchers working in their own organisations and collaborating across organisations.

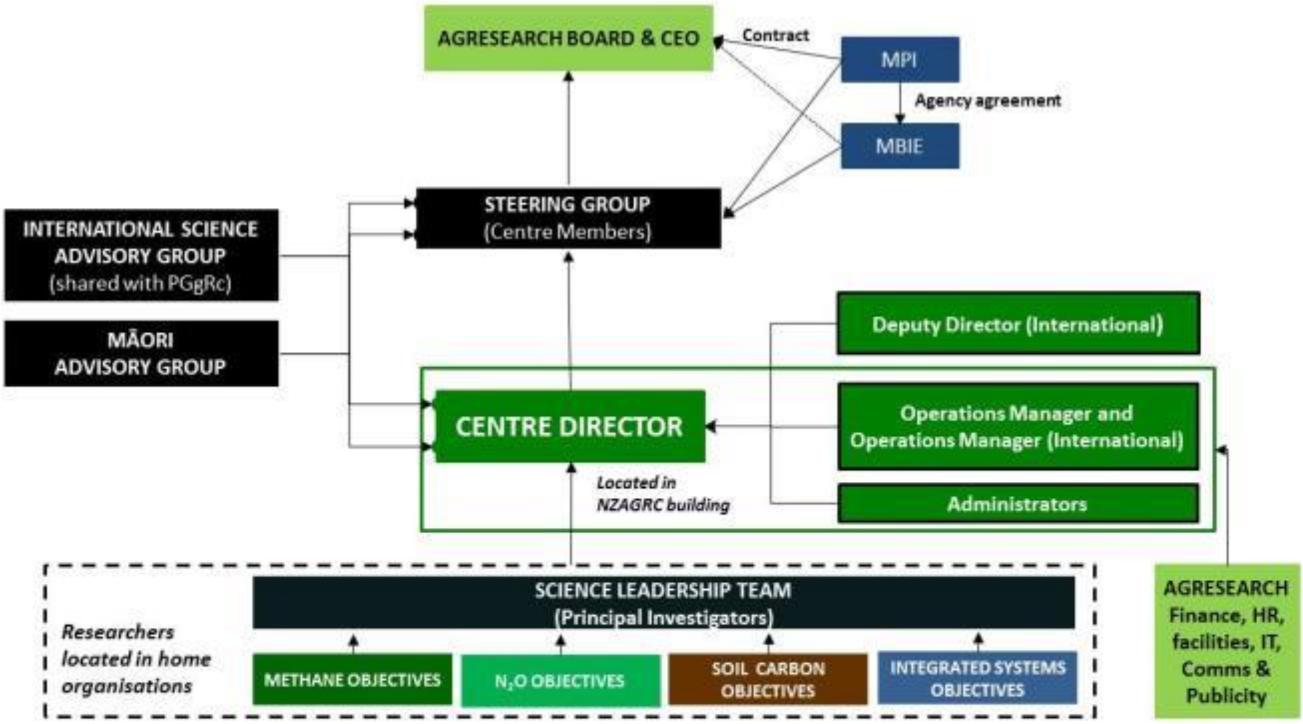
NZAGRC is not the only significant investor into agricultural GHG mitigation research in New Zealand. Much of NZAGRC methane research builds on research investments made by the PGgRc, and since 2013 the NZAGRC and PGgRc investments have been formally aligned. This involves a single research strategy with shared advisory groups and administrative processes. Targeted mitigation research and proof-of-concept trials are also carried out under the Sustainable Land Management and Adaptation to Climate Change (SLMACC) programme coordinated by MPI. In addition, the New Zealand government provides funding for projects that support the goals and objectives of the Global Research Alliance, which build on and extend New Zealand-based research through international collaboration and data sharing. Various investments by industry into on-farm tools and trials and extension complete the picture. Research investment by NZAGRC within this funding landscape is based on an assessment of national needs and priorities, existing knowledge and expertise, and major gaps.

The NZAGRC is physically located on the AgResearch Grasslands Campus in Palmerston North. The Director, Operations Manager, Operations Manager (International), Project Analyst and Administrator are employed by AgResearch on behalf of the NZAGRC and are based in this building. The Deputy Director (International), also employed by AgResearch, is located in Wellington. The Operations Manager (International) shared her time between the NZAGRC and the Food and Agriculture Organization of the United Nations (FAO) in Rome, on a full-time secondment for part of the year.

NZAGRC GOVERNANCE

As the NZAGRC is set up as a unit operating within AgResearch, the Board and Chief Executive (CEO) of AgResearch have ultimate responsibility for the NZAGRC. However, a Steering Group (SG) comprising a representative of each NZAGRC Member provides advice and recommendations to the AgResearch CEO and Board on the operation of the NZAGRC. The NZAGRC Director reports to the AgResearch CEO and Board via the NZAGRC's SG. The International Science Advisory Group (ISAG) monitors, advises and reports on the NZAGRC's science quality and direction to the SG and NZAGRC Director. The NZAGRC SG meets formally with the PGgRc Board every six months and this provides guidance in relation to the needs of the industries that are intended to take up its research outcomes. The advisory roles of the ISAG and PGgRc Board are primarily in the areas of science quality, research direction and industry relevance.

A Māori Advisory Group (MAG) was established in 2011/12 to ensure that the research and development undertaken by the NZAGRC is relevant and accessible to all sectors of New Zealand society.



NZAGRC Governance Structure

Role of the Steering Group (SG)

The NZAGRC Director reports to the Steering Group of the NZAGRC Members and via them to the AgResearch CEO and Board on the performance of the NZAGRC, including (with appropriate quantitative measures):

- Relevance of the NZAGRC's R&D to the agriculture sector and New Zealand
- Science quality
- Performance to contracted goals
- Human resource development and constraints
- Financial performance.

The main roles of the SG over the past financial year have been to ensure that the NZAGRC is operating effectively, funding decisions are made in a robust fashion and that the new science programme contracts are in line with the Centre strategy.

During 2015/16 the SG met quarterly, once in Wellington and three times in Palmerston North. They also provided comment and feedback on documents via video/teleconference and email as required. Quarterly face-to-face meetings were run in a similar fashion to Board meetings with papers circulated prior to, and detailed minutes signed off after, each meeting.

The compositions of the SG, ISAG and MAG and meeting dates during 2015/16 can be found in Appendix 1.

2015/16 SUMMARY OF ACTIVITIES AND ACHIEVEMENTS

The need for research to find cost-effective practices, tools and technologies to reduce agricultural GHG emissions that are consistent with New Zealand's pastoral farming base is as important as ever. Consequently, the Centre's vision and mission (see below) remain highly relevant in the changing context in which it operates. Progress towards achieving the specific goals set out under the vision and mission of the Centre is documented below.

The Vision

'To be an internationally renowned centre for research and development into agricultural greenhouse gas mitigation solutions'

The NZAGRC plans to be (i) a source of practical, cost effective technologies and/or practices that reduce emissions/increase sinks and clearly demonstrate that farm businesses can be both lower emitting and profitable; (ii) a focal point for New Zealand activities in agricultural greenhouse gas mitigation/soil carbon sink solutions; (iii) the key authoritative source of technical advice and support on agricultural greenhouse gas emissions and soil carbon sinks. Additionally, the NZAGRC will lead NZ's science input into the Global Research Alliance.

The Mission

'To provide knowledge, technologies and practices which grow agriculture's ability to create wealth for New Zealand in a carbon-constrained world'

The Goals

The NZAGRC has five major goals:

1: Advance knowledge and understanding
2: Enhance awareness among stakeholders
3: Contribute to policy
4: Develop science capability
5: Develop science and commercial partnerships

These have been defined and quantified in order to be consistent, realistic and achievable and detailed targets are included in the NZAGRC Strategic Plan. The Centre has made substantial progress towards achieving its Vision and Mission through its on-going achievements in the five major business goal areas. Each goal is discussed in more detail in the following pages.

Centre progress towards achieving vision and mission

In 2015/16 particular high level achievements include:

- Continuing to act as a focal point for New Zealand research activities in agricultural GHG mitigation, building on international reputation for the quality of our research and progressing towards solutions. Annual workshops in April 2016 provided opportunities for interaction and discussion between researchers from across the NZAGRC programme, key stakeholders and scientists from non-NZAGRC funded aligned work.
- Running an efficient organisation with sound governance and financial control. The NZAGRC is now using the MPI grants management system to manage both NZAGRC and GRA contracting.
- On-going alignment with the PGgRc and, through this relationship, starting to actively engage with commercial entities to establish pathways to market for our technologies.

- Enhanced engagement with Māori, including a number of huis and on-farm field days as part of the Māori-focussed research programme.
- Continued efforts to communicate our science and how it fits into the bigger picture to stakeholders, media and the general public through the production of fact sheets, press releases and an actively managed media profile.
- Actively contributing to the success of the Global Research Alliance and coordinating New Zealand's science input to the Alliance and providing strategic advice to MPI. Co-ordination of an international project that is jointly led by FAO and NZAGRC (funded by the United Nations Environment Programme).
- Proactive engagement with New Zealand policymakers.
- Contribution to, and in some cases coordination of, key science networks and funding mechanisms, including the Sustainable Land Management and Climate Change (SLMACC) fund and Methanet, and internationally, the Intergovernmental Panel on Climate Change (IPCC), the global Climate and Clean Air Coalition, and European FACCE-JPI and Horizon 2020 committees.
- Actively contributing to the development and retention of GHG-related scientific capability.

Goal 1: Advance knowledge and understanding

The NZAGRC will be the most important and trusted NZ source of scientific knowledge in the field of agricultural GHG emission mitigation.

Since its establishment in 2010, the NZAGRC has endeavoured to fund scientifically robust research and provide reliable new knowledge to its stakeholders, the wider scientific community and the general public.

The NZAGRC supports four Science Programmes in alignment with other agencies and private investors.

Programme	Objectives
Mitigating Methane Emissions*	• Breeding - sheep and deer (Obj 5.1) • Low GHG feeds (Obj 5.2) • Vaccines (Obj 5.3 & 5.11) • Inhibitors (Obj 5.4) • Modelling (Obj 5.8) • Capture & mitigation by soil (Obj 5.9) • Breeding - cattle (Obj 5.12)
Mitigating Nitrous Oxide Emissions	• Plant effects on N_2O emissions (Obj 6.1) • Manipulating denitrification processes (Obj 6.2) • Feed management options (Obj 6.3) • Management effects on emission factors (Obj 6.4) • Urine patch detector development (Obj 6.5) • Potential inhibitor effects on N_2O emission (Obj 6.6)
Increasing Soil Carbon Content	• Manipulating inputs to stabilise and enhance soil C (Obj 7.1) • Tools to quantify stabilisation and vulnerability of soil C (Obj 7.2) • Modelling management manipulations (Obj 7.3)
Integrated Farm Systems	• Emissions on Sheep and Beef Farms (Obj 8.1) • Emissions on Dairy Farms (Obj 8.2)

*Joint programme with the PGgRc, with the exception of Obj 5.9 which is solely NZAGRC funded and managed.

Formal alignment with the PGgRc led to a joint science plan and subsequent joint contracting in the Methane programme being implemented from 1 July 2013. Initial contracts covered the period 1 July 2013 – 30 June 2015 and had an annual review clause in them to ensure that the research remained solution-focussed. These contracts came to an end and high level research plans, with associated levels of funding, were agreed to 30 June 2019. Based on these, new contracts were issued for the period 1 July 2015 – 30 June 2016 in line with the high level plans. Updated work plans have been negotiated for the period up to 30 June 2017 based on progress and results in the recent year.

Additional vaccine work, co-funded by AgResearch, was contracted in 2016. The purpose of this extra contract was to accelerate the testing of antigens, by funding two more animal trials, and to investigate the identification of new vaccine antigen candidates using monoclonal antibodies. This is an alternative and complementary approach to the use of bioinformatics for target identification.

The methane breeding programme has been extended to cattle in 2015/16. The first goal of this work is to validate a method of measuring methane and dry matter intake rapidly versus ‘gold standard’ respiration chambers. The outcome will be confidence that the developed equipment provides accurate and repeatable measures of daily methane output and methane/kg DMI and, thereby, facilitate the inclusion of methane as a genetic trait for selection should the industry deem it a priority. In the N_2O programme, two new contracts were established involving a prototype urine patch detector, known as Spikey®. Developed by Pastoral Robotics Limited, Spikey® has been found to be able detect urine patches immediately after a grazing event and before any visible grass growth response. The first contract related to development and on-farm testing of the detector. The second brings together the scientific expertise in Urine-N transformations and the understanding of processes leading to gaseous and leaching losses of N of Landcare Research, Massey University, AgResearch and technical expertise of Pastoral Robotics in assessing the efficacy of different nitrogen transformation inhibitors (NTIs; urease and nitrification) and gibberellic acid applied during late autumn/early winter using Spikey® in reducing gaseous (ammonia and nitrous oxide) and leaching losses of N from cattle urine.

Descriptions of the Objectives outlined above, and their progress during 2015/16, are contained in Appendix 2.

In 2015/16, key science achievements included:

- Proof that differences in methane emissions between sheep selection lines persist and are repeatable on fresh pasture.
- Validated evidence that methane measurements made in PAC are heritable and repeatable and that PAC can be used as a low cost alternative to respiration chambers in a commercial breeding programme.
- Feeding fodder beet (FB) at high levels of inclusion (>75%) results in repeatable reductions in CH_4 emissions. Demonstration that provision of FB in the diet is an effective way to reduce the total amount of N excreted in the urine.
- Results from animal trials showing that prototype vaccinations can produce high levels of methanogen-specific antibody in the saliva and rumen. Two methanogen antigens have been identified as leads for further development.
- Four inhibitors reduced methane from sheep over two days. Two of these were effective in short term cow trials. Three of these inhibitors are being further developed and tested.
- Over 40 new inhibitors have been identified and confirmed to conclude the screening programme for inhibitor development. The best of these will undergo animal testing in 2016/17.
- A comprehensive lab study using glycosinolate hydrolysis products that can be found in brassica crops, has shown that some compounds can reduce nitrification and lower N_2O emissions. A lab study using aucubin, a key compound in plantain, showed that aucubin could also lower N_2O emissions.
- Development work has shown that it is practical to use Spikey®, an array of electrodes and associated hardware and software to locate and treat urine patches on a ‘follow the cows’ basis.
- An improved model for predicting soil C stabilisation capacity has been developed by studying more samples and using better soil sample handling techniques. Using the improved model, it is estimated that a relatively high proportion of NZ's pastoral soils can potentially store more C.
- A number of win-win scenarios for decreasing GHG emissions and increasing farm profitability have been identified by the Maori project. These include: (i) lowering stocking rates on dairy farms; (ii) increasing sheep:cattle ratios; (iii) increasing farm efficiency; and (iv) planting marginal areas in forestry on non-dairy farms.

More detailed information regarding science progress during 2015/16 can be found in Appendix 2 which includes the submitted annual reports from all NZAGRC-funded Objectives.

Goal 1 metrics:

Measure	*Progress in 2015/16*
Peer-reviewed scientific journal papers	17 papers published plus 13 papers submitted
Scientific conference papers	46
Patents relating to agricultural GHG emission mitigation technologies	Patenting decisions are the joint responsibility of MPI and PGgRc (not the Centre directly); new IP protected and managed as commercial (in confidence) IP or shared freely as public-good information.
Practical on-farm mitigation practices and technologies identified and being promoted	Promotion of improved efficiency as the immediate action farmers can take to help reduce emissions

Goal 2: Enhance awareness among stakeholders

The NZAGRC will be the most important and trusted source of information for New Zealand agricultural stakeholders on agricultural GHG emission mitigation.

PGgRc Alignment

From 2002-2012, the PGgRc invested more than $37m into agricultural GHG mitigation research with equal shares from industry and government. During 2012/13, PGgRc successfully renewed its Partnership funding with MBIE for a further $37m joint investment over seven years. This renewal triggered a move for the NZAGRC, which had always aligned its activities to the PGgRc, to develop a much closer formal working relationship with the PGgRc.

Close cooperation with the PGgRc is a key pathway for the Centre to interact with industry stakeholders, assist MPI to manage IP and enable knowledge transfer through commercialisation of new tools, technologies and practices. Current industry co-investors within PGgRc are: Fonterra, DairyNZ, Beef+Lamb NZ, Deer Research and AgResearch. Since February 2013, the Centre Steering Group members have been periodically meeting jointly with the PGgRc Board members to monitor progress on joint initiatives and co-funded R&D. The Centre Director is an observer on the PGgRc Board and the PGgRc Manager is a member of the NZAGRC Steering Group.

Key joint initiatives in 2015/16 with the PGgRc included:

- Collaborating in an annual review of the joint Methane research programme to establish new work plans in order to contract from 1 July 2016 – 30 June 2017.
- Continuing to develop and implement the joint communications strategy and plan. A range of joint communication activities have been conducted in the past year. These include science workshops, a range of co-branded factsheets and proactive media engagement.
- NZAGRC support for PGgRc-led engagement to find commercialisation partners.

Other Stakeholder Engagement

Although the PGgRc provides a robust pathway for the NZAGRC to link with industry stakeholders, the Centre continues to maintain direct links with a broad range of other stakeholders, including policy makers, end-users, the science community and the wider public.

In its on-going support of knowledge transfer the Centre was involved in key activities in 2015/16 that included:

- Meetings with farmer groups, individual companies and organisations and giving presentations at stakeholder forums (e.g. NZAGRC workshops, Fonterra, Royal Society of New Zealand).
- Presenting at outreach events and giving expert lectures (e.g. IPCC public outreach events, FAO workshops, Victoria University course, Royal Society launch of reports on climate change adaptation and GHG mitigation opportunities).
- Dedicated publications (e.g. annual Highlights document, factsheets and e-newsletter) and articles in farming and general press and presenting on television and radio.
- Membership of MPI science-related advisory groups (e.g. SLMACC, Methanet, Agricultural Inventory Advisory Panel).
- Providing scientific information and expert advice to key stakeholders including government officials and industry (e.g. MPI, DairyNZ, Fonterra, Parliamentary Commissioner for the Environment, MfE).
- Hosting international visitors and showcasing New Zealand agricultural GHG science, including for ambassadors and high-ranking science delegations.

- Working directly with industry organisations and farmers as part of the Integrated Farm Systems programme (Pastoral 21 and B+LNZ) and Māori programme (29 farms in network).

Māori Engagement

During 2013/14 NZAGRC staff worked closely with the MAG to develop an RfP for a focussed Māori research project. A proposal for a three year programme of work was accepted from a cross-organisation team (AgFirst, AgResearch, Lincoln University and Scion) led by AgFirst, in late 2013/14 and work began on 1 July 2014.

Māori-focussed research

- Development of farm systems and farm typologies and selection of case study focus farms
- Mitigation modelling and scenario design
- Sector adoption and integration of project outcomes and practice change strategies

The "Low emission farm systems for the Māori sector" programme aims to assist the Māori pastoral sector to improve its collective capacity to increase resource efficiency and farm productivity while lowering greenhouse gas emissions. During 2015/16 the programme team has worked closely with the Trustees of their four focus farms. A range of individual, tailored GHG mitigation scenarios have been modelled for each property, based on a first round of meetings. Huis were held to discuss the results of the initial modelling, and feedback incorporated into a second round of scenarios. The focus farm Trustees and other interested parties have provided significant feedback on the modelling results and potential implications for their farms. As part of the programme, a model has been developed which incorporates of forestry economics and carbon sequestration alongside pastoral farming. Thereby allowing a most holistic view of the impacts of making on-farm changes intended to reduce GHG emissions.

Communications and media

In early 2014 a joint communication strategy and action plan (CSAP) was approved by the NZAGRC SG and PGgRc Board. The aim of this was to raise visibility, understanding and relevance of the work undertaken by the Consortium and Centre. The plan provided 12 months of activity from July 2014 to June 2015. Following the implementation, a new programme of activities for 2015/16 was prepared to continue engagement activities with the identified target audiences to improve their understanding of where our work fits in the overall 'NZ Inc' approach to increasing agricultural production within environmental and GHG constraints.

Work to implement the action plan has progressed well, with highlights as follows:

- Production and active dissemination of two factsheets:
    - 'Reducing New Zealand's Agricultural Greenhouse Gases: Gibberellins'
    - 'Reducing New Zealand's Agricultural Greenhouse Gases: Efficiency in the whole farm system'

  Two additional factsheets are in production, due for completion in early 2016/17. Scripting of video content and a redevelopment plan for the Centre website is also underway.
- A small social media presence has been created on LinkedIn and short updates and stories have been shared.
- Engagement with New Zealand journalists and the international media. E.g. In February 2016, the NZAGRC hosted the BBC children's television show "Naomi's nightmares of nature", which aims to share scientific information on animals and global situations (nature orientated) at a level that children can understand.

- Periodic e-newsletter produced and distributed to approximately 300 recipients.
- Proactive media engagement. In particular with respect to commentary on agricultural aspects of COP 21 and the Deputy Director's involvement with release of Royal Society of New Zealand reports on climate change adaptation and GHG mitigation opportunities.
- NZAGRC staff led the preparation of media material for the release of the New Zealand Government funded project "Global Rumen Census" results.

Additionally, during 2015/16 the NZAGRC has both hosted and attended a significant number of meetings and presentations with a diverse group of external parties, both in New Zealand and internationally. The NZAGRC has also actively promoted itself and its role in the media and to a scientific audience via conference papers and peer-reviewed publications. These are summarised below and detailed in Appendix 3.

Type of interaction/output	# in 2015/16
Meetings and Presentations (New Zealand)	66
Meetings and Presentations (International)	24
International Visitors and Groups	7
Global Research Alliance related interactions	28
Media interactions	6
Conference presentations	46
Journal articles in press	13
Journal articles published	17
Other interactions/publications	26

Goal 2 metrics:

Measure	*Progress in 2015/16*
Page views of Centre's website	30,200
Senior Centre staff presentations to meetings of New Zealand industry and policy stakeholders	18
Centre funded scientist presentations to the farming community and general public	17

Goal 3: Contribute to policy

The NZAGRC will be the authoritative source of information for the New Zealand government on agricultural GHG emission mitigation.

Policy Advice

A key aim of the Centre is to be a trusted and independent source of knowledge - particularly to policy agencies – to enable sound, evidence-based policy development. The Centre's relationship with MPI (and other government departments in general) has continued to grow stronger and deeper in 2015/16, reflecting in part the changing international context and successful international agreement on climate change at the UN Climate Change Conference in December 2015.

Policy staff from MPI and other government departments continue to appreciate the NZAGRC's robust scientific input and encourage and foster a culture of trust and open engagement, evidenced by frequent requests for technical reports as well as input to draft policy documents, presentations, and departmental strategy workshops.

The Centre's on-going inputs into the GRA and other international initiatives, as well as technical advice to support domestic policy development, are prime examples of activities that the Centre engaged in during 2015/16 related to this goal.

Other activities by the Centre in 2015/16 include:

- Director and Deputy Director are members of MPI's Agricultural Inventory Advisory Board.
- Director is Chair of MPI Methanet (science grouping advising MPI on methane inventory development).
- Director is a member of the FACCE-JPI Science Advisory Board and Chair of the FACCE-JPI GHG Mitigation call International Advisory Committee.
- Deputy Director was elected vice-chair of the Bureau of Working Group III of the Intergovernmental Panel on Climate Change (IPCC). In this role, he participated in negotiations to produce a Special Report on land-use related issues.
- Deputy Director served on expert panels convened by the Royal Society of New Zealand on risks and implications of climate change and low-carbon pathways for New Zealand.
- NZAGRC hosted a number of international as well as senior-level domestic visitors.

Goal 3 metrics:

Measure	*Progress in 2015/16*
Senior Centre staff presentations to meetings of New Zealand government policy staff	8
Written reports prepared for government policy makers	2
Centre's science contributions directly influence and reflected in government policy	Range of technical advisory roles

Goal 4: Develop science capability

The NZAGRC will be a major source of new capability in the field of agricultural GHG emission mitigation.

Students and Post-doctoral fellows

Increasing the pool of researchers with skills in the agricultural greenhouse gas mitigation area is a major objective for the NZAGRC. To achieve this objective the NZAGRC is strategically directing funding to build capability for the future. Some of this funding is embedded within the funding of the core science programme, with additional funding being available on a discretionary basis when high quality students or projects are identified.

1. The provision of short term scholarships to promising undergraduate students with the aim of encouraging them to undertake post graduate studies
2. The provision of well-funded PhD stipends to high quality undergraduates
3. Employing high quality post-doctoral fellows and early stage scientists on 2-3 year contracts

In 2015/16 the dedicated undergraduate "pipeline" scholarship scheme continued with Massey, Lincoln and Waikato Universities. The soil carbon programme recruited a new PhD student to investigate the fate of carbon and nitrogen inputs from animal dung at Ashley Dene Farm. The NZAGRC also contributed funding to a post-doctoral researcher to allow her to extend her scientific knowledge and develop new capabilities working with soil.

Type of Capability Development	# active in 2015/16	Total funded to date*
Undergraduate - Summer student	3	22
Undergraduate - Honours student	3	8
Undergraduate - Intern	0	2
Masters Project	0	3
Masters	1	5
PhD	10	15
Post-doctoral fellow	4	6
Early career scientist	0	2
	21	63

*Including active 15/16 numbers

The NZAGRC continues to be a major funder of PhD students in agricultural sciences related to nutrition, animal and plant performance and greenhouse gas emissions in New Zealand.

Funding for international students under the LEARN fellowship scheme (under separate contract with MPI; see below under Goal 5) provides an international dimension to NZAGRC's overall capacity building efforts.

Goal 4 metrics:

Measure	*Progress in 2015/16*
PhD students studying and graduated	10 active students
Post-doctoral researchers completed 2-year projects	4 active post docs
FTEs of professional researchers working on NZAGRC research programmes	16.04 FTE* contributing to the Centre's research programme

*Includes some PhD and post doc FTE contribution to the core NZAGRC programme. This figure only covers NZAGRC funding. 30.36 FTEs (>130 researchers, of which ~50 contribute >0.1 FTE) contribute to the overall NZAGRC and PGgRc funded science programme.

Goal 5: Develop science and commercial partnerships

The NZAGRC will be a key player in many research and commercial partnerships relating to agricultural GHG emission mitigation.

International

The Global Research Alliance on Agricultural Greenhouse Gases (GRA), initiated by the New Zealand Government, remains a key pillar in New Zealand's international science and policy engagement in climate change and agriculture. It also offers significant opportunities for New Zealand to build global research and commercial partnerships and strengthen domestic capability.

NZAGRC is able to maximise these opportunities through its co-leadership of the GRA's Livestock Research Group and its role in providing strategic advice and support to MPI (who administers the GRA Secretariat and the Government's dedicated GRA budget). The Centre Director continues to co-chair GRA's Livestock Research Group (LRG) together with his colleague from Wageningen UR (Netherlands), and the Centre Deputy Director acts as New Zealand's representative on the LRG. The Deputy Director, Operations Manager (International) and Project Analyst along with external contractors support the co-chairs in developing and monitoring the LRG's work plan including work with partner organisations.

Specific activities include facilitating New Zealand involvement in flagship GRA research/capability building activities, monitoring and administering research contracts on behalf of MPI, advising on the further evolution of the GRA, including connecting with key member countries and global partners (e.g. World Bank, FAO), pursuing collaborative funding opportunities and linking research projects with existing international initiatives. NZAGRC also works to raise awareness of LRG activities including via newsletters, a regularly updated website, and presentations at scientific conferences and expert meetings.

The opportunities for New Zealand will continue to grow in light of the Government's announcement of an additional $20m in support of the GRA, and also the explicit reference to both the GRA and the NZAGRC in New Zealand's Intended Nationally Determined Contribution (INDC), pledged at the UN Climate Change Conference in December 2015. These commitments reflect the importance of developing domestic solutions as well as fostering international collaboration to address a globally significant problem.

Key activities for 2015/16 included:

- NZAGRC organised and led the annual meeting of the LRG in February 2016 in Melbourne, Australia. This was held after the Greenhouse Gases and Animal Agriculture (GGAA) 2016 conference, the premier global science conference on this topic. The LRG meeting reviewed progress with the research networks and collaborative research projects and identified capacity building needs across LRG member countries. Priority actions with GRA partners were discussed, focusing on CCAFS (the Climate Change, Agriculture and Food Security programme of the CGIAR), FAO and the World Bank. A joint session was also held with the GRA's newly established Integrative Research Group.
- NZAGRC collaborated in a joint project with FAO to identify and test intervention packages for different world regions that can jointly increase productivity of selected livestock systems, contribute to livelihoods and food security, and reduce emissions intensity of livestock production. The NZAGRC Operations Manager (International) was seconded to FAO headquarters in Rome, Italy to coordinate this flagship activity. The project is expected to be completed by March 2017. An application for a second phase of the project, which will demonstrate the most promising interventions in selected farm systems in target regions, is currently under consideration.

- Acting as agent for MPI, NZAGRC continues to manage contracts for a wide range of research projects in support of the GRA. Examples include:
  - ✓ Completion of the Global Rumen Census, a flagship project that compared rumen microbial communities in different ruminant species and a variety of diets, using more than 700 rumen samples contributed by 140 scientists from 73 organisations. The project found that rumen methanogens were highly similar in rumens across the world, with only a few species appear to be responsible for the methane produced by ruminants everywhere. This means mitigation strategies can be developed to target the few dominant methanogens, and a technology that's developed in one place should be applicable everywhere. NZAGRC coordinated domestic and global news releases on the project.
  - ✓ A significant new project conducted, in collaboration with the US-based company C-Lock, to design and test a system to rapidly screen methane emissions from dairy bulls along with feed intake. This will assist in the identification and selection of naturally lower-emitting dairy animals for New Zealand. Preliminary results are very positive and further evaluation through direct comparison with respiration chamber measurements is planned.
  - ✓ Advice and input to MPI on new collaborative research investments. These included the design of a fourth round of the New Zealand Fund for Global Partnerships in Livestock Emissions Research, totalling $9.2 million, and New Zealand participation in the European collaborative fund ERA-GAS, which seeks to advance collaborative research to monitor and mitigate GHG emissions from agriculture including livestock.
  - ✓ NZAGRC continued to commission and manage a suite of LRG priority research projects in the area of methane and nitrous oxide.
- NZAGRC produced high-level brochures summarising activities and successes of the three system-specific Research Groups of the GRA (LRG, Paddy Rice and Croplands), and a series of case studies of successes of countries in reducing the emissions intensity of their livestock systems.
- NZAGRC continued to administer the LEARN/GRASS fellowship scheme, with six fellows involved this year. The scheme was comprehensively reviewed with changes made to increase accessibility and uptake, including updating the LEARN website and developing a marketing plan to promote the scheme, and the establishment of a new policy award to support developing countries build capability for emissions inventories.
- NZAGRC led a number of international capacity building and engagement activities:
  - ✓ Two week technician training course on measurement of GHG emissions from livestock in Thailand in March 2016 in collaboration with the Bureau of Animal Husbandry and Genetic Improvement, Department of Livestock Development, Thailand. Participants came from seven countries across south and south-east Asia.
  - ✓ Regional capability building workshop on developing advanced greenhouse gas emission inventories for livestock systems in south and south-east Asia, in Bangkok, September 2015. Participants were introduced to a Tier 2 approach for livestock inventories and the benefits of such an approach for capturing the benefits of improved productivity and links with climate and development goals. A follow-up workshop will take place in August 2016 in Bali, Indonesia.
  - ✓ Support provided to individual countries (Thailand, Indonesia, Malaysia) to help them develop research strategies that encompass broader development as well as climate change goals, with a particular focus on advanced inventories that reflect changing productivity of livestock systems.
  - ✓ Participated in workshops led by the FAO regional office for south-east Asia in Bangkok, linking climate change targets and reporting obligations from UN climate change agreements to the science needed to report livestock emissions and identify opportunities for improvements in livestock systems.

- The Centre Deputy Director was appointed to the Bureau of the Intergovernmental Panel on Climate Change (IPCC) in October 2015, establishing an important link between the GRA and the world's foremost scientific advisory body on climate change to the United Nations.

IP and knowledge management

The Centre does not own IP generated from its science investments and patenting and commercialisation decisions are the direct responsibility of MPI and/or PGgRc. The Centre's role is simply advisory and administrative. An on-line Release of Information (ROI) system, established and maintained by the NZAGRC, is used to keep track of the number and type of publications/presentations generated under NZAGRC funding and ensures that new IP is appropriately identified, protected and managed. The system is also used for approval and tracking of PGgRc and GRA outputs.

During 2013/14, the possibility of establishing a NZAGRC on-line reporting and progress management system for science contracts was investigated. This was superseded by MPI establishing a new grant management system (GMS) and the NZAGRC being invited to use this in early 2014/15. The GMS is now being used to manage NZAGRC and GRA contracts. Plans have been developed to extend the use of the system to allow science leaders to enter their reports directly into the system. If implemented, this will streamline reporting processes for all involved.

Thus far, only the methane mitigation area has identified products (e.g. methanogen inhibitors, anti-methanogen vaccines and low emitting sheep), with clearly identified commercial potential. During 2015/16, the NZAGRC has supported the PGgRc in its efforts to engage with industry partners to move these research areas closer to commercial reality.

Goal 5 metrics:

Measure	*Progress in 2015/16*
Leadership of science input into Global Research Alliance and coordination of Livestock Research Group with the Netherlands	Proactive NZAGRC input into Alliance during 2015/16
Visiting fellows from overseas research organisations hosted	6 exchanges funded by LEARN/GRASS Fellowships
Memoranda of understanding covering research collaborations agreed with research centres around the world	Agreements with national and international research centres on-going and productive
Confidentiality agreements with companies to discuss information related to agricultural GHG mitigation technologies	Signing confidentiality agreements with interested companies is the joint responsibility of MPI and PGgRc. The PGgRc are taking a lead role with regards to adoption and commercialisation, on behalf of industry and MPI. The NZAGRC role is one of advice and support.
Licenses to companies to sell agricultural GHG emission mitigation technologies that the NZAGRC or its partners have developed or imported and implemented to suit NZ requirements	Signing licensing arrangements with interested companies is the joint responsibility of MPI and PGgRc. The PGgRc are taking a lead role with regards to adoption and commercialisation, on behalf of industry and MPI. The NZAGRC role is one of advice and support.

SCIENCE FUNDING REPORT

Funding

In accordance with the NZAGRC's Business, Strategy and Science Plans, and with the approval of the SG, $4.88 million was allocated to research and ancillary activities in the 2015/16 financial year. The detailed funding allocated to the core scientific programmes is reported in detail later in this section. All figures are exclusive of GST.

Infrastructure Update 2015/16

A major spending initiative on infrastructure was completed in the 2010/11 financial year with the New Zealand Ruminant Methane Measurement Centre (at the AgResearch Grasslands campus in Palmerston North) and the New Zealand Nitrous Oxide Measurement Centre (situated at Lincoln University) becoming operational. No expenditure on capital was made in the past financial year.

Capability Development Funding 2015/16

The NZAGRC's strategy in this area is outlined under Goal 4 (see previous section). A portion of the Centre funding for this is embedded within the core science programme, another portion is provided via the undergraduate "pipeline" scholarship schemes, with the remaining funding being available on a discretionary basis when high quality students are projects are identified. Additionally, the NZAGRC advises MPI with respect to international capability building efforts and assists with the administration of Alliance funds in this area (see Goal 5).

Research Programmes 2015/16

The current Science Plan consists of 23 active Research Objectives which align under five key areas: (i) methane; (ii) nitrous oxide; (iii) soil carbon; (iv) integrated farm systems; and (v) Māori. Those programmes marked with a dagger (‡) are co-funded with the PGgRc, AgResearch and/or PGgRc/MPI and those marked with a diamond (◊) are solely funded by the PGgRc in this financial year. Those left unmarked are solely funded by the NZAGRC.

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Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2015/16 NZAGRC Research FTE	2015/16 $NZ NZAGRC (GST excl)	2015/16 TOTAL Research FTE	2015/16 $NZ TOTAL (GST excl)
Methane	5.1◊	Breed low methane ruminants	S Rowe & A Jonker	AgResearch	0	0	3.92	$1,548,929
	5.2◊	Identifying low GHG feeds	D Pacheco	AgResearch	0	0	0.97	$40,000
	5.2	Feeds Review	P Muir	On-Farm Research	0.15	$52,000	0.15	$52,000
	5.3‡	Vaccine	N Wedlock	AgResearch	0.75	$250,000	5.38	$1,537,289
	5.4‡	Identify inhibitors that reduce ruminant methane emissions	R Ronimus	AgResearch	0.68	$250,000	4.60	$1,437,801
	5.5‡	Microbial genomics to underpin methane mitigation	E Altermann & S Leahy	AgResearch	0	0	0	0
	5.7‡	Understanding the low methane rumen	M Tavendale & G Henderson	AgResearch	0	0	0	0
	5.8	Modelling rumen methane production	D Pacheco	AgResearch	0	0	0	0
	5.9	Dairy housing methane capture and mitigation by soil	S Saggar	Landcare Research	0.39	$97,950	0.39	$97,950
	5.11‡	Conduct 2 additional animal vaccine trials and identification of methanogen vaccine targets using monoclonal antibodies	N Wedlock & A Subharat	AgResearch	0.52	$175,000	1.40	$475,000
	5.12	Validation of a rapid, low cost measurement system for measuring methane	J Roche	DairyNZ	0.15	$139,274	0.15	$139,274
Nitrous Oxide	6.1	Plant Effects on N_2O Emissions	S Bowatte	AgResearch	0.33	$126,500	0.33	$126,500
	6.2	Denitrification Processes	S Saggar	Landcare Research	0.96	$90,000	0.96	$90,000
	6.3	Feed management options for mitigating N_2O emissions from grazed systems	C de Klein	AgResearch	1.37	$447,000	1.37	$447,000

Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2015/16 NZAGRC Research FTE	2015/16 $NZ NZAGRC (GST excl)	2015/16 TOTAL Research FTE	2015/16 $NZ TOTAL (GST excl)
	6.4	Additional N_2O work	H Di, J Luo & T van der Weerden	Lincoln University, AgResearch	0.49	$154,000	0.49	$154,000
	6.5	Spikey 2 Optimisation	Geoff Bates	Pastoral Robotics	0.50	$75,000	0.50	$75,000
	6.6	Effects of N transformation inhibitors and gibberelic acid on N_2O emissions	S Saggar	Landcare Research	0.44	$110,000	0.44	$110,000
Soil Carbon	7.1	Manipulation of carbon inputs to stabilise and enhance soil carbon stocks	D Whitehead	Landcare Research	2.85	$409,000	2.85	$409,000
	7.2	Tools to quantify the stabilisation capacity and vulnerability of carbon in grassland soils	F Kelliher	AgResearch	1.96	$276,000	1.96	$276,000
	7.3	Modelling management manipulations using the HPM	J Rowarth	Waikato University	0.18	$75,000	0.18	$75,000
Integrated Farm Systems	8.1	GHG Emissions on Sheep and Beef Farms	R Dynes & K Hutchinson	AgResearch	0.41	$144,830	0.41	$144,830
	8.2	GHG Emissions from Dairy Systems	R Dynes & K Hutchinson	AgResearch	2.92	$848,600	2.92	$848,600
Māori	20.1	Low emissions for the Maori sector	P Journeaux	AgFirst	1.00	$243,132	1.00	$243,132
				Total	16.04	$3,963,286*	30.36	$8,327,305*

*Other research costs of $115,755 are not included in this table.

Notes:

- 2015/16 funding includes personnel costs, consumables and in certain cases, items such as SNP chips or services such as DNA sequencing.
- FTE values include some PhD students and post-doctoral researchers time.
- Total funding and FTEs are shown for jointly contracted objectives.

Methane Research Programme Report - 2015/16

Principal Investigators: Dr Peter Janssen and Dr Graeme Attwood

The majority of the NZAGRC CH_4 programme is jointly funded with the PGgRc and aligns with existing MPI programmes funded through SLMACC and the New Zealand Global Research Alliance fund. It aims to reduce emissions by directly targeting the CH_4-producing methanogens through small molecule inhibitors and vaccines and indirectly through feeding and changes in animal phenotype. The current objectives within the NZAGRC CH_4 programme have made significant progress this year.

Using respiration chambers, the breeding programme has shown that that the contrasting CH_4 yield trait of sheep selected on lucerne pellets is repeatable when animals from high and low lines are fed fresh pasture. This was consistent over three consecutive measurement periods. Additionally, having now measured over 1,000 adult ewes and 1,200 lambs in portable accumulation chambers (PAC), the conclusion is that PAC are a suitable tool for ranking individual animals for use in selection programmes. This provides a low cost and rapid tool to aid breeding for the low methane trait. The low and high emitting selection lines continue to diverge, with the differences now just over 10%. Preliminary economic analysis shows the average estimated breeding values for sheep from the low methane line are $5.48 higher (gross margin per ewe, per year) than the average sheep in the high methane line due to higher growth rates, lean % and wool production although this does not take into account any extra feed costs. Further data are being collected to better assess the financial implications of selecting for low CH_4 yield and these initial results need to be seen as indicative interim results only.

Following the breeding work conducted on sheep, a cattle breeding programme commenced at the end of 2015/16. The first goal of this work is to validate a rapid, low cost system for measuring both methane and feed intake for individual cows in real-time. An initial trial funded by the New Zealand GRA fund has clearly demonstrated that there are no issues with animals using the system, and that data on both intake and methane emissions can be reliably obtained from individual animals on a daily basis. A second NZAGRC-PGgRc trial comparing the methane measurements from the new system with those obtained from respiration chambers commenced in June 2016.

In the feeds area, animal experiments to assess the potential of fodder beet (FB) as a low-GHG feed were completed. These confirmed that feeding FB at inclusion levels greater or equal to 75% of the dry matter intake result in repeatable reductions in CH_4 emissions. Provision of FB in the diet was an effective way to reduce the total amount of N excreted in the urine. However, inclusion of FB at 90% of the DMI resulted in a negative N balance. Provision of FB at 50% resulted in a better balance of protein and energy, leading to improved N retention and reduced N excretion compared to pasture alone. FB has potential to reduce both CH_4 and N excretion to the environment when fed to sheep, but attention needs to be given to ensure that nutrient supply from FB mixtures with pasture is sufficient and balanced to support animal productivity.

During 2015/16 a review was conducted to assess the available literature on the effects of feeding brassica and fodder beet forages to livestock on methane and nitrous oxide (N_2O) emissions. This found that there is enough data to confirm that forage rape reduced methane emissions by up to 30%, but there is insufficient data to extend this finding to all brassica species. In addition, there is insufficient data to draw any conclusions on the impact of feeding brassicas on nitrous oxide emissions. These data gaps need to be filled before any assessment can be made regarding the consequences of including brassicas in the New Zealand Inventory model as a mitigation tool.

The vaccine programme has progressed significantly during 2015/16. Nine different prototype vaccine antigens were trialled in sheep during the year. Three antigens were shown to induce antibodies that inhibit methanogens in *in vitro* assays, or resulted in apparent rumen microbial community changes, and are being evaluated further. Bioinformatic analysis of genome sequences generated in the programme identified and ranked other potential vaccine antigens for testing, greatly increasing the scope for effective vaccine development. From a comparison of antibody responses to antigens given to animals as a mix or singly, it was concluded that it is best to test antigen candidates for a vaccine singly rather than as batches (i.e. combining two or more antigens in a mix). This has implications for the programme going forwards. This doesn't preclude a final vaccine containing multiple antigens with proven effectiveness.

The inhibitor programme conducted seven animal trials this year. These tested the effects of 9 different compounds to reduce methane emissions. These were conducted in either 2 day sheep trials, 16 day sheep trials, and/or 2 day trials in cattle. Eight of these compounds resulted in methane inhibition that warrants further compound development and investigation. Additionally, thousands of compounds have been screened this year in rumen fluid-based assays. A large number of active compounds have either been identified or reconfirmed. Numerous dose-response curve assays were also performed to find the range of concentrations at which the compounds were active. The next steps are to progress the most effective of the new inhibitors to testing in animals in 2016/17.

In addition, a feasibility study funded solely by the NZAGRC has continued in 2015/16. The aim of this study is to test the practicality of capturing CH_4 emitted from housed cattle and stored animal waste and injecting it in the soil for oxidation by methanotrophs. To date, results from the field trial have established that feeding methane at low concentrations (<120 ppm) for a short-period (6 weeks) does not achieve the methanotroph activity to enhance methane oxidation efficiency. However, feeding methane at high concentration (3600 ppm) for 8 weeks removed more than 95% of methane from the pasture soil.

Nitrous Oxide Research Programme Report - 2015/16

Principal Investigators: Dr Cecile de Klein and Prof Hong Di

The nitrification inhibitor DCD is a proven nitrous oxide mitigation technology, but its withdrawal from the market means that the focus of the NZAGRC's current nitrous oxide research programme is on quantifying the effects that pasture plants and pasture plant communities have on nitrous oxide emissions. This work is closely aligned to the MBIE P21 and Forages for Nitrate Leaching programmes (FRNL) which focus primarily on nitrate leaching. We have also commissioned work to better quantify the GHG impacts of the use of stand-off pads/housing by looking at differences in emissions between pasture applied urine and pasture applied farm dairy effluent (FDE). During 2015/16, new projects involving optimisation of a prototype urine patch detector, known as Spikey®, and a subsequent research project on the use of this technology to target-apply mitigation options were funded.

Having demonstrated that plant species identity can influence N_2O emissions in short term plot trials, this year a field experiment was conducted to better understand why these differences occur; a better understanding of how plants alter N_2O emissions would put us in a stronger position to devise ways to manipulate plants for N_2O mitigation purposes. N_2O emissions were measured from plots of ryegrass, white clover, plantain and a pasture mixture alongside simultaneous measurements of soil pH, soil moisture, plant growth, potential nitrification and soil nitrogen pools and fluxes. These data are now being analysed.

Trials aligned with the FRNL programme have demonstrated the potential of feed management options and plant species to reduce N_2O emissions from urine patches during 2015/16. Monoculture trials have shown that plantain and lucerne had c. 35-70% lower emissions than perennial or Italian ryegrass and white clover at the same level of N supply, when using urine collected from cows grazing standard ryegrass/white clover pasture. Field trials with mixed pasture swards also suggested lower N_2O emissions from mixed species swards compared with traditional ryegrass/white clover swards, but this was due to lower N concentration in the urine, rather than a plant effect. Trials that used the urine collected from cows feeding on the different species being investigated have shown that N_2O emissions from urine patches on Italian ryegrass/plantain pasture were similar to those on perennial ryegrass/white clover pasture, despite the fact that the urine from the IR/plantain mix had a lower N content than the PR/WC urine. Linking in with a P21 trial using winter forage crops and crop-specific urine, showed that, at the same rate of urine-N returned, N_2O emissions from fodder beet were about 40% lower than from a kale crop.

Lab and field trials from the two PhD programmes on the effect of diet-induced urine composition on N_2O emissions, have revealed two potential compounds for reducing N_2O emissions. A comprehensive lab study using glycosinolate hydrolysis products that can be found in brassica crops, has shown that some compounds can reduce nitrification and lower N_2O emissions. Similarly, a lab study using aucubin, a key compound in plantain, showed that aucubin could also lower N_2O emissions. In contrast, a field trial using different purine-derived N compounds in urine, such as hypoxantine and allantoin, has shown that these compounds do not affect N_2O emissions.

The investigative work on Spikey®, a technology to locate and treat urine patches within a paddock shortly after grazing, has clearly demonstrated its efficacy. The study tested the technology in six soils and under both irrigated and non-irrigated conditions. The collated data base of conductivity readings will be used as a reference data source for the on-going development of the urine patch identification algorithms. A hand-held version of Spikey® has since been developed and will be used in a new project to test the efficacy of targeted application of nitrogen transformation inhibitors (urease and nitrification) and gibberellic acid for reducing ammonia and N_2O emissions and leaching losses of N from cattle urine. This study will also assess the effect of these treatments applied beyond the detectable urine patch to cover the edge effect.

Soil Carbon Research Programme Report - 2015/16

Principal Investigators: Prof Frank Kelliher and Dr David Whitehead

Increasing the quantity of carbon stored in agricultural soils has the potential to offset emissions of greenhouse gases to the atmosphere. However, realising this potential is technically challenging when soil carbon stocks are already high (as they are in New Zealand), potential changes in soil carbon are small and spatial variability is high. The current NZAGRC programme has three distinct components (1) testing specific management practices that may increase the long term soil carbon store in field situations (2) developing and using models to predict how a range of management practices may influence long and short term soil carbon storage and (3) identifying those factors that influence the stability of current or newly added soil carbon.

In the past year, findings from our work using direct measurements of carbon inputs has shown that:

- More diverse pasture swards had greater root biomass and turnover than a ryegrass/clover sward suggesting greater carbon inputs to soils (1.2 t carbon/ha).
- Direct measurements using carbon isotopes did not detect a difference in carbon inputs from roots to soil between diverse and ryegrass/clover swards. Variability was high so the power to detect differences was weak.
- Large inputs of carbon from dying ryegrass/clover roots (an extra 1.5 t carbon per ha) were measured using carbon isotopes during a pasture renewal event (killing swards, cultivation and reseeding). The long-term fate of this new carbon input is poorly known.

We conclude that the diverse sward had more root biomass and turnover but it was not possible to determine whether this would translate to increased carbon inputs to soil. However there were large carbon inputs into soil during pasture renewal events that was available for stabilisation.

Our measurements of carbon exchange at paddock scales before and after pasture renewal and following establishment of swards with ryegrass/lucerne and mixed species have shown that:

- Minimising the period between spraying off pasture, reseeding and pasture re-emergence minimises the immediate loss of carbon particularly when soils were wet.
- In the three years subsequent to pasture renewal, all treatments had lost carbon, but there were no differences in carbon balances between treatments after accounting for initial differences between sites.

We conclude that, following pasture renewal, there is a short-term loss of carbon. Once the new pastures are established there is little difference between a diverse sward and a ryegrass/clover sward, however, site specific factors may have limited our ability to detect differences. Parallel work suggests other sward mixes may enhance carbon accumulation and be suitable as part of a farm system, e.g., inclusion of a lucerne base (with deeper roots) as opposed to ryegrass. We intend to start measurements with these treatments in spring 2016.

We have undertaken a strong modelling component in parallel with our measurements. Using data, we have tested the process-based CenW model and have extended it to simulate changes in soil carbon for different management practices. The CenW model compares well with other international models and this has confirmed the confidence we have in using the model to analyse and predict the effects of climate and management effects on long-term changes in soil carbon.

Collecting, preparing and analysing soils is of critical importance in soil C studies. In particular, how soil samples are prepared for analysis can influence analytical results. A study of the nano-scale structure and specific surface area (SSA) of allophane-rich and non-allophanic pastoral soils to assess how sample preparation can affect soil properties was completed in 2015/16. Soil water contents after supercritical drying (SD) and air drying (AD) were strongly correlated. The results provided a better understanding of how SD helps to preserve the nanoporosity of allophane-rich soils and the role of short-range ordered constituents contribute to specific surface area and the accumulation of soil organic matter. This will allow us to better prepare soil samples to obtain meaningful measurements.

A study which measured the soil physical and chemical properties expected to contribute to C stabilisation, tested key assumptions of a statistical model developed by the NZAGRC soil C programme (Beare et al. 2014) and developed an improved model has also been completed. Key findings are that (i) allophanic-rich soils have a greater potential to stabilise more soil C than the non-allophanic pastoral soils; and (ii) cropping had depleted stabilised C from the allophanic-rich soils, compared to pastoral agriculture, but this had not happened for the non-allophanic soils. Earlier research has suggested a maximum C loading rate onto soils of 1 mg C m^{-2} SSA. For this study, a new methodology was developed to estimate a soil's C loading rate which yielded 0.66 mg C m^{-2} for the allophane-rich pastoral soils and 0.85 mg C m^{-2} for the non-allophanic pastoral soils. Both values were less than 1 mg C m^{-2} which was interpreted to indicate that not all of the soil's specific surface area was "available" for stabilising C, more so for the allophanic-rich pastoral soils. This suggests that NZ soils may have a larger capacity to store more soil C than previously thought.

A modelling analysis was completed using full C and N accounting, for all components of C and N input, cycling and fate of temperate grazed pastures. The analysis covered all key drivers of C and N cycling and emissions and identified the role of the key management options: stocking rate; fertiliser (or legume) N input rate; animal class (dry-meat/lactating for sheep, cattle; off-season stocking policy; supplement use (amount per animal per day, N content and degree of substitution by animals). In addition the role in all the above of changes in partitioning in the animal (of both C and N); changes in plant traits (e.g. fructans or altered energy content); plant species requirements for N; and speculative changes in the rate of degradation of surface litter and soil organic matter, were illustrated.

Conclusions included that the shift to dairy has resulted in a major *increase* in the efficiency of animal product per unit N input, and per unit emissions. Animal product is nearly doubled while N release halved under dairy compared to meat, at the same intermediate total N input rate. Supplements were shown to play a major role in improving the efficiency (increasing the amount of product produced per ha, while reducing losses/releases of N per ha, and increasing C sequestration). This was shown to not depend on the C:N ratio of the supplemented feed, nor altered partitioning in the animal, nor the level of substitution nor stocking rate. Rather, it is a feature of how feeding supplements allows the limitations to additional pasture C supply (energy supply) caused when greater input of N leads to diminishing returns of energy, when this energy depends on photosynthesis. For brought-in feed, the C gained per unit N remains 'linear' and written on the bag. However, a full life cycle analysis is needed to gauge the broader effects of using supplements.

Integrated Farm Systems Research Programme Report - 2015/16

Principal Investigator: Dr Robyn Dynes

The overall aim of this programme of work is to identify and demonstrate that management strategies to reduce **GHG emissions intensity** already exist and that they are practical, adoptable and cost effective. The programme covers dairy, beef and sheep farms and is closely aligned to the dairy industry's P21 programme and the Beef+Lamb NZ environment focused farm programme.

Two Beef+Lamb NZ monitor farms have been studied. The two S+B Monitor farms now have substantial robust data and baseline farm systems models which demonstrate the extent to which the key management decisions and efficiency drivers impact on current emissions intensity. The farms are at very different points in development cycle, so provide useful perspectives for informing the wider industry.

Three practice-change scenarios have been modelled to predict GHG emissions intensity for Onetai station, a B+LNZ environmental focus farm situated in coastal King country. Scenarios incorporating an increase in soil fertility and animal production and a change in stock policy have predicted that a 20 to 38% improvement in GHG emissions intensity is possible.

The project partnership between AgResearch, B+LNZ, Farmax and AgFirst has increased the monitoring capability of the Onetai farm management team and increased their ability to make information based key strategic decisions. At the start of the project the farm management team were unclear on many key monitoring metrics (animal weights, pasture covers, growth rates etc). We now have a more robust monitoring model for the farm from which we can develop a more robust estimation of environmental emissions. Pasture growth and quality measurements are being collected to monitor the effect of increasing soil fertility; a phosphate fertiliser response trial has been established as a strong visual indicator of this method of improving animal production and reducing emissions intensity.

A successful field day was held at Onetai station in September 2015. The project team facilitated substantial discussion around GHG issues and mitigations with the group of keen and interested farmers.

Three practice-change scenarios modelled for Highlands (South Canterbury) monitor farm demonstrated the potential for a win-win solution from increasing the area sown to Lucerne and Tall Fescue. This scenario enabled more lambs to be finished faster and had the greatest effect on lowering the GHG emissions intensity. This scenario was assessed as being readily adoptable by the farmers.

During 2015/16, the dairy component of the programme has progressed toward the objective of understanding the potential for practical mitigation options to result in lower GHG footprint of dairy farming systems.

The measurement of methane and nitrous oxide within dairy farmlets which have a range of mitigation options including high genetic merit cows (Waikato), low N fertiliser input (Waikato) and diverse pastures (Canterbury) has now been completed. Collecting these data has enabled the mitigation options to be considered within a farming system. The first analysis was the completion of an inventory-GHG footprint for Canterbury in conjunction with an MPI SLMACC funded programme. The information is now available to enable the validation of existing farm systems modelling.

The new data on methane emissions from cows grazing fodder beet during winter and early lactation is timely. Indications are that, under these conditions, fodder beet can lead to a reduction in daily methane emissions of 10-20%. Industry uptake of fodder beet both as a winter feed, but increasingly as a transition feed used on the milking platform in both late and early lactation is continuing. Further, these data together with data from the FRNL programme on fodder beet will enable farm systems modelling to consider the wider environmental impacts of this potential mitigation to both GHG and emission to water.

Māori-focussed Research Programme Report - 2015/16

Project Manager: Phil Journeaux

This programme aims to assist the Māori pastoral sector to improve its collective capacity to increase resource use efficiency and farm productivity while lowering greenhouse gas emissions.

The approach has been to develop a set of Māori farm typologies which represent the predominant pastoral farming systems, identify key factors that underpin farm productivity, resource and emission efficiency, sustainable profitability, and then identify and test a range of mitigation strategies. Farm typologies are important to avoid the problems of homogenizing a heterogeneous group that range from very small farms to large multi-enterprise corporates. These typologies have been compared against existing databases and helped in the selection of four in-depth representative focus farms where emissions from alternative farm system configurations are being evaluated.

Farm system mitigation scenarios have been developed based on interaction and knowledge sharing between the farmers (including land entities), scientists and industry advisors which has taken place in focus farm workshops around the country.

A key contribution to the literature will be an enhanced understanding of the Māori farm typologies with economic, environmental, social and cultural implications of low emission farming systems within the Māori sector, with wider implications across NZ. In the final year of the project, materials will be developed to extend the learnings from the research to the wider sector.

Progress in 2015/16:

- Modelling of GHG mitigation scenarios carried out, based on earlier meetings held with each of the 4 focus farm Trustees to discuss modelling scenarios.
- Further meeting held with focus farm Trustees to discuss results of initial modelling work, and determine further scenarios for modelling.
- Second round of modelling carried out.
- Further meeting held with focus farm Trustees and other interested parties to discuss the modelling results and implications for the farms.
- Development of the MyLand computer model, which incorporates forestry economics and carbon sequestration, in a spatial framework, alongside Farmax and OVERSEER inputs – so incorporates pastoral farming with forestry.
- Presentations on the modelling work have been made to the 2016 International Rangeland Conference, and the 2016 NZARES conference.

A summary of the modelling results are;

- Many of the changes in farm systems resulted in relatively marginal changes in GHG emissions & profitability. Often if GHG emissions decreased so did profitability, and vice versa.
- Some system changes did give a win-win in that GHG emissions decreased while profitability increased.
- These included;
    - Lowering stocking rates on dairy farms

- Increasing sheep:cattle ratios
- Increasing farm efficiency (e.g. increasing lambing percentages)
- Planting marginal areas in forestry

- Planting marginal areas in forestry was marginal on the dairy farms given the small areas available; this mitigation had a much larger impact on the sheep & beef farms.
- In the absence of any mitigations, the advent of a carbon charge had a significant impact on farm profitability

FINANCIAL SUMMARY

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EXPENDITURE	
Core research spending	
Methane	964,224
Nitrous Oxide	1,027,500
Soil Carbon	850,755
Integrated Farm Systems	993,430
Māori	243,132
Research Total	**4,079,041**
Other research costs	
Additional Fellowships and Studentships	78,000
Planning, engagement & knowledge transfer	10,026
Policy support	85,033
Special IT and communications	13,419
Other Total	**186,478**
Administration	**615,549**
Total Expenditure (actual)	***4,881,068***
REVENUE*	***5,157,185***
Balance unspent carried over**	***276,117***

*Includes $307,185 carried over from 2014/15.
**A delay in contracting the low methane cattle validation work (Obj 5.12) has contributed to the under spend in 2015/16. $300,000 was budgeted for this work in 2015/16. This work is contracted and commenced in June 2016, therefore most of the funds have been carried into 2016/17.

DIRECTORY

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Tania Brown from Sept 2015
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APPENDIX 1 – COMPOSITION OF NZAGRC SG, ISAG and MAG

Compositions of the SG, ISAG and MAG

The tables below set out the compositions of the SG, ISAG and MAG and the dates of governance meetings held during the course of the financial year.

Steering Group

Four Quarterly meetings were held in 2015/16 (13th August 2015, 18th November 2015, 2nd March 2016 and 18th May 2016).

Name	Organisation
Prof. Warren McNabb	AgResearch (Chair)
Dr Rick Pridmore	DairyNZ
Dr Peter Millard	Landcare Research
Dr Stefanie Rixecker	Lincoln University
Prof. Mike Hedley	Massey University
Dr Rob Murdoch	NIWA
Mr Warrick Nelson	Plant & Food Research
Mr Mark Aspin	PGgRc
Dr Brian Richardson	Scion (to 31 December 2015)
Dr Tim Payn	Scion (from 1 January 2016)
Matthew Perkins	MPI (Observer*)
Dr Gerald Rys	MPI (Observer*)
Dr Andrea Pickering	MPI (Observer**)
Dr Marc Lubbers	MBIE (Observer*)

*MPI and MBIE hold Observer (non-voting) positions on the Steering Group.

**Dr Andrea Pickering was invited to attend SG meetings in 2011/12 following recommendation from MPI that an Alliance representative attend SG meetings to ensure coordination.

International Science Advisory Group

The ISAG did not meet in 2015/16. They conducted a review of the methane programme in 2014/15 and the rest of the programme will be reviewed in 2016/17. The review in 2016/17 will be conducted by the specialist panel named below. The panel will be chaired by Dr Ian Ferguson of MPI.

Name	Organisation
Prof Keith Goulding	Rothamsted Research, UK
Prof Peter Grace	Queensland University of Technology, Australia
Dr Denis Angers	Agriculture and Agri-Food Canada
Prof G Philip Robertson	Michigan State University

Membership runs from 1 March to 28 February in each year.

Māori Advisory Group

The current membership of the Māori Advisory Group is detailed below. The group did not meet formally during 2015/16, however they provided advice on the NZAGRC Māori project as required.

Name	Organisation
Lorraine Stephenson	Independent
Jamie Tuuta	Māori Trustee
Ariana Hemara Wahanui	AgResearch
Tony Finch	DairyNZ
Keith Ikin	Landcare Research
Charlotte Severne	Lincoln University
Dr Nick Roskruge	Massey University
Marino Tahi	NIWA
Alby Marsh	Plant & Food Research
Mark Aspin	PGgRc
Tanira Kingi	Scion
Erica Gregory	MPI

APPENDIX 2 – ANNUAL OBJECTIVE SUMMARY SCIENCE REPORTS (SUBMITTED)

Objective Level Summary – 2015/16

Key:

Objective completed
Objective on track
Objective on track apart from publications
Current issues with Objective (e.g. behind on experimental work)

Those programmes marked with a dagger (‡) are co-funded with the PGgRc, AgResearch and/or PGgRc/MPI and those marked with a diamond (◊) are solely funded by the PGgRc in this financial year. Those with no markings are solely NZAGRC funded.

Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2015/16 $NZ NZAGRC (GST excl)	Status End 2015/16
Methane	5.1◊	Breed low methane ruminants	S Rowe & A Jonker	AgResearch	0	Minor delays to manuscripts
	5.2◊	Identifying low GHG feeds	D Pacheco	AgResearch	0	
	5.2	Feeds Review	P Muir	On-Farm Research	52,000	
	5.3‡	Vaccine	N Wedlock & A Subharat	AgResearch	250,000	Minor delays in data analysis due to DNA sequencing contractor.
	5.4‡	Identify inhibitors that reduce ruminant methane emissions	R Ronimus	AgResearch	250,000	
	5.5‡	Microbial genomics to underpin methane mitigation	E Altermann & S Leahy	AgResearch	0	
	5.7‡	Understanding the low methane rumen	M Tavendale & G Henderson	AgResearch	0	
	5.8	Modelling rumen methane production	D Pacheco	AgResearch	0	Manuscript delayed whilst student focuses on PhD thesis.
	5.9	Dairy housing methane capture and mitigation by soil	S Saggar	Landcare Research	97,950	
	5.11‡	Conduct 2 additional animal vaccine trials and identification of methanogen vaccine targets using monoclonal antibodies	N Wedlock & A Subharat	AgResearch	175,000	Minor delays in data analysis due to DNA sequencing contractor.
	5.12	Validation of a rapid, low cost measurement system for measuring methane	J Roche	DairyNZ	139,274	
Nitrous Oxide	6.1	Plant Effects on N_2O Emissions	S Bowatte	AgResearch	126,500	
	6.2	Denitrification Processes	S Saggar	Landcare Research	90,000	
	6.3	Feed management options for mitigating N_2O emissions from grazed systems	C de Klein	AgResearch	447,000	
	6.4	Additional N_2O work	H Di, J Luo & T van der Weerden	Lincoln University, AgResearch	154,000	
	6.5	Spikey 2 Optimisation	Geoff Bates	Pastoral Robotics	75,000	
	6.6	Effects of N transformation inhibitors and gibberelic acid on N_2O emissions	S Saggar	Landcare Research	110,000	

Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2015/16 $NZ NZAGRC (GST excl)	Status End 2015/16
Soil Carbon	7.1	Manipulation of carbon inputs to stabilise and enhance soil carbon stocks	D Whitehead	Landcare Research	409,000	
	7.2	Tools to quantify the stabilisation capacity and vulnerability of carbon in grassland soils	F Kelliher	AgResearch	276,000	
	7.3	Modelling management manipulations using the HPM	J Rowarth	Waikato University	75,000	Minor delay to manuscript due to review by overseas collaborator.
Integrated Farm Systems	8.1	GHG Emissions on Sheep and Beef Farms	R Dynes & K Hutchinson	AgResearch	144,830	
	8.2	GHG Emissions from Dairy Systems	R Dynes & K Hutchinson	AgResearch	848,600	
Māori	20.1	Low emissions for the Maori sector	P Journeaux	AgFirst	243,132	Minor delay to manuscript.

5.1 - Breed low methane ruminants

Jointly supported programme

Objective Leader – Drs Suzanne Rowe & Arjan Jonker (AgResearch)

The aim of this research is to understand the genetics of host control of ruminant methane emissions. If successful, it then aims to develop and make genetic and genomic selection technologies available to reduce methane yield (gCH_4/kgDMI) and methane intensity (gCH_4/kg product) in sheep. This would be via a beta-test format with subsequent full scale industry implementation. This is a comprehensive program that harnesses efficiencies by using Central Progeny Test animals where possible to ensure that results cannot only be used in research but also become a training resource for commercial application. Using animals that are involved in other research programs provides low cost access to a comprehensive set of phenotypes needed to evaluate the impact of selection for methane on commercial sheep production systems in New Zealand. The selection lines are closed and maintained only for methane research but are derived from and genetically linked to the Central Progeny Test flocks. This enables predictions to be made across flocks enabling the evaluation of the effect of methane selection on difficult to measure or sex limited traits such as carcass quality and maternal ewe traits. Maintenance of these links is crucial to full evaluation of the effects of selection for methane on commercial sheep production and for the utility of the research. The use of high density genomics is also required to extend the applicability of research findings across species.

An important aspect of using genetic change is that progress may be slow, but is permanent and cumulative. As a consequence it is important that an on-going monitoring of genetic changes in other traits is undertaken to detect any unfavourable changes at an early stage. Sheep are being used first, as they are markedly cheaper and we expect broad consistency of results across other ruminant species. In particular, research in sheep will be aligned to research in cattle on a continual basis. This will be achieved with planned regular discussion and sharing of results between DairyNZ and AgResearch.

It is important in the next years to:

- Demonstrate that methane rankings when low selection line progeny are fed lucerne pellets in respiration chambers are the same under pasture conditions.
- Continue understanding the physiological changes associated with breeding for low methane emissions. By ongoing selection and monitoring of these lines for detailed production and methane traits, e.g., lamb survival, and carcass composition as well as all other production traits.
- Validate a method that can rank animals based on methane emissions per unit of feed intake or production: test 1-hour portable accumulation chamber (PAC) measurements and rumen microbial profiles.
- Compare volatile fatty acid (VFA), rumen microbial community (RMC) and rumen morphologies in deer with those from sheep, to show that the same principles may apply to both species, and allow extrapolation from sheep to deer, in the absence of methane emission data from deer.
- Use knowledge gained from the work with sheep in work to develop selection tools for low-methane cattle.
- Genotype sheep for genomic prediction, calculate breeding values for NZ maternal breeds of sheep, and provide selection indices to Sheep Improvement Ltd (SIL), to allow industry to use breeding values for methane emissions combined into economic index equations that include other production traits.

- Determine the relationship between Residual Feed Intake (RFI) and methane emissions in sheep.

5.1 – Progress in 2015/16

This program determines the genetic basis of methane (CH_4) emissions from ruminants. The phenotype used is grams of methane emitted per kg feed (measured as dry matter intake (DMI)). Two lines of sheep have been maintained, with one line selected for high methane yield and the other for low methane yield. These lines were selected from New Zealand Central Progeny Test flocks to ensure that the results are immediately relevant and applicable in the national flock. The lines are used to determine the effect on health and production traits of selection for low emitting ruminants, to develop proxies for low cost measures suitable for selection and to inform other ruminant research programs.

Results from the 2015/2016 year have shown that the divergent lines are highly significantly different in methane yield ($P<3.7x10^{-7}$). The born 2015 cohort in the low line emit 10.4% less g CH_4/kg DMI than the high line ($P<0.001$). To date, these lines have been selected using respiration chamber data where sheep are fed lucerne pellets according to live-weight. As these are not standard NZ grazing conditions, an animal experiment was performed where 96 ewe lambs were measured in respiration chambers whilst being fed ad-libitum cut pasture over 3 consecutive measuring rounds. Selection line differences were confirmed with methane yield being on average 10% lower on lucerne pellets and 9% lower on cut pasture for the low compared with high CH_4 selection line sheep. Results show that methane yield can successfully be selected for in ruminants under standard grazing conditions. Further, evaluation of standard production traits measured on the lines show that the low emitting line animals tend to have faster, leaner growth and higher wool production leading to a $5.48 greater gross margin per ewe wintered, although this margin does not take into account cost of additional feed. As methane production is from fermentation of feed in the rumen, the relationship of methane production with both feed eaten and feed efficiency is of vital importance and the focus of further work.

Portable accumulation chambers (PAC) have been developed for sheep as a low cost alternative to respiration chamber measurements. Advantages are manifold. PAC can be used on farm under normal grazing conditions, and 2 or 3 one-hour measures are equivalent to a 48-hour respiration chamber (RC) measure. Currently 12 chambers are used to measure 72 animals per day at a cost of ~$30 per measure. Combined with low cost genotyping, this offers the opportunity for genomic selection for low methane at no additional cost to those breeders already using molecular breeding values (MBVs) for standard production traits. During the 2015/16 year, ~2,000 PAC measures were carried out in young and adult animals from selection lines and key progeny test flocks. We have shown that PAC methane measured in young animals is highly predictive of adult emissions and can be used as a lifetime performance indicator. PAC measures were also shown to be heritable and highly correlated with RC measures of methane yield (0.57 ±013) and are therefore a suitable low cost, welfare friendly, replacement for RC in methane selection programs in sheep. The PAC equivalent of methane yield involves using total moles of both carbon dioxide and methane gas emitted as a proxy for feed intake. This offers an exciting opportunity to add significant value to a methane mitigation technology. During the 2015/2016 year, 200 sheep measured through a feed intake facility were also measured through PAC chambers. Next year, 400 animals are due to be measured including 96 ewe lambs from the methane selection lines. Given that PAC present a solution for sheep breeders but not for cattle, we have continued to collect rumen samples with every methane measure and to develop rumen microbial community sequencing as an additional proxy.

For dissemination of methane mitigation nationwide, genomic selection offers the greatest opportunity. To implement genomic selection, a sufficient training resource is required to 1) train methane predictions from genetic markers and 2) estimate correlations with all other production traits for inclusion in national selection indices. Over the life of this research program, a mixture of high and low density genotyping has been used. A key collaboration with FarmIQ and Beef + Lamb New Zealand Genetics (BLNZG) was used this year to impute all animals to high density creating a training resource of 2818 animals with 600k marker genotypes and methane and production records. For commercial dissemination, we are likely to require 2-3 times this number. We have shown this year that this is entirely possible by the use of PAC chambers. To estimate accuracies, research MBVs have been calculated and will be disseminated to a select number of breeders in the coming year. This is a major step towards implementation within industry. We have shown (Rowe, 2016 Report 5.1.12) that ultimately the economic value of including methane in a selection index will be highly dependent on the relationship with feed intake and feed efficiency.

Finally, results of the research programme on breeding were presented at several conferences (2 international and invited talks) and 5 peer reviewed publications were prepared.

Key achievements for 2015/16:

- Using a respiration chamber trial, we have shown that that the low CH_4 yield trait of sheep selected on lucerne pellets is repeatable (i.e., selection line differences are the same) when animals from high and low lines are fed fresh pasture. This was consistent over three consecutive measurement periods.
- Research from the selection line sheep measured for methane on pasture using the SF_6 tracer technique and PAC was presented at the Greenhouse Gas and Animal Agriculture (GGAA) conference in Melbourne, and a subsequent manuscript titled 'Sheep from methane yield (g/kg DMI) selection lines also have differences in methane yield under pastoral farming conditions' has been submitted to a peer reviewed journal.
- Having measured over 1,000 adult ewes and 1200 lambs in PAC chambers, we can now show that the genetic correlation between measures in young and adults is close to 1 and that gases measured in PAC chambers are heritable and repeatable. This indicates that PAC chambers are a suitable tool for ranking individual animals and for use in selection.
- Two invited presentations were given at the QMB and AAABG conferences on the statistical handling of microbial community composition data. A manuscript from the samples contributed to the Australian DAFF project has been submitted.
- The selection lines continue to diverge, and the differences are now highly significant and average estimated breeding values for sheep from the low methane line are $5.48 higher (gross margin per ewe, per year) than the average sheep in the high methane line. Three separate manuscripts on the lines on carcass traits, PAC measures, and maternal characteristics have been prepared for submission to peer reviewed journals.

5.2 - Identifying low GHG feeds

Jointly supported programme

Objective Leader – Dr David Pacheco (AgResearch)

We aim to develop feeds and feeding strategies that result in reduced GHG emissions from ruminants. Nutritional strategies will take advantage of desirable characteristics of different forages, feed crops and feed ingredients to design appropriate feeding systems. Such feeds and feeding systems will then direct rumen fermentation towards pathways that are conducive to reduced methane and increased nitrogen utilisation efficiency. The devised nutritional strategies will provide benefits on GHG that are above and beyond any benefits in emission intensity achievable via increased productivity when current feed supplementation practices are used. We will not only identify nutritional strategies that work, but also understand the mechanisms behind the GHG reductions so that low GHG feeding systems can be designed for current and future markets of livestock feed.

Initially, we have used the leads from forage brassica experiments to develop hypothesis of mechanisms underpinning the reduction in GHG emissions. From a mechanistic perspective, the initial lines of enquiry have been the quantification of the contribution of pH and carbohydrate structure as factors affecting fermentation patterns leading to lower methane production in the rumen. The purpose of understanding these rumen processes is to design manipulations of rumen fermentation to reduce GHG emissions, while maintaining or increasing animal productivity. In all animal experiments, nitrogenous aspects of rumen fermentation are being studied to ensure that feeds and feeding strategies will deliver reductions for both methane and nitrous oxide.

The knowledge generated will be used by scientists in the NZAGRC-PGgRc programme. For example, it is being used to help define the role of digestive processes as a contributor to the variation in animal to animal methane emissions and also to understand their potential role as modulator of responses to methanogen inhibitors and vaccines.

In the medium term, knowledge generated from this objective will be used by nutrition scientists, applied nutritionists, forage and crop breeders to develop feeds, feeding practices and forages that will result in reduced methane emissions from the process of feed digestion.

5.2 – Progress in 2015/16

Activities during this year included the presentation at the Greenhouse Gas and Animal Agriculture (GGAA) conference of our research on brassicas in general and forage rape in particular, as dietary strategies to mitigate methane (CH_4) emissions across ruminant species. Additional dissemination of the brassica research was the acceptance of a peer-reviewed manuscript in Animal Production Science summarising all the research conducted in New Zealand by our group on the effects of brassica crops on methane emissions.

A second stream of activity consisted in conducting the animal experiments to assess the potential of fodder beet (FB) as a low-GHG feed. FB is a crop of increasing importance as a feed for New Zealand ruminants. Besides its high DM yields per hectare, the carbohydrate and crude protein ratios in the FB bulb could be used to manipulate nutrient supply to ruminants to reduce methane (CH_4) and nitrogen (N) emissions.

We conducted two experiments in which FB was fed to sheep in mixtures with ryegrass-based pasture, and CH_4 emissions measured in respiration chambers. In a separate phase of each experiment, digestibility and N balances were determined. In both experiments, ryegrass pasture fed alone was used as a benchmark to compare the effects of including FB in the diet. Experiment 1 consisted of two periods. In period 1, FB was fed at 75% of the dry matter intake (DMI), and CH_4, digestibility and N balance were measured. In period 2, sheep were fed 90% of their DMI as FB. In Experiment 2, an indoor experiment with graded amounts of FB (0, 25, 50, 75 and 90% of the DMI) was conducted to assess the effect of FB on CH_4 emissions, digestibility and N balance across a wider range of inclusion levels.

Findings from both studies provided evidence that CH_4 emissions can be reduced when FB is fed at 75% or more of the DMI, but the magnitude of the response was variable for comparable treatments between experiments (75% and 90% FB in the diet). Yields of CH_4 per unit of DMI were similar between the 2 experiments for 75% FB groups (18.6 and 18.8 g/kg DM) but were twice as large in the 90% FB treatment in experiment 2 (7.7 vs. 16.4 g/kg DM for experiments 1 and 2, respectively). The occurrence of acidotic episodes in sheep during experiment 1, differences in intake levels for the 90% FB treatment between experiments and differences in pasture quality which we speculate could have impacted rumination and salivation in experiment 1 could, alone or in combination, help explain the differences observed between experiments.

Provision of FB in the diet was an effective way to reduce the total amount of N excreted in the urine. However, inclusion of FB at 90% of the DMI resulted in a negative N balance in Experiment 2. Provision of FB at 50% resulted in a better balance of protein and energy, leading to improved N retention and reduced N excretion compared to pasture alone. FB has potential to reduce both CH_4

and N excretion to the environment when fed to sheep, but attention needs to be given to ensure that nutrient supply from FB mixtures with pasture is sufficient and balanced to support animal productivity (Figure 1).

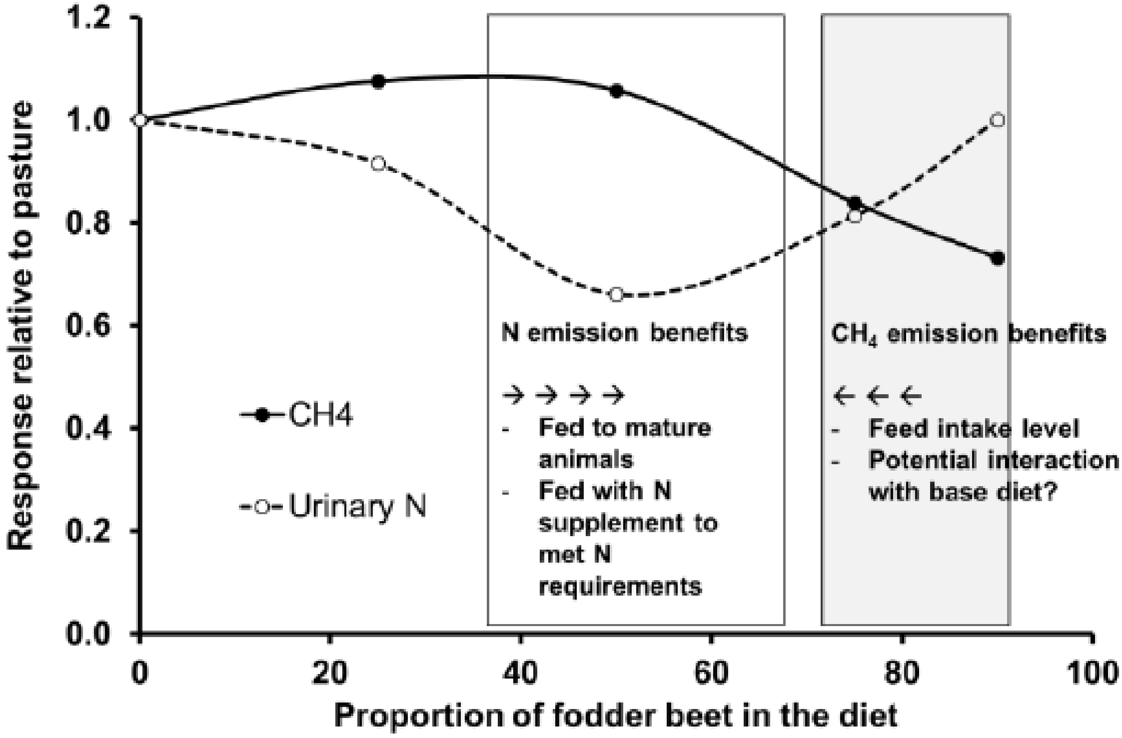


Figure 1. *Simplified representation of the responses in CH_4 emissions and urinary nitrogen excretion with graded inclusion of fodder beet in the diet. Responses are adjusted relative to the values measured from sheep fed ryegrass-based pasture (i.e., 0% fodder beet in the diet). Inclusion levels in which benefits in terms of emissions to the environment are captured are indicated by the white and grey boxes for N and CH_4, respectively. Overlapping these areas would result in benefits (mitigation) for both N and CH_4. Some factors that could move or expand the areas or response are indicated in the boxes under the arrows, which suggest the desirable direction of the movement/expansion of the boxes.*

Key achievements for 2015/16:

- Confirmed that feeding fodder beet at inclusion levels greater or equal to 75% of the dry matter intake result in repeatable reductions in CH_4 emissions.
- Presented a review of our research with brassica crops at the Greenhouse Gas and Animal Agriculture Conference.
- Published an international, peer-reviewed journal manuscript describing NZ research assessing brassica crops as a low GHG feed for ruminant livestock.

5.3 & 5.11 – Vaccine

Jointly supported programme

Objective Leader – Drs Neil Wedlock & Art Subharat (AgResearch)

The immediate goal of the vaccine programme is to produce a prototype vaccine which has shown efficacy in either sheep or cattle such as a change in methanogen communities in the rumen. Further development of the vaccine (by optimising antigens, adjuvants and delivery) will lead to a vaccine which is targeted at reducing methane emissions in sheep and cattle by at least 20%.

To achieve this, experimental vaccine formulations, consisting of new antigens selected by bioinformatics analysis of genomes from the most rumen-abundant methanogens, and formulated with current 'best' adjuvants will be administered to sheep. In each trial, animals will be monitored for their antibody responses to the methanogen antigens, anti-methanogen activity measured in in vitro assays and rumen microbial profiling undertaken to determine antibody induced changes in microbial populations in the rumen.

A vaccine will require both right antigens and correct adjuvants to be effective and produce positive outcomes.

Key questions that will be addressed in the programme and guide future plans are:

1. Do the serum antibodies produced against candidate vaccine antigens inhibit the target methanogens in pure culture?
2. Do the adjuvants increase salivary IgA, and ruminal IgA (and other classes of antibody) resulting in very high levels of antibody in the rumen?
3. Do any combinations of adjuvant and antigen change the ruminal methanogen community?
4. Does a vaccine consisting of suitable antigens and adjuvant result in a reduction of methane emissions from sheep by at least 20%?

Because of the structure of the process, if both the right antigen and the correct adjuvant are administered, positive results will be gained for points 1 to 3, and possibly 4. If the right adjuvant is combined with an ineffective antigen, increased IgA (or IgG) will be measured in the saliva and rumen (point 2), but there will be no impact on pure cultures (point 1) or on methanogens and methane production in the rumen (points 3 and 4). If an effective antigen is tested with an ineffective adjuvant, results from points 2 to 4 will be negative, but from point 1 will be positive. In each round of trials, we will formulate the 'best' antigens with the 'best' adjuvants and test those combinations, and also introduce new antigens or adjuvants.

Once we have obtained positive results in points 3 and/or 4, we will have the next 'proof-of-concept' step needed. Depending on the nature/magnitude of the change in the rumen methanogen community, we can then proceed to conduct larger vaccination trials in sheep and cattle with quantification of the reduction in methane emissions using respiratory chambers. This will be negotiated with the Funders, since it is likely to require reallocation of resources, and changes in milestones. This change will be done in conjunction with plans for commercialisation and developing a relationship with a commercial partner.

The intention is to develop candidate vaccine formulations to the point that PGgRc-NZAGRC can develop a relationship and engage with a commercial partner to develop a vaccine as soon as possible. The ultimate aim is to deliver a technology that can be used in New Zealand (and elsewhere) to reduce methane emissions from ruminants, without reducing production. The milestones are written as largely concurrent activities with end dates over two years. However, commercial engagement will occur as soon as a suitable formulation has been protected by patent with the research programme striving to achieve this in the shortest possible time. The objective will progress promising antigens through the pipeline, and gather such data as are necessary about them to facilitate commercial engagement. It is expected that successful engagement with a commercial partner, or specific requirements to facilitate this engagement, will also result in a reprioritisation of the objective or programme, to balance continued development toward additional vaccine formulations with continued development work on the successful formulation.

5.3 & 5.11 – Progress in 2015/16

During the past 12 months, good progress has been made towards identifying suitable antigenic targets (methanogen surface protein accessible for antibody binding) for an anti-methanogen vaccine. A list of prioritised targets to test has been produced and these targets are now been systematically tested in a series of sheep vaccine trials to assess their suitability for inclusion in a prototype vaccine.

Prioritising targets for a vaccine
A list of prioritised vaccine targets has been produced for testing in animal trials. A pipeline was developed that used available genome information from hydrogen-using ruminal methanogens in the genus *Methanobrevibacter* to identify candidate vaccine targets. This pipeline comprised three steps: (i) assessment of overall gene conservation in ruminal methanogens, (ii) identification of conserved cell surface proteins, and (iii) ranking of these proteins to identify the most promising targets. A total of 236 targets were identified that are conserved across ruminal *Methanobrevibacter* spp. and that featured extracellular protein domains. To identify the most relevant vaccine targets, a ranking system was developed for these 236 conserved targets. Scoring of the 236 ORFs was achieved by combining a series of independent parameters that contribute to the final score according to a consensus weighting algorithm. The outcome of this process was a scored and ranked list of candidate vaccine targets that can now be systematically assessed for their use in a vaccine.

A ranking algorithm was developed to identify and prioritise conserved genetic targets suitable for testing as vaccine candidates. This was used to rank the 385 possible vaccine targets for testing in animal vaccine trials.

Testing vaccine candidates in animal vaccine trials
Selected targets were tested in three new vaccine trials conducted in sheep. Bioinformatic input on the selected targets was provided. In these trials, a total of nine different targets were tested, either as recombinant proteins, peptides or in the case of several the targets in both forms. Each target was tested in a minimum of 3 sheep. Antisera was also produced against whole methanogen cells or crude fractions for use as controls.

From the results to date, two new vaccine candidates have shown promise and will be studied with additional bioinformatics and testing in vaccine trials. Antisera generated in three sheep against one of these inhibited growth and methane production in *in vitro* cultures of *M. ruminantium* M1, as well as causing other biological effects. This has provided proof that antibodies generated via vaccination with this antigen, produced as a recombinant protein, can recognise and bind to the 'native' protein on the surface of methanogens. Animals vaccinated with these antigens have also shown changes in rumen microbial populations, suggesting a vaccine-induced impact with these targets, but caution is urged here because these are results from only 3 sheep each. These antigens are being retested in more sheep to follow up that result.

In additional to the above two vaccine candidate, a third new vaccine candidate has been identified from the results of additional animal trials, and will be investigated further.

A table documenting progress on testing candidate antigens has been compiled.

A critical question that needed answering was whether lower antigen-specific titres of antibody would be produced in animals vaccinated with a mix of several different antigens. In our sheep vaccine trial, there were strong serum antibody responses to the individual antigens in animals vaccinated with a mixture of 4 different protein antigens. The serum antibody titres to two of these proteins in the animal vaccinated with the mix were between 2-fold and 6-fold lower than the corresponding antigen-specific titres observed in animals that were vaccinated with the corresponding single antigens. Thus for some antigens, lower antibody titres may be produced against the antigen if it is administered to animals in combination with other antigens. *From these results, we recommend to test new antigens singly* rather than in mixes (batches) to avoid the possibility of producing antibody responses that are insufficient to produce an effect in either *in vitro* assays or have an impact on rumen microbial populations. This will eliminate the possibility of 'false negatives' and overlooking good antigens for a vaccine. Note that this doesn't preclude a final vaccine having multiple antigens – in that case, all components will be effective ones.

Key achievements for 2015/16:

- A list of prioritised vaccine targets has been produced.
- Two sheep vaccine trials were conducted testing 9 different vaccine targets (produced as recombinant proteins and/or peptides).
- Two potential vaccine antigens have shown positive results in *in vitro* assays and potentially in sheep, and are being evaluated further. A third, new vaccine candidate has been identified.
- Antibodies against one of the antigens resulted in biological effects on the methanogen cells. A possible molecular mechanism for this antibody-induced effect has been identified which can explain this phenomenon. This result has provided further proof that antibodies generated against this target (produced as a recombinant protein) via vaccination can recognise and bind to the 'native' protein on the surface of methanogen cells.
- From a comparison of antibody responses to antigens given to animals as a mix or singly, it was concluded that it is best to test antigen candidates for a vaccine singly rather than as batches (combining 2 or more antigens in a mix).
- A paper was published showing that antigen-specific antibody levels in saliva and entering the rumen are theoretically sufficient to inhibit methanogens in the rumen. Identifying the correct antigens remains a major challenge,

5.4 - Identify inhibitors that reduce ruminant methane emissions

Jointly supported programme

Objective Leader – Dr Ron Ronimus (AgResearch)

The aim of this Objective is to develop cost-effective inhibitors that reduce methane emissions by at least 20% in sheep and cattle without reducing productivity. A number of hits and lead compounds have been identified to date, and this discovery process will be completed in 2015/16. The discovery process has used rumen methanogen enzyme assays, enzyme structures for *in silico* screening, AbM4 screening and rumen *in vitro* screening (miniaturised and standard methods). The most promising compounds will be further derivatised to enhance effectiveness and to provide data for patents. Promising hits, leads and/or their derivatives will be tested in short term sheep trials and if they possess desirable properties, such as leading to a reduction in methane of at least 20% with no adverse effects on the animals, will be further tested in longer term trials (≥14 day). The data from the animal trials will be used to engage a commercial partner (or partners) for the development of appropriate technologies for delivering the inhibitor and support for patenting.

The intention is to develop hit and lead compounds to the point that the PGgRc can develop a relationship and engage with a commercial partner to develop an inhibitor or set of inhibitors as soon as possible. The ultimate aim is to deliver a technology that can be used in New Zealand (and elsewhere) to reduce methane emissions from ruminants, without reducing production. The requirements for this engagement will be informed by regular meetings between the research providers and PGgRc inhibitor commercialisation experts working together as an Inhibitor Commercialisation Team (ICT).

The milestones are written as largely concurrent activities with end dates over two years. However, commercial engagement will occur as soon as a compound has been protected by patent with the research programme striving to achieve this in the shortest possible time. The objective will progress promising compounds through the pipeline, and gather such data as are necessary about them to facilitate commercial engagement. This may include demonstrating the effectiveness of multiple derivatives of the lead compound *in vitro*, the effectiveness of at least two variants (or derivatives) of any class at reducing methane emissions *in vivo* in sheep for 2 days, and of one compound (the "lead") in sheep for 14 to 16 days and in cattle for 2 days. An inhibitor (and its derivatives) that meets most or all of these criteria, to be decided on a case-by-case basis by the ICT, may form the basis for patent development and a commercialisation arrangement. It is expected that such a success will also result in a reprioritisation of the objective or programme, to balance continued discovery and development toward additional protected inhibitors with continued development work on the successful inhibitor.

It is understood that long-term production trials will be required (designed in coordination with the PGgRc-NZAGRC and a commercial partner(s)) and should be undertaken with the best inhibitors (the ones most likely to be used commercially) to examine potential gains in productivity and provide comprehensive data on residues. Registration will be required to use an inhibitor on-farm. This will involve extensive residue analyses conducted according to appropriate regulatory requirements which must utilise laboratories that have stringent quality control criteria in place. Development of a suitable delivery technology ready for commercial use will require a partnership with a suitable commercial company. For the avoidance of doubt, if long-term production trials, registration work or delivery technology research is required, this will be contracted separately at a later date.

5.4 – Progress in 2015/16

In the previous year we used a number of methods to screen compound libraries and discover numerous initial hit compounds with inhibitory activity. These methods included: methanogen enzyme structures for computer-based screening; direct enzyme assays; pure cultures of rumen methanogens; and rumen fluid-based assays (both a small-scale assay system in 96-well plates and a larger volume method). The enzyme-based screening assays target specific methanogen enzymes while the methanogen pure culture and rumen fluid methods simultaneously target all the methanogen genes present (circa 300-500 genes). These methods are complementary to each other and represent a powerful suite of screening methods. Overall, tens of thousands of compounds were screened against enzymes and pure cultures, and thousands using rumen fluid-based methods.

In many instances, the hits that were potentially identified in the above screens required reconfirmation of their activities either through duplication of the original tests or testing in other assays. In this year, we have retested the previous year's hits, mostly in the rumen fluid-based assay systems, and also checked numerous derivatives of the most promising hit compounds. This required approximately 2,000 rumen fluid-based assays. The most promising of the hit compounds, or their derivatives, have been assessed in seven short and/or mid-term animal trials. The results from some of these were highlighted, and the overall programme summarised, in invited talks at the Greenhouse Gas and Animal Agriculture Conference in Melbourne in February 2016. The current results suggest that high levels of methane emission mitigation can be obtained using small molecule inhibitors in an animal-safe manner, which is very encouraging, and indicates the potential for mitigating methane emissions both in New Zealand, and globally.

Key achievements for 2015/16:

- Seven animal trials were conducted this year which tested the effects of 9 different compounds to reduce methane emissions. These were conducted in either short-term sheep trials (2 days), 16 day sheep trials, or a short-term trial in cattle, and 8 resulted in methane inhibition that warrants further development.
- Thousands of compounds have been screened this year in rumen fluid-based assays. A large number of active compounds have either been identified or reconfirmed. Numerous dose-response curve assays were also performed to find the range of concentrations at which the compounds were active.
- An article was published in the Journal of Biological Chemistry on the archaeal lipid synthesis enzyme that is key for biosynthesis of rumen methanogen lipids. This is the first enzyme structure for this enzyme, despite its unique activity being recognised nearly 40 years ago.
- A review on the use of gene- and enzyme-based inhibitors of rumen methanogens was published in the Journal of Animal Sciences associated with the premier greenhouse gas conference, the Greenhouse Gas and Animal Agriculture (GGAA) conference, in Melbourne in February.
- Two invited oral presentations were also given at the above GGAA conference, including a Key Note speaker presentation.

5.8 - Modelling rumen methane production

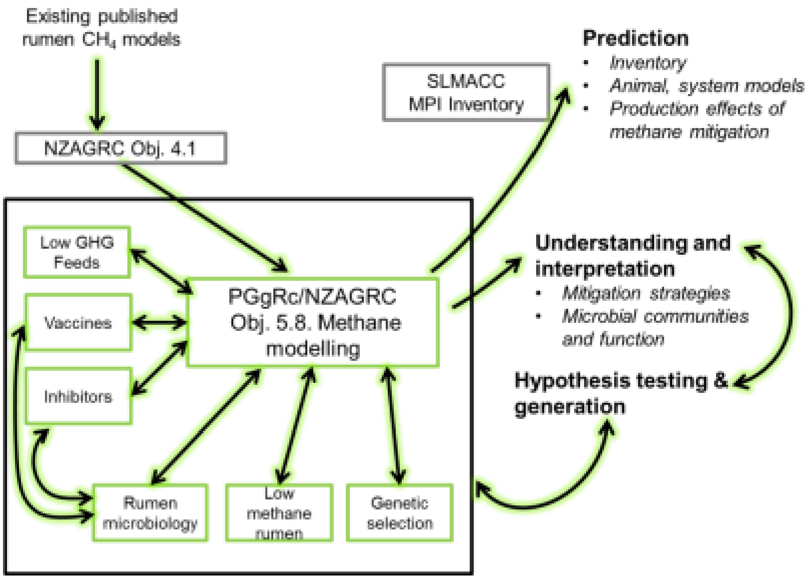
Jointly supported programme

Objective Leader – Dr David Pacheco (AgResearch)

The development and evaluation of methane mitigation strategies requires a mechanistic understanding of the processes influencing methane formation in the rumen. Work in this objective seeks to improve our ability to predict responses in methane formation from NZ ruminants.

The outcomes from this project will be used by scientists in the NZAGRC/PGgRc programme as a tool to develop hypotheses regarding methanogens growth and activity in the rumen in response to current and future intervention such as feeding practices, inhibitors and vaccines. In the medium term, a predictive model of methanogenesis will be available for the wider scientific community for incorporation into whole animal models, which in turn will be able to generate knowledge on methane production and animal productivity. Ultimately, such models will be used to improve inventories and tools for monitoring the effects of mitigation options on farm practices.

The methane modelling objective will serve as an integration point for knowledge related to the development of methane mitigation strategies. This objective builds on previous work conducted as part of the "Integrated Systems" programme of the NZAGRC (Objective 4.1). The relationships between this objective and the rest of the NZ programme on methane accounting and mitigation are presented in the diagram below. The integrative role of the methane modelling project will be formalised in the form of six-monthly meetings with other objective leaders within the programme, to discuss advances in the modelling capabilities, with the purpose of defining simulations to validate the model with empirical findings. Also, as the model progresses, it is expected that simulations will the conducted to test likely outcomes of empirical research, leading to improved design and power of experiments.



5.8 – Progress in 2015/16

Work this year has largely focused on James Wang writing his PhD thesis.

Despite the slow progress, the PhD programme is exploring some new ground in mathematical modelling of methane production in the rumen. This new ground is embodied by the latest (and last) chapter to be written by the PhD candidate.

This key chapter integrates all the concepts developed during this PhD. These are: modelling of hydrogen concentrations and methanogen growth dynamics (published as Wang et al. 2016: J Theor Biol 393: 75-81), development of a term to represent thermodynamic feedback from reactions occurring in the rumen and finally linking this thermodynamic feedback to bacterial metabolism leading to formation not only of hydrogen, but also important products such as volatile fatty acids and microbial cells.

Additional outputs from this project include a poster presentation at the 2016 Greenhouse Gas and Animal Agriculture conference (GGAA) in Melbourne. The poster described the evaluation of the sheep's rumen model (MollyRum14) developed as part of this objective last year using an independent dataset of methane emissions from forage-fed sheep. Overall, the error in prediction was mostly random (i.e., no systematic bias), with only a slight slope bias for methane production (15% of the observed mean). The predictions were good for methane production (g/d: concordance coefficient of 0.79) and moderate for yield (g/kg DMI: concordance coefficient of 0.66). Despite the fact that the MollyRum14 model was originally parameterised using ryegrass diets, the independent evaluation demonstrated that the model predictions are adequate for a variety of forages. Although the predictions from MollyRum14 seem appropriate enough to explore other forages and feeding scenarios to mitigate methane from sheep, a need to improve its predictions for VFA profiles was identified.

In the future, and outside this programme, linking the advancement in modelling of fermentation developed as part of Mr Wang's thesis, together with rumen models such as Molly, will provide an important tool to understand the implications of enteric methane mitigation on animal productivity.

Key achievements for 2015/16:

- Publishing the model of the dynamics of the interaction of hydrogen concentration and methanogen growth, developed as part of James Wang's PhD project, in the Journal of Theoretical Biology.
- Presenting at the GGAA conference the evaluation of the MollyRum14 model (a model of a sheep rumen), which is evidence that the model re-parameterisation is able to predict methane production across a range of fresh forages.
- The incorporation of the rumen model MollyRum14 (Vetharaniam et al. 2015. Journal of Animal Science 93: 3551-3563) into the AusFarm model as part of the project "Impacts of Carbon Farming Initiatives on whole farm systems". This project was an Australian-led project that also involved US and NZ researchers, and was funded as part of the "Filling the Research Gap" fund. The inclusion of the model provides evidence of the strong international linkages developed over the life of the PGgRc/NZAGRC project. It also provides evidence about the benefits of international collaborations to progress on the development of predictive models to assess methane mitigation options.

5.9 - Dairy Housing Methane Capture and Mitigation by soil - a feasibility study

Objective Leader – Dr Surinder Saggar (Landcare Research)

Landcare Research Manaaki Whenua

The aim of this study is to test the practicality of capturing methane (CH_4) emitted by housed cattle and their waste and mitigating by injecting it in the soil for oxidation by methanotrophs.

Research conducted by Landcare Research since 1995 has demonstrated that soils containing active methanotrophs (CH_4-eating bacteria) and exposed to CH_4 can remove these emissions. Our research over the past decade showed that a biofilter made from a suitable soil containing a very active population of methanotrophs could potentially remove almost all of the high CH_4 emissions produced from an average dairy farm waste pond. Thus, soil containing active methanotrophs could also potentially capture and mitigate enteric and waste CH_4 from dairy housing. As methanotrophs are strict aerobes, efficient oxidation of CH_4 requires a well aerated soil environment. This would be hard to achieve in some poorly drained heavier soils, especially in winter when cows are usually housed. Thus the proposed research aims to assess the capacity of soil, or artificial material mixed with soil, to mitigate the low concentrations of CH_4 produced in dairy housing. This will be achieved by injecting the CH_4-rich air into the soil for oxidation by methanotrophs, and then measuring the potential mitigation by these bacteria, and the influence of changes in soil moisture and aeration conditions. To ensure that the "dairy shed air" is representative of the air in a dairy house, a suitable level of ammonia will be included in the enriched air.

5.9 – Progress in 2015/16

We analysed methane concentration data, collected between October and December 2015, from the chambers, from near the inlet pipes, sides of the raised-beds. These data indicated the lateral and downward dissipation of methane and/or its release from the sides of raised-beds. Therefore, methane uptake in the raised-beds was determined from the inlet methane concentration fed to the raised-beds and output equilibrium methane concentration measured in the chambers above the raised-beds.

When we connected the ammonia supply, the faulty ammonia Mass Flow controllers malfunctioned, ammonia supply was disconnected and the UK suppliers were approached for replacement of faulty mass flow controllers.

Subsequently, during the Christmas-New Year break a gas leak in the circulation system resulted in methane loss within the shed and this methane containing air from the shed circulated to both the treatment and the control plots. The feeding of methane was stopped to all the plots and only air was circulated for a few weeks to clear the methane from the control plots and resolve these technical problems.

Thus we have had limited data available after 6-week of methane feeding. These data indicated that the methane which flows through the soil beds is currently not being oxidised. Results of a laboratory experiment using soil columns conducted for 5-weeks and batch experiment on priming the raised-bed soil further complemented that this soil has not yet attained the methane oxidation capacity required to remove the methane being fed. Moreover, from these results it is not possible to determine the time required by the methanotrophs in this soil to reach optimum oxidation efficiency.

We subjected the raised bed soil to feeding methane at high concentration (3600 ppm) in a batch experiment. This soil was removing more than 95% of methane within 8 weeks of feeding indicating that – higher concentrations activated the activity of methanotrophs in the pasture soil.

Further batch experiments studies are required to establish the threshold methane levels for priming methane oxidation in pasture soils contrasting in soil organic matter and soil microbial biomass and these threshold methane priming levels be confirmed in soil column studies.

The project is extended till 30 June 2017, to conduct batch, column studies and to adequately prime the raised-bed soil and build up an active methanotroph population for oxidation of methane at low level of methane feeding and assess the impact of changes in soil moisture.

Key achievements for 2015/16:

- Feeding methane at low concentrations (<120 ppm) for the short-period does not achieve the methanotroph activity to enhance methane oxidation efficiency.
- Feeding methane at high concentration (3600 ppm) in a batch experiment for 8 weeks removed more than 95% of methane from the pasture soil.

5.12 - Validation of a rapid, low cost measurement system for measuring methane

Jointly supported programme

Objective Leader – Dr John Roche (DairyNZ)

Greenhouse gases from agricultural activities account for approximately half of New Zealand's anthropogenic contribution. There is, therefore, considerable interest in ways to reduce emissions from this source. Genetic selection of lower emission ruminant livestock is proposed as one potential avenue. Recent reports have estimated a heritability for methane production of 13% (g methane/kg dry matter intake) and 29% (g methane/day; Cesar-Pinares et al., 2013). However, ways of measuring methane and dry matter intake rapidly have been unavailable, making the task of evaluating breeding stock for methane emissions impractical.

In 2015/16, we commissioned the build of seven units that would measure methane and feed disappearance (intake) for individual cows in real-time. These units were tested in December 2015 and the results presented in a final report in March 2016. Methane results were similar to those published previously (22.1 g methane/kg DM intake) and the experiment provided valuable information on the required number of visitations/animal, required number of animals, and the required trial duration to have confidence in the results. Nevertheless, the equipment has, as yet, not been validated against the 'gold standard' Respiratory Chambers.

This Objective will validate the equipment against respiratory chambers using 30 one year old heifers. This is the number of animals recommended by our statistician following analysis of the previously collated experimental data.

The outcome will be confidence that the developed equipment provides accurate and repeatable measures of daily methane output and methane/kg DMI and, thereby, facilitate the inclusion of methane as a genetic trait for selection should the industry deem it a priority.

Presuming the validation concludes that the equipment provides a robust measure of methane output, the system could be adapted and applied to the sheep, beef, and deer industries.

In addition to the genetic selection objectives, the ability to rapidly screen large numbers of animals could provide an opportunity:

- to identify the causes of variation between individuals and enable even greater selection for reduction in agricultural greenhouse gases through a better knowledge of the phenotype
- to screen large numbers of methane mitigation options *in vivo*, accelerating the development of technology that could underpin a reduction in agricultural greenhouse gas emissions.

5.12 – Progress in 2015/16

Trials commenced during June 2016 and measurements are underway.

6.1 – Plant Effects on N_2O Emissions

Objective Leaders – Drs Saman Bowatte & Paul Newton (AgResearch)

It is well established that nitrification rates in soil are strongly influenced by the presence of plants and can differ markedly depending on the plant species. Plants can influence nitrification in soils by a variety of mechanisms: (a) they may secrete inhibitory compounds known as biological nitrification inhibitors (BNI compounds) that directly influence nitrifying organisms, (b) they may compete strongly for nitrogen and thus reduce the substrate for soil nitrifiers, and (c) they may alter the identity of the microbial community and/or microbial activity by altering the soil environment e.g. soil pH and moisture content.

Our previous work has found differences in nitrification between species, between cultivars and between endophyte-grass combinations. This programme will test whether differences apparent in these initial experiments are evident in a field situation, and if so, whether the effect is quantitatively important and whether there are trade-offs (e.g. in forage production) that might reduce the desirability of a low emitting species as a mitigation option. Our broad screening approach will also complement industry testing of alternative pasture species by providing valuable information on the most suitable material for testing in grazing trials.

6.1 – Progress in 2015/16

Having demonstrated that plant species can influence N_2O emissions we moved this year to do an experiment that would help identify why these differences occur. We measured N_2O emissions from plots of ryegrass, white clover, plantain and a pasture mixture and simultaneously measured soil pH, soil moisture, plant growth, potential nitrification and soil nitrogen pools and fluxes. These data are now being analysed with the expectation that we will have a better understanding of how plants alter N_2O emissions and thus be in a strong position to manipulate plants for mitigation purposes.

Data from the previous year was analysed and written up as a journal paper. We tested whether plant species identity influenced emissions of nitrous oxide (N_2O) in response to the addition of urine at a rate of 530 kg N ha^{-1}. The plants tested are all used in temperate pastoral agriculture and comprised 11 C_3 grasses, 3 forbs and 2 legumes with controls of bare ground and a standard ryegrass/white clover mixture used in the region. Total N_2O emitted over 6 weeks after urine application was highest in the bare ground. Plant identity was important with emissions ranging from an average of 0.67 kg N_2O-N ha^{-1} for the Italian ryegrass Grasslands Moata (*Lolium multiflorum*) to 3.20 kg N_2O-N ha^{-1} for the upland brome Grasslands Gala (*Bromus stamineus*). The 4 perennial ryegrass (*Lolium perenne*) cultivars had generally low emissions (average of 1.02 kg N_2O-N ha^{-1}) and the white clover (*Trifolium repens*) cultivars high emissions (average of 2.86 kg N_2O-N ha^{-1}).

The N_2O emitted was negatively related to plant biomass. However, the greater proportion of emissions (range of 49-78%) occurred in the first two weeks after urine was applied when nitrogen (N) was in excess of plant demand. We suggest that plant biomass may be related to some factor – such as microbial community size and activity – that influences rates of immobilization and mineralization of the urine N as there were significant differences in the soil mineral N pool among species 7 days after urine was applied.

Key achievements for 2015/16:

- Manuscript produced demonstrating that there are significant differences in N_2O emissions associated with different plant species.
- A field experiment was completed where potential explanatory variables (soil pH, soil moisture, plant growth, potential nitrification, soil nitrogen pools and fluxes) were measured

in order to explain differences in N_2O emissions associated with a grass, legume, forb and pasture mixture.

6.2 – Denitrification Processes (Wrap-up of previous Objective 2.3)

Objective Leader – Dr Surinder Saggar (Landcare Research)

Denitrification is the primary process of N_2O production in New Zealand pasture soils. However, we lack a comprehensive, quantitative understanding of denitrification rates and controlling factors across agrosystems. Denitrification is a facultative anaerobic microbial process producing nitric oxide, nitrous oxide and N_2 from nitrate and nitrite. Abiotic denitrification can occur under some conditions. Understanding those mechanisms (microorganisms; biotic processes and mineral oxide; abiotic processes) and soil & environmental factors that have the potential to reduce the production of N_2O during denitrification is vital to the development of new and effective N_2O mitigation technologies.

This objective will wrap up the previous NZAGRC Objective 2.3 which focussed on testing and improving the latest microbiological techniques to identify pathways to reducing N_2O production during denitrification and develop mitigation technologies that reduce N_2O emissions by lowering N_2O/N_2 ratio during denitrification, including in areas where denitrification is maximised to reduce nitrate leaching losses (e.g. riparian buffer zones). Mitigation option of liming for modifying denitrifier community structure, accelerating complete denitrification and mitigating N_2O emissions from urine is evaluated.

6.2 – Progress in 2015/16

Laboratory studies to determine efficacy of lime at low, medium and high temperature for modifying denitrifier community structure, accelerating complete denitrification and reducing N_2O emissions in allophanic and no-allophanic soils treated with and without urine and DCD were completed during Q4 of 2014-15. This also included analyses of soil and gas samples and qPCR of half of the samples extracted DNA. The qPCR of remaining DNA extracts, data collation and processing to write up this work was delayed due to the researcher Neha Jha being on maternity leave. The Contract was varied to extend the end date for this contract to 31 December 2015.

The key findings of this study suggest that application of lime and incubation of soils at saturated water condition increased denitrifier gene abundance, N_2O production, and denitrification rate in limed soil as compared to no lime applied soils. The extent of increase in denitrification with liming was variable in soils and higher in fluvial soil (22% increases) than the allophanic soil (19% increase). Addition of urine increased N_2O production and denitrification in soils, and the increases was higher in the limed soils than the no lime soils. Addition of DCD with urine reduced N_2O production and denitrification. Reduction in denitrification with DCD addition was more in limed soil than the no lime soil.

There was no effect of urine and urine + DCD amendment on denitrifier gene abundance in two soils (either limed or un-limed). Although no direct measurements for N_2O and dinitrogen (N_2) production were made in incubated soils there was higher N_2O production in the acetylene treated incubation jars than in non-acetylene incubation jars. This difference in N_2O production implied reduction of N_2O to N_2, which was higher with liming than no lime.

The results suggest that liming-induced increases in pH enhanced denitrification and also probably reduce N_2O to N_2 in soils. Thus liming could be considered as a mitigation option to reduce N_2O production from grazed pasture soils. Further laboratory incubations and field trials with lime application and direct measure of N_2O and N_2 production are needed to support our findings from this study.

A manuscript written based on the results of the study submitted to Soil Biology and Biochemistry Journal and an abstract submitted for presentation at the Massey University Fertiliser & Lime Research Centre 29th Annual Workshop 9-11 Feb, 2015.

6.3 – Feed management options for mitigating N_2O emissions from grazed systems

Objective Leader – Dr Cecile de Klein (AgResearch)

Animal urine patches are the key source of N_2O emissions from grazed systems and the amount of urinary N excreted is largely determined by plant and dietary N content. A key issue is that in New Zealand pasture-based systems, animals consume more N than they need for growth and production, and hence surplus N is excreted and contributes to N_2O emissions.

Key research questions are whether feed management options can (a) reduce N urinary output, and (b) reduce the N_2O produced per unit N excreted?

Forage species (pasture species and forage crops) differ in N content and some of them (e.g. tannin containing plants) can also influence how N is partitioned between dung and urine. Furthermore, there is evidence that plant species can affect N_2O emissions through their impact on N cycling and on soil microbial processes e.g. increased N use efficiency and/or biological nitrification inhibition. Finally, plant chemical composition may influence the chemical composition of the urine which in turn may influence the amount of N_2O released from a urine patch.

6.3 – Progress in 2015/16

The work conducted in this objective has demonstrated the potential of feed management options and plant species to reduce N_2O emissions from urine patches. Monoculture trials have shown that plantain and lucerne had c. 35-70% lower emissions than perennial or Italian ryegrass and white clover, when using urine collected from cows grazing standard ryegrass/white clover pasture. Field trails with mixed pasture swards also suggested lower N_2O emissions, but this was due to the anticipated lower N concentration in the urine, rather than a plant effect.

Trials that used the urine collected from cows on the different species being investigated have shown that N_2O emissions from urine patches on Italian ryegrass/plantain pasture were similar to those on perennial ryegrass/white clover pasture, despite the fact that the urine from the IR/plantain mix had a lower N content than the PR/WC urine. Trials conducted with winter forage crops and using crop-specific urine, showed that, at the same rate of urine-N returned, N_2O emissions from fodder beet were about 40% lower than from a kale crop.

Lab and field trials have also been conducted to examine the effect of diet-induced urine composition on N_2O emissions. A comprehensive lab study using glycosinolate hydrolysis products that can be found in brassica crops, has shown that some compounds can reduce nitrification and lower N_2O emissions. A lab study using aucubin, a key compound in plantain, showed that aucubin could also lower N_2O emissions. However, a field trial using different purine-derived N compounds in urine, such as hypoxantine and allantoin, has shown that these compounds do not affect N_2O emissions.

Key achievements for 2015/16:

- Gardiner CA, Clough TJ, Cameron KC, Di HJ, Edwards GR and de Klein CAM (2016) The potential for forage diet manipulation in New Zealand pasture ecosystems to mitigate ruminant urine derived N_2O emissions: a review. New Zealand Journal of Agricultural Research
- Di, H.J., Cameron, K.C., Podolyan, A., Edwards, G., de Klein, C.A.M., Dynes, R. and Woods, R. (2016). The potential of using alternative pastures, forage crops and gibberellic acid to

mitigate nitrous oxide emissions. *Journal of Soils and Sediments*. DOI 10.1007/s11368-016-1442-1.

- Balvert S, Luo J, Schipper L and de Klein CAM. Naturally occurring compounds in animal urine that may inhibit nitrous oxide emissions from soils. Poster presented at the 6th GGAA conference, 14-18 February 2016, Melbourne, Australia.
- A range of field and lab trials completed to examine the effect of plants/forages on N_2O emissions, either through a direct plant effect, through the effect of the diet on urinary N output or urine composition, or through a combination of both.
- A data-base has been compiled to summarise the results of all trials on effects of plants/forages on N_2O emissions

6.4.1 – Effects of 'Italian Ryegrass plus Plantain' versus 'Perennial ryegrass' on N_2O emission factor for urine

Objective Leader – Prof Hong Di (Lincoln University)

In collaboration with the MBIE funded 'Forages for Reduced Nitrate Leaching (FRNL)' research programme, determine N_2O emission factors from animal urine (EF_3) applied to 'Italian Ryegrass plus Plantain' vs 'Perennial ryegrass' pastures using urine collected from cows grazing on the Italian/Plantain plots as well as cows on the P Ryegrass plots (i.e. urine inputs of 0, rate as collected from different pasture mixes, and standard urine at 700 kg N/ha). Thus 2 pasture mixes x 3 urine rates x 5 reps gives a total of 30 lysimeter gas chambers.

6.4.1 – Progress in 2015/16

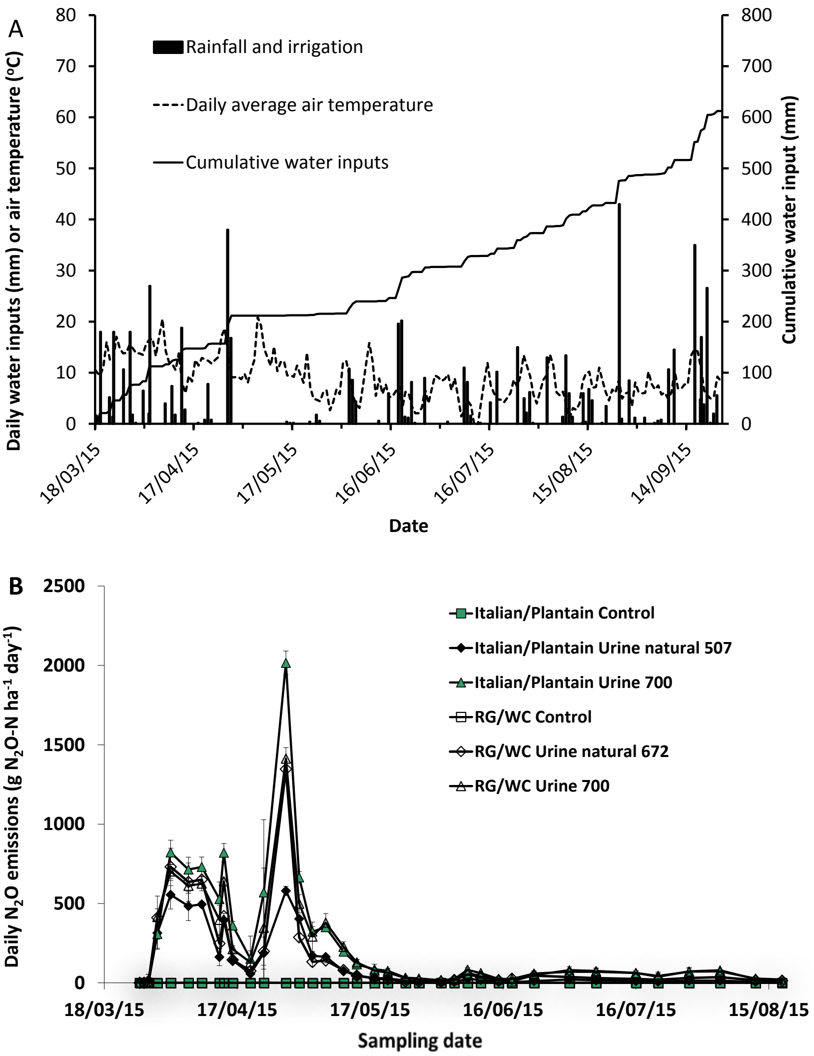
The aim of this experiment was to assess if including a winter active Italian ryegrass together with plantain in a mixed pasture would reduce N_2O emissions compared with standard ryegrass/white (RG/WC) clover pasture. It has previously been shown that NO_3^- leaching from an Italian ryegrass pasture was lower than that from the standard RG/WC pasture because the Italian ryegrass was actively growing and therefore taking up N from the soil during the cold winter leaching period in New Zealand. In this experiment, urine-N was applied at 0 and 700 kg N ha^{-1} (standard), and another rate dictated by the urine N concentration collected from the dairy cows grazing the two different pastures. These rates were 507 kg N ha^{-1} for the Italian/plantain mixed pasture and 672 kg N ha^{-1} for the RG/WC pasture. A standard 2 L volume of urine was applied in each urine treatment. These treatments were applied to the lysimeters with the correct pastures in a randomised block design. During March, irrigation was applied following local farming practice. From April onwards until the finish of the experiment, supplementary irrigation was applied, if necessary, to provide a standard water input of the 75th percentile of local winter rainfall records. The experiment started on the 26th March 2015 and finished on the 18th August 2015.

During March and April 2015, there were substantial rainfall and irrigation inputs to the lysimeters, and this was then followed by a relatively dry period in May (Fig. 1A). Substantial rainfall inputs resumed during the June to September period. Cumulative water input reached 428 mm during the experimental period. Average air temperature during the period varied from a high of 20.5^oC in April to a low of -0.4^oC in July.

Daily N_2O emissions were very high in the urine treatments (Fig. 1B), peaking on the 28th of April. The peak emissions varied between 579.7 g N_2O-N ha^{-1} day^{-1} in the Italian/plantain natural 507 treatment (urine as collected from the cows grazing this pasture) to 2016.3 g N_2O-N ha^{-1} day^{-1} in the Italian/plantain 700 treatment (using standard urine). The daily emissions then declined sharply reaching background levels.

Total N_2O emissions from the Italian ryegrass/plantain pasture with natural urine from cows grazing this pasture applied at 507 kg N/ha (as measured) were 47% lower than that in the ryegrass/white clover pasture with standard urine applied at 700 kg N/ha (*P* < 0.05) (Fig 1C). The emission factor (EF_3) for the urine in the Italian/plantain pasture was 2.91% and this was 39% lower than the 4.74% for the standard urine with the ryegrass/white clover pasture. However, there was no significant difference in the total N_2O emissions between the two pasture types when urine was applied at the standard 700 kg N ha^{-1}. Total N_2O emissions and the emission factor in the Italian/plantain natural urine were lower than those in the ryegrass/white clover natural urine treatments, although these differences were not statistically significant (P > 0.05). These results indicate that diverse pastures including Italian/plantain species may lead to lower N_2O emissions compared with the standard ryegrass/white clover pastures mainly because of the lower urinary-N deposition rate. However, a systems analysis is required to include greenhouse gas emissions from the renewal of annual grasses (e.g. Italian ryegrass) is required to take into account emissions from different components of the production system.

The emission factors of 2.91 to 4.74 from this trial were considerably higher than the EF_3 value used in the New Zealand Inventory calculations (1%). This was mainly due to the wet and warm conditions following urine application in this trial which would have been conducive for higher N_2O emissions.



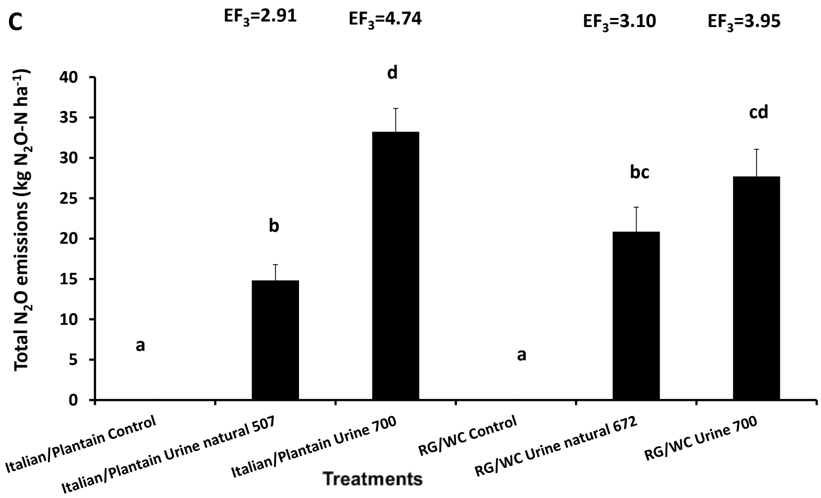


Fig. 1. A: Daily average air temperatures, water inputs and cumulative water inputs; B: Daily and C: total N_2O emissions from different pastures with and without standardised animal urine or actual urine collected. Treatments with the same letter labels above the bars are not significantly different.

6.4.2 – Effect of diverse pasture on the N_2O emission factor for urine

Objective Leader – Dr Jiafa Luo (AgResearch)

In collaboration with the NZAGRC soil C programme on Troughton farm in the Waikato, compare the N_2O emission factor (EF_3) for animal urine applied to diverse pasture with that for animal urine applied to conventional ryegrass/white clover pasture.

N_2O emissions will be measured following application of synthetic urine at 500 and 700 kg N /ha (to mimic expected urine N concentrations of diverse and conventional pasture, respectively) to both diverse and conventional pasture plots at Troughton farm. A non-urine control treatment will also be included to allow emission factors to be calculated. Measurements will continue for 4 months to allow the full emission envelop to be captured.

Soil mineral N and soil moisture contents will also be measured to provide additional information on explanations of any differences in EF_3 found.

6.4.2 – Progress in 2015/16

A New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) programme is testing the potential for management practices to affect the rates of input, incorporation and stabilisation of carbon (C) in soils on the Troughton farm in the Waikato. This programme includes a study comparing conventional ryegrass/clover and diverse pasture consisting of grasses, legumes and herbs with more and deeper roots than the conventional sward. A trial was established within adjacent areas of these two pasture types to measure nitrous oxide (N_2O) emissions and emission factors for urine (EF_3, percentage of applied N emitted as N_2O).

Sampling of the gas was carried out using an established static chamber method. Chambers were placed in a diverse pasture paddock and in three strips of conventional ryegrass/clover within the paddock. In May 2015, urine at two different nitrogen (N) concentrations (0.5% and 0.7%) was applied to the chambers at a rate of 10 L m^{-2} to give application rates of 500 and 700 kg ha^{-1}. Gas sampling took place once two days before treatment application, and then over the following 4 months. Samples were also taken from control chambers that received no urine. Plots were set up in areas adjacent to the chambers and synthetic urine was applied at the same time at a rate of 700 kg N ha^{-1} to enable monitoring of soil mineral N concentrations during the trial.

Although there was a trend for emissions to be lower from the diverse pasture, results showed no statistically significant difference between the total N_2O emissions from the diverse pasture and those from the conventional ryegrass/clover. Similarly, there was no statistically significant difference in EF_3 values (Table A). There was no significant difference in soil mineral N concentrations between the diverse pasture and the ryegrass/clover pasture.

Table A. Urine N_2O emission factors (EF_3) for ryegrass/clover pasture and diverse pasture after application of urine at N rates of 500 and 700 kg N ha^{-1}.

	500 N		**700 N**	
Emission factors (EF_3)	**(%)**	**SEM**	**(%)**	**SEM**
Ryegrass/clover	0.18	0.03	0.18	0.03
Diverse	0.16	0.02	0.13	0.02

The diverse pasture in this study contains a mixture of species. A concurrent NZAGRC trial in the Waikato has shown a much lower EF_3 value from a plantain monoculture than from a clover monoculture or a ryegrass monoculture, therefore further research is required to determine the effects of diverse pasture with varying amounts of these species on EF_3.

6.4.3 – N_2O emission factor for dairy farm effluent (FDE) applied to pasture

Objective Leader – Dr Tony van der Weerden (AgResearch)

To enable a more robust assessment of the effect of housing systems on N_2O emissions, determine whether the emission factor for FDE applied to pasture (EF_1) differs from the emission factor for urine deposited onto pasture (EF_3).

N_2O emission measurements will be conducted following FDE application at 50 kg N/ha and real cow urine application at 700 kg N/ha to pasture field plots at c 70% water filled pore space (WFPS) in autumn. A non-FDE/non-urine control treatment will also be included to allow emission factors to be calculated. Measurements will continue for 4 months to allow the full emission envelop to be captured.

In addition, the effect of soil moisture content (to mimic a 'timing of application effect') on the N_2O emission factor will be determined following FDE application in autumn to pasture field plots at an additional three soil moisture contents (c. 40, 60 and 80% WFPS). Measurements will continue for 4 months to allow the full emission envelop to be captured.

6.4.3 – Progress in 2015/16

The objectives of the study were:

1. to determine if farm dairy effluent (FDE) has a significantly different nitrous oxide emission factor (EF_1) to that for dairy cattle urine (EF_3), and
2. to determine if FDE EF_1 is influenced by the soil water content at the time of application.

FDE and urine were applied at typical application rates of 70 and 570 kg N ha^{-1}, respectively, to a series of plots with differing initial soil water contents. Nitrous oxide emissions were measured for four months, after which emission factors (FDE EF_1 and urine EF_3) were calculated.

Results from this study showed the following:-

1. EF_1 value for FDE was 0.01%, which was significantly lower ($P < 0.05$) than the dairy cattle urine EF_3 value of 0.27%.
2. FDE EF_1 was not affected by the soil volumetric water content, ranging from 23.5 to 43.7% at the time of application, and FDE EF_1.

These results are based on the application of FDE and urine to a moderately well drained soil. Therefore, we recommend this study is repeated on a poorly drained soil, where N_2O emissions tend to be greater due to higher soil water content being maintained for longer periods, to ensure the current findings are applicable to contrasting soil types. We also recommend a follow-up study should include a dung treatment, as FDE is a mixture of urine and dung, and that measurements are made over a 12 month period to account for N_2O emissions that may occur following mineralisation of the dung and FDE organic N fraction.

6.5 – Spikey® 2 Optimisation

Objective Leaders – Geoff Bates and Bert Quin (Pastoral Robotics Ltd)

The prototype urine patch detector, known as Spikey®, developed by Pastoral Robotics Limited (PRL) has been found to be able detect urine patches immediately after a grazing event and before any visible grass growth response. The ability of Spikey® to provide early detection of urine patches enables the urine to be treated with the urease inhibitor nbpt. This keeps the urine-urea in this form for several days, allowing the urea to spread laterally, increasing the effective size of the urine patch by an average of 70%, and increasing urine-N recovery by the same percentage. As a direct consequence, pasture production is increased, and nitrate leaching and nitrous oxide emission are both considerably reduced (48% and 30% respectively). Both gibberellic acid (GA3) and the mineralisable C source AlpHa® can be added where beneficial, and even DCD could be added should it receive Codex registration eventually. Chemical costs are very low because only the fresh urine patches are treated.

Just as importantly, the technology provides the farm-profitable platform that will allow a wide range of other tasks to be undertaken that are have not previously been viable in pastoral agriculture. These include automatic highly accurate determination of grazing residuals and spot-treatment of weeds.

To optimise on-farm performance of Spikey® over a wide range of field conditions, some features (both hardware and software) of this innovative tool have been redesigned on paper and its planned commercial width increased to 8 meters. These changes are intended to both further enhance its ability to detect changes in soil properties resulting from urine deposition after a grazing event, and reduce the daily detection and treatment time to less than 30 minutes, *plus* allow prilled urea to be applied at the same time.

In addition to the increased width and ability to apply urea, the new Spikey® version, known as Spikey® 2, has been designed to include:

- new electrode suspension system featuring fully independent electrodes, damping and a much greater overall mass that can be balanced between dolly wheels and electrodes if this proves necessary.
- an increase (100%) in electrode sense voltage to reduce the effect of contact resistance relative to soil conductivity.
- the measurement of soil/electrode capacitance data to provide information that will permit optimum circuit design.

This Spikey 2 needs to be constructed, tested, analysed and optimised across a suitable range of soil types. First, its robustness will be proven on a farm near Auckland for convenience. The next step will be to measure the effectiveness of the design on two very different soil types, under a wide range of soil moisture conditions, in areas that are known to be conducive to both nitrate leaching and GHG emissions.

6.5 – Progress in 2015/16

This investigation has shown that it is practical to use Spikey®, an array of electrodes and associated hardware and software to locate and treat urine patches on a follow the cows basis. The study tested the technology over a range of 6 soil types and both irrigated and non-irrigated conditions.

The use of a threshold and urine patch minimum size criteria gives realistic urine patch identification. The threshold is however variable with the biggest factor being soil moisture. The study has identified a basis on which the threshold can be automatically and continuously tuned.

A significant data base of conductivity readings has been collected and will be used as a reference data source for the on-going development of better for urine patch identification algorithms. This data base will save time and money as it will eliminate the need to repeat testing on different soil types.

The capacitance of the soil does not appear to effect the reading of the soil conductivity at a frequency of 1000Hz.

The design of Spikey® has evolved during the project to give a very high level of electrode ground contact using the visco-elastic properties of rubber cordage.

It has been shown to be unnecessary to allow the load bearing wheels to track the electrodes and in fact this feature caused practical and safety issues in real on farm use and was disabled.

The design of the spray nozzle system to ensure accurate patch treatment requires particular attention and a number of improvements have been identified.

Urine patches tend to be oval in shape and the size of the surface patches varied for the major axes between 330mm to 560mm and the minor axes between 250mm to 390mm.

6.6 - Effects of N transformation inhibitors (NTIs) and gibberellic acid on N_2O emissions.

Objective Leader – Dr Surinder Saggar (Landcare Research)

Pastoral Robotics Ltd (PRL) have designed and built a machine that detects fresh urine patches to selectively apply treatments to reduce N losses and NZAGRC funded some earlier work on testing of this machine “Spikey2®”. A typical dairy farm of 300 cows would graze 3-4 ha per day and Spikey2 has the potential to cover 10ha per hour.

The present project brings together the scientific expertise in Urine-N transformations and the understanding of processes leading to gaseous and leaching losses of N of Landcare Research, Massey University, AgResearch and technical expertise of Pastoral Robotics in assessing the efficacy of different nitrogen transformation inhibitors (NTIs; urease and nitrification) and gibberellic acid applied during late autumn/early winter using the “Spikey” technology in reducing gaseous (ammonia and nitrous oxide) and leaching losses of N from cattle urine. This study will also assess the effect of these treatments applied beyond the detectable urine patch to cover the edge effect. The results from the field experiments of this project will provide quantitative data on reduction in urine-N EF3 values, and changes in ammonia emissions and nitrate leaching with late autumn/early winter applied NTIs and gibberellic acid to grazed pasture soils.

6.6 – Progress in 2015/16

A well-drained pasture site at Massey University dairy No.1 was selected and fenced-off from grazing for 12 weeks to avoid fresh excretal N inputs and to reduce the variability in pasture growth as affected by previous excretal depositions. A hand-held Spikey treatment applicator was developed by PRL. Before the application of the treatments about 220 litres fresh cow urine for the treatments were collected and analysed.

Six treatments (control, Urine, Urine+nBTPT, Urine+Nitrapyrin, Urine+nBTPT+ Nitrapyrin, Urine+ ORUN®) were randomly applied in five replicate blocks. Small and large Chambers were set-up for collecting nitrous oxide gas samples.

Dynamic chamber system with four replicates was also established for the collection of ammonia emissions in the following six treatments: control, Urine, Urine+Irrigation, Urine+nBTPT, Urine+nBTPT+irrigation and Urine+Nitrapyrin. Air samples were collected from the dynamic chambers by sucking at a constant flow rate (at 6-10 L min^{-1}, monitored daily) and passed through the acid trap containing 0.025 M H_2SO_4 every day for the first 5 days and then on days 8, 10, 12, 15 and 18. The sub-samples of the H_2SO_4 solution in the acid traps will be analysed for NH_4-N concentrations on a FIA.

Five replicated plots of these treatments were separately established for determining nitrate transport in the soil profile at the Massey site and soil samples were collected to 60 cm at 0-2.5, 2.5-7.5, 7.5-15, 15-30, 30-45, 45-60 intervals for measuring urea, ammonium and nitrate-N periodically. Daily surface sampling for these measurements is in progress. There was heavy rainfall following the application of the treatments that may influence the effectiveness of the treatments and enhance the leaching losses of urine-N. As required, the experimental site will not be grazed for one year following the application of treatments including urease and nitrification inhibitors.

Undisturbed soil monolith Lysimeters from AgResearch Tokanui dairy research farm were established and six treatments (control, Urine, Urine+nBTPT, Urine+Nitrapyrin, Urine+nBTPT+ Nitrapyrin, Urine+ ORUN®) are being applied a randomized complete block design with 4 replicates, and collection of gas samples for analysis of nitrous oxide, with small and large chambers, and collection of leachate (when happens) will take place.

7.1 - Manipulation of carbon inputs to stabilise and enhance soil carbon stocks

Objective Leader – Dr David Whitehead (Landcare Research)

Measurements and models will be used to quantify and forecast changes in soil carbon attributable to manipulation of carbon input, incorporation and retention. The experimental manipulation procedures (including diverse swards, irrigation, addition of nitrogen fertiliser, grazing intensity and imported feed) are selected to test the following hypotheses:

1. Conversion of ryegrass clover to diverse grassland swards increases root inputs of carbon
2. Irrigation and associated management intensification increases carbon inputs to the soil

Farm carbon balances will be constructed from measurements of carbon exchange and carbon imports and exports and used to estimate conversion of carbon inputs to soil carbon.

Detailed process-based dynamic modelling will be used to forecast the combined impacts of different management options and environmental changes on soil carbon inputs, incorporation and stabilisation.

The research will focus on experimental sites at Troughton Farm (Waikato) and an irrigated dairy farm in Canterbury (location to be confirmed).

7.1 – Progress in 2015/16

Our work has continued to be focused on two major experimental platforms at Troughton Farm, Waikato and Ashley Dene Farm, Canterbury. Our work in the Waikato, led by the University of Waikato, is well established and, following several years of measurements, our findings demonstrate clear effects of management practices on changes in soil carbon storage. We have demonstrated best management practices to avoid losses of soil carbon following pasture renewal and the potential to increase soil carbon storage using swards with mixed species compared with carbon storage under conventional ryegrass/clover swards. We intend to continue the measurements for two further years at selected sites and start new measurements at sites with different management practices identified from our work as having potential to increase carbon storage. Our second field platform is at a recently converted dairy farm on shallow, stony soils at Ashley Dene, Canterbury, led by Landcare research, where we are investigating the effects of conversion from dryland farming to intensive dairy farming using irrigation and addition of nitrogen fertiliser on soil carbon storage. This work is relevant to identify best management practices for sites in eastern areas where there is extensive conversion from dryland to irrigated dairy farming. Site experimental facilities are operational and measurements in programme with aligned funding are underway but the work funded by NZAGRC will not start until August 2016 with the arrival of a PhD student.

Our findings at the site in the Waikato have consisted of two approaches. We made direct measurements of carbon inputs and losses using stable isotopes of carbon and measured paddock-scale rates of carbon exchange for the different treatments.

Findings from our work using direct measurements of carbon inputs has shown that:

- More diverse pasture swards had greater root biomass and turnover than a ryegrass/clover sward suggesting greater carbon inputs to soils (1.2 t carbon/ha).
- Direct measurements using carbon isotopes did not detect a difference in carbon inputs from roots to soil between diverse and ryegrass/clover swards. Variability was high so the power to detect differences was weak.

- Large inputs of carbon from dying ryegrass/clover roots (an extra 1.5 t carbon per ha) were measured using carbon isotopes during a pasture renewal event (killing swards, cultivation and reseeding). The long-term fate of this new carbon input is poorly known.

We conclude that the diverse sward had more root biomass and turnover but it was not possible to determine whether this would translate to increased carbon inputs to soil. However there were large carbon inputs into soil during pasture renewal events that was available for stabilisation.

Our measurements of carbon exchange at paddock scales before and after pasture renewal and following establishment of swards with ryegrass/lucerne and mixed species have shown that:

- Minimising the period between spraying off pasture, reseeding and pasture re-emergence minimises the immediate loss of carbon particularly when soils were wet.
- In the three years subsequent to pasture renewal, all treatments had lost carbon, but there were no differences in carbon balances between treatments after accounting for initial differences between sites.

We conclude that, following pasture renewal, there is a short-term loss of carbon. Once the new pastures are established there is little difference between a diverse sward and a ryegrass/clover sward, however, site specific factors may have limited our ability to detect differences. Parallel work suggests other sward mixes may enhance carbon accumulation and be suitable as part of a farm system, e.g., inclusion of a lucerne base (with deeper roots) as opposed to ryegrass. We intend to start measurements with these treatments in spring 2016.

We have undertaken a strong modelling component in parallel with our measurements. Using data, we have tested the process-based CenW model and have extended it to simulate changes in soil carbon for different management practices. We have completed our contribution to an international network to test models to simulate long-term changes in soil carbon in relation to climate and management. The CenW model has compared well with other international models and this has confirmed the confidence we have in using the model to analyse and predict the effects of climate and management effects on long-term changes in soil carbon. We have further modified the CenW model from a daily to sub-diurnal time step so that it could more directly be compared against the eddy-covariance from our field sites. The revised model compares well with the available data.

We have continued to inform stakeholders of our findings at workshops, seminars and field days throughout the year and in the publication of articles in farming magazines.

Our work has been undertaken principally by University of Waikato and Landcare Research and we have mentored and grown capability with a Post-Doctoral Researcher, 3 PhD students (one completed) and other associated students.

Key achievements for 2015/16:

- McNally SR, Laughlin DC, Rutledge S, Dodd MB, Six J, Schipper LA. 2015. Herbicide application during pasture renewal increases root turnover and carbon input to soil in perennial ryegrass and white clover pasture. *Plant and Soil* (in press). This paper describes changes in carbon inputs following application of herbicide prior to establishing new pasture. The use of glyphosate during pasture renewal increased root turnover and resulted in a greater short term cumulative carbon input to soil. This study provides the first values of root turnover and carbon input to soil during a pasture renewal event in New Zealand pasture systems and contributes to the understanding of how pasture roots influence the soil carbon input following plant death from other factors such as drought, fire, and other abiotic environmental stresses in grassland systems
- Kirschbaum MUF et al. The trade-offs between milk production and soil organic carbon storage in dairy systems under different management and environmental factors. Submitted to *Science of the Total Environment*. This provides an analysis of scenarios of the impacts of

different management strategies and environmental variables on changes in soil carbon and identifies options for farmers for best management practices. This demonstrates the usefulness of the CenW model to inform research programmes and the use of data to validate the model.

- Rutledge S et al. The carbon balance of temperate grasslands Part II: The impact of pasture renewal via direct drilling. Submitted to *Agriculture, Ecosystems & Environment*. This paper describes evidence from several years of data collected at sites in the Waikato showing carbon gains and losses following pasture renewal. For pasture renewal, minimising the period between spraying off pasture, reseeding and pasture re-emergence minimises the immediate loss of carbon particularly when soils were wet. Once the new pasture is established there is little difference in carbon inputs between a diverse sward and a ryegrass/clover sward. However, site specific factors may have limited our ability to detect differences.
- Whitehead D, Schipper L, Kirschbaum M 2015. Where has all the carbon gone? – the answer lies in the soil. Presentation of LINK seminar to stakeholders, MfE, Wellington, August 2015. Summary of findings to date with an overview of all knowledge of changes in soil carbon for New Zealand presented to stakeholders in Wellington.
- Louis Schipper provided briefing notes to Paul Melville (MPI) for use by Minister Groser to use when on a discussion panel addressing a proposed soil carbon initiative at the Paris Climate Change meeting. David Whitehead met with Milena Palka and Bruce Arnold, policy analysts for the Climate, Land & Water Team at MPI to summarise state of knowledge on estimating and increasing changes in soil carbon. These meetings demonstrate our close interactions to advise policy on mitigating greenhouse gas emissions.

7.2 - Tools to quantify the stabilisation capacity and vulnerability of carbon in grassland soils

Objective Leader – Prof Frank Kelliher (AgResearch)

Developing and deploying management practices that maximise the long-term storage of soil carbon depend on understanding the capacity of soils to stabilise carbon and its vulnerability to loss. We aim to identify the soil properties and management practices that most affect the stability of soil carbon and its vulnerability to loss. This will contribute to objective 7.1 by collaboration on the modelling of soil carbon incorporation, distribution and stabilisation. We will:

1. Test key assumptions to develop a second generation statistical model (developed from previous milestones) for predicting the soil carbon stabilisation capacity for New Zealand's grassland soils
2. Apply soil chemical and physical fractionation methods and a soil carbon mineralisation assay to quantify the stability and vulnerability to loss of soil carbon
3. Synthesise findings to identify soil properties and grassland management practices that most affect soil carbon stabilisation and vulnerability to loss

7.2 - Progress in 2015/16

Massey University Post-Doctoral Fellow Roberto Calvelo Pereirara led a study of the nano-scale structure and specific surface area (SSA) of allophane-rich and non-allophanic pastoral soils. Soil water contents after supercritical drying (SD) and air drying (AD) were strongly correlated and the slope was not significantly different to one. Soil water content was strongly correlated with the reactive aluminium content associated with short-range order (SRO) constituents as well as the carbon (C) concentration. After SD, on average, organic matter (OM) removal increased the pore volume and SSA by nearly 50%. This was interpreted to OM removal having “unblocked” the mesopores (2–50 nm diameter). By also removing the SRO constituents, the pore volume and SSA area then decreased by nearly 80% on average. This was interpreted to indicate the proportion of the pore volume and SSA which can be attributed to the SRO constituents. While after SD, the SSA was not significantly correlated with the C concentration, there were statistically significant and progressively stronger correlations after (i) OM removal (accounting for 77% of the variability) and (ii) estimating the SSA attributable to SRO constituent (83%). Further studies are needed to develop a better understanding of the effects of soil sample preparation methods, especially drying, on the nano-scale structure, SSA and relationships with the C concentration.

Plant and Food Research Post-Doctoral Fellow Sam McNally led a study which measured the soil physical and chemical properties expected to contribute to C stabilisation, tested key assumptions of a statistical model developed by the NZAGRC soil C programme (Beare et al. 2014) and developed an improved model. For the study, 168 allophane-rich and non-allophanic agricultural soils were sampled across NZ (mostly pastoral but also cropping). For the allophanic-rich pastoral soils, the mean C saturation deficit was 22 mg C kg^{-1} soil was nearly twice that of the non-allophanic soils (11 mg C kg^{-1} soil). This difference was interpreted to indicate that the allophanic-rich soils have a greater potential to stabilise more soil C than the non-allophanic pastoral soils. For the allophanic-rich cropping soils, the mean C saturation deficit was 40 mg C kg^{-1} soil or twice that of the corresponding pastoral soils. In contrast, for the non-allophanic cropping soils, the mean C saturation deficit of 13 mg C kg^{-1} soil was not significantly different to that of the corresponding pastoral soils. This difference was interpreted to indicate that cropping had depleted stabilised C from the allophanic-rich soils, compared to pastoral agriculture, but this had evidently not happened for the non-allophanic soils. Earlier research has suggested a maximum C loading rate onto soils of 1 mg C m^{-2} SSA. This was interpreted as a “monolayer” of C covering the surface area of fine soil particles. For this study, a new methodology was developed to estimate a soil’s C loading rate which yielded 0.66 mg C m^{-2} for the allophane-rich pastoral soils and 0.85 mg C m^{-2} for the non-allophanic pastoral soils. Both values were less than 1 mg C m^{-2} which was interpreted to indicate not all of the soil’s SSA was “available” for stabilising C and more so for the allophanic-rich pastoral soils. This conclusion represents an important connection between the McNally and Calvello Pereira studies. We will continue to investigate the nano-scale structure, SSA and C concentration of allophanic-rich and non-allophanic pastoral soils to better understand their potentials to stabilise more C in future.

At a workshop in Wellington on 12 March 2015, representatives from science providers and stakeholder organisations recommended scenario modelling to explore the effects of land management practices on soil C stocks and GHG emissions. At a workshop organised by PIs Frank Kelliher and David Whitehead in Lincoln on 5 April 2016, Frank gave a presentation about the development of a soil C accounting system which is compatible with NZ’s agricultural GHG emissions inventories. In addition, Jeff Baldock from CSIRO gave a presentation about Australia’s agricultural soil C accounting system and there were presentations by Louis Schipper and Miko Kirschbaum from the NZAGRC soil C programme.

Key achievements for 2015/16:

- Calvelo Pereira R, Camps Arbestain M, Kelliher FM, Theng BKG, Noble ADL, McNally SR. 2016. Assessing the pore structure and surface area of allophane-rich and non-allophanic soils by supercritical drying and chemical treatment. Geoderma (submitted to NZAGRC ROI, 13/7/16)B

- McNally SR, Beare MH, Curtin D, Kelliher FM, Camps Arbestain M, Calvelo Pereira R, Baldock J. 2016. Predicting the organic carbon stabilisation capacity and saturation deficit of soils: Verification of measurements and models. Global Change Biology (to be submitted to NZAGRC ROI by 31/7/16)

- Kelliher FM 2016. Soil carbon and greenhouse gas accounting on a hill country farm. Presented at an NZAGRC workshop in Lincoln on 5 April to inform and engage GHG scientists and policy makers about soil carbon accounting.

7.3 - Modelling management manipulations using the HPM

Objective Leader – Prof Jacqueline Rowarth (University of Waikato)

There are substantial changes in management associated with the intensification seen in NZ agriculture. These include increases in fertiliser input, increases in livestock intake demand, changes in the offtake of nitrogen and carbon as dairy cows replace dry stock (e.g. sheep) and/or there are increases in milk yield per cow, the increased use of purchased feed, in cutting (vs grazing) of forages, and the increased use of irrigation. Individually and together these changes lead to major changes in the C and N cycles, because animals 'uncouple' the C and N cycles, so the more animals that are involved, the more that cycles are uncoupled. Prospects for future development in the NZ pastoral industry also include making fundamental changes to the fate of C and N in plants (via new species/traits), animals (altering N partition), and soils (e.g. reducing SOM decomposition). Very importantly intensification (and the reverse), and all such manipulations, give rise to transient changes that are not necessarily indicative of the longer term changes that can occur when a particular management(s) is sustained. Understanding and clearly separating long term sustainable (c.f. steady-state) changes from transient changes is a priority if we are to understand how changed management practices and system manipulations will impact soil carbon storage in the future. We also need improved understanding of how climate change itself will interact with anticipated management changes.

The Hurley Pasture Model (HPM) is a mechanistic C and N cycling model that incorporates soil, plant and animal processes, in depth; it is an appropriate model for studying short and long term changes in C and N cycling in response to management and environment. It works from first principles and does not rely on 'tuning' using experimental data when making predictions. Results from the HPM are already giving insight that indicators such as emission factors and C and N balances based on measurements collected during the period of transition (some 2 to 10 years minimum) between managements can be misleading. This applies to identification of the fundamental drivers of changes in soil carbon and nitrogen, and to the general direction of changes in, and the scale of, these changes.

Our aim is to use the HPM to provide indications of how, and in what direction, C and N emissions, fluxes, and sequestration (of both) will change, what the changes will look like over different time scales after changes in management are introduced, and whether the outcome is sustainable, and at what state. Changed management rarely involves a single action and we will use the model to analyse systematically just which of the components of a management change have the largest impact. This is of value as in any system several factors are often changed simultaneously, potentially leading to sustained false impressions of what needs to be focussed on to offer mitigation.

7.3 - Progress in 2015/16

An analysis was completed using full C and N accounting, for all components of C and N input, cycling and fate of temperate grazed pastures. The analysis covered all key drivers of C and N cycling and emissions and identified the role of the key management options: stocking rate; fertiliser (or legume) N input rate; animal class (dry-meat/lactating for sheep, cattle; off-season stocking policy; supplement use (amount per animal per day, N content and degree of substitution by animals); singly and in combinations. In addition the role in all the above of changes in partitioning in the animal (of both C and N); changes in plant traits (e.g. fructans or altered energy content); plant species requirements for N; and speculative changes in the rate of degradation of surface litter and soil organic matter, were illustrated. These analyses reveal major valuable insights that were conveyed to stake-holders and policy makers (with NZAGRC steering and advisory group) as well as to the other teams involved in NZAGRC contracts (workshops April 2016). The insights have been used in practical articles, by Prof Rowarth, correcting presumptions of impacts of intensification and dairy, made in the farming media.

For ease of comprehension in a practical context; figures (graphs and numbers) were also presented showing the impacts on C and N cycles (notably wrt 'yield' of food; C (and N) sequestration; methane emissions; and all components of N release (including nitrous oxide emissions)), for a wide series of managements that represent the sequence from low input meat (dry) sheep, through increasing intensification of inputs and a shift to dairy cows, notably including the use of supplements, but also showing the impacts of any attempts to revert from dairy cows to lower input dairy, or to meat. Considerable effort was made to stress how the shift to dairy has been by far the greatest cause of a major *increase* in the efficiency of food production per unit N input, and per unit emissions. Food production is near twice as great, while N releases some ½ as great, under dairy compared to meat, at the same intermediate total N input rate. Supplements were shown, to our surprise, to play a major role in improving the efficiency (increasing the amount of food produced per ha, while reducing losses/releases of N per ha, and while increasing C sequestration. This was shown to NOT depend on the C:N ratio of the supplemented feed, nor altered partitioning in the animal, nor the level of substitution nor stocking rate. It is a 'simple' feature of how feeding supplements allows one to overcome the limitations to C (energy supply) seen as N input increases, when the input of N leads to only diminishing returns of energy, when this depends on photosynthesis. For brought-in feed, the C gained per unit N remains 'linear' and written on the bag.

A deeper analysis revealed how shifts between managements, such as those described, could induce 'transients' notably in the components of N cycling and loss, and so observations made even exhaustively in the first 5 years (a typical duration of a major field trial) could seriously under-estimate (for example) the N losses and N based GHG emissions. In addition, because yield PER HECTARE (e.g. milk or meat) 'saturates' (plateaus) as N inputs increases; as does C sequestration and also methane PER HECTARE, the analyses strongly recommend a focus of research toward the fundamental drivers of N emissions, as the increase in these is sustained (almost exponentially). That research cannot be based on further field observations (due to the misleading transients in releases following a shift in management, but must focus on the fundamental mechanisms of how plants interact with and can control N releases (as mineral N or as nitrous oxide). Examples of such work, previously funded by NZAGRC, were recommended.

All the above can be re-run in a changing climate (elevating CO_2 and temperature/ water e.g.) as a future component. Options are readily worked out, from the already produced analyses, for the benefits of using twice as much land, but at half the N input rate, albeit contrary to the 'Trewavas' principle.

Invitations have been received (by CAB International) to 'review' advances in understanding the role of changes in agriculture, and its impacts notably in the context of Paris type 'recommendations for govt./policy action'. A publication on soil microbial function (and the identity of soil fungal and bacterial species) as affected by altered plant species and traits (incl endophyte) is nearing completion. A paper on the practical key issues (as above) is also nearing completion. A paper was published on the prospects for developing high producing, but lower input N requiring) variants of common plants (ryegrass) (see Rasmussen et al 2016), which included the discovery (and sequences) of several of the key plant genes.

It is the capture of carbon (energy), PER HECTARE and its biological inefficiency when stimulated by N inputs that drives and constrains the efficiency of the whole, coupled C and N cycles. Advances will come therefore from work on plants, and their associations with microbes, and less so from a focus on heterotrophy, e.g. studies made on a per animal basis.

Key achievements for 2015/16:

- Resolved key role of animal class (meat, dry sheep/cattle; lactating, sheep/cattle) in C and N cycling and fate, and stressed to stake-holders the critical importance of 'dairy' being by far the most the most efficient in use of C and N, wrt more food but reduced emissions, when compared at (any) same fertiliser input rate, and while using optimal grassland management (making best use first of grass).

- Resolved key role of supplements (brought in feed) in increased efficiency of C and N cycles, and explained (for first time) the basis of that advantage on site (i.e. not LCA level). Identified major prospects for backing off fertiliser N when using supplements, while using optimal grassland management (making best use first of grass).

- Presented comprehensive comparison of impacts of a sequence of managements that mimic NZ industry over last 20 years (low input dry sheep > intensive dairy), and potential reversion to lower input systems, and impacts on food, methane, C sequestration, and nitrogen release/emissions. Stressed concern over mis-interpretation of on farm experimental observations, due to long-term (20-50 year) ‘transients’ (time course) during shifts between managements

- Laid out (and presented to stake-holder (below)) a basis for critical analysis of getting the best balance of food production, methane emission, C sequestration, and N release (and N_2O emission), for any combination of animal class, supplements, fertiliser input and even novel plant traits. From this the best focus for research, management and mitigation effort was evident and was advised.

- A presentation was delivered (by invitation of NZAGRC Director) to stake-holder, policy (MPI), PGGRC, Advisory Group (SAG) to convey findings, and a basis offered for identifying the most effective strategy for the focus of efforts in mitigation (of both C and N cycle GHG impacts) and the most effective research focus. This was well received.

8.1 - GHG Emissions on Sheep and Beef Farms

Objective Leader – Drs Kathryn Hutchinson & Robyn Dynes (AgResearch)

The programme will identify the drivers of GHG emissions intensity on two S+B farms and determine whether these drivers result in decreased GHG emissions intensity when integrated into commercial farm systems. Key outputs will include a peer-reviewed journal article, a popular fact sheet and alignment with B+LNZ's extension programme to communicate the findings of the research.

The programme proposes to align with a new environment extension program within B+LNZ and partner with its extension activities. The North Island and South Island environment-focussed farms (EFF) will be evaluated for suitability as study farms. Drivers of GHG emissions intensity on S+B farms will be identified using data from previous projects. These mitigations will then be evaluated within commercial farming systems via a comprehensive measurement and monitoring programme which will include measurement of components of farm systems efficiency as a proxy for direct measurement of GHG which will not be undertaken. A farm systems analysis, including GHG and nutrient losses to the environment will be completed with historical and current farm operational data and for future scenarios including farming within limits, with change to stocking policy and forage supply.

8.1 – Progress in 2015/16

The two S+B Monitor farms now have substantial robust data and baseline farm systems models which demonstrate the extent to which the key management decisions and efficiency drivers impact on current emissions intensity. The farms are at very different points in development cycle, so provide useful perspectives for informing the wider industry.

Three practice change scenarios have been modelled to predict GHG emissions intensity for Onetai station, a B+LNZ environmental focus farm. Scenarios incorporating an increase in soil fertility and animal production and a change in stock policy have predicted a 20 to 38% improvement in GHG emissions intensity.

The project partnership between AgResearch, B+LNZ, Farmax and AgFirst has increased the monitoring capability of the Onetai farm management team and increased their ability to make information based key strategic decisions. At the start of the project the farm management team were unclear on many key monitoring metrics (animal weights, pasture covers, growth rates etc). We now have a more robust monitoring model for the farm, from which we can develop a more robust estimation of environmental emissions.

A successful field day was held at Onetai station in September 2015. The project team facilitated substantial discussion around GHG issues and mitigations with the group of keen and interested farmers.

Pasture growth and quality measurements are being collected to monitor the effect of increasing soil fertility on Onetai station. This has been established as a phosphate fertiliser response trial as a strong visual indicator of this method of improving animal production and emissions intensity.

Key achievements for 2015/16:

- On-farm data collection and farm systems modelling and analysis has been demonstrated to be robust and relevant to both farm management and research teams.

- Developed three scenario models (production, environmental) for each farm. This has informed the Onetai farm management team and promote practice change to improve the GHG emissions intensity on farm.
- Field day held at Onetai station; high attendance and engagement on environmental issues, including GHG was notable.

8.2 - GHG Emissions from Dairy Systems

Objective Leader – Drs Kathryn Hutchinson & Robyn Dynes (AgResearch)

The dairy sector programme will assess the GHG emissions for dairy systems demonstrating a range of practical mitigation options including high genetic merit cows (Waikato), diverse pastures and low stocking rate efficient systems (Canterbury) and off pasture systems (South Otago) for management of environmental impact. The programme will partner with established P21 farmlet systems in the Waikato, Canterbury and South Otago, and NZAGRC funding will fund additional data collection and analysis of GHG emissions to:

a. Assess whether new mitigations within farming systems will also reduce GHG footprint
b. Validate previous farm systems modelling by demonstrating that these new mitigations deliver real GHG benefits within functional and practical farm systems
c. Identify risk areas for pollution swapping within the farm system.

Key outputs will include data and resources contributing to the existing DairyNZ extension program, industry conference presentations, journal publications and new data on emission factors for GHG

8.2 – Progress in 2015/16

The research program this year has progressed toward the objective of understanding the potential for practical mitigation options to result in lower GHG footprint of dairy farming systems.

The measurement of methane and nitrous oxide within dairy farmlets which have a range of mitigation options including high genetic merit cows (Waikato), low N fertiliser input (Waikato) and diverse pastures (Canterbury) has now been completed. This data collection has enabled the mitigation options to be considered within a farming system. The first analysis was completed, with the completion of the inventory-GHG footprint (DeKlein et al NZAGRC/SLMACC) for Canterbury. The information is now available to enable the validation of existing farm systems modelling.

The new data on methane emissions from cows grazing fodder beet during winter and during early lactation is timely. Industry uptake of fodder beet both as a winter feed, but increasingly as a transition feed used on the milking platform in both late and early lactation is continuing. Further, this data together with data from the FRNL programme on fodder beet will enable farm systems modelling to consider the wider environmental impacts of this potential mitigation to both GHG and emission to water.

Key achievements for 2015/16:

- Successful completion of research trials to determine N_2O emission factors from urine from cows managed with different mitigations in both Waikato and Telford which have been reported.
- Completion and reporting on methane emissions from both dry and lactating cows grazing fodder beet plus supplement or fodder beet as a supplement to pasture.

- Acceptance of paper on methane emissions from fodder beet research for Australasian Dairy Science Symposium.
- A summary of the estimate of the GHG footprint of the Canterbury P21 dairy systems was presented at the Methanet/NzOnet/Soil C meeting in Wellington on 26-27 May 2016

20.1 - Low emission farm systems for the Māori sector

Objective Leader – Phil Journeaux (AgFirst)

This programme aims to assist the Māori pastoral sector to improve its collective capacity to increase resource efficiency, farm productivity and while lowering greenhouse gas (GHG) emissions.

The programme will achieve this by developing a set of Māori farm typologies, which represent the predominant pastoral farming systems, identify key factors that underpin farm productivity, resource and emission efficiency and sustainable profitability, and then identify and test a range of mitigation strategies. Farm typologies are important to avoid the problems of homogenizing a heterogeneous group that range from very small farms to large multi-enterprise corporates. These typologies will be compared against existing databases and help in the selection of in-depth representative case study farms for scenarios of alternative farm system configurations that will evaluate mitigation options.

Two metrics will be used in parallel to identify and assess mitigation scenarios, their costs, and options for implementation: absolute reduction in GHG emissions, and reduction in emission intensity (the ratio of emissions per unit of output, e.g. Kg CO_2-eq/KgMS).

Farm system mitigation scenarios will be based on the interaction and knowledge sharing that will occur between the farmers (including land entities), scientists and industry advisors that will take place in case study workshops around the country. The research team will apply a range of suitable tools to model these scenarios including Farmax, Overseer, Mitigator and MyLand along with others where required (e.g. LCA, LP optimisation). The integration of forestry models (MyLand) alongside pastoral sector farm systems (Farmax) and emissions models (Overseer) to derive whole farm mitigation strategies is a key feature of the modelling in this programme.

The programme will improve our understanding of the critical characteristics of GHG profiles (both in terms of absolute emissions and emissions intensity) of existing Māori pastoral farming systems and to produce a range of mitigation options to modify farm systems to lower absolute emissions and/or emissions intensity.

A key contribution to the literature will be an enhanced understanding of the Māori farm typologies with economic, environmental, social and cultural implications of low emission farming systems within the Māori sector, with wider implications across NZ. The programme will build on several research programmes including: “SFF Farmers Climate Change and GHGs (C08/008)” led by Margaret Brown; “Tuhono Whenua Māori Benchmarking Framework (M12/173)” led by Tanira Kingi; “Aohanga Incorporation: Climate change mitigation and adaptation: A social process framework for engagement and the development of a climate change resilience strategy (SLMACC C10x1003)” led by Bruce Small; and “Identifying small and medium sized forest owner typologies”, MPI contract 16969, led by Steve Wakelin. The programme will also contribute to the integrated systems programme within the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC).

20.1 – Progress in 2015/16

The project is designed to assist Māori farmers in New Zealand to improve their collective capacity to increase resource efficiency and farm productivity while lowering greenhouse gas (GHG) emissions.

Progress in 2015-16:

- Modelling of GHG mitigation scenarios carried out, based on earlier meetings held with each of the 4 focus farm Trustees to discuss modelling scenarios.

- Further meeting held with focus farm Trustees to discuss results of initial modelling work, and determine further scenarios for modelling.
- Second round of modelling carried out.
- Further meeting held with focus farm Trustees and other interested parties to discuss the modelling results and implications for the farms.
- Development of the MyLand computer model, which incorporates forestry economics and carbon sequestration, in a spatial framework, alongside Farmax and OVERSEER inputs – so incorporates pastoral farming with forestry.

A summary of the modelling results are;

- Many of the changes in farm systems resulted in relatively marginal changes in GHG emissions & profitability. Often if GHG emissions decreased so did profitability, and vice versa.
- Some system changes did give a win-win in that GHG emissions decreased while profitability increased.
- These included;
    - Lowering stocking rates on dairy farms
    - Increasing sheep:cattle ratios
    - Increasing farm efficiency (e.g. increasing lambing percentages)
    - Planting marginal areas in forestry
- Planting marginal areas in forestry was marginal on the dairy farms given the small areas available; this mitigation had a much larger impact on the sheep & beef farms.
- In the absence of any mitigations, the advent of a carbon charge had a significant impact on farm profitability

Key achievements for 2015/16:

- Completion of modelling of a range of farm system change scenarios (6-7) for each focus farm.
- Discussions with the focus farms on the results and implications.
- Development of MyLand which will allow for easier inclusion of forestry options.
- Paper written on the modelling results, to be presented at the International Rangeland Conference.
- Paper written on the modelling results, to be presented at the 2016 NZARES conference.

APPENDIX 3 – NZAGRC INTERACTIONS AND OUTPUTS

NZAGRC Meetings and Presentations (New Zealand)

- Meeting: NZCCC Annual Meeting: 17 June, 2015 - Wellington
- Meeting: Jean-Pascal van Ypersele, IPCC: 10 August, 2015 - Wellington
- Lecture: Environmental Policy, VUW: 18 August, 2015 - Wellington
- Briefing: Anais Vedovati, Embassy of France: 21 August, 2015 - Wellington
- Meeting: RSNZ Climate Implications Panel : 25 August, 2015 - Wellington
- Meeting: RSNZ Mitigation Panel: 31 August, 2015 - Wellington
- Green Party climate launch: 3 September, 2015 - Wellington
- Workshop: NZAGRC Team Planning: 27 -28 October, 2015 - Raumati
- Meeting: RSNZ Mitigation Panel: 4 November, 2015 - Wellington
- Meeting: Group One Consultancy Ltd: 6 November, 2015 - Palmerston North
- Meeting: Overseer review: 9 November, 2015 - Wellington
- Meeting: Office of the Parliamentary Commissioner for the Environment: 26 November, 2015 - Wellington
- Meeting: Gates Foundation and Global Good: 27 November, 2015 - Wellington
- Meeting: Agricultural Inventory Advisory Panel: 1 December, 2015 - Wellington
- Meeting: Matt Hooper, MPI: 17 December, 2015
- Reception: Embassy of France: 1 February, 2016 - Wellington
- Meeting: RSNZ Mitigation Panel: 2 February, 2016 - Wellington
- Meeting: IPCC Bureau: 3 February, 2016 - Wellington
- Meeting: MfE Chief Executive, Vicky Robertson: 10 February, 2016 - Palmerston North
- Presentation: Spikey project team: 11 February, 2016 - Palmerston North
- Meeting: NZCCC Review: 25 February, 2016 - Wellington
- Meeting: PGgRc: 1 March, 2016 - Wellington
- Meeting: BusinessNZ Climate Initiative: 16 March, 2016 - Video conference
- Workshops: NZAGRC science: 4 -6 April, 2016 - Christchurch
- Visit: Parliamentary Commissioner for the Environment: 18 April, 2016 - Palmerston North
- Workshop: Climate Change First: 18 April, 2016 - Wellington
- Workshop: RSNZ Climate Change Implications for New Zealand Panel: 19 April, 2016 - Wellington
- Meeting: MFAT discussion re agricultural GHGs & development projects: 21 April, 2016 - Wellington
- Workshop: RSNZ Climate Change Mitigation options for New Zealand: 27 April, 2016 - Wellington
- Meeting: Jim Skea: 27 April, 2016 - Wellington
- Workshop: PFR climate change workshop: 28 April, 2016 - Christchurch
- Workshop: NZAGRC-PGgRc methane review: 2 May, 2016 - Palmerston North
- Meeting: PGgRc: 3 May, 2016 - Wellington
- Meeting: Prescient Nutrition Ltd: 6 May, 2016 - Palmerston North
- Meeting: NZAGRC Principal Investigators: 9 May, 2016 - Palmerston North
- Workshop: Productivity gains by AbacusBio/MPI: 16 May, 2016 - Wellington
- Meeting: Kennedy Graham: 26 May, 2016 - Wellington
- Presentation: RSNZ report on transition to a low carbon economy to Wellington Quakers group: 29 May, 2016 - Wellington
- Workshop: Motu Land and Climate Economics: 30 May, 2016 - Wellington
- Workshop: Breeding for low methane animals: 31 May, 2016 - Palmerston North
- Meeting: PGgRc Review: 9 June, 2016 - Wellington
- Meeting: Climate change forum scoping: 9 June, 2016 - Wellington
- Meeting: Andrew Bayly MP: 14 June, 2016 - Wellington
- Workshop: ETS planning: 22 June, 2016 - Wellington

Meetings and Presentations (New Zealand)

- Ron Ronimus, 'Developing methanogen inhibitors to reduce methane emissions: the story behind the story' - AgResearch internal Inside Story - 03 July, 2015
- Sandeep Kumar, 'Microbiology of sheep rumens emitting different amounts of methane' - Massey University - 03 July, 2015
- Yang Li, 'The Genome Sequence of a Rumen Methanomassiliicoccales' - Massey University Wednesday Seminar - 15 July, 2015
- Andy Reisinger, 'Productivity and agricultural improvement: Why are agriculture/national inventories important?' - presentation to MPI-hosted workshop for delegates from African countries - 31 July, 2015
- Preeti Raju, Gemma Henderson, Michael Tavendale, Jasna Rakonjac, Peter Janssen, 'Measuring homoacetogenic activity in the rumen' - Massey University, Palmerston North - 05 August, 2015
- Andy Reisinger, 'Climate Change Scenarios to 2100 for New Zealand' - invited presentation at workshop for marine sector stakeholders, part of MBIE project "Climate Change Impacts and Implications (CCII)" - 10 August, 2015
- Andy Reisinger, 'Agricultural Greenhouse Gases: a complex policy problem' - invited guest lecture as part of Victoria University course PUBL 207, 'environmental policy' - 18 August, 2015
- David Whitehead, Louis Schipper & Miko Kirschbaum, 'Where has all the carbon gone? The answer lies in the soil' - LINK Seminar for stakeholders - 25 August, 2015
- John McEwan, 'Animal Breeding: mitigation research progress and strategies' - U3A presentation in Invercargill - 06 November, 2015
- Andy Reisinger, 'Climate Change Scenarios to 2100 for New Zealand' - invited presentation at workshop for local government, part of MBIE project "Climate Change Impacts and Implications (CCII)" - 08 December, 2015
- Andy Reisinger, 'Scenarios to understand Climate Change Risks and Implications for New Zealand' - keynote lecture as part of MBIE project 'Climate Change Impacts and Implications (CCII)' at The Treasury - 18 April, 2016
- Andy Reisinger, 'Transition to a low-carbon economy for New Zealand' - Royal Society launch on low-carbon pathways - 21 April, 2016
- Andy Reisinger, 'Agriculture' - Royal Society launch on low-carbon pathways - 26 April, 2016
- Andy Reisinger, 'RSNZ-Climate change implications' - Royal Society launch on low-carbon pathways - 26 April, 2016
- Andy Reisinger, 'Climate Change: Challenges and Opportunities for New Zealand’s Food Production Sector' - invited guest lecture as part of Plant and Food Research strategic planning workshop - 28 April, 2016
- Andy Reisinger, 'Agricultural Greenhouse Gases: a complex policy problem' - invited guest lecture as part of Victoria University course PUBL 307, 'environmental policy' - 19 May, 2016
- Andy Reisinger, 'The New Zealand Agricultural Greenhouse Gas Research Centre' - presentation to delegation from MfE, Palmerston North - 24 May, 2016
- Grant Rennie & Robyn Dynes, 'Environmental monitoring of sheep and beef farm systems' - B+LNZ workshop - 27 May, 2016
- Andy Reisinger, 'Quakers' - invited guest lecture for Wellington Quakers monthly meeting - 29 May, 2016
- Andy Reisinger, 'Agricultural GHG emissions trends and abatement potentials' - invited guest lecture as part of Motu land-use research workshop - 30 May, 2016
- Andy Reisinger, 'New Zealand's agricultural GHGs and policy options' - invited guest lecture for MfE workshop on ETS and strategic policy review - 22 June, 2016
- Phil Journeaux, 'Modelling GHG Emissions from Maori Farms Presentation' – Huis during 2016

NZAGRC Meetings and Presentations (International)

- Workshop: Thai Government advisory group: 15-16 July, 2015 - Bangkok, Thailand
- Presentation: IPCC Outreach: 12-13 August, 2015 - Canberra, Australia
- Meeting: FACCE-JPI SAB: 10-11 September, 2015 - London
- Meeting: Land Sector Abatement, Dept of Environment: 21 October, 2015 - Canberra
- Meeting: Inventory team, Dept of Environment: 21 October, 2015 - Canberra
- Meeting: Policy delivery, Department of Agriculture: 22 October, 2015 - Canberra
- Meeting: CSIRO/ANU: 22 October, 2015 - Canberra
- Meeting: FAO INDC : 18-21 November, 2015 - Bangkok, Thailand
- Meeting: FACCE-JPI Scientific Advisory Board: 26-27 January, 2015 - Brussels, Belgium
- Conference: GGAA: 15-18 February, 2016 - Melbourne, Australia

- Meeting: IPCC Bureau: 15-18 February, 2016 - Geneva, Switzerland
- Presentation: How much does livestock actually contribute to global warming?: 17 February, 2016 - Melbourne, Australia
- Workshop: FACCE ERA-GAS fund: 10 March, 2016 - Teleconference
- Workshop: FACCE ERA-GAS fund: 17 March, 2016 - Teleconference
- Meeting: IPCC Panel: 9-15 April, 2016 - Nairobi
- Meeting: FACCE-JPI SAB Advisory Board: 26 - 27 April, 2016 - London
- Workshop: Panama: 20-24 June, 2016 - Panama City

Meetings and Presentations (International)

- Ron Ronimus, Stefan Muetzel, Mike Tavendale, Kristy Lunn, Yanli Zhang, Carrie Sang, Debjit Dey, Renne Atua, Marion Weimar, James Cheung, Andrew Sutherland-Smith, Patrick Edwards, William Whitman, William Denny, Greg Cook, Vince Carbone, Linley Schofield, 'Methanogen Metabolism and How Their Unique Enzymes' - University of Vicosa, Brazil (invited 50 minute seminar) - 12 August, 2015
- Andy Reisinger, 'IPCC 5th Assessment Report: key findings for Australia' - keynote address as part of IPCC public outreach event, Canberra - 12 August, 2015
- Andy Reisinger, 'New Zealand experience in reporting agricultural GHG emissions' - keynote address as part of Malaysia Agricultural Research and Development Institute (MARDI), Kuala Lumpur - 21 March, 2016
- Andy Reisinger, 'Climate change and livestock: Impacts and response options' - keynote address as part of Malaysia Agricultural Research and Development Institute (MARDI), Kuala Lumpur - 22 March, 2016
- Sandeep Kumar, 'Walsh Felloship student progress report ' - Teagasc, Ireland - 31 May, 2016
- Andy Reisinger, 'Reducing emissions from agriculture to meet the 2°C target' - invited presentation at FAO workshop on enhanced transparency framework for climate change, Bangkok - 27 June, 2016
- Andy Reisinger, 'Measuring progress for actions to reduce GHG emissions' - invited presentation at FAO workshop on enhanced transparency framework for climate change, Bangkok - 28 June, 2016

International Visitors and Groups

- Meeting: US Ambassador to New Zealand: 12 June, 2015 - Palmerston North
- Meeting: French Ambassador to New Zealand: 23 July, 2015 - Palmerston North
- Meeting: African inventory delegation: 27 -31 July, 2015 - Wellington/Palmerston North
- Delegation: Brazilian researchers (EMBRAPA): 24 -28 August, 2015 - Various
- Delegation: Paraguayan researchers: 28 August, 2015 - Palmerston North
- Delegation: Uruguay researchers: 23 September, 2015 - Palmerston North
- Meeting: DSM: 12 February, 2016 - Palmerston North

NZAGRC Global Research Alliance related interactions

- Meeting: GRA LRG: 23-24 June, 2015 - Lodi, Italy
- Meeting: LRG Co-Chairs: 26 August, 2015 - Teleconference
- Meeting: GRA/WFO Study Tour: 1 September, 2015 - Palmerston North
- Meetings: Annual GRA projects: 1 September, 2015 - Wellington
- Meeting: GRA Council: 8-10 September, 2015 - Des Moines
- Meeting: CCAC Steering Group: 21 September, 2015 - Teleconference
- Workshop: South East Asia Inventory - policy & practice: 23-29 September, 2015 – Bangkok

- Andy Reisinger, 'Constructing Tier 2 inventories for livestock sub-sectors' - keynote address as part of LRG workshop on developing advanced emission inventories, Bangkok - 23 September, 2015
- Meeting: Livestock Manure Management Advisory Board: 10 October, 2015 - Addis Ababa
- Meeting: LRG Co-Chairs: 14 October, 2015 - Teleconference
- Meeting: GRA Quarterly Meeting: 5 November, 2015 - Paraparaumu
- Meeting: LEARN Awards Assessment Panel: 3 December, 2015 - Palmerston North
- Meeting: New Zealand research priorities: 9 December, 2015 - Paraparaumu
- Meeting: GRA Co-Chairs: 16 December, 2015 - Teleconference
- Meeting: FAO : 20 January, 2016 - Rome, Italy
- Andy Reisinger, 'NZ GRA profile' - NZ Washington DC Embassy science reception - 05 February, 2016
- Meeting: LRG NZ Coordinators Quarterly meeting: 9 February, 2016 - Wellington
- Meeting: LRG Co-Chairs: 9 February, 2016 - Teleconference
- Meeting: GRA Co-chairs: 12 February, 2016 - Teleconference
- Meeting: GRA ASGGN: 14 February, 2016 - Melbourne, Australia
- Meeting: GRA MMN: 14 February, 2016 - Melbourne, Australia
- Meeting: LRG Network Coordinators: 16 February, 2016 - Melbourne, Australia
- Meeting: GRA FNN: 18 February, 2016 - Melbourne, Australia
- Meeting: LRG: 19-20 February, 2016 - Melbourne, Australia
- Workshop: South East Asia Inventory development: 20-24 March, 2016 - Kuala Lumpur
- Meeting: GLEAM/CCAC project: 6-7 April, 2016 - Rome
- Workshop: S.E. Asia Inventory development : 12-15 April, 2016 - Jakarta
- Workshop: GRA-FAO Inventory: 27-30 June, 2016 - Bangkok

Media Interactions

The NZAGRC has provided comment on a range of issues to the media over the past year. This is not all captured in the interactions below.

- Media: Business Desk: 14 December, 2015
- Media: Nine to Noon: 17 December, 2015
- Susanna Rutledge, Louis Schipper & Paul Mudge, 'Can we build our soil carbon bank balance? ' - NZFarmer.co.nz / Waikato Times Farmer / New Zealand farmers weekly / NZ DairyExporter / Country-wide - 02 December, 2015
- Interview: Global Research Alliance & ETS: 24 January, 2016
- Media: BBC "Nightmares of nature": 1 February, 2016
- Media: Interview with Rebecca Macfie for the Listener: 25 February, 2016

Conference Presentations

- Suzanne Rowe, Neville Jopson, Eleanor Linscott, Mark Young, Ken Dodds, Shannon Clarke, Tim Byrne, Graham Alder, 'Contract session: Application of genetic technologies to the New Zealand sheep industry' - New Zealand society of animal production - conference proceedings - 01 July, 2015
- Saman Bowatte, Coby Hoogendoorn, Paul Newton, Shona Brock, Phil Theobald, 'Pasture species and cultivar effects on nitrous oxide emissions after cattle urine application' - conference - 03 July, 2015
- Andy Reisinger, 'Reducing GHGs from agriculture: promises and challenges' - keynote address to Blue Greens meeting as part of New Zealand National Party conference - 26 July, 2015
- Ron Ronimus, Stefan Muetzel, Mike Tavendale, Kristy Lunn, Yanli Zhang, Carrie Sang, Debjit Dey, Renne Atua, Marion Weimar, James Cheung, Andrew Sutherland-Smith, Patrick Edwards, William Whitman, William Denny, Greg Cook, Vince Carbone, Linley Schofield, 'Targeting rumen methanogens to aid the development of methane mitigation agents' - Joint Annual International Union for Biochemistry and Molecular Biology (IUBMB) with Brazil Society - 11 August, 2015
- Ron Ronimus & Wiebke Kaziur, 'Investigation of metabolic enzymes from thermophilic pseudomurein-containing methanogens' - University of Duisburg-Essen - 14 August, 2015
- John McEwan, Ken Dodds, Suzanne Rowe, Rudi Brauning, Shannon Clarke, 'Frontiers of sheep genomics in New Zealand' - International Workshop on Sheep Genetics and Genomics (the 2nd Beijing Sheep Forum) - 21 August, 2015
- Vince Carbone, Kristy Lunn, Stefan Muetzel, Michael Tavendale, Yan-li Zhang, Carrie Sang, Debjit Dey, Renee Atua, Marion Weimar, James Cheung, Patrick Edwards, William Whitman, William Denny, Siva Ganesh, Mark Morrison, Christopher McSweeney, Yasuo Kobayashi, Linley Schofield, Greg Cook, Ron Ronimus, 'High-throughput screening of rumen methanogens is aiding the development of methane mitigation agents' - ComBio 2015 - 25 August, 2015
- Suzanne Rowe, Sandra Kittelmann, Peter Janssen, John McEwan, Graham Wood, Ken Dodds, Siva Ganesh, Michelle Kirk, Sharon Hickey, 'Genetic Control of the rumen microbiome' - Queenstown Medical Conference - 04 September, 2015
- Ron Ronimus, 'High-throughput screening of rumen methanogens is aiding the development of methane mitigation agents' - New Zealand Microbiological Society Meeting in Rotorua, November 1-5, 2015 - 09 October, 2015
- Ron Ronimus & Kristy Lunn, 'Accelerating the Development of Inhibitors for the Reduction of Ruminant Methane Emissions using High-Throughput Screening Methods' - New Zealand Microbiological Society annual conference, Rotorua, Nov 2-6 - 03 November, 2015
- John McEwan, Suzanne Rowe, Peter Janssen, Sharon Hickey, Arjan Jonker, 'PAC: New Zealand Experience' - Project Workshop Attwood Melbourne: DAFF Filling the research gap II: Host control of methane emissions - 09 November, 2015
- Susanna Rutledge, Paul Mudge, Aaron Wall, Dave Campbell, Louis Schipper, Jack Pronger, 'CO_2 and water dynamics following pasture renewal to a moderately diverse pasture' - Ozflux Conference 2015 (Australian-New Zealand flux researchers network annual meeting) - 17 November, 2015
- Cecile de Klein, Mike Harvey & Neil Cox, 'Nitrous oxide chamber methodologies: Evolving issues' - ASA-CSSA-SSSA Conference, Minneapolis, USA - 19 November, 2015
- Andy Reisinger, 'Making the UNFCCC work for Agriculture in Asia and the Pacific' - FAO workshop: Making the UNFCCC work for agriculture in the Asia-Pacific - 19 November, 2015
- Linley Schofield, Yanli Zhang, Carrie Sang, Renee Atua, Salome Molano, Amy Beattie, Debjit Dey, Greg Cook, James Cheung, Yasuo Kobayashi, William Whitman, Chris McSweeney, Mark Morrison, Bill Denny, Andrew Sutherland-Smith, Vince Carbone, Ron Ronimus, 'High-throughput screening for the discovery of novel inhibitors to mitigate ruminant methane emissions' - Pacifichem 2015 (Dec 15-20) - The International Chemical Congress of Pacific Basin Societies 2015 - 04 December, 2015
- Susanna Rutledge, Dave Campbell, Aaron Wall, Jack Pronger, Paul Mudge, Louis Schipper, 'CO_2 dynamics following pasture renewal to a moderately diverse pasture' - WaiBoP soils conference - 04 December, 2015
- Hong Di, 'Mitigation of nitrous oxide emissions using a nitrification inhibitor, alternative pasture and forage plants and gibberellic acid' - 19th Nitrogen Workshop - 09 December, 2015
- Ron Ronimus, 'Using chemogenomic methods to develop anti-methanogen inhibitors' - Gordon Research Conference, antibacterial drug development - 16 December, 2015
- Ruidong Xiang, Jody McNally, Suzanne Rowe, Arjan Jonker, Cesar Pinares-Patino, Alan Archibald, Jude Bond, Hutton Oddy, Phil Vercoe, John McEwan, Brian Dalrymple, 'The transcriptomic and regulatory dynamics of the rumen epithelium of sheep' - Plant and Animal Genome XXIV - 07 January, 2016

- Hong Di, 'Nitrous oxide emissions and relationships with ammonia oxidisers, soil conditions, and application of a nitrification inhibitor' - GGAA conference Melbourne - February, 2016
- Sheree Balvert, Jiafa Luo, Louis Schipper, Cecile de Klein, 'Naturally occurring compounds in animal urine that may inhibit nitrous oxide emissions from soils' - Greenhouse Gas and Animal Agriculture Conference 2016 - February, 2016
- Arjan Jonker, Sharon Hickey, Suzanne Rowe, Brooke Bryson, Emily Jones, German Molano, Stephen Olinga, Sarah MacLean, Cesar Pinares-Patino, John McEwan, 'Progeny from low methane selection line sheep also have lower emissions when grazing pasture' - GGAA2016 - February, 2016
- Ron Ronimus & Greg Cook, 'Development of Multi-Well Plate Methods Using Pure Cultures of Methanogens to Identify Novel Inhibitors For Suppressing Ruminant Methane Emissions' - GGAA conference - February, 2016
- Sandeep Kumar, Gemma Henderson, Sandra Kittelmann, Mark L. Patchett, Sinead M. Waters, Peter H. Janssen, 'Quinella: low-methane associated bacteria in the sheep rumen' - 16th International Symposium on Microbial Ecology - 05 February, 2016
- Xuezhao Sun, David Pacheco, Dongwen Luo, 'Forage brassicas as a mitigation tool for enteric methane emissions' - 2016 Greenhouse Gas and Animal Agriculture (GGAA) Conference - February, 2016
- Vince Carbone, Linley Schofield, Yanli Zhang, Carrie Sang, Debjit Dey, Ingegerd Hannus, William Martin, Andrew Sutherland-Smith, Ron Ronimus, 'Structure and Evolution of the Archaeal Lipid Synthesis Enzyme sn-Glycerol-1-phosphate Dehydrogenase' - SCANZ CRYSTAL 30 - 08 February, 2016
- David Pacheco, Indrakumar Vetharaniam, Ronaldo Vibart, Xuezhao Sun, 'Evaluation of methane predictions from a sheep rumen model' - 2016 Greenhouse Gas and Animal Agriculture Conference - February, 2016
- Ron Ronimus, Greg Cook & Gemma Henderson, 'Enzyme- and gene-based approaches for developing methanogen-specific compounds to control ruminant methane emissions: a review' - GGAA conference - February, 2016
- Ron Ronimus & Greg Cook, 'Using chemogenomic methods to develop anti-methanogen inhibitors' - GGAA, Feb 14-18 - February, 2016
- Ron Ronimus & Greg Cook, 'An integrated compound library screening approach for discovery of specific inhibitors for mitigating ruminant methane emissions' - GGAA Feb 14-18 - February, 2016
- Neha Jha, Surinder Saggar, Thilak Palmada, Peter Berben, Andrew McMillan, Jiafa Luo, 'Lime enhances denitrification and denitrifier gene abundance in soils treated with urine and urine+DCD' - Fertilizer and Lime Research Centre Annual Workshop 2016 - 10 February, 2016
- Sandeep Kumar, Sandra Kittelmann, Gemma Henderson, Ganesh Siva, Mark L. Patchett, Sinead M. Waters, Peter H. Janssen, 'Diagnostic rumen bacteria associated with low-methane emitting sheep' - 6th Greenhouse Gas and Animal Agriculture Conference (GGAA2016) - February, 2016
- Sheree Balvert, Jiafa Luo, Louis Schipper, Cecile de Klein, 'Methodology for rapid and initial assessment of the reduction potential of nitrous oxide mitigation options.' - 6th Greenhouse Gas in Animal Agriculture Conference, Melbourne, Australia - February, 2016
- Andy Reisinger & Harry Clark, 'How much does livestock actually contribute to global warming?' - GGAA 2016 - February, 2016
- Stefan Muetzel, Katherine Lowe, Sarah Maclean, Sandra Kittelmann, 'Are methanogens an essential part of the rumen microflora' - MICROHD2016, Bangalore, India - 25 February, 2016
- Ron Ronimus, 'Using chemogenomic methods to develop anti-methanogen inhibitors' - Gordon Research Conference, antibacterial drug development - 01 March, 2016
- Ruidong Xiang, Jody McNally, Suzanne Rowe, Arjan Jonker, Cesar Pinares-Patino, Jude Bond, Hutton Oddy, Phil Vercoe, John McEwan, Brian Dalrymple,, 'Gene network analysis identifies rumen epithelial processes perturbed by diet and correlated with methane production and yield' - 35th International Society of Animal Genetics Conference July 2016 Utah USA. - 07 March, 2016
- Vince Carbone, Kristy Lunn, Stefan Muetzel, Michael Tavendale, Yan-li Zhang, Carrie Sang, Debjit Dey, Renee Atua, Marion Weimar, James Cheung, Patrick Edwards, William Whitman, William Denny, Siva Ganesh, Mark Morrison, Christopher McSweeney, Yasuo Kobayashi,Linley Schofield, Greg Cook, Ron Ronimus, 'High Throughput Chemical Screening of Rumen Methanogens' - ASM conference 2016 - 14 March, 2016
- Miko Kirschbaum, 'Modelling changes in soil carbon stocks in New Zealand grazed pastures in response to variations in management and environmental factors' - International Crop Modelling Symposium (iCROPM2016) - 15 March, 2016
- Andy Reisinger, 'Climate Change impacts and implications: an integrated assessment in a lowland environment of New Zealand' - 8th International Congress on Environmental Modelling and Software(iEMSs) - 08 April, 2016
- Neil Wedlock, Art Subharat, Sarah Hook, Eric Altermann, Sinead Leahy, Peter Janssen, 'Vaccination of ruminants to reduce methane emissions' - IVIS 2016 - 28 April, 2016
- Arjan Jonker, David Scobie Robyn Dynes, Grant Edwards, Cecile De Klein, Russel McAuliffe, Anna Taylor, Trevor Knight, Garry Waghorn, 'Methane emissions from dairy cows

fed fodder beet' - Australasian Dairy Symposium - 30 April, 2016

- Vince Carbone, Kristy Lunn, Stefan Muetzel, Michael Tavendale, Yan-li Zhang, Carrie Sang, Debjit Dey, Renee Atua, Marion Weimar, James Cheung, Patrick Edwards, William Whitman, William Denny, Siva Ganesh, Mark Morrison, Christopher McSweeney, Yasuo Kobayashi,Linley Schofield, Greg Cook, Ron Ronimus, 'High Throughput Chemical Screening of Rumen Methanogens' - ASM conference 2016 - 23 May, 2016
- Arjan Jonker, John McEwan, Suzanne Rowe, 'Selection of low CH_4 yield sheep' - Methanet/NzOnet meeting - 27 May, 2016
- Miko Kirschbaum, Louis Schipper, Paul Mudge, Susanna Rutledge, Nicolas Puche, David Campbell, 'Estimating changes in soil carbon stocks on a dairy farm in response to management and environmental changes' - Joint MethNet, NzONet, CarboNet meeting. - 27 May, 2016
- Ron Ronimus, Greg Cook, Stefan Muetzel, William Denny, Wiulliam Whitman, Mike Tavendale, Vince Carbone, Linley Schofield, 'Ronimus potser for INRA-Rowett Gut Microbiology' - INRA-Rowett Gut Microbiology Conference - 19 June, 2016

Journal Articles

Submitted

- Cherubini, F., Fuglestvedt, J., Gasser, T., Reisinger, A., Cavalett, O., Huijbregts, M. A. J., Levasseur, A. et al (2016). Bridging the gap between impact assessment methods and climate science. *Environmental Science & Policy, 64*, 129-140. doi: http://dx.doi.org/10.1016/j.envsci.2016.06.019
- Di, H. J., Cameron, K. C., Podolyan, A., Edwards, G. R., de Klein, C. A. M., Dynes, R., & Woods, R. (2016). The potential of using alternative pastures, forage crops and gibberellic acid to mitigate nitrous oxide emissions. [Article]. *Journal of Soils and Sediments, 16*(9), 2252-2262. doi: 10.1007/s11368-016-1442-1
- Henderson, G., Cox, F., Sun, X., Ganesh, S., Altermann, E., Pacheco, D., & Janssen, P. H. (Submitted). The impact of fresh forage brassica diets and sampling time on sheep rumen microbial community compositions. *TBC*.
- Jonker, A., Hickey, S., McEwan, J. C., Pinares-Patino, C., Olinga, S., Diaz, A., . . . Rowe, S. (Submitted). Sheep from methane yield (g/kg DMI) selection lines also have differences in methane yield under pastoral farming conditions. *Journal of Animal Science*.
- Kirschbaum, M. U. F., Schipper, L. A., Mudge, P. L., Rutledge, S., Puche, N., & Campbell, D. I. (Submitted). The trade-offs between milk production and soil organic carbon storage in dairy systems under different management and environmental factors. *Science of the Total Environment*.
- Levasseur, A., Cavalett, O., Fuglestvedt, J. S., Gasser, T., Johansson, D. J. A., Jørgensen, S. V., Cherubini, F. et al (2016). Enhancing life cycle impact assessment from climate science: Review of recent findings and recommendations for application to LCA. [Review]. *Ecological Indicators, 71*, 163-174. doi: 10.1016/j.ecolind.2016.06.049
- Li, Y., Leahy, S. C., Jeyanathan, J., Cox, F., Altermann, E., Kelly, W. J., . . . Attwood, G. T. (Submitted). The Complete Genome Sequence of the Methanogenic Archaeon ISO4-H5 Provides Insights into the Methylotrophic Lifestyle of a Ruminal Representative of the Methanomassiliicoccales. *Standards in Genomic Sciences*.
- McEwan, J. C., Xiang, R., McNally, J., Rowe, S., Jonker, A., Pinares-Patino, C., Dalrymple, B. P. et al (Submitted). Gene network analysis identifies rumen epithelial cell proliferation, differentiation and metabolic pathways perturbed by diet and correlated with methane production. *Nature Publishing Group: Systems biology and Applications*.
- Reisinger, A. (Submitted). How much does livestock actually contribute to global warming? *Environmental Research Letters*.
- Ronimus, R. S., Carbone, V., Schofield, L. R., Hannus, I., & Sutherland-Smith, A. J. (Submitted). The Crystal Structure of 2,5-diamino-6-(ribosylamino)-4(3H)-pyrimidinone 5-phosphate reductase (MthRED) from Methanothermobacter thermautotrophicus.
- Schipper, L. A., McNally, S. R., Laughlin, D. C., Rutledge, S., Dodd, M. B., & Six, J. (Submitted). Herbicide application during pasture renewal increases root turnover and carbon input to soil in perennial ryegrass and white clover pasture.
- Subharat, S., Shu, D., Zheng, T., Buddle, B. M., Kaneko, K., Hook, S., Wedlock, D. N. et al (2016). Vaccination of Sheep with a Methanogen Protein Provides Insight into Levels of Antibody in Saliva Needed to Target Ruminal Methanogens. *PLoS ONE, 11*(7), e0159861. doi: 10.1371/journal.pone.0159861
- West, G., Journeaux, P., Wakelin, S., & Kingi, T. (Submitted). Collective land tenure systems and greenhouse gas mitigation among Maori farmers in Aotearoa, New Zealand *Pan Pacific Indigenous Resource Management*: Australian National University Press.

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- Allen, M. R., Fuglestvedt, J. S., Shine, K. P., Reisinger, A., Pierrehumbert, R. T., & Forster, P. M. (2016). New use of global warming potentials to compare cumulative and short-lived climate pollutants. [Letter]. *Nature Clim. Change, 6*(8), 773-776. doi: 10.1038/nclimate2998
- Gardiner, C. A., Clough, T. J., Cameron, K. C., Di, H. J., Edwards, G. R., & de Klein, C. A. M. (2016). Potential for forage diet manipulation in New Zealand pasture ecosystems to mitigate ruminant urine derived N2O emissions: a review. *New Zealand Journal of Agricultural Research, 59*(3), 301-317. doi: 10.1080/00288233.2016.1190386
- Gregorini, P., Beukes, P., Waghorn, G., Pacheco, D., & Hanigan, M. (2015). Development of an improved representation of rumen digesta outflow in a mechanistic and dynamic model of a dairy cow, Molly. *Ecological Modelling, 313*, 293-306. doi: http://dx.doi.org/10.1016/j.ecolmodel.2015.06.042
- Hoogendoorn, C. J., Luo, J., Lloyd-West, C. M., Devantier, B. P., Lindsey, S. B., Sun, S., . . . Judge, A. (2016). Nitrous oxide emission factors for urine from sheep and cattle fed forage rape (Brassica napus L.) or perennial ryegrass/white clover pasture (Lolium perenne L./Trifolium repens). *Agriculture, Ecosystems & Environment, 227*, 11-23. doi: http://dx.doi.org/10.1016/j.agee.2016.04.029
- Kelly, W. J., Henderson, G., Pacheco, D. M., Li, D., Reilly, K., Naylor, G. E., . . . Leahy, S. C. (2016). The complete genome sequence of Eubacterium limosum SA11, a metabolically versatile rumen acetogen. [Article]. *Standards in Genomic Sciences, 11*(1). doi: 10.1186/s40793-016-0147-9
- Kelly, W. J., Li, D., Lambie, S. C., Cox, F., Attwood, G. T., Altermann, E., & Leahy, S. C. (2016). Draft Genome Sequence of the Rumen Methanogen Methanobrevibacter olleyae YLM1. *Genome Announcements, 4*(2). doi: 10.1128/genomeA.00232-16
- Kelly, W. J., Li, D., Lambie, S. C., Jeyanathan, J., Cox, F., Li, Y., . . . Leahy, S. C. (2016). Complete Genome Sequence of Methanogenic Archaeon ISO4-G1, a Member of the Methanomassiliicoccales, Isolated from a Sheep Rumen. *Genome Announcements, 4*(2). doi: 10.1128/genomeA.00221-16
- Kelly, W. J., Pacheco, D. M., Li, D., Attwood, G. T., Altermann, E., & Leahy, S. C. (2016). The complete genome sequence of the rumen methanogen Methanobrevibacter millerae SM9. [Article]. *Standards in Genomic Sciences, 11*(1). doi: 10.1186/s40793-016-0171-9
- Kittelmann, S., Kirk, M. R., Jonker, A., McCulloch, A., & Janssen, P. H. (2015). Buccal Swabbing as a Noninvasive Method To Determine Bacterial, Archaeal, and Eukaryotic Microbial Community Structures in the Rumen. *Applied and Environmental Microbiology, 81*(21), 7470-7483. doi: 10.1128/aem.02385-15
- Liu, Q., Jones, C. S., Parsons, A. J., Xue, H., & Rasmussen, S. (2015). Does gibberellin biosynthesis play a critical role in the growth of Lolium perenne? Evidence from a transcriptional analysis of gibberellin and carbohydrate metabolic genes after defoliation. [Article]. *Frontiers in Plant Science, 6*(NOVEMBER). doi: 10.3389/fpls.2015.00944
- McMillan, A. M. S., Pal, P., Phillips, R. L., Palmada, T., Berben, P. H., Jha, N., . . . Luo, J. (2016). Can pH amendments in grazed pastures help reduce N2O emissions from denitrification? - The effects of liming and urine addition on the completion of denitrification in fluvial and volcanic soils. [Article]. *Soil Biology and Biochemistry, 93*, 90-104. doi: 10.1016/j.soilbio.2015.10.013
- Schon, N. L., Mackay, A. D., Gray, R. A., & van Koten, C. (2016). Establishment of Aporrectodea longa and measurement of dung carbon incorporation in soils under permanent pasture. [Article]. *European Journal of Soil Biology, 75*, 174-179. doi: 10.1016/j.ejsobi.2016.05.005
- Sparling, G. P., Chibnall, E. J., Pronger, J., Rutledge, S., Wall, A. M., Campbell, D. I., & Schipper, L. A. (2016). Estimates of annual leaching losses of dissolved organic carbon from pastures on Allophanic Soils grazed by dairy cattle, Waikato, New Zealand. [Article]. *New Zealand Journal of Agricultural Research, 59*(1), 32-49. doi: 10.1080/00288233.2015.1120222
- Sun, X., Pacheco, D., & Luo, D. (2016). Forage brassica: a feed to mitigate enteric methane emissions? *Animal Production Science, 56*(3), 451-456. doi: http://dx.doi.org/10.1071/AN15516
- Vetharaniam, I., Vibart, R. E., Hanigan, M. D., Janssen, P. H., Tavendale, M. H., & Pacheco, D. (2015). A modified version of the Molly rumen model to quantify methane emissions from sheep. [Article]. *Journal of Animal Science, 93*(7), 3551-3563. doi: 10.2527/jas2015-9037
- Wang, Y., Janssen, P. H., Lynch, T. A., Brunt, B. v., & Pacheco, D. (2016). A mechanistic model of hydrogen–methanogen dynamics in the rumen. *Journal of Theoretical Biology, 393*, 75-81. doi: http://dx.doi.org/10.1016/j.jtbi.2015.12.026
- Wollenberg, E., Richards, M., Smith, P., Havlík, P., Obersteiner, M., Tubiello, F. N., . . . Campbell, B. M. (2016). Reducing emissions from agriculture to meet the 2 °C target. *Global Change Biology*, n/a-n/a. doi: 10.1111/gcb.13340

Other interactions/publications

- Neil Wedlock, Suparsak Subharat, Dairu Shu, Faith Cox, Tania Wilson, Sandra Kittelmann, Tao Zheng, Bryce Buddle, Sarah Hook, Eric Altermann, Sinead Leahy, William Kelly, Graeme Attwood, Peter Janssen, 'Vaccination of ruminants to reduce methane emissions' – abstract for GGAA 2016 - 26 June, 2015
- Ron Ronimus & Greg Cook, 'An integrated compound library screening approach for discovery of specific inhibitors for mitigating ruminant methane emissions' - abstract for GGAA conference - 01 July, 2015
- Natasha Swainson, Stefan Muetzel & Harry Clark, 'Additional data to the methane inventory for sheep and the effect on the current predictions' - abstract for GGAA 2016 - 01 July, 2015
- Sandeep Kumar, Sandra Kittelmann, Gemma Henderson, Ganesh Siva, Mark Patchett, Sinead Waters, Peter Janssen, 'Diagnostic rumen bacteria associated with low-methane emitting sheep' - abstract for GGAA conference 2016 - 09 July, 2015
- Sandra Kittelmann, Michelle R Kirk & Peter H Janssen, 'Deposition of sequence and meta data for PGGRC-NZAGRC objective 5.6.2' - NCBI Short Read Archive - 10 July, 2015
- Arjan Jonker, Sharon Hickey, Suzanne Rowe, Brooke Bryson, E. Jones, German Molano, Stephen Olinga, Sarah MacLean, Cesar Pinares-Patino, John McEwan, 'Progeny from low methane selection line sheep also have lower emissions when grazing pasture' - abstract for GGAA2016 - 14 July, 2015
- Ruidong Xiang, Jody McNally, Suzanne Rowe, Arjan Jonker, Cesar Pinares-Patino, Jude Bond, Hutton Oddy, Phil Vercoe, John McEwan, Brian Dalrymple, 'Transcriptomic analysis identifies rumen volatile fatty acids metabolism as a candidate pathway for host regulation of methane production' - abstract for GGAA 2016 - 15 July, 2015
- David Pacheco, Indrakumar Vetharaniam, Ronaldo Vibart, Xuezhao Sun, 'Evaluation of Methane Predictions using a Sheep Rumen Model' - abstract for 6th Greenhouse Gas and Animal Agriculture Conference - 15 July, 2015
- Andy Reisinger, 'How much does livestock actually contribute to climate change?' - abstract for GGAA 2016 conference - 15 July, 2015
- Sandra Kittelmann & Peter H Janssen, 'Cheek swabs shortcut rumen sampling process' - NZ Genomics Limited Annual Report - 17 July, 2015
- Dragana Gagic, 'Use of rumen methanogen genomes sequences for Marsden funded work ' - Marsden Fast Start final report/ Filomena Ng PhD thesis/ manuscript in Applied and Enviromental Micr - 20 August, 2015
- Natasha Swainson, Stefan Muetzel & Harry Clark, 'Examining the New Zealand methane emissions dataset to obtain updated predictions of methane emissions from sheep suitable for incorporation into the national greenhouse gas inventory' - Report on sheep inventory to Ministry for Primary Industry, New Zealand - 10 September, 2015
- Sandra Kittelmann, Peter H. Janssen & Michelle R. Kirk, 'Deposition of sequence and meta data for PGGRC-NZAGRC objective 5.6.1. (3633 progeny)' - NCBI-SRA - 15 September, 2015
- David Whitehead, 'Map of soil carbon from previous contract' - For use by PhD student - 28 September, 2015
- Susanna Rutledge, Dave Campbell & Louis Schipper, 'Scott Farm soil moisture data' - Data sharing with DairyNZ for N leaching model - 09 October, 2015
- Andy Reisinger, Michele Hollis, Cecile de Klein, Dave Frame, Mike Harvey, Martin Manning, Suzi Kerr, Anna Robinson, 'Cows, sheep and science: consensus and divergence on the science of agricultural non-CO_2 emissions' - Report produced by Motu under contract to the Parliamentary Commissioner to the Environment - 04 December, 2015
- Preeti Raju, 'Identifying alternative hydrogen utilisers in the rumen' - PhD thesis submission, Massey University - 15 January, 2016
- Geoff Bates & Bert Quin, 'Urine patch detection optimisation' - Email to database - 09 February, 2016
- Vince Carbone & Ron Ronimus, 'Marsden abstract' - Marsden fund council by the Royal Society of New Zealand - 10 February, 2016
- Susanna Rutledge, Dave Campbell, Aaron Wall, Jack Pronger, Paul Mudge, Louis Schipper, 'CO_2 and water dynamics following pasture renewal to a moderately diverse pasture' - Seminar at Wageningen University and Research Centre, Wageningen, The Netherlands - 10 February, 2016
- Ron Ronimus, 'Pulling the plug on global warming: elucidation of the activation pathway for methane formation in methanogenic archaea' - Marsden proposal - 12 February, 2016
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