NEW ZEALAND
AGRICULTURAL GREENHOUSE GAS
Research Centre

Annual Report 2017

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 may 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 2016/17 and their envisaged impacts.

NZAGRC/PGgRc output	*Expected impact*
The breeding work has found: • Differences in methane (CH_4) emissions between sheep selection lines persist and can be expanded with continued breeding. • Differences in economic value in favour of the low CH_4 selection line based on the NZ dual purpose overall maternal index were seen this year and this looks to be an on-going trend. • Using genomic markers to select for low methane animals is looking promising.	Direct breeding for low emissions and selection via genomic markers has the potential to reduce emissions from the sheep sector by up to 1% per annum. Impact will rely on proving the economic benefits of selecting for the low methane trait. Results are encouraging so far but need to be evaluated in the context of other breeding goals.
Initial work into cattle breeding for lower methane emissions has shown that integrated DMI*-CH_4 measurement stations provide a good measure of daily CH_4 production and CH_4/kg DMI from groups of animals and is a suitable technology to evaluate nutritional treatments aimed at mitigating CH_4 emissions for groups of animals. However, initial analysis of the data suggest that the technique may be too variable for the new measurement technology to be used to identify individuals with contrasting emissions. *(DMI = Dry matter intake)	Breeding for low emitting cattle is still constrained by the lack of a measurement facility that can screen sufficient numbers of animals to identify animals with contrasting emissions. New Zealand now has a well-validated method for estimating methane emissions from cattle that is highly suited to comparing treatment differences applied at a group level. Previously measurement facilities existed for only 4 cattle. This new facility which can measure intake and emissions from up to 40 animals will enhance our ability to undertake work with cattle.
Three inhibitors reduced methane from sheep by greater than 20% over 16-day and 28-day trials. Two other compounds retained some activity (15-20%) over 16 days. A commercial partner for the project has been engaged.	The successful trialling of potential inhibitors *in vivo* with a substantive impact on methane emissions means that this programme is now firmly into the product development and commercialisation stage. Further work will be led by the PGgRc in collaboration with a commercial partner.
Studies have clearly demonstrated that plants can have a direct effect on nitrous oxide (N_2O) emissions. One plant species, plantain, seems to affect nitrogen partitioning in the animal. However, the effect on emissions so far has been inconsistent.	Current results have pointed the way forward for a more targeted approach to examine the impact of plants on N_2O emissions. Plantain, which also reduces nitrogen (N) leaching, will be targeted for more detailed studies which include looking at the net impacts on CH_4, N_2O and soil carbon (C).

Modelling the impact of irrigation on soil C storage suggests that N supply is crucial in determining whether irrigation results in gains or losses of soil C.	The insights from the modelling work will help design management practices that lower the risk of irrigation reducing soil carbon stocks
Work on Maori farms developed a spreadsheet calculator that can readily summarise the effect of different mitigation scenarios on farm profitability and GHG/nitrogen emissions, and visualise options using the MyLand model. Work with four focus farms showed that while many farm system changes that reduce GHG emissions also reduce profitability, there are some apparent win-win situations where decreasing emissions are coupled with increased profitability.	The tool allows farmers to consider changes in their farm management based on currently available practices to include GHG mitigation as a management goal alongside profitability and other environmental goals, such as water quality. The approach relies on good farm data but where these are available, can help farmers on win-win situations and barriers to, as well as support for, their increased adoption. The approach can be readily adapted to incorporate novel mitigation options as these reach the market.

CHAIR'S REPORT

The past year has seen a rapidly changing international situation with respect to the environment. Following agreement by all governments at the Paris meeting in December 2015 to act on climate change, many countries thought that they would have a few years to finalise the details. This has not been the case. Governments around the world have been fast tracking climate change issues and ratifying the global agreement much earlier than anticipated. New Zealand ratified the agreement in October 2016 and it came into force on 4th November 2016.

The New Zealand government has set a target to reduce greenhouse gas emissions to 30 per cent below 2005 levels by 2030. It 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) in 2015/16. This reflects the importance of developing domestic solutions, as well as fostering international collaboration to address a globally significant problem.

There is a growing urgency at all levels to address climate change. Governments, businesses and research organisations are all coming on board and the Paris agreement is influencing long range thinking and planning. When contemplating agricultural GHGs, there are a number of science and policy challenges. Large technical questions remain about how to mitigate agriculture's emissions whilst still producing food in sufficient quantities to supply an expanding population. It is critical to develop strategies, both short and long term, to achieve the duel objectives of reducing GHG emissions and maintaining food security. New mitigation technologies and practices will make a valuable contribution to government strategies and subsequent action plans. There is also a need to consider international coalitions and alliances in the future in order to find lasting global solutions.

In the case of New Zealand, the agriculture sector contributes 48% to the country's GHG emissions. It's becoming widely accepted that this sector will have to contribute to achieving the Paris target and even more to longer term goals. The emissions intensity of New Zealand agriculture, that is the emissions 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 15%. Without the efficiency gains on farms, emissions would have grown much more, by over 30%, given the increase in total food production. 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, on its own 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. Developing these approaches is the role of the NZAGRC alongside the jointly industry/government-backed PGgRc. Our efforts are a great 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 2016/17 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 continue to increase through successive breeding cycles, and several compounds which inhibit methane in the short term have been successfully trialled in animals. Commercial partners are now being engaged for the inhibitor programme, under the leadership of the PGgRc.

Through its national and international roles and responsibilities, particularly 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.

Dr Peter Millard
Chair of NZAGRC Steering Group
August 2017

NZAGRC DIRECTOR'S REPORT

Following the ratification of the Paris agreement, there has been increased momentum in the climate change space. There is mounting political and public pressure to develop practical tools and strategies to achieve the ambitious emissions reductions targets needed to restrict global warming to below 2^{o}C. 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.

A highlight for us this year was our New Zealand Agricultural GHG Mitigation Conference in March 2017 which was attended by 150 scientists, policy makers and industry representatives. The day provided an excellent opportunity to reflect on the role that NZ can play in minimising agriculture's environmental footprint to achieve local and global emission reduction targets. The Centre now has less than two years of funding left and Centre partners and stakeholders will need to begin thinking about the potential role and delivery of research supporting climate change policy and the agriculture sector once the Centre's current contract comes to an end on 30 June 2019.

Working alongside MPI and the PGgRc, our research continues to produce usable results, outputs and publications. 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, research has shown that these approaches work at the pilot scale. A particular highlight this year is that commercial partners are now engaged in discussions around the next phase of the inhibitor programme. This is being led by the PGgRc in line with agreed commercialisation strategies.

In addition to experimental work, NZAGRC-funded scientists continue to increase their engagement with farmers. In the Integrated Farm Systems and Māori programmes, meetings and hui involving scientists and farmers have increased the understanding of how current management practices can impact GHG emissions and the development of practical alternative scenarios which could reduce farming's environmental impact. This work aims 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 core 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 been increased and extended to run until June 2019. This scheme provides opportunities for undergraduates to gain experience in a research environment and stipends for post-graduates. In addition, we currently also provide direct support to 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 extension of our international collaboration with the FAO and the Climate and Clean Air Coalition and undertaking work to support the Government's Biological Emissions Reference Group. At an operational level, Victoria Hatton, who has been with us since 2010, left the NZAGRC to join MPI and work on national and international agricultural climate change policy issues while we welcomed Sinead Leahy and Laura Kearney to the team.

I would like to express my thanks to all of our Advisory Groups. The Steering Group continues to be exceptionally dedicated to the Centre and has provided valuable and knowledgeable advice throughout the last year. An international panel was brought together to review the NZAGRC science programme (excluding methane) this year. Their expertise and recommendations have been exceedingly valuable for planning the last two years of NZAGRC research programmes in soil carbon and nitrous oxide.

Dr Harry Clark
NZAGRC Director
August 2017

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.

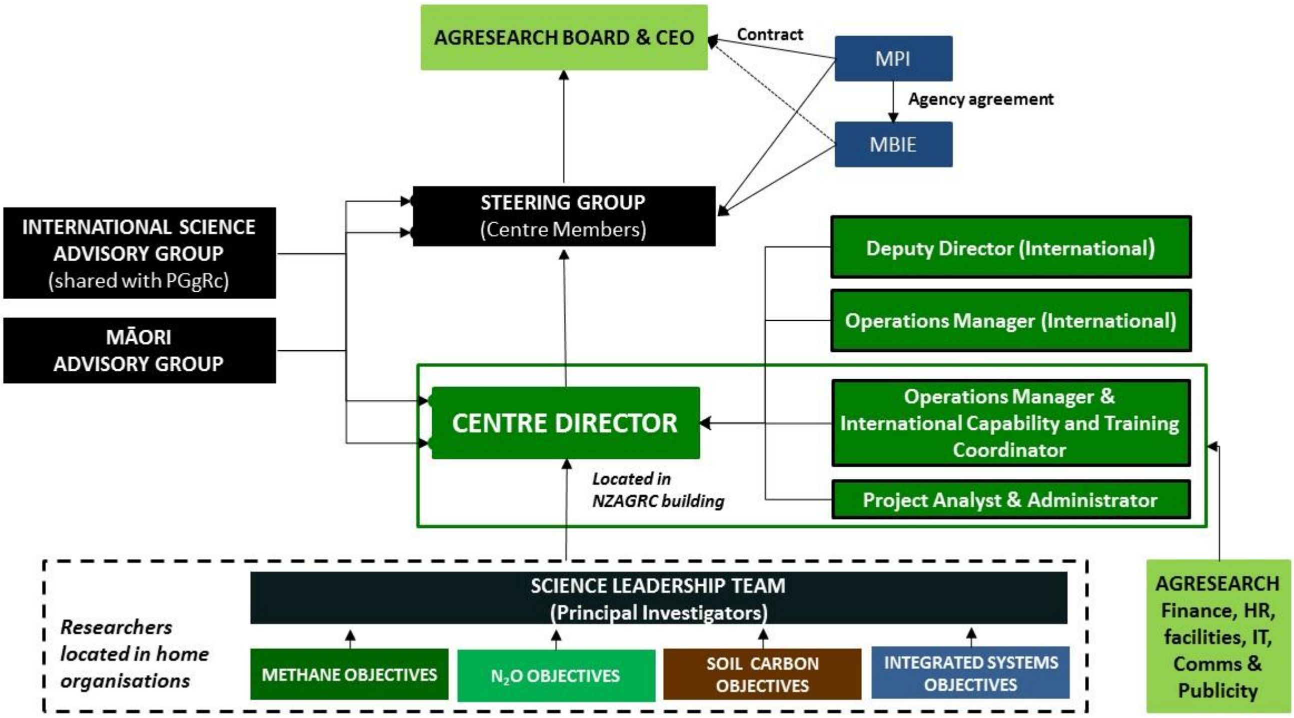
NZAGRC is not the only significant investor into agricultural GHG mitigation research in New Zealand. Much of NZAGRC methane research builds on research investments made by the PGgRc, and since 2013 the NZAGRC and PGgRc investments have been formally aligned. This involves a single research strategy 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, International Capability and Training Coordinator, 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) role was on a full-time secondment to MPI for part of the year and joined MPI permanently in March 2017. A new person, employed by AgReseach, joined the NZAGRC team to fulfil the Operations Manager (International) role, working remotely but with a routine presence in both Wellington and Palmerston North.

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) is available to monitor, advise and report on the NZAGRC's science quality and direction to the SG and NZAGRC Director as required. Input from PGgRc Board members via the SG 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 international panel's review and Centre strategy.

During 2016/17 the SG met quarterly at the NZAGRC building 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 2016/17 can be found in Appendix 1.

2016/17 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 2016/17 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. A joint NZAGRC-PGgRc New Zealand Agricultural GHG Mitigation Conference in March 2017 provided an excellent opportunity for scientists, policy makers and industry representations to reflect on the role that NZ can play in minimising agriculture's environmental footprint to achieve global emission reduction targets. Aligned workshops and a science review provided opportunities for the science teams to plan for the future.
- On-going alignment with the PGgRc and, through this relationship, active engagement with commercial entities to establish pathways to market for our technologies, including for genomic selection and breeding of low-emissions sheep, and methanogen inhibitors.

- Enhanced engagement with Māori, including a number of hui 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 and MPI).
- Proactive engagement with New Zealand policymakers including active scientific input into the Biological Emissions Reference Group.
- Contribution to, and in some cases coordination of, key science networks and funding mechanisms, including the Sustainable Land Management and Climate Change (SLMACC) fund, Methanet and NzOnet, and internationally, the global Climate and Clean Air Coalition, and European FACCE-JPI and Horizon 2020 committees.
- Active contribution of agricultural and New Zealand-specific expertise to the work of the the Intergovernmental Panel on Climate Change (IPCC), including in the scoping of upcoming IPCC reports and nomination and selection of experts to contribute to the work of the IPCC.
- Actively contributing to the development and retention of GHG-related scientific capability in New Zealand, and fostering capability in other countries.
- Running an efficient organisation with sound governance and financial control. The NZAGRC continues to use the MPI grants management system to manage both NZAGRC and GRA contracting.

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.

Mitigating Methane Emissions*	• Breeding - sheep and deer (Obj 5.1) • 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	• Feed management options (Obj 6.3) • Potential inhibitor effects on N_2O emission (Obj 6.6) • Review of the current understanding of the effects of plant species & animal forages on N_2O emissions (Obj 6.7)
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 Objs 5.9 & 5.12 which are 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. In 2016/17 updated work plans were negotiated for varying time periods, in agreement with the PGgRc Board, based on progress and results in the recent year.

Additional support for the vaccine programme was provided by the NZAGRC in 2016/17. This committed extra spending of $300,000 per annum for two years (2016/17 and 2017/18) to bring in added capability that will enable more fundamental studies on understanding the ruminant immune system to be undertaken. This funding is to cover two dedicated post-doctoral fellows. One post-doctoral fellow was appointed in late 2016/17 and the other will be recruited in early 2017/18 once the new work plan has been signed off.

A review of the existing and past work on plants and N_2O emissions in New Zealand and internationally was commissioned in 2016/17. The focus of the review is on temperate grasslands and emissions from urine patches. Since the withdrawal of DCD, identifying promising mitigation options for N_2O from urine patches has been difficult. The dairy industry has large research programmes looking at the role of plants in reducing N leaching losses and this, allied with overseas work indicating that plants can reduce N_2O emissions in some circumstances, led to the NZAGRC commencing work on plant effects on N_2O emissions in 2014. The results show promise but the inconsistencies and methodological issues mean that prior to further investment a thorough look is taken at what we do and don't know. In particular, clearer identification the routes via which plants can influence N_2O emissions is needed. The information contained in this report (due in early 2017/18) will be incorporated into research planning going forwards.

A formal review of the N_2O, Soil C and Integrated Farm Systems programmes was undertaken by an international science panel in April 2017. The recommendations of their report have been accepted by the Steering Group and have been taken into consideration for future planning.

Descriptions of the Objectives outlined above, and their progress during 2016/17, are contained in Appendix 2.

In 2016/17, key science achievements included:

- Differences in methane emissions between sheep selection lines persist and diverge. Additionally, differences in economic value in favour of the low CH_4 selection line based on the NZ dual purpose overall maternal index were seen this year and this looks to be an on-going trend.
- Using genomic markers to select for low methane animals is looking promising.
- Integrated DMI-CH_4 measurement stations have been validated and shown to be a suitable method for estimating methane emissions from cattle that is highly suited to comparing treatment differences applied at a group level. Previously measurement facilities existed for only 4 cattle. This new facility which can measure intake and emissions from up to 40 animals will enhance our ability to undertake work with cattle.
- Three inhibitors reduced methane from sheep by greater than 20% over 16-day and 28-day trials. Two other compounds retained some activity (15-20%) over 16 days. A commercial partner for the project has been engaged.
- Studies on the effect of plants on soil N_2O studies have clearly demonstrated that plants can have a direct effect on emissions. One plant species, plantain, seems to affect nitrogen partitioning in the animal. However, the effect on emissions is inconsistent.
- Modelling the impact of irrigation on soil C storage suggests that N supply is crucial in determining whether irrigation results in gains or losses of soil C.
- Development of a spreadsheet calculator that can readily summarise the effect of different mitigation scenarios, based on currently available options, on farm profitability and GHG/nitrogen emissions.

More detailed information regarding science progress during 2016/17 can be found in Appendix 2 which includes the submitted annual reports from the NZAGRC-funded Objectives.

Goal 1 metrics:

Measure	*Progress in 2016/17*
Peer-reviewed scientific journal papers	20 papers published plus 15 papers submitted
Scientific conference papers	35
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. 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 2016/17 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 2017 onwards.
- 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 a one day public conference, a range of co-branded factsheets and proactive media engagement.
- NZAGRC support for PGgRc-led activity and 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, farmers and other 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 2016/17 that included:

- A one day joint NZAGRC-PGgRc New Zealand Agricultural GHG Mitigation Conference in March 2017. This was attended by about 150 GHG scientists, policy makers and industry representatives. The day included 11 presentations, was well received by those that attended and led to positive media stories.
- Meetings with farmer groups, individual companies and organisations and giving presentations at stakeholder forums (e.g. NZAGRC planning workshops, Fonterra, Dairy Environment Leaders Forum, Royal Society of New Zealand, Intelact).
- Presenting at outreach events and giving expert lectures in New Zealand and internationally (e.g. IPCC public outreach events, FAO workshops, Victoria University course, NZ Law Society).
- Dedicated publications (e.g. annual Highlights document, factsheets and e-newsletter) and articles in farming and general press and interviews on television and radio.
- Membership of MPI science-related advisory groups (e.g. SLMACC, Methanet, Agricultural Inventory Advisory Panel, GPLER Technical Advisory Panel).

- Providing scientific information and expert advice to key stakeholders including government officials and industry (e.g. MPI, DairyNZ, Fonterra, Biological Emissions Reference Group, MfE).
- Hosting international visitors and showcasing New Zealand agricultural GHG science, including for ambassadors, high-ranking science delegations and international farming groups.
- 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).
- Increasing presence on social media.

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 2016/17 the programme team worked closely with the Trustees of their four focus farms. Field days were held on the focus farms to discuss the results of the modelling, demonstrate a spreadsheet calculator which had been developed, and discuss results with the Trustees and attending farmers. The field days were held with assistance and input from DairyNZ, Beef+Lanb NZ, and Fonterra. The focus farm Trustees and other interested parties have provided significant feedback on the modelling results and potential implications for their farms. Reaction from farmers was quite universal; they were interested in scenarios which improved farm profitability accompanied by either a decrease in GHG emissions or a slight increase in emissions. They were not interested in mitigations that decreased emissions but at a significant cost to profitability. The work identified some potential win-win interventions that could reduce emissions and increase profitability, although more work is needed to better understand barriers and risks to their adoption. The project has been well received and feedback from the MAG has been positive. The team will work on extending the project during 2017-19.

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, new programmes of activities have been developed each year for 2015/16 and 2016/17. These have ensured that we 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 with highlights as follows:

- Organisation and coordination of a one day NZ Inc Agricultural GHG Mitigation Conference in March 2017. This was attended by local and national media and helped to profile the Centre and its partners, stakeholders and funders as working together towards a common goal. Post conference information was added to the website to enable a wider audience to access presentations of interest.

- Production and dissemination of two new factsheets:
    - ‘The structure of agricultural greenhouse gas funding in New Zealand’
    - ‘Reducing New Zealand’s agricultural greenhouse gases: Methane Inhibitors’

- Regular content added to the NZAGRC website and redevelopment of navigation to enable information from our factsheets to be repackaged into web content. These changes to the website contributed to our increased web traffic over the 2016/17 year.
- A small social media presence on LinkedIn has been maintained and short stories posted with links to science, people and policy stories of relevance. This presence provided 44% of our increase in page views over the year. The Centre’s social media presence will be expanded to other platforms in 2017/18.
- Engagement with New Zealand journalists and the international media including whether seaweed is an option to mitigate methane, options for New Zealand farmers to reduce emissions, and the impact of livestock on climate change.
- Proactive media comment on the Ministry for the Environment’s ‘New Zealand’s Action on Climate Change’ and the Parliamentary Commissioner for the Environment’s report ‘Climate change and agriculture: Understanding the biological greenhouse gases’.
- NZAGRC staff assisted with extensive scientific input into the PCE report ‘Climate change and agriculture: Understanding the biological greenhouse gases’ (published October 2016).
- An updated joint communication strategy and action plan is being developed for implementation from 1 July 2017. This will dedicate increased NZAGRC resources towards communication and engagement activities in the final two years of the Centre contract.

Additionally, during 2016/17 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 2016/17
Meetings and Presentations (New Zealand)	63
Meetings and Presentations (International)	22
International Visitors and Groups	8
Global Research Alliance related interactions	25
Media interactions	26
Conference presentations	35
Journal articles in press	15
Journal articles published	20
Other interactions/publications	9

Goal 2 metrics:

Measure	*Progress in 2016/17*
Page views of Centre’s website	32,187 (+7% increase vs 2015/16)
Senior Centre staff presentations to meetings of New Zealand industry and policy stakeholders	21
Centre funded scientist presentations to the farming community and general public	13

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 in 2016/17, reflecting in part the rapidly changing international and domestic context and New Zealand's ratification of the Paris Agreement in October 2016.

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. NZAGRC senior staff made significant contributions to the work of the Biological Emissions Reference Group over the past year including a number of presentations to the Group.

The Centre's on-going inputs into the GRA and other international initiatives, as well as technical advice to government agencies and industry stakeholders to support domestic policy development, are prime examples of activities that the Centre engaged in during 2016/17 related to this goal.

Other activities by the Centre in 2016/17 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 is 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 and the scoping of the upcoming 6th Assessment Report.
- NZAGRC hosted a number of international, as well as senior-level domestic, visitors.

Goal 3 metrics:

Measure	*Progress in 2016/17*
Senior Centre staff presentations to meetings of New Zealand government policy staff	11
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 2016/17 the dedicated undergraduate “pipeline” scholarship scheme was renewed and extended with Massey, Lincoln and Waikato Universities. Prior to renewing the scheme, the scheme to date was informally evaluated. From an NZAGRC perspective the scheme has been very successful. It has encouraged students to undertake further study, provided valuable practical experience for promising students, assisted in their career development and provided valuable public exposure for the NZAGRC. In addition to the scholarship scheme, a high achieving Master’s student, aligned with the methane programme and based at Massey University/DairyNZ, received funding in 2016/17. The NZAGRC also contributed funding to hire two new dedicated post-doctoral researchers to support the vaccine programme.

Type of Capability Development	# active in 2016/17	Total funded to date*
Undergraduate - Summer student	0	22
Undergraduate - Honours student	3	11
Undergraduate - Intern	0	2
Masters Project	0	3
Masters	3	7
PhD	12	19
Post-doctoral fellow	4	7
Early career scientist	0	2
	22	73

*Including active 16/17 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/GRASS 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 2016/17*
PhD students studying and graduated	12 active students
Post-doctoral researchers completed 2-year projects	4 active post-doctoral researchers
FTEs of professional researchers working on NZAGRC research programmes	13.69 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. 23.92 FTEs (>70 researchers, of which ~45 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 ongoing co-leadership of the GRA's Livestock Research Group (now in its seventh year) and its role in providing strategic advice and support to MPI (which 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), International Capability and Training Coordinator (a role created in November 2016) and the Project Analyst, along with external contractors, support the LRG co-chairs in developing and monitoring the LRG's work plan including work with partner organisations.

Specific activities supported or led by NZAGRC in support of the GRA include leading and/or facilitating New Zealand involvement in GRA research and capability building activities, monitoring and administering research contracts on behalf of MPI, providing science advice on the strategic direction 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 raises awareness of LRG and GRA activities including via newsletters, a regularly updated website, LinkedIn, and presentations at scientific conferences and expert meetings.

NZAGRC organised and led the annual meeting of the LRG in April 2017 in Washington D.C. This was the LRG's biggest meeting yet with nearly 30 countries represented as well as eight international and regional partner organisations including the FAO, World Bank, CCAFS (the Climate Change, Agriculture and Food Security programme of the CGIAR), and a number of Latin American organisations. The LRG meeting reviewed progress with the research networks and collaborative research projects (including workshopping the Enteric Fermentation Flagship) and agreed a continued capability building focus on supporting countries to progress to Tier 2 greenhouse gas inventories for livestock emissions.

Other key achievements in 2016/17 included:

- NZAGRC concluded the first phase of a major capability building project undertaken in partnership with the FAO on 'Reducing enteric methane for livestock development', involving 13 countries across South Asia, Latin America and Sub-Saharan East Africa. The project was able to identify and test intervention packages that can jointly increase productivity of selected livestock systems, contribute to livelihoods and food security, and reduce emissions intensity of livestock production. Building on this success, NZAGRC worked closely with the World Bank and FAO to secure funding for a second phase starting in 2017/18.
- NZAGRC led the development of a GRA flagship research programme on enteric fermentation. The flagships have been adopted by the GRA Council as a mechanism for securing resourcing and enhancing international collaboration for high priority research projects. Successful projects will be decided at the Council meeting in August 2017. The three projects put forward under the Enteric Fermentation Flagship are all highly relevant to New Zealand, including:

- ✓ Expanding an existing GPLER project on rapid low cost profiling of sheep rumen microbiomes to include dairy and beef systems (led by Suzanne Rowe, AgResearch)
- ✓ Improving the quantification of the effects of feed and nutrition on methane emissions from cattle by creating global feed/methane relationship databases
- ✓ Relating ruminant diet, methane output and animal production to the rumen microbiome, building on the results found in the New Zealand-led Hungate 1000 and Global Rumen Census projects

- NZAGRC further increased its activities to build capability in developing countries to account for their livestock GHG emissions and identify mitigation options:
  - ✓ NZAGRC supported a number of countries in South and South East Asia to improve their greenhouse gas inventories for livestock, including organising a regional workshop on the benefits of Tier 2 inventories and identification of mitigation options; commencing country-specific work with Sri Lanka; and providing a technical peer review of Indonesia's newly developed Tier 2 inventory.
  - ✓ NZAGRC worked closely with CCAFS and FAO to write an influential white paper taking stock of developing countries' systems for monitoring, reporting and verifying (MRV) livestock greenhouse gas emissions – in the context of their Nationally Determined Contributions (NDCs) under the Paris Agreement on climate change. This paper makes a number of recommendations for MRV improvements, which will be picked up by NZAGRC and MPI during 2017/18 (when the paper is also expected to be published).
  - ✓ NZAGRC continued to administer the LEARN/GRASS fellowship scheme, with six fellows involved this year.
- 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 a package of work focused on fast-tracking the development of methanogen-specific inhibitors. The development of new methodologies in the search for inhibitors directly benefitted the NZAGRC-PGgRc inhibitor development pipeline.
  - ✓ Completion of two projects on soil carbon in collaboration with Australia, leading to improved methodologies for measuring soil carbon in the field – giving more certainty and decision options to farmers and policy makers.
  - ✓ Generation of a reference set of rumen microbial genome sequences through the Hungate 1000 project, underpinning the development of a wide range of new mitigation technologies and practices for ruminant livestock
  - ✓ Strong progress in the search for novel nitrification inhibitors that are likely to meet regulatory guidelines and benefit both water quality and GHG mitigation.
  - ✓ Discoveries arising from a GRA project on the interaction between low-emitting animals and differences in their rumen microbiome provide insights that support other parts of the NZAGRC-PGgRc domestic research programme.
  - ✓ Extensive support to MPI on new collaborative research investments. This includes the fourth round of the New Zealand Fund for Global Partnerships in Livestock Emissions Research (GPLER) that has seen eight new contracts signed between New Zealand and international collaborators, valued at nearly $9 million. NZAGRC also supported New Zealand's successful involvement in a European co-fund for monitoring and mitigation of greenhouse gases from agri- and silvi-culture, known as 'ERA-GAS'. Five projects were contracted with New Zealand providers, drawing on $2.3 million from the Government's GRA budget. This comes on top of a further $22.8 million invested in those five projects from the European Union and participating European providers.
- NZAGRC also supported MPI to secure formal observer status for the GRA in the Intergovernmental Panel on Climate Change (IPCC). As an official IPCC observer, the GRA is now well placed to influence the IPCC's perception of livestock greenhouse gas emissions

and the links between productivity and mitigation gains. Through the Deputy Director's role as IPCC bureau member, the NZAGRC was also able to facilitate New Zealand inputs to several global workshops co-sponsored by the IPCC addressing food production, land-use, climate change and soil carbon.

IP and knowledge management for commercial partnerships

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.

Thus far, the methane mitigation area has identified products (e.g. methanogen inhibitors, anti-methanogen vaccines and low emitting sheep), with clearly identified commercial potential. During 2016/17, the NZAGRC has supported the PGgRc in its engagements with industry partners to move these research areas closer to commercial reality. A highlight for the year is the engagement of a commercial partner for the further development of a methane inhibitor. The inhibitior programme is now at a point where the NZAGRC will stop funding to allow a clearer route to market via the PGgRc and a commercialisation partner.

Goal 5 metrics:

Measure	*Progress in 2016/17*
Leadership of science input into Global Research Alliance and coordination of Livestock Research Group with the Netherlands	Proactive NZAGRC input into Alliance during 2016/17
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; NZAGRC is a partner in the global soil carbon project CIRCASA led by INRA, France.
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, $4.73 million was allocated to research and ancillary activities in the 2016/17 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 2016/17

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 2016/17

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 university "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 2016/17

The current Science Plan consists of 16 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.

The Science Plan shown here excludes any activities where NZAGRC is acting as agent on behalf of MPI in support of the GRA, either as contract manager or service deliverer.

Research Programmes 2016/17

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.

Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2016/17 NZAGRC Research FTE	2016/17 $NZ NZAGRC (GST excl)	2016/17 TOTAL Research FTE	2016/17 $NZ TOTAL (GST excl)
Methane	5.1‡	Animal Breeding – Sheep and deer	S Rowe & A Jonker	AgResearch	1.06	300,000	2.82	800,000
	5.3‡	Vaccine	N Wedlock & A Subharat	AgResearch	1.52	570,559	6.14	2,302,492
	5.4‡	Identify inhibitors that reduce ruminant methane emissions	R Ronimus	AgResearch	0.87	300,000	4.98	1,708,120
	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	0.19	48,000	0.19	48,000
	5.11‡	Conduct 2 additional animal vaccine trials and identification of methanogen vaccine targets using monoclonal antibodies	N Wedlock & A Subharat	AgResearch	0.37	125,000	0.37	125,000
	5.12	Validation of a rapid, low cost measurement system for measuring methane	J Roche	DairyNZ	0.89	300,000	0.89	300,000
Nitrous Oxide	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
	6.6	Effects of N transformation inhibitors and gibberelic acid on N_2O emissions	S Saggar	Landcare Research	0.61	110,000	0.61	110,000
	6.7	Review of the current understanding of the effects of plant species and animal forages on N2O emissions	C de Klein	AgResearch	0.26	65,000	0.26	65,000
Soil Carbon	7.1	Manipulation of carbon inputs to stabilise and enhance soil carbon stocks	D Whitehead	Landcare Research	2.12	409,000	2.12	409,000

Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2016/17 NZAGRC Research FTE	2016/17 $NZ NZAGRC (GST excl)	2016/17 TOTAL Research FTE	2016/17 $NZ TOTAL (GST excl)
	7.2	Tools to quantify the stabilisation capacity and vulnerability of carbon in grassland soils	F Kelliher	AgResearch	1.94	276,000	1.94	276,000
	7.3	Modelling management manipulations using the HPM	T Parsons	Massey University	0.29	100,000	0.29	100,000
Integrated Farm Systems	8.1	GHG Emissions on Sheep and Beef Farms	R Dynes & K Hutchinson	AgResearch	0.43	152,425	0.43	152,425
	8.2	GHG Emissions from Dairy Systems	R Dynes & K Hutchinson	AgResearch	1.12	304,070	1.12	304,070
Māori	20.1	Low emissions for the Maori sector	P Journeaux	AgFirst	0.65	155,008	0.65	155,008
				Total	13.69	3,662,062	23.92	7,302,115

*Other research costs of $25,000 are not included in this table. This is funding to support a post-doctoral fellow who is involved with an NZAGRC project, but contracted separately.

Notes:

- 2016/17 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 - 2016/17

Principal Investigators: Dr Peter Janssen and Dr Graeme Attwood

The NZAGRC methane (CH_4) programme is jointly planned and funded in partnership with the PGgRc and aligns with existing MPI programmes funded through SLMACC and New Zealand funding in support of the Global Research Alliance. It aims to reduce emissions by directly targeting the CH_4-producing methanogens through the discovery of 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.

During 2016/17, specialist selection lines for the evaluation of the effect of selecting sheep for CH_4 yield were maintained and continue to diverge. Apparent differences in economic value in favour of the low CH_4 selection line based on the NZ dual purpose overall maternal index were seen this year. Although this looks to be an on-going trend, there are large sampling errors associated with these lines with only 3 sires used in the high line and only 4 in the low. Analysis of meat yield, carcass and maternal traits of a large cohort of relatives with adjustment for sampling errors did not show significant genetic correlations between CH_4 yield and production traits other than wool growth; the implications are that low CH_4 traits do not occur at the expense of other desirable traits, although the economic value of specifically breeding for low-emissions traits has to be evaluated in the context of other breeding objectives.

Using genomic markers to select for low CH_4 animals is looking promising. Data to date imply that if no phenotypic measures were to take place, we could make ~54% of the current genetic gain by using only genomic marker data. The correlation of estimated breeding values between relationships from the imputed and the high density markers was 0.98, indicating that, providing core industry training animals continued to be measured and genotyped with a high number of markers (>50,000), predictions can be made in the national sheep flock with fewer markers (~5-10,000).

Following the breeding work conducted on sheep, ~118 deer rumen samples were sequenced for microbial composition analysis. CT scans from the same animals were also analysed and rumen size and volume were estimated for each animal. Analysis of these data showed a trend for colonisation of different archaea dependent on rumen size. This is a first step towards evaluating in detail whether the rumen microbial profiles indicative of low CH_4 emitting sheep are found in other ruminant species in New Zealand, and to explore whether they are a suitable predictor for indirectly identifying low CH_4 producing animals with cross-species utility.

Additionally, a cattle evaluation programme commenced at the end of 2015/16. The first goal of this work was to validate a rapid, low cost system for measuring both CH_4 and feed intake for individual cows in real-time. An initial trial supported by the New Zealand Government in support of the GRA clearly demonstrated that there are no issues with animals using the system in a confined environment, and that data on both intake and CH_4 emissions can be reliably obtained from individual animals on a daily basis. A second NZAGRC-PGgRc trial comparing the CH_4 measurements from the new system with those obtained from respiration chambers was completed and analysed during 2016/17. This work concluded that the integrated DMI (Dry matter intake)-CH_4 measurement station provides a good measure of daily CH_4 production and CH_4/kg of DMI from groups of animals and is a suitable technology to evaluate nutritional treatments aimed at mitigating CH_4 emissions. However, the large within-animal variation relative to the respiratory chambers indicates it might not be a suitable technology to identify individual animals with contrasting CH_4 emissions per kg of DMI.

Further detailed analysis of the data is needed to confirm this, as short term measurements of CH_4 emissions have shown to be suitable for identifying low and high emitting sheep.

Four sheep vaccination trials were conducted during 2016/17. These trials tested 34 previously un-tested methanogen surface protein antigens (vaccine candidates) from the prioritised target list for their suitability for a prototype vaccine. Issues with repeatability have arisen with the antigen testing assay and work has temporarily focused on resolving these before continuing to systematically test new vaccine candidate antigens. A new NZAGRC-funded post-doctoral fellow has been appointed to support work on the fundamental aspects of the programme. During 2016/17 a trial was conducted to compare our current adjuvant Montanide ISA61 with three alternative adjuvants. The results confirm that Montanide ISA61 is a potent adjuvant and it has been appropriate to use Montanide ISA61 as the adjuvant in the antigen discovery/testing pipeline.

The inhibitor programme is progressing well and the current results strongly suggest that high levels of CH_4 emission mitigation (>20%) can be obtained using small molecule inhibitors in an animal-safe manner. Four trials were conducted in the last year that tested eight compounds in 2-day, 16-day and/or 28-day trial formats. Significantly, three compounds showed sustained activity of greater than 20% over 16-day and 28-days (2344%). Two other compounds retained some activity (15-20%) over 16 days. The NZAGRC involvement in this programme will not continue in 2017/18. From now on, the project will be solely funded by the PGgRc as the lead commercialising partner.

In addition, a feasibility study of a novel mechanism for capturing and breaking down CH_4 has continued in 2016/17. 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. In practice, priming soils with air containing low concentrations of CH_4 so as to build up sufficient levels of methanotrophs to break down CH_4 from housed animals has proved difficult. Laboratory column studies assessed priming of three soil types of medium to high organic carbon contents with continuous feeding at ~2400 ppm of CH_4 for >4 months, and these indicated that even at such high CH_4 concentrations, the soils did not prime adequately to make removal of CH_4 from housed animals practicable (average CH_4 removal of 60 to 80%). The studies will be extended for a further 4-6 weeks and, if not sufficiently primed by then, the experiments will be stopped and the final reports submitted. Based upon current results this line of work will not be continued.

Nitrous Oxide Research Programme Report - 2016/17

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 main 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. During 2016/17, a review of the current understanding of the effects of plant species and animal forages on N_2O emissions was commissioned, and this report is currently being finalised.

A range of field trials and laboratory studies have been conducted to investigate feed management options for mitigating N_2O emissions from grazed systems. Results to-date have indicated some potential for plant species to reduce N_2O emissions, with the highest potential shown by plantain and fodder beet, to a lesser extent brassicas and possibly certain cultivars of Italian ryegrass. However, the results are not consistent and any conclusions around the ability of particular plants to reduce N_2O emissions are premature. None of these studies has provided conclusive evidence of the mechanisms by which these plants reduce N_2O emissions. However, based on the evidence to-date and the results from published studies, key mechanisms might include reduction in the total urinary output of the grazing animals, and regulation of N cycling processes (either through biological nitrification inhibition or through effects on the soil microclimate).

Research has been conducted to determine the efficacy of three different nitrogen transformation inhibitors (NTIs) and gibberellic acid applied when applied to urine amended soils during late autumn/early winter using the "Spikey" technology. This work focused on the ability to reduce gaseous (ammonia (NH_3) and nitrous oxide (N_2O)) and leaching losses of N from cattle urine, including consideration of a urine patch 'edge effect' and irrigation. Results of these studies showed that the efficacy of NTIs in reducing N loss when added to a freshly deposited urine patch varied depending on site/time of year applied and measurement method.

The NZAGRC provided additional operating funds to support the development of a new system to measure N_2O fluxes at paddock scale, aligning with funding from the University of Waikato. This project has reached a stage where the QCL-EC (Quantum Cascade Laser and Eddy Covariance) system is being deployed on farm and measurements are being taken. The next stage is to use chambers to compare results from the paddock scale approach and traditional chamber measurements of N_2O fluxes. Measurements of carbon exchange are being taken at the same sites as for the paddock-scale measurements, which will allow integration of research into mitigation approaches for nitrous oxide emissions at paddock scales and management practices to enhance soil carbon stocks.

Soil Carbon Research Programme Report – 2016/17

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, while soil carbon losses would further add to those emissions. However, realising this mitigation 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.

With respect to testing management practices:

- Conversion of a ryegrass/clover grassland to a sward with diverse species resulted in lower carbon losses than those from regrassing to ryegrass/clover. Diverse swards also maintained the same level of dry matter production as the new ryegrass/clover mix and both were greater than production from the old ryegrass/clover grassland.
- Preliminary carbon balance conducted for maize production suggests large losses that are most likely due to high carbon offtakes during harvest and the need for two cultivations (first to maize and then to winter crop/permanent grassland). Initial estimates suggest a net loss of about a 10 tC ha^{-1} throughout the establishment and harvest cycle. We intend maintaining the measurements at the site throughout the second rotation of maize to determine the consequences for changes in soil carbon stocks for the full maize rotation, including both the import and export of maize feed.

Work has been conducted into the possibility of using a split footprint approach to measure differences in changes in soil carbon between two adjacent treatments. The conclusion is that, using a single point measurement of net carbon exchange, it is possible to detect differences in carbon balances from adjacent plots using a split footprint approach of about 1000 kg C ha^{-1} yr^{-1} reducing to about 500 kg ha^{-1} yr^{-1} after 4 years of measurements. However, caution should be taken when concluding adjacent plots are the same or different on short timescale (i.e. one year) due to possible slight differences in management of the plot.

A study to determine whether mid-infrared spectroscopy/partial least squares regression (MIR/PLSR) analyses could be used to provide accurate estimates of the content and composition of soil carbon in a field trial incorporating a range of agronomic treatments has been completed. The C contents predicted from MIR/PLSR measurements provided reliable estimates of the impact of agricultural management on C stocks to a depth of 0.25 m, as well as an indication of the vulnerability of soil carbon to change. Development of this capability, although likely to require local calibration and validation to confirm the reliability of predicted results, will facilitate the rapid and cost effective collection of C content data for detecting the impact of agricultural management treatments on C stocks, composition and potential vulnerability to change.

A modelling analysis was completed for all components of C and N input, cycling and their fate in temperate irrigated grazed grassland at Winchmore Farm in Canterbury using local meteorological data and soil type. Reductions in soil carbon following irrigation were shown to be due to increasing N limitation. Although both water and N inputs increase plant C capture (and so growth), and might be anticipated to increase opportunities for soil C gain, these two co-limiters of growth interact. If irrigation stimulates C fixation and plant growth, this leads to greater uptake of N by plants, which in turn leads to greater removal of N in products (meat, milk). So for any constant N input rate, this leads over time to increasing N deficiency. Management practices that are more effective in harvesting N taken up by plants into products exacerbate the onset of N deficiency. Our findings suggest that the use of irrigation during dry periods in dry regions can greatly increase plant growth, carbon sequestration and yields of products, provided N inputs are also increased. The overall adverse environmental impacts of combining a change to dairy, introducing irrigation and increasing N input increases, were little greater than if the system had remained low input dry-stock.

Integrated Farm Systems Research Programme Report - 2016/17

Principal Investigator: Dr Robyn Dynes

The overall aim of this programme of work is to identify and demonstrate that management strategies to further 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.

In the sheep and beef research area, the on-farm monitoring at Highlands farm (South Canterbury) focused on forage production, especially from crops, with limited animal production measurements taken this year. The complexity of the forage supply systems and a lack of knowledge of expected yields for some crops in this area required accurate monitoring of crop production for inclusion into farm systems and environmental models. Onetai station (coastal King country) monitoring mainly used animal production data that was available to the farmer. Additional measurements were taken by the project team to investigate the influence of fertiliser and climate on pasture production. The phosphate fertility trial started the previous year provided one platform for measuring pasture response to fertiliser as well as seasonal growth profiles to help calibrate modelled pasture growth.

Discussions were held with the S+B monitor farmers to inform further development of farm system scenarios to help drive practice change. The preference for the owners to continue optimising forage production and feed conversion efficiency on Highlands required no further scenario models as monitoring information was sufficient to identify incremental changes required. The management team at Onetai identified cropping for lamb finishing as a way to boost animal production, feed conversion efficiency and ewe condition. Consequently, an additional farm system modelling scenario helped to inform practice change in this area. Without significant investment in fertiliser for large areas of the farm, cropping in small areas was shown to be able to increase the ability to finish lambs at Onetai. This allowed an increase in production and profit without increasing farm nutrient outputs and while decreasing GHG emissions intensity.

In this financial year there were two field days at Highlands and one at Onetai. These were well attended and led to positive media stories and publicity. There has also been a gradual increase in interest from the S+B industry body B+LNZ during 2016/17. Support and interest has always been positive at local extension manager level for each of the monitor farms and with the Environment extension manager, however this has now moved up through B+LNZ including to their policy team and director-level staff.

In the dairy space, the programme has demonstrated the potential of future systems to meet multiple environmental drivers. Farm systems with lower N losses tend to have lower GHG emission intensity and some future systems (lower stocking rate + plus higher BW) had reduced total emissions. This is a significant opportunity for the dairy sector to reduce the environmental footprint of their systems. However, the introduction of some technologies (e.g. wintering barns or stand-off pads) could carry the risk of pollution swapping and their effect on emissions on- and off-farm must be both well understood and have appropriate mitigation practices budgeted for. Assessments of system- and location-specific emissions factors are providing critical new knowledge of the potential of mitigation practices to change GHG emission profiles on farm.

The tools and approaches (including measuring emission factors) developed and tested to-date are valuable for assessing new mitigations or technologies within a dairy farming system. Both the relative impact and the co-benefits with nutrient leaching can be determined.

- Practical farming systems which include near to market practices and technologies can deliver both lower intensity of GHG emissions in addition to lower nutrient leaching losses.

- New ‘technologies’ on both milking platform and for dry dairy cows during wintering provide new opportunities for reductions in GHG emissions intensity.
- Changes to genetic merit of herd (breeding worth), with associated changed in stocking rate, lower supplement and fertiliser nitrogen (N), use of wintering barns and specialist forage crops (fodderbeet and kale) have the potential to reduce absolute emissions, depending on implementation. These mitigation interventions have been analysed for GHG footprint and emissions intensity within practical farming systems in the current programme.

Māori-focussed Research Programme Report - 2016/17

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 quantified.

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 and hui around the country.

Progress in 2016/17:

- Further development of the MyLand model, which incorporates input from Farmax, OVERSEER, and the Radiata Pine Calculator, and can display land use scenarios spatially by block within a farm, and summarise profitability and GHG/nutrient emissions.
- All 4 focus farms run through Myland to demonstrate the scenarios modelled.
- Development of a spreadsheet calculator, which can readily summarise scenario impacts on farm profitability, and changes in GHG/nitrogen emissions.
- Field days held on the focus farms to discuss the results of the modelling, demonstrate the spreadsheet calculator, and discuss results with the focus farm trustees and attending farmers. Field days held with assistance/input from Dairy NZ, Beef+Lanb NZ, and Fonterra.
- Use of the focus farm models to model scenarios based on the Forages for reduced Nitrate Leaching (FRNL) research work.

Summary of the modelling results:

- 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 (which increased per cow production/reduced bought-in supplements)
    - Increasing sheep:cattle ratios
    - Increasing farm efficiency (e.g. increasing lambing percentages)
    - Planting marginal areas in forestry

- Identifying areas for planting in forestry or tree crops (e.g. mānuka) was not a serious consideration for the dairy case study farms given the small areas available; this mitigation had a much larger impact on the sheep & beef farms.

Displaying the scenarios in a spatial context improved the understanding of the impact of any land use change.

Reaction from farmers was quite universal; they were interested in scenarios which improved farm profitability accompanied by either a decrease in GHG emissions or a slight increase in emissions. They were not interested in mitigations that decreased emissions but at a significant cost to profitability.

FINANCIAL SUMMARY

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EXPENDITURE	
Core research spending	
Methane	1,643,559
Nitrous Oxide	647,000
Soil Carbon	785,000
Integrated Farm Systems	456,495
Māori	155,008
Research Total	**3,687,062**
Other research costs	
Additional Fellowships and Studentships	130,000
Planning, engagement & knowledge transfer	75,274
Policy support	164,500
Special IT and communications	29,068
Other Total	**398,842**
Administration	**648,015**
Total Expenditure (actual)	***4,733,919***
REVENUE*	***5,130,867***
Balance unspent carried over**	***396,948***

*Includes $280,867 carried over from 2015/16.
**Not contracting proposed work on feed, monoclonal antibodies, nitrification inhibitors and the OVERSEER GHG routines in 2016/17 has contributed to the under spend. This underspend will be allocated in 2017/18.

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NZAGRC Director

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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 2016/17 (12th September 2016, 16th November 2016, 22nd February 2017 and 17th May 2017).

Name	Organisation
Dr Greg Murison	AgResearch
Dr Rick Pridmore	DairyNZ
Dr Peter Millard	Landcare Research (Chair)
Dr Elizabeth Hopkins	Lincoln University (to Nov 2016)
Prof. Grant Edwards	Lincoln University (from Feb 2017)
Prof. Mike Hedley	Massey University
Dr Rob Murdoch	NIWA (to Feb 2017)
Dr Sam Dean	NIWA (from May 2017)
Mr Warrick Nelson	Plant & Food Research
Mr Mark Aspin	PGgRc
Dr Tim Payn	Scion
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 2016/17. A review of the N_2O, Soil Carbon and Intergrated Farm Systems programmes was conducted in March 2017 by the specialist panel named below. The panel was 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

Māori Advisory Group

The current membership of the Māori Advisory Group is detailed below. The group met once in July 2016.

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 (AS SUBMITTED)

Objective Level Summary – 2016/17

Key:

Objective completed
Objective on-going

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	2016/17 $NZ NZAGRC (GST excl)	Status End 2016/17
Methane	5.1‡	Animal Breeding – Sheep and deer	S Rowe & A Jonker	AgResearch	300,000	On track
	5.3‡	Vaccine	N Wedlock & A Subharat	AgResearch	270,559	On track
	5.4‡	Identify inhibitors that reduce ruminant methane emissions	R Ronimus	AgResearch	300,000	Completed
	5.8	Modelling rumen methane production	D Pacheco	AgResearch	0	Manuscript delayed whilst student revises PhD thesis.
	5.9	Dairy housing methane capture and mitigation by soil	S Saggar	Landcare Research	48,000	Experiments extended for technical reasons
	5.11‡	Conduct 2 additional animal vaccine trials and identification of methanogen vaccine targets using monoclonal antibodies	N Wedlock & A Subharat	AgResearch	125,000	Completed
	5.12	Validation of a rapid, low cost measurement system for measuring methane	J Roche	DairyNZ	300,000	Completed
Nitrous Oxide	6.3	Feed management options for mitigating N_2O emissions from grazed systems	C de Klein	AgResearch	447,000	Minor delay to manuscript.
	6.6	Effects of N transformation inhibitors and gibberelic acid on N_2O emissions	S Saggar	Landcare Research	110,000	Completed
	6.7	Review of the current understanding of the effects of plant species and animal forages on N2O emissions	C de Klein	AgResearch	65,000	On track with agreed revisions
Soil Carbon	7.1	Manipulation of carbon inputs to stabilise and enhance soil carbon stocks	D Whitehead	Landcare Research	409,000	Manuscripts delayed
	7.2	Tools to quantify the stabilisation capacity and vulnerability of carbon in grassland soils	F Kelliher	AgResearch	276,000	Completed
	7.3	Modelling management manipulations using the HPM	T Parsons	Massey University	100,000	Minor delay to manuscript.
Integrated Farm Systems	8.1	GHG Emissions on Sheep and Beef Farms	R Dynes & K Hutchinson	AgResearch	152,425	Delayed presentation & manuscript
	8.2	GHG Emissions from Dairy Systems	R Dynes & K Hutchinson	AgResearch	304,070	Manuscripts delayed
Māori	20.1	Low emissions for the Maori sector	P Journeaux	AgFirst	155,008	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 and genetically linked research flocks, 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 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 to produce and monitor, have a lower generation interval and multiple births enabling greater selection pressure to be applied. We expect broad consistency of results across 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. To date, the programme has successfully demonstrated selection for lower methane yield and that methane rankings for animals selected whilst monitored on a lucerne pellet diet hold under pasture conditions (Milestone 5.1.13).

The next stage of the programme involves the development and dissemination of practical tools for selection for lowered emissions. A major part of maximising impact and uptake is to explore relative economic value from increased production and potential increased feed utilisation associated with lowered methane. Crucially, to maximise uptake, aims are:

- To determine the relationship between Residual Feed Intake (RFI) and methane emissions in sheep and explore the relationship between portable accumulation chamber (PAC) measures of CO_2 and feed intake (Milestone 5.1.19).
- To continue understanding the physiological and production changes associated with breeding for low methane emissions. This is achieved by ongoing selection and monitoring of the selection lines for detailed production and methane traits, e.g. lamb survival, and carcass composition as well as all other production and disease traits (Milestone 5.1.14).
- Validation of a method that can rank animals based on methane emissions per unit of feed intake or production: by testing 1-hour PAC measurements for phenotypic measurement and collection of rumen samples for potential rumen microbial community (RMC) profiling (Milestone 5.1.15)

- To continue to 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 (Milestone 5.1.18).

In addition we will:

- Evaluate methane emissions and nitrogen (N) balance from selection line males for a full annual cycle relevant to the NZ production environment (Milestone 5.1.20).
- Compare RMC and computed tomography (CT) scanner profiles 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 (Milestone 5.1.16).
- Determine if the RMC "ruminotypes" associated with the low methane lines fed lucerne pellets are also found when the sheep are fed cut pasture, to confirm that the mechanism for low methane emissions is similar on the two diets (Milestone 5.1.13).

5.1 – Progress in 2016/17

A manuscript describing the validation of methane phenotypes grazing pasture using the SF6 technique was submitted and has been accepted for publication by the Journal of Animal Science. Results from the validation of methane phenotypes in respiration chamber (RC) when fed cut pasture were presented (and published in the proceedings) at the British Society of Animal Science annual meeting held in Chester, UK.

Three manuscripts were prepared for submission to the Journal of Animal Science, these manuscripts described i) PAC measures to date and relationships between PAC and RC, ii) the relationship between methane measures with production and meat quality traits and iii) the relationship between methane measures and maternal and reproduction traits.

Specialist selection lines for the evaluation of the effect of selecting for methane yield were maintained. Lambing percentage in the low line was 1.4, but lower in the high line due to a sire failure. Surplus ewes were culled firstly on health traits, then on genetic line, then on index. Ram selection (selection on sire line and breeding value) and mating for the 2017 birth cohort took place. These selection lines continue to diverge. Currently, the average methane yield measure is 16g CH4 kg/DMI. Low line rams are on average 0.91 g below this (range is -0.5, -1.5g) and high line rams are on average 0.8g above this average (range is +0.1-+1.1). Physiological differences and breed proportions are beginning to show considerable divergence with a higher proportion of Texel genetics and a lower proportion of Romney genetics in the low line. Large differences in economic value based on the NZ dual purpose overall maternal index were seen this year, in favour of the low line, between the born 2017 low and high birth cohorts. Although this looks to be an on-going trend, there are large sampling errors associated with these lines with only 3 sires used in the high line and only 4 in the low. It should be noted that analysis of meat yield, carcass and maternal traits of a large cohort of relatives with adjustment for sampling errors did not show significant genetic correlations between methane yield and production traits other than wool growth.

Seventy-five born 2016 ram lambs, selected from 104 animals after being measured for methane with portable accumulation chambers (PAC) off pasture, were transported to Palmerston North and measured twice through respiration chambers (RC) while fed cut pasture in two seasons. A subset of 30 were also measured for Nitrogen excretion (in both seasons) with the aim of determining the full environmental footprint of the selection lines.

Ninety six born 2015 ewe lambs from the selection line flock (3633) were measured for methane through respiration chambers (on lucerne pellets and cut pasture), through PAC twice off pasture, through a residual feed intake (RFI) facility, through PAC twice whilst in the RFI, and were scanned using both computer tomography and ultrasound. Rumen samples were also collected. In the

2017/18 year a further 96 b2016 ewe lambs will be measured for RFI and PAC but not through respiration chambers.

Hoggets and adult ewes from selection line flock, a large research flock and a beef and lamb central progeny flock were measured twice through PAC chambers. 1878 PAC measures of methane were collected from 939 animals directly off pasture, with a further 1000 PAC measures collected from 600 animals measured through RFI. A rumen sample was collected from each animal sampled. This data from multiple sources will be a valuable resource for estimation of genomic breeding values in the wider industry. Based on preliminary data from 1184 PAC records from 594 animals (96 from flock 3633) measured with PAC and for RFI, current estimates of the phenotypic correlation between RFI and methane are very close to zero. Thus, there is no evidence, to date, that selection for methane would result in any change in animal efficiency. The data will be discussed further at a planned workshop on the 11th August 2017.

Breeding values were estimated for ~150,000 animals using pedigree data, this includes the selection lines and all relatives recorded on the SIL database. These BVs were used to select rams for the 2017 mating. Genomic BVs were estimated for the selection line animals using high density data (600k markers) and using low density marker data (15k markers) imputed to high density. Accuracies (correlation of prediction and actual phenotype) were 0.54 for both methods. This shows that the high density reference data is proving comprehensive cover of the variation and an appropriate resource for imputation. It also implies that if no phenotypic measures were to take place that we could make ~54% of the current genetic gain by using only marker data. The correlation of estimated breeding values between relationships from the imputed and the high density markers was 0.98.

Finally, ~118 deer rumen samples were sequenced for microbial composition analysis. CT scans from the same animals were also analysed and rumen size and volume were estimated for each animal. Analysis of the data showed a trend for colonisation of different archaea dependent on rumen size. This is a first step towards evaluating whether rumen microbial profiles are comparable across ruminant species, and to explore whether they are a suitable predictor with cross-species utility.

Key achievements for 2016/17:

- Validation of methane phenotypes grazing pasture while using the SF6 technique was submitted and has been accepted for publication by the Journal of Animal Science. Results from the validation of methane phenotypes in respiration chamber (RC) when fed cut pasture were presented at BSAS.
- Ninety six born 2015 ewe lambs from the selection line flock (3633) were measured for methane through respiration chambers, through portable accumulation chambers (PAC) twice off pasture, through a residual feed intake (RFI) facility, through PAC twice whilst in the RFI, and were scanned using both computer tomography and ultrasound.
- Seventy-five born 2016 ram lambs were transported to Palmerston North and measured twice through respiration chambers when fed cut pasture in two seasons. A subset of 30 were also measured for Nitrogen excretion (in both seasons) with the aim of determining the full environmental footprint of the selection lines.
- 1878 PAC measures of methane were collected from 939 animals directly off pasture, with a further 1000 PAC measures collected from 600 animals measured through RFI. A rumen sample was collected from each animal sampled. This data from multiple sources will be a valuable resource for estimation of genomic breeding values in the wider industry.
- Three manuscripts were prepared for submission to the Journal of Animal Science, these manuscripts described i) PAC measures to date and relationships between PAC and RC, ii) the relationship between methane measures with production and meat quality traits and iii) the relationship between methane measures and maternal and reproduction traits.

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 or guide future plans and partner engagement 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 (as per the Methane vaccine commercialisation agreement with MPI) 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 2016/17

During the past 12 months we conducted four sheep vaccination trials (2016-4, 2016-5, 2016-6, 2016-7) and tested 34 previously un-tested methanogen surface protein antigens (vaccine candidates) from the prioritised target list for their suitability for a prototype vaccine. Montanide ISA61 was used as the adjuvant. In addition, a number of previously tested antigens such as whole M1 cells and R120_001, which had produced positive results in earlier animal vaccine trials were included in the new set of trials. All animals responded strongly to the injected antigens and, in the majority of cases high levels of antigen-specific IgG antibodies were measured in serum and saliva post-vaccination. Most of these antisera have been tested for inhibition of growth of *Methanobrevibacter ruminantium M1* in *in vitro* cultures, the primary screening method for identifying potential targets. Antisera generated against whole cell vaccines and some 'lead' antigens did not inhibit growth of M1 in culture. This was a surprising result as antisera produced against these targets had inhibited growth of M1 in cultures previously. The implication of these findings is that antigen testing using the current M1 growth system, our primary screening assay for inhibitory antibodies needs to be refined. There is a risk that positive results could be overlooked. This needs to be resolved before continuing systemic testing of vaccine candidate antigens.

A series of experiments were conducted to investigate ways of making the *in vitro* methanogen culture assay system more sensitive and determine whether the choice of adjuvant has a role in the producing 'effective' antibodies. While Montanide ISA61 adjuvant does produce the highest IgG levels among a range of adjuvants tested, efforts needed to be made to determine of these antibodies are not (always) effective against the protein antigens on the cell surface. This includes understanding if this is caused by the assay, by the accessibility of antibodies to the antigens, or the nature of the adjuvants being used. This has been the focus of considerable effort over the past 6 months.

Both the adjuvant and the media used to grow up the M1 cells (antigen) may be important factors in generating cross-reactive antibodies that recognise and bind to surface antigenic determinants on M1 cells. To investigate these possibilities, a trial (2017-1) was conducted using M1 whole cells and Freund's adjuvant. Previously sheep antisera against whole M1 cells grown in BY media and formulating the M1 antigens with Freund's adjuvant was shown to be inhibitory to M1 in *in vitro* cultures. These antibodies also caused cell agglutination (antibody induced clumping of cells). Recently when sheep were vaccinated with the antigens from M1 cells that had been grown in RM02 media and formulated with Montanide ISA61, the antisera that was generated failed to inhibit growth and induce agglutination of M1 in culture. In the 2017-1 trial, M1 was produced in both BY and RM02 media and Montanide ISA61 and Freund's adjuvant were compared. None of the antisera produced in sheep against the M1 cells grown in either BY or RM02 media and formulated with either Montanide ISA61 or Freund's adjuvant inhibited growth of M1 in culture and no antibody-mediated agglutination was observed. While these results were surprising and disappointing, there are a number of further possible reasons for these results, and we conducted a series of experiments to understand why this trial didn't replicate earlier studies. From the tests conducted to date, a number of possibilities have been excluded, including the method used to collect blood from animals and possible incompatibility of the in vitro culture system with sera, inadvertent negative consequence of recent improvement to the culture methods such a degassing the serum with CO_2 rather than with N_2 (to remove inhibitory O_2), addition of methanol and also operator error.

Further experiments are being conducted to resolve the current assay problem with testing antisera to candidate vaccine targets and since mid-May, these experiments have been conducted by the newly appointed Postdoctoral fellow, Dr Dairu Shu. Immunofluorescence microscopy conducted on M1 cells confirmed that the antisera produced against M1 antigens by the animals in the 2017-1 trial contained antibodies that recognised and bound to the surface of M1 cells. Progress has been made on identifying other methods, such as culture independent agglutination assay to test antisera produced against M1 cells. The problem may be biological in nature, rather than technical and studies involving vaccinating both sheep and rabbits with whole M1 cells are planned to address this possibility. There have been multiple meetings with the PGgRc General manager and the NZAGRC Director to update them about these developments, and our plans to solve any problems and recommence antigen identification.

Adjuvants
A trial using 45 sheep was conducted to compare our current adjuvant Montanide ISA61 with three alternative adjuvants. Recombinant GT2 was used as the model methanogen protein antigen. While Montanide ISA61 is very effective at inducing antigen-specific IgG antibody in saliva, it promotes only low levels of antigen-specific IgA. Our aim was to identify a superior adjuvant that promotes maximal and long-lasting antigen-specific antibody responses, in particular an adjuvant that promotes strong antigen-specific IgA in saliva and also causes minimal or no vaccination site reactions. One of the three new adjuvants tested (001) stimulated similar but not higher levels of IgG in saliva as Montanide ISA61. The results confirm that Montanide ISA61 is a potent adjuvant and it has been appropriate to use Montanide ISA61 as the adjuvant in the antigen discovery /testing pipeline. Neither Montanide ISA61 nor 001 promoted significant levels of IgA in saliva although this may in part, reflect the parenteral (injection) route of administration used in the trial.

Next steps
Our immediate goal is to get ‘back on track’ to identify and test vaccine candidate antigens from our prioritised list of antigens for an anti-methanogen vaccine. To achieve this, a plan for new animal trials and lab-based investigations is being formulated by the methane vaccine research team and this will be discussed with PGgRc-NZAGRC.

Key achievements for 2016/17:

- Conducted 4 animals trials (each trial with 36 sheep) to test candidate vaccine antigens (predicted methanogen surface proteins).
- Tested 34 previously untested antigens in addition to several previously tested antigens for potential inclusion in a prototype vaccine.
- The inability to replicate previous positive results indicated there is a technical and/or biological problem with the current methods used to evaluate vaccine antigen candidates. An animal trial using Freund’s adjuvant and a series of lab-based tests and experiments were conducted to solve these problems and get back on track with antigen discovery/testing. Progress has been made on identifying other methods for screening sera for inhibitory antibodies.
-
- The results confirmed that Montanide ISA61 is a potent adjuvant for stimulating IgG antibody responses in ruminants but other adjuvants and/or routes of vaccination may stimulate stronger IgA responses in saliva.

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. Approx. 70 hits and lead compounds in approx. 20 classes have been identified. 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 aim is now to rank the confirmed hits for potency, recognising that highly potent inhibitors can be applied at lower doses, decreasing cost, increasing the likelihood of delivery through intra-ruminal technologies, and also potentially deceasing any potential residue levels.

The research forms a pipeline that is structured as follows, recognising that the process can be recursive:

> Milestone 5.4.9, in which hits discovered are confirmed and ranked.
>
> Milestone 5.4.11, in which lead classes and other promising hits are developed further, including testing derivatives, to identify candidates for testing in animals. This step is informed by regular meetings with the ICT.
>
> Milestone 5.4.10. Best leads are tested in sheep for 2 days to show they work in the rumen and do not have an immediate negative impact on rumen function.
>
> Milestone 5.4.12. Lead compounds that are effective in sheep (milestone 5.4.10) are further tested in sheep for 16 days and in cattle for 2 days.
>
> Milestones 5.4.13 and 5.4.14. Development for commercialisation, and patenting.

The most highly ranked hits will be tested in short term sheep trials (Milestone 5.4.10) 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 as leads in longer term trials (≥14 day; Milestone 5.4.12). 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 (Milestone 5.4.13). Less potent but otherwise promising inhibitors (hits) will be will be further derivatized to enhance effectiveness, while derivatives of lead inhibitors that are being developed further will also be tested to provide data for patents (Milestone 5.4.11).

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. 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 a 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 2016/17

The main goal of this Objective is to develop methanogen-specific small molecule inhibitory compounds. The use of inhibitors of rumen methanogens is a leading strategy for producing long-term and substantial (20% to as high as 60%) reductions in methane emissions. Dosing on farm in New Zealand grass-fed production systems could use new bolus technologies that can deliver compounds for up to 6-8 months or be applied in supplementary feed, which is suitable in dairy production.

In the last year, excellent progress has been made in a number of focus areas including enhancing the properties of inhibitory compounds within the top five classes, and testing in both short-term (2-day) and longer-term animal trials (16-day and 28-day). For example, in the last year we tested >1000 individual samples *in vitro* (RIV), the majority of these analyses with compound derivatives in support of five highest priority classes of compounds. Results were also used in support of patents to protect the investment in these classes. RIV testing of derivatives this year has led to the discovery of compounds that are at least two to three-fold more potent, in some cases, than their parent compounds. Derivatives cannot only increase potency, but can also reduce toxicity, reduce the potential for accumulation/presence of residues in animal product, and reduce the cost of syntheses, but also increase their stability and their long-term effectiveness in the rumen.

Another major focus has been to test the most potent compound in each class in sheep trials. This requires prior chemical assessment of the toxicity of the compounds by published toxicity algorithms and review by an expert chemist, acute toxicity testing in mice, and acute toxicity testing in sheep before the ability of the compounds to reduce methane can be determined. Animal ethics approvals are sought and obtained prior to all trials and the Agricultural Compounds and Veterinary Medicines (Food Safety, New Zealand Government) notified prior to any trial commencing. Four trials were conducted in the last year that tested eight compounds in 2-day, 16-day and/or 28-day trial formats. Significantly, three compounds showed sustained activity of greater than 20% over 16-day and 28-days (23%-44%. Two others retained some activity (15-20%) over 16 days.

Ames testing has also been performed for four classes of compounds (five compounds in total). The Ames test uses specific strains of bacteria (*Salmonella typhimurium* and *Escherichia coli*) to examine the potential for compounds to induce mutations (DNA base substitutions and frame shift mutations). They also test for cell toxicity using extracts that mimic processing of drugs in vivo in mammals. The results are encouraging, and together with the above PK studies suggest that work should continue on all of the current main classes of interest.

Overall, the current results strongly 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 indicate the potential for mitigating methane emissions both in New Zealand, and globally.

Key achievements for 2016/17:

- Guided by an Inhibitor Commercialisation Team, and collaborators with expert chemical expertise, a large number of derivatives of the main classes of current interest have been examined in an effort to improve their properties (e.g., potency and stability) and tested using *in vitro* assays. Over a 100 derivatives of the main classes of compounds have been tested in rumen fluid-based *in vitro* assays in an effort to improve the properties of the highest priority classes. Several show improved properties and will be tested *in vivo* in the next financial year.
- Four animal trials were conducted in the last year, that tested eight different compounds in sheep in either 2-day, 16-day or 28-day formats. Four have shown activity over 28-days close to 20% inhibition or greater.
- An invited oral talk was presented at the USA Gut Microbiology and Function Conference, Chicago, April 10-12. In addition, several posters were also presented at three other conferences, including ASM, in New Orleans (June, 2017), that attracted the potential for media attention.

5.8 - Modelling rumen methane production

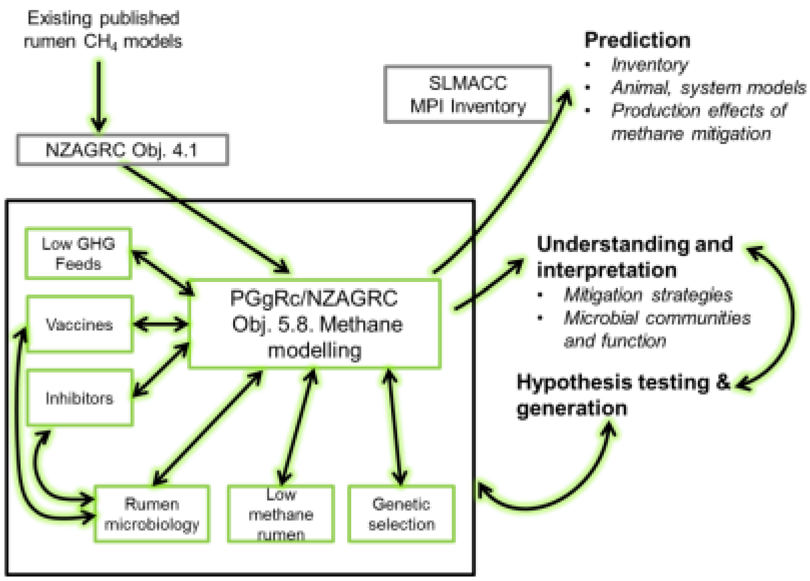
Jointly supported programme

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 2016/17

The work this year has focused in mentoring and support of Mr James Wang to write his PhD thesis. The thesis was submitted for examination by mid-December 2016 and the oral defence took place in mid-April 2017. James' thesis provides a mechanistic mathematical framework to model the interactions between hydrogen concentrations in the rumen and methanogen metabolism. Having such mechanisms represented in a mathematical model will help our understanding when developing methane mitigation strategies that target the methanogen cell (some of which are being developed in research programmes funded by the PGgRc/NZAGRC). James' model also describes the role of hydrogen concentrations as a controller of other important aspects of rumen metabolism, such as short-chain fatty acid production, by introducing a thermodynamic feedback that link hydrogen, methanogens and the glucose fermenters. It is an important contribution to improve current models of rumen function.

In the future, and outside this programme, linking the models described in Mr Wang's PhD thesis into existing rumen models (e.g. Molly and AusBeef models, which this programme has networked with) will provide an important tool to understand the implications of enteric methane mitigation on animal productivity. This is because the models generated as part of this research provide an improved framework to understand and predict both methane and the products of microbial fermentation that drive ruminant production.

Key achievements for 2016/17:

- Submission of the PhD thesis by Yuancheng (James) Wang: Mechanistic modelling of enteric methane production. A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Mathematics at Massey University, Palmerston North, New Zealand.
- Development of a new, strong research collaboration with Drs Bruce van Brunt and Tammy Lynch (Institute of Fundamental Sciences, Massey University), which represent a diversification of scientific disciplines involved in the research of methane mitigation strategies for New Zealand.
- Emergence of a new collaboration with UCDavis (Prof Ermias Kebreab and Dr Henk van Lingen) to study aspects of GHG and productivity co-benefits and trade-offs. This new collaboration emerged from common research interests in understanding rumen fermentation, particularly with regards to the understanding of thermodynamic control of rumen fermentation.

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

Objective Leader – Dr Surinder Saggar (Landcare Research)

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 2016/17

In the field trial, the continued feeding of low concentrations of methane (~150ppm) to Massey Dairy Farm 1 soil raised-beds with ammonia could not build up an active methanotroph population for oxidation of methane but ammonia damaged the mass flow controllers and also the velocity sensors which controlled the fans blowing methane and ammonia to the raised-beds due to the corrosive action of the ammonia gas on the metallic components of the equipment.

In the batch experiments, four dairy pasture soils contrasting in soil organic matter (low to high) and textural class (loamy sand to silt loam) from across North Island, New Zealand (including the Massey Dairy 1 soil used for the raised-bed study) were primed with 1200, 2400 and 3600 ppm methane. Three soils increased methane oxidation potential except Dairy 1 soil (currently used in raised-bed field experiment). Subsequent exposure of these primed soils with low concentrated CH_4 (150 ppmv), resulted in an average 90% removal by the Taranaki soil with the highest organic carbon content followed by an average 63% removal by Ruakura and Massey Dairy 4 soils but Massey Dairy 1 soil removed the least with an average CH_4 oxidation of 21% during the study period. These results from batch experiments suggested that primed pasture soils high in organic matter have the potential for mitigating low levels of methane emitted from housed animals.

The column studies to assess the priming of the three soils of medium to high organic carbon contents with continuous feeding at ~2400 ppm of methane for >4 months has not achieved the same level of priming (average methane removal of) in any of the soils studied compared to the 60 to 80% achieved in the batch experiments within 3-month period. This has delayed the planned subsequent exposure of these soils in the columns to continuous feeding of low concentrated CH_4 (~150ppm) and completion of the study by 30 June 2017. It is proposed to extend the priming experiment till these soils attain 60 to 80% methane removal and then expose the primed soils to priming of the low concentrated CH_4 (~150ppm).

Key achievements for 2016/17:

- Dairy pasture soils can be primed in up to 3-months in batch experiments with 1200 to 3600 ppm methane.

- Of these primed pasture soils, the soils only high in organic matter have the potential for mitigating low levels of methane emitted from housed animals.
- In the field trial the continued feeding of low concentrations of methane (~150ppm) to raised-beds with low organic matter Massey Dairy Farm 1 soil with ammonia had little effect on oxidation of methane but ammonia damaged the mass flow controllers and also the velocity sensors which controlled the fans blowing methane and ammonia to the raised-beds due to the corrosive action of the ammonia gas on the metallic components of the equipment.

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 2016/17

One of the potential strategies to reduce the dairy industry Greenhouse Gas (GHG) footprint is to select animals that produce less methane (CH_4) per kg of dry matter intake (DMI) and per kg of milk produced. However, measuring CH_4 accurately using respiratory chambers (i.e., the Gold Standard) is logistically very difficult in large numbers of animals and is cost-prohibitive. Alternative methods (SF6-tracer gas method and GreenFeed in-paddock measurements) have their limitations that reduce accuracy.

The current project investigated whether we could incorporate patented technology into a feed bin and measure CH_4 and DMI in real time in large numbers of animals and whether this technology provided an accurate measure of CH_4 produced when compared with the respiratory chamber.

Thirty, one-year old heifers (i.e., virgin female cattle) were evaluated in the new system for measure methane (DMI-CH_4 Station) twice and in between these measurement periods they were evaluated in respiratory chambers. This allowed us to account for changes in age of the animals, as this can affect both DMI and CH_4 emissions and to evaluate the repeatability of methane measurements.

On average, heifers visited the DMI-CH_4 Station between 6 and 8 times/day, providing a very representative profile of methane release during the day. CH_4 and DMI were measured automatically while the animals ate during the day. The equipment did not limit DMI; in fact, growth rates were at least 50% greater than we expect in this age group of cattle, highlighting that they ate well in the facilities. On average, the CH_4 measurements from the DMI-CH_4 Station were similar to the respiratory chambers. However, the relationship between CH_4 measured using the DMI-CH_4 Station and the respiratory chamber differed between animals; this means that we would not have confidence in the CH_4 value that the DMI-CH4 Station assigned to each individual animal, but when looking at the average of a group of animals the DMI-CH_4 Station was very accurate compared with the respiratory chamber.

The results mean that New Zealand now has CH_4 measurement system suitable for medium to long term testing of different treatments where the measurements CH_4 and DMI are automated. However, the new system may not be suitable for ranking individual animals for CH_4 yield.

Key achievements for 2016/17:

- We confirmed the usability of the new equipment, with growth rates indicating that DMI was not compromised by the change in the animals' surroundings; in fact, DMI was greater than we would expect if these animals were outdoors.
- The DMI-CH_4 Station was very accurate compared with the respiratory chamber. This means that New Zealand now has a CH_4 measurement system suitable for medium to long term testing of different treatments, which will speed up the evaluation of mitigation technologies as they become available.

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 2016/17

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.

In monoculture trials, plantain had the lowest N_2O emissions from urine from animals on standard ryegrass white clover pasture, compared with ryegrass and lucerne monocultures that received the same type and rate of urine. Plantain reduced N_2O emissions from urine patches by c. 35-70% compared with perennial ryegrass.

Field trials with mixed pasture swards that included plantain also suggested lower N_2O emissions, but this was due to the lower N concentration in the urine from the diverse sward, rather than a plant effect.

The mechanism for the reduced N_2O emissions from plantain is not known, but it could be due to the impact of the plants on the soil microclimate (in particular soil water content) and/or through biological nitrification inhibition compounds in plantain root exudates or in the urine from animals grazing plantain.

'Winter active' species such as Italian ryegrass had no effect on N_2O emissions from urine patches, but did reduce N leaching, which is an indirect source of N_2O emissions. However, different cultivars of Italian ryegrass had different N_2O emissions from urine applied to soil. (e.g. Italian ryegrass cultivar Moata had lower emissions than cultivar Tama).

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. Again, the reasons why fodder beet had lower N_2O emissions are unknown, but it could be due to differences in the urine composition or due to plant-effects on the soil microclimate.

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 by up to 44%. In a field study, aucubin also reduced N_2O emissions from urine (up to 70%).

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 as they are rapidly degraded in pasture soil.

In summary, the results to-date have clearly highlighted the potential of plant species to reduce N_2O emissions, with the plantain and fodder beet, and to a lesser extend brassicas and possibly certain cultivars of Italian ryegrass, showing the greatest potential. None of these studies has provided conclusive evidence of any mechanisms by which these plants reduce N_2O emissions. However, based on the evidence to-date and the results from published studies, key mechanisms with which forage species such as plantain, fodder beet and forage rape decrease N_2O emission include reduction in the total urinary output of the grazing animals, and regulation of N cycling processes (either through biological nitrification inhibition or through effects on the soil microclimate.

Key achievements for 2016/17:

- Paper: Balvert, Sheree; Luo, Jiafa; Schipper, Louis (2017) Do glucosinolate hydrolysis products reduce nitrous oxide emissions from urine affected soil? Science of the total Environment, 603-604, 370-380. (doi.org/10.1016/j.scitotenv.2017.06.089)
- Book chapter: Balvert, Sheree; Luo, Jiafa (2017) Dietary manipulation as a tool for mitigating nitrous oxide emissions. In Greenhouse Gas Emissions and Nitrogen Losses from Grazed Dairy and Animal Housing Systems (J Luo and Y Li Eds). Chapter 5. PP 61-70. Nova Science publishers, New York.
- Paper: Gardiner CA, Clough TJ, Cameron KC, Di HJ, Edwards GR, de Klein CAM (2017) Non-urea ruminant urine nitrogen compounds: assessing their fate in soils and impact on the urine patch nitrous oxide emission factor. Journal of Environmental Quality
- Paper: Gardiner CA, Clough TJ, Cameron KC, Di HJ, Edwards GR, de Klein CAM (2017) The potential inhibitory effects of Plantago lanceolata and its active secondary metabolite aucubin on soil nitrification and nitrous oxide emissions under ruminant urine patch conditions. New Zealand Journal of Agricultural Research
- Paper: Luo J, Balvert S, Wise B, Welten B, Ledgard S, de Klein C, Lindsey S, Judge A (2017) Using Alternative Forage Species to Reduce Emissions of the Greenhouse Gas Nitrous Oxide from Cattle Urine Deposited onto Soil. Science of the Total Environment
- Paper: L. C Smith, R M Monaghan, C A M de Klein (2017) Effect of Italian and perennial ryegrass pastures grazed by dairy cows on N leaching losses and N2O emissions from urine patches in southern New Zealand. New Zealand Journal of Agricultural Research

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 2016/17

Landcare Research, Pastoral Robotics, Massey University and AgResearch have conducted research (objective 6.6) to determine the efficacy of three different nitrogen transformation inhibitors (NTIs) and gibberellic acid applied when applied to urine amended soils during late autumn/early winter using the "Spikey" technology for reducing gaseous (ammonia (NH_3) and nitrous oxide (N_2O)) and leaching losses of N from cattle urine with and without taking into consideration a urine patch 'edge effect' and also with and without irrigation.

Ammonia emission was determined from the Control (C), urine (U), Urine + Urease inhibitor (UUI) and Urine + Nitrification inhibitor (UNI) treatments with an additional irrigation treatment of 10 mm of irrigation applied 4 h after urine application (i.e. at the same time as the UI was applied) was included for the U (IU) and UUI (IUUI) treatments only. Cumulative NH_3 losses for the U treatment averaged 48 kg N ha–1 (Fig. 2), giving an average FracGASM (% of excreta N applied which is volatilised as NH_3) value of 7.3%. This comparatively lower NH_3 emission from urine may be attributed partly to the slower rate of urea hydrolysis (lower soil temperature) and also to deeper distribution of applied urine into this already moist and well-drained soil. The UI reduced emissions by 23%, and irrigation applied with or without the inhibitor reduced emissions by just over 40%. However, the application of the NI had no significant effect on NH_3 emissions. N_2O emissions, which were highest from the U and U+UI treatments (average 10.2 kg N ha–1; EF3 1.5%), were reduced by 30% in the U+NI+UI and U+O treatments and by 60% in the U+NI treatment (4.4 kg N ha–1; EF3 0.6%) at the Manawatu field site. However, N_2O emissions in the lysimeters at Waikato site were much lower than in the Manawatu field trial, and adding NTIs or Gibberellic acid had no significant effect on total N_2O emissions (range: 0.28 – 0.48 kg N ha–1) or EF3 (range: 0.06 – 0.08%). Between the standard and edge effects methods, the edge effects method had consistently lower fluxes over time and therefore total N_2O emissions were much lower. Total inorganic N leached from lysimeters was 94 mg N m-2 (0.94 kg N ha-1) for UO (with and without 'edge effect', which was higher than for U (with and without 'edge effect' (average of 35 mg N m-2 or 0.35 kg N ha-1) and also for any of the other treatments (average of 22 mg N m-2 or 0.22 kg N ha-1). On average, the majority (93%) of inorganic N leached was in the NO_3–form.

Key achievements for 2016/17:

- Application of urease inhibitor reduced NH_3 emissions by 23% but 10 mm irrigation reduced NH_3 emissions further but had no effect on N_2O emissions.
- Application of NI had no effect on NH_3 emission but reduced N_2O emission by 60%.

- There is potential for reducing NH_3 losses from animal urine deposition in grazed pastures by either applying approximately 10 mm irrigation or treating the urine patch with nBTPT 4 h after deposition.
- N_2O emissions from urine deposited during grazing may be overestimated when flux measurements are restricted to just the area directly affected by urine (wetted area)
- Plant and soil influence on urine N dispersion, transformations and uptake at the periphery of the patch area should be important considerations when estimating N_2O emissions from grazed pastures

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

Objective Leader – Dr David Whitehead (Landcare Research)

LANDCARE RESEARCH
MANAAKI WHENUA

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 2016/17

The focus of the year was on (i) aligning outputs of scenarios modelling to identify farm management practices that will ensure the maintenance of soil carbon stocks and increase stocks with (ii) findings from field measurements for selected practices and (iii) planning for future opportunities for management practices to increase soil carbon stocks. Our work is focused on two contrasting research sites that are representative of good regional management practices. The effects of converting ryegrass/clover grassland to a sward with diverse species on net carbon exchange, including the impacts of tillage have been determined on deep brown loamy soils at Troughton Farm in the Waikato region (rainfall 1 250 mm y-1). In August 2016, measurements began to determine the effect of irrigation on shallow, stony Balmoral soils at Ashley Dene Farm in the Canterbury region (rainfall 600 mm y-1).

Our progress and achievements have been:

- We completed an international model inter-comparison project that tested and validated the CenW model against other international models using experimental data. We published findings from the CenW model showing improved forecasting of the potential management effects on soil carbon stocks and on productivity of milk solids from grazed dairy farms in relation to carbon and nitrogen and losses under a range of management conditions.
- Conversion of a ryegrass/clover grassland to a sward with diverse species resulted in lower carbon losses than those from reconversion to ryegrass/clover. Diverse swards also maintained the same level of production as the new ryegrass/clover mix and both were greater than production from the old ryegrass grassland but only conversion to a diverse sward lead to the potential to increase soil carbon stocks.
- We found that, to minimise soil carbon loss during grassland renewal, farm management practices should ensure that the period between herbicide application and reseeding is as short as possible and that this can be achieved most easily through no-tillage preparation. Grassland renewal when soils are drier can reduce soil respiration but sufficient soil water will be needed for rapid re-establishment of grassland to minimise the net loss of soil carbon.

This finding was based on field measurements of net carbon balance made throughout a grassland renewal cycle.

- Preliminary carbon balance conducted for maize production suggests large losses that are most likely due to high carbon offtakes during harvest and the need for two cultivations (first to maize and then to winter crop/permanent pasture). Initial estimates suggest about a 10 tC loss. It is planned that this site will be planted back to maize in spring and we intend maintaining the measurements at the site throughout the second rotation of maize to determine the consequences for changes in soil carbon stocks for maize rotation, both for importing and exporting maize feed.
- At the sites for paddock-scale measurements of carbon exchange, we have been making measurements of nitrous oxide emissions at the same scale since December 2016. This allows testing of mitigation approaches for reducing nitrous oxide emissions at paddock scales and demonstrates our intention to align our research to address the effects of management practices on soil carbon stocks and nitrous oxide emissions.
- Laboratory studies are underway to investigate the effects of irrigation on changes in soil diffusivity leading to impacts on the rates of carbon loss and nitrous oxide emissions from soil.

We have completed publication of our findings from the previous four years and have summarised the status of the new knowledge we have gained in presentations at national and international conferences.

Key achievements for 2016/17:

- Rutledge S, Wall AM, Mudge PL, Troughton B, Campbell DI, Pronger J, Joshi C, Schipper LA 2017. The carbon balance of a temperate grassland Part I: The impact of increased species diversity. Agriculture, Ecosystems and Environment. 239:310–323.
- Rutledge S, Wall AM, Mudge PL, Troughton B, Campbell DI, Pronger J, Joshi C, Schipper LA 2017. The carbon balance of a temperate grassland Part II: The impact of pasture renewal via direct drilling. Agriculture, Ecosystems and Environment. 239:132-142.
- Puche N 2017. Detailed temporal modelling of carbon and water fluxes from pastures in New Zealand: Case study of an experimental dairy farm in the Waikato Region. PhD Thesis submitted to Massey University.
- Wall, AM, Campbell DI, Schipper LA 2017. Split footprint approach for eddy covariance studies in grazed pastoral systems. Report to NZAGRC.
- Schipper, LA et al. 2017. Do soils gain carbon following conversion of ryegrass/clover to a moderately diverse pasture? New Zealand and Australian Societies of Soil Science Conference, Queenstown, December 2016.

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 2016/17

Understanding soil organic carbon (SOC) sequestration potential is important to developing strategies to increase the SOC stock and, thereby, off-set some of the increases in atmospheric carbon dioxide (CO_2). Although the capacity of soils to store SOC in a stable form is commonly attributed to characteristics of the fine (clay + fine silt) fraction, properties of the fine fraction that determine the SOC stabilisation capacity are poorly known. For a paper published in Global Change Biology, McNally et al. developed an improved model to estimate the SOC stabilisation capacity of Allophanic and non-Allophanic topsoils (0-15 cm) and, as a case study, to apply the model to predict the sequestration potential of soils across New Zealand. A quantile (90th) regression model based on the specific surface area and extractable aluminium (pyrophosphate) provided the best prediction of the upper limit of fine fraction carbon (FFC) (i.e. the stabilisation capacity), but with different coefficients for Allophanic and non-Allophanic soils. The C saturation deficit was estimated as the difference between the stabilisation capacity of individual soils and their current C concentration. For long-term pastures, the mean saturation deficit of Allophanic soils (20.3 mg C g^{-1}) was greater than that of non-Allophanic soils (16.3 mg C g^{-1}). The saturation deficit of cropped soils was 1.14 to 1.89 times that of pasture soils. The sequestration potential of pasture soils ranged from 10 t C ha^{-1} (Ultic soils) to 42 t C ha^{-1} (Melanic soils). Although meeting the estimated national soil C sequestration potential (124 Mt C) is unrealistic, improved management practices targeted to those soils with the greatest sequestration potential could contribute significantly to off-setting New Zealand's greenhouse gas emissions. As the first national-scale estimate of SOC sequestration potential that encompasses both Allophanic and non-Allophanic soils, this serves as an informative case study for the international community.

In New Zealand, pastoral soils have substantial SOC stocks which may be vulnerable to loss from disturbance and environmental perturbations. For a paper submitted to Soil Research, McNally et al. assessed OC vulnerability using two approaches. For the first approach, they postulated that the OC deficit of continuously cropped soils relative to nearby pastoral soils would provide a measure of the quantity of potentially vulnerable OC in pastures. As a test, soils were sampled to a depth of 15 cm at 149 sites and the total organic carbon (TOC) and particulate organic carbon (POC) contents were measured. The second approach involved measurement of OC mineralisation in a laboratory assay (98 day aerobic incubation at 25˚C). For the pastoral soils, the mean TOC and POC was about twice that of the cropped soils. On average, 89% more OC was mineralised from the pastoral soils compared with the cropped counterparts. However, the quantity of OC mineralised in pasture soils was small relative to the potential for OC loss inferred from the difference in TOC between pastoral and cropped soils. Carbon mineralisation was best explained using a two-pool exponential model with rate constants of the "fast" and "slow" pools equating to 0.36 ± 0.155 and 0.007 ± 0.003 d^{-1} respectively. The larger, slow OC pool correlated strongly with hot water extractable OC whereas the fast pool was related to OC extracted using cold water. The results suggest that water extraction (using cold and hot water) can provide a rapid estimate of the quantity of “mineralisable” OC across a wide range of New Zealand soils.

Knowledge of the molecular composition of soil organic matter (OM) and the interaction of OM with soil minerals is needed to better understand the persistence of OM and effects of land use and management. For a paper submitted to Nature Communications, Shen et al. investigated OM chemistry, organic carbon fractions, and reactive surface concentrations of aluminium and iron oxy-hydroxides for 45 agricultural top soils across a range of orders and management regimes in New Zealand. For the sedimentary soils, the results support our current understanding of soil OM preservation by organic molecules forming an “onion-type” structure on reactive surfaces with the bonding strength decreasing with distance from the surface, while the contribution of microbial-derived OM decreases in the same sequence. Alternatively, for the allophanic soils, we propose the “onion-type” structure needs a greater number of “layers”. The new evidence accounts for the allophanic soils’ greater OM preservation under permanent pasture, but under cropping, the OM was more susceptible to loss.

For a paper submitted to Soil Research, Baldock et al. determined whether mid-infrared spectroscopy/partial least squares regression (MIR/PLSR) analyses could be used to provide accurate estimates of the content and composition of soil OC (SOC) in a field trial incorporating a range of agronomic treatments. A total of 954 soil samples were collected over the 2000-2009 period from the 0-25 cm soil depth layer under different land use (pasture, arable cropping and bare fallow) and tillage (intensive, minimum and no tillage) treatments. MIR/PLSR algorithms were successfully developed to predict the contents of SOC, POC and ROC. The MIR/PLSR predicted SOC contents provided reliable estimates of the impact of agricultural management on the 0-25 cm SOC stocks, as well as an indication of the vulnerability of SOC to change. Development of this capability can facilitate the rapid and cost effective collection of SOC content data for detecting the impact of agricultural management treatments on SOC stocks, composition and potential vulnerability to change.

Key achievements for 2016/17:

- McNally SR, Beare MH, Curtin D, Meenken ED, Kelliher FM, Calvello Pereira R, Baldock J. 2017. Soil carbon sequestration potential of permanent pasture and continuous cropping soils in New Zealand. Global Change Biology. DOI:10.1111/gcb.13720.
- McNally S, Beare M, Curtin D, Tregurtha C, Qiu W, Kelliher F, Baldock J. 2017. Assessing the vulnerability of organic matter to C mineralisation and loss in pasture and cropping soils. Submitted to Soil Research
- Shen Q, Suarez-Abelenda M, Camps-Arbestain M, Calvello Pereira R, McNally SR, Kelliher FM. New Evidences supporting the self-assembly of organic molecular fragments on soil mineral surfaces. Submitted to Nature Communications
- Baldock JA, Beare MH, Curtin D, Hawke B. 2017. Predicting the content, composition and management impacts on stocks and vulnerability of soil organic carbon using mid-infrared spectroscopy. Submitted to Soil Research
- The results of our work to determine the carbon stabilisation potential of agricultural soils were reported in a popular article (Black Gold: Can soil save the climate?) in the New Zealand Listener magazine (circulation 56,000; 19 November 2016 issue).

7.3 - Modelling management manipulations using the HPM

Objective Leader – Prof Tony Parsons (Massey University)

Previous work in this objective laid out what would be both the long term outcomes for, and also the time courses of changes in, major components of the balance of animal productivity, GHG emission, N releases and carbon sequestration, following a wide range of combinations of changes in management. These covered singly, and in combination: stocking policy, fertiliser inputs, animal type (dry v dairy), the use of supplements and contrasting intensities of pasture use, such as might exist between lowland and hill-land regions. We compared the outcomes for a wide series of scenarios that matched the recent (20 year) changes in focus as NZ progressed from low-input drystock, to intensive dairy, as well as the likely future outcomes of a reduction in intensity of dairy production. A framework was presented for policy and as a focus for the direction of future research to pursue the insights gained regarding improvements in system wide C capture, and the N use efficiency of this.

The next stage of the work recognises that many of the options for improving the balance of animal productivity and mitigation of its impacts, by way of managements alone have already been deployed on farms; further advances in reducing GHG emissions (or offsetting them) in pastures will be difficult, and so a clear focus is needed on making fundamental changes in the biology of C capture, and N use, in plants, soils and animals, indeed in their combined C and N production cycles. The previous work identified some critical areas where major advances could be made, some of which have been pursued in experimental work (already published) that provides 'proof of concept', for the efficacy of the change. That fundamental progress provides the 'data' required for altering key processes embodied in the model.

In the new work this year we will focus on how altering fundamental plant traits (e.g. the longevity of stored sugars; and changes in plant N uptake and N use efficiency) influence the fate of C and N in plants, animals and soils. The consequent impacts on nitrification and denitrification based emissions to air and water and for C sequestration will be described for these fundamental changes in biology under a wide range of relevant practical management scenarios. Optimal solutions will be identified.

The work, being soundly based on existing (HPM) modelling and backed by our recent empirical (e.g. molecular plant, and plant/soil organism interactions) studies, will form the basis of recommendations for optimal solutions to meet the challenge of balancing animal productivity with its environmental impacts.

7.3 - Progress in 2016/17

A paper was submitted (accepted and in print Dec 2016) to CAB International clarifying issues regarding the impacts of intensification in NZ on the balance of (food) production; nitrogen release; C sequestration and methane emissions. Key findings are presented there (see its Abstract), and are too wide to be summarised briefly here. Looking forward, that paper highlighted how the productive grassland ecosystem is C input limited. The paper makes clear that increasing carbon fixation (and so plant growth) at each and any given N 'presence' (kgN/ha), and so C capture per unit N, is the precise definition of the most desired plant trait overall. 'Greater uptake of N' is an inevitable consequence of this, and the work stressed that unless 'greater uptake of N' was associated with greater C fixation per unit N, then it (greater N uptake per se) would not be a beneficial trait. Strong reference was made to how, despite sounding simple, getting more C fixation per unit of N 'presence' would represent a shift in paradigm, indeed altering the entire classic 'explanation' of how plant growth relates to nitrogen 'availability' (the so called 'N response' curve). The paper referred to past work by Rasmussen/Parsons (some 5 journal papers) (e.g. see Parsons et al 2013; Liu et al 2015) showing full evidence for this being far from fanciful, but plausible and achievable, and indeed, achieved. The papers present proof of concept, the genes, and the molecular mechanism of such a re-setting of the 'auto-control' of plant meristems. The expected impacts of such a trait on all associated aspects of GHG emissions (and food production) were modelled during Q1.

Requests were received to shift focus to present analyses explaining declines in soil C seen in long-term field trials/data when using irrigation (e.g. Schipper et al recent publications). Concern has been expressed how NZ commitments to the Paris accord, (to reduce GHG emissions from its predominantly pastoral agriculture, and hence interest in C sequestration (offsets), reducing methane emission, and reducing/limiting nitrous oxide emissions), sit alongside government encouragement to increase milk (and meat) production with the aid of irrigation. Concern was heightened when recent (empirical) publications showed soil C losses following irrigation (see Mudge et al). A deep understanding of how irrigation interacts with all OTHER aspects of C and N cycling in pastoral systems, and not just soil C, was paramount. Discussions on the focus for the work (in this Obj 7.3) met with strong enthusiasm from Prof Frank Kelliher (PI and water/irrigation expert). The contract was revised and re-directed to model the impacts of irrigation on soil carbon.

Reductions in soil carbon following irrigation were shown (confirmed) to be due to increasing N limitation. Although both water input, and N inputs, increase plant C capture (and so growth), and so might be anticipated to both/either increase opportunities for soil C gain, these two co-limiters of growth interact. Besides the obvious (whichever is most limiting, limits most) the interaction is dynamic. If/when adding water stimulates C fixation and plant growth, this leads to greater uptake of N by plants, which in turn leads to greater removal of N in products (meat, milk), so for any sustained N input rate, this leads over time to an increasing N deficiency. Managements that are more effective in harvesting N taken up by plants, into products (note relevance with respect to some propositions for plant traits), therefore exacerbate the onset of N deficiency. The model was run for the Winchmore (near Lincoln) met data and soil type. Starting from low N input dry-stock systems, a shift to dairy reduced soil carbon, likewise the use of irrigation further reduced soil carbon, but increasing fertiliser N input (on top of both) increased soil C. Moreover, the outcomes (in respect to yield of products, nitrogen emissions/losses and methane) were all far more favourable than if nitrogen alone had been added. In short, use of irrigation during dry periods in dry regions can greatly increase plant growth, carbon sequestration and yields of products, provided N inputs are also increased. This is essential. Paradoxically, the overall adverse environmental impacts of dairy, water and N input increases, were little greater (potentially lesser) than if the system had remained low input dry-stock… such is the difference in system wide efficiency under dairy and irrigation. Developing N limitation, and not (as was proposed by Mudge et al) increases in soil respiration under irrigation were the driver of the decline in soil C under irrigation. Respiration increases were indeed seen, but these followed (not drove) changes in C inputs and sequestered C.

A number of factors led during Q4 2017 to a recognition by Parsons (me) that although the model outputs did give a fully integrated perspective of all GHG emissions, C sequestration, and food production, and did attend to ‘management manipulations (as well as traits), that there was one final need to present this information in a way that attended directly to the question of how could one better balance the concerns for increasing (or sustaining) food production (understandably championed by industry) with (rather than against) the concerns to reduce ‘environmental impacts’. Though water quality (nitrate and microbes) is highly topical at present, and these are not NZAGRC remit, the issue of GHG emissions must surely be considered in that same context. Discussions, by chance, with a lead representative of DairyNZ (also expressing such concerns) led to my preparing an analysis of how management manipulations, and trait changes, considered by this model, could be re-displayed in such a way that it was clear just how each would affect the balance of ‘production’ v GHG dimensions of ‘environmental impact’. The approach adopted portrays the exact same information, seen from my studies of ‘depth and detail’, but now in a simple visual map that matches people’s perceptions (and mis-perceptions). The approach is one taken from behavioural disciplines, which include micro-economics, and behavioural ecology. It summarises how ‘actions’ affect ‘outcomes’… reveals if and where there are alternatives / options. It makes clear what those mitigation options are, and offers all possible ways to seek the best overall outcomes despite there being multiple (seemingly conflicting) goals.

A publication covering this ground, and the implications for policy and the focus of research, will be prepared during spring 2017.

Key achievements for 2016/17:

- Major invited review paper published by CAB International. While a paper is not deemed an outcome, the advice it contains, acted upon, would deliver several.
- Multiple presentations in the public press (NBR, farming bodies, industry bodies, and govt) by Prof J. Rowarth disseminating key insights directly. (n.b. using content from above, now officially in public domain).
- Invited joint keynote address (to Agronomy Society of Australia) with industry representative (Dr D.F. Chapman) on the need to reduce GHG impacts of dairy industry and methods to achieve this.
- Invitation by Massey University to contribute to wider, more “balanced” perception of the challenge of food production (industry) and its environmental consequences.

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 2016/17

The summary of the 2016/2017 year for the NZAGRC Integrated Farm Systems program should be separated into three areas: on-farm monitoring, GHG emissions scenario and system modelling, extension activities and publicity.

On-Farm monitoring: The on-farm monitoring at Highlands focused on forage production, especially from crops, and limited animal production measurements. The complexity of the forage supply systems and a lack of knowledge of expected yields for some crops in this area required accurate monitoring of crop production for inclusion into farm systems and environmental models. Onetai monitoring mainly used animal production data that was available to the farmer. Additional measurements were done by the project team to investigate the influence of fertiliser and climate on pasture production. The phosphate fertility trial started the previous year provided one platform for measuring pasture response to fertiliser as well as seasonal growth profiles to help calibrate modelled pasture growth.

GHG emissions modelling: Discussion was held with the monitor farmers to inform further development of farm system scenarios to help drive practice change. The preference for the Wrights to continue optimising forage production and feed conversion efficiency on Highlands required no further scenario models (monitoring information was sufficient to identify incremental changes required. The management team at Onetai identified cropping for lamb finishing as a way to boost animal production, feed conversion efficiency and ewe condition. Consequently, an additional farm system modelling scenario helped to inform practice change in this area. Without significant investment in fertiliser for large areas of the farm, cropping in small areas was shown to increase the ability to finish lambs at Onetai. This allowed an increase in production and profit without increasing farm nutrient outputs and while decreasing GHG emissions intensity.

Extension and media: In this financial year there were two field days at Highlands and one at Onetai. The November field day at Onetai included the practice change scenarios and a more in depth discussion and demonstration of N_2O measurement from hill country farm systems with Tony van der Weerden. This was presented along with other developments on farm including farm improvements, sediment loss mitigation, and wetland development. The field tour for the NZ Grassland Association conference brought over 200 scientists, farmers, and industry professionals to Highlands. Robyn Dynes and team presented GHG emissions intensity data from the Wright's farm monitoring and practice change scenarios as well as the good-news story around an increase in GHG emissions intensity in the red meat sector. A second, public field day at Highlands allowed around 50 farmers and industry professionals to view the farm and hear about the trials with a focus on how the forage cropping programme increases environmental efficiencies.

A media release by AgResearch and Bill and Shirley Wright highlighted the GHG emission and nutrient loss work under investigation at Highlands. This was re-published in several popular press outlets and gained extensive exposure, including four weeks of repeated exposure via social media. This publicity led to the filming of a rural delivery programme focused on: the Wrights, their farm and the research findings from the Forages for Reduced Nitrate Leaching and NZAGRC Integrated Farm Systems programmes of work.

A particularly pleasing component of the S+B monitor farms this year has been the gradual increase in interest from the S+B industry body B+LNZ. Support and interest has always been positive at local extension manager level for each of the monitor farms and with the Environment extension manager, however this has now moved up through B+LNZ including to their policy team and director responsible for GHG (Andrew Morrison).

Key achievements for 2016/17:

- Field days attended by approximately 300 farmers, scientists, professionals and rural leaders.
- Filming of a Rural Delivery television programme which includes coverage of the GHG emissions intensity 'good-news story' for the sheep and beef sector.
- Being able to demonstrate the wide spectrum GHG emissions, acceptable practice changes and priorities for farm owners and land managers in the sheep and beef sector through the variation in the two monitor farms and the variation in weather between seasons.
- Scientific paper showing the variability of monitoring and three key mitigations at the farm system level drafted for submission.
- Industry engagement: the increasing engagement from B+LNZ and the capacity of the programme to provide relevant and robust data into the discussions –this achievement must continue to be developed further.

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 2016/17

The programme has demonstrated the potential of future systems to meet multiple environmental drivers.

Farm systems with lower N losses tend to have lower GHG emission intensity and some future systems (lower stocking rate + plus higher BW) had reduced total emissions. This is a significant opportunity for the dairy sector to reduce the environmental footprint of their systems. However, the risk of pollution swapping with introduction of some technologies (e.g. wintering barns or stand-off pads) must be both well understood and have appropriate mitigation practices budgeted for. Assessments of system- and location-specific emissions factors are providing critical new knowledge of the potential of mitigation practices to change GHG emission profiles on farm.

The tools and approaches (including measuring emission factors) developed and tested to-date are valuable for assessing new mitigations or technologies within the farming system. Both the relative impact and the co-benefits with nutrient leaching can be determined.

- Practical farming systems which include near to market practices and technologies can deliver both lower intensity of GHG emissions in addition to lower nutrient leaching losses.
- New 'technologies' on both milking platform and for dry dairy cows during wintering provide new opportunities for reductions in GHG emissions intensity.
- Changes to genetic merit of herd (breeding worth), with associated changed in stocking rate, lower supplement and fertiliser nitrogen (N), use of wintering barns and specialist forage crops (fodderbeet and kale) are the mitigation interventions which have been analysed for GHG footprint and emissions intensity within practical farming systems in the current programme.
- Further opportunities to 'add' recently available technologies to these future systems have not been evaluated. These include spatial and precision farm management tools, the pasture species plantain and new concepts in off-pasture management.

Key achievements for 2016/17:

- Practical farming systems which include near to market practices and technologies can deliver both lower intensity of GHG emissions in addition to lower nutrient leaching losses. Some of these 'future' systems also have lower absolute greenhouse gas emissions.
- Uptake of knowledge, data and understanding of the complexity of these systems into training and extension presentations and material via Dairy Industry Action Plan activities.

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 2016/17

- Further development of the MyLand model, which incorporates input from Farmax, OVERSEER, and the Radiata Pine Calculator, and can display scenarios spatially by block within a farm, and summarise profitability and GHG/nutrient emissions.
- All 4 focus farms run through Myland to demonstrate the scenarios modelled.
- Development of a spreadsheet calculator, which can readily summarise scenario impacts on farm profitability, and changes in GHG/nitrogen emissions.

- Field days held on the focus farms to discuss the results of the modelling, demonstrate the spreadsheet calculator, and discuss results with the focus farm trustees and attending farmers. Field days held with assistance/input from Dairy NZ, Beef+Lanb NZ, and Fonterra.
- Use of the focus farm models to model scenarios based on the Forages for reduced Nitrate Leaching (FRNL) research work.

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
- Identifying areas for planting in forestry or tree crops (e.g. mānuka) was not a serious consideration for the dairy case study 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

Displaying the scenarios in a spatial context improved the understanding of the impact of any land use change.

Reaction from farmers was quite universal; they were interested in scenarios which improved farm profitability accompanied by either a decrease in GHG emissions or a slight increase in emissions. They were not interested in mitigations that decreased emissions but at a significant cost to profitability.

Key achievements for 2016/17:

- Modelling of the scenarios within the MyLand model
- Development of the spreadsheet calculator
- Presentation of the results, in conjunction with industry bodies
- Feedback from farmers as to their attitudes to the scenario/mitigation modelling

APPENDIX 3 – NZAGRC INTERACTIONS AND OUTPUTS

NZAGRC Meetings and Presentations (New Zealand)

- Meeting: International review group on ISO LCA & Environmental Footprinting Standards: 5 July, 2016 - Wellington
- Meeting: Jan Wright, Parliamentary Commissioner for the Environment: 5 July, 2016 - Wellington
- Meeting: PGgRc Board: 6 July, 2016 - Wellington
- Workshop: Sir Peter Gluckman "Conversation on Science & Society": 12 July, 2016 - Palmerston North
- Meeting: NZAGRC Maori Advisory Group: 27 July, 2016 - Palmerston North
- Meeting: NZAGRC Team: 28 July, 2016 - Paraparaumu
- Meeting: SLMACC Assessment Panel: 2 September, 2016 - Wellington
- Meeting: youth climate group: 8 September, 2016 - Wellington
- Meeting: NZAGRC Steering Group: 12 September, 2016 - Palmerston North
- NZ Inc planning for WFO study tour: 15 September, 2016 - Wellington
- Discussion with MFAT on ag gases: 15 September, 2016 - Wellington
- Presentation: Biological Emissions Reference Group: 15 September, 2016 - Wellington
- Meeting: Special Vivid Economics briefing on GLOBE-NZ climate Initiative: 26 September, 2016 - Wellington
- Meeting: GLOBE-NZ land-use sector session: 26 September, 2016 - Wellington
- Panel discussion: Climate Change and Business Conference: 11 October, 2016 - Wellington
- Briefing: PCE report: 14 October, 2016 - Wellington
- Presentation: IFS Climate Change Seminar: 19 October, 2016 - Massey University
- Meeting: Fonterra/DairyNZ emission trends and mitigation options: 8 November, 2016 - Wellington
- Meeting: MPI to discuss BERG modelling project: 9 November, 2016 - Wellington
- Presentation: NZ Law Society Seminar: 15 November, 2016 - Christchurch
- Presentation: NZ Law society seminar: 16 November, 2016 - Auckland
- Meeting: NZAGRC Steering Group: 16 November, 2016 - Palmerston North
- Visit: James Shaw, Green Party of Aotearoa New Zealand: 22 November, 2016 - Palmerston North
- Meeting: Ag Inventory Panel meeting: 24 November, 2016 - Wellington
- Meeting: outline of report to BERG: 29 November, 2016 - Wellington
- Forum: Dairy Environment Leaders Forum: 8 December, 2016 - Wellington
- Meeting: Royal Society Powering Potential session : 12 December, 2016 - Wellington
- Meeting: BERG modelling meeting: 12 January, 2017 - Wellington
- Meeting: IPCC pre meeting catch up: 8 February, 2017 - Telecon
- Meeting: NZAGRC steering group meeting: 22 February, 2017 - Palmerston North
- Meeting: Climate Leader's Session 3: 27 February, 2017 - Wellington
- Meeting: PGgRC Board meeting: 1-2 March, 2017 - Wellington
- Meeting: discussion with David Whitehead and MPI on soil carbon, 4/1000: 10 February, 2017 - Telecon
- Meeting: Ben Preston (RAND) and Deep South Challenge: 13 March, 2017 - Wellington
- Meeting: MPI re next steps in BERG work: 21 March, 2017 - Wellington
- Meeting: Integrated Farm Systems Workshop: 27 March, 2017 - Palmerston North
- Meeting: Nitrous Oxide Workshop: 27 March, 2017 - Palmerston North
- Conference: NZAGRC Conference: 28 March, 2017 - Palmerston North
- Meeting: NZAGRC Collaborative Workshop: 29 March, 2017 - Palmerston North
- Review: NZAGRC International Science Review: 29-31 March, 2017 - Palmerston North
- Meeting: BERG/NZAGRC: 5 April, 2017 - Wellington
- Meeting: Methnet/NZOZnet meeting: 8-9 May, 2017 - Wellington
- Meeting: SLMACC 2017/18 Panel Meeting: 16 May, 2017 - Wellington
- Meeting: NZAGRC Steering Group meeting: 17 May, 2017 - Palmerston North
- Meeting: inputs to IPCC refinement of inventory guidance: 19 May, 2017 - Wellington
- Lecture: Intro to NZ Ag GHG Emissions & Mgmt: 23 May, 2017 - Massey University
- Lecture: PUBL 307 lecture: 31 May, 2017 - Wellington
- Meeting: NZAGRC collective science planning workshop: 6 June, 2017 - Lincoln
- Meeting: Dairy Climate Change Partnership: 7 June, 2017 - Wellington
- Meeting: Agriculture Inventory Research Focus Group: 7 June, 2017 - Wellington
- Presentation: AgResearch Board meeting: 8 June, 2017 - Palmerston North
- Meeting: NZAGRC-PGgRC Methane Programme annual meeting: 23 June, 2017 - Palmerston North
- Presentation: Intelact farm advisors: 29 June, 2017 - Telecon

Meetings and Presentations (New Zealand)

- Andy Reisinger, 'Transition to a low-carbon economy for New Zealand' - Youth Party Climate Change Roundtable - British High Commission - 08 September, 2016
- Phil Journeaux, 'Greenhouse Gas Mitigation for Maori Focus Farms Final Modelling Report' - Report for internal use & discussion with focus farms & key stakeholders - 03 October, 2016
- Robyn Dynes & Tony Van der Weerden , 'Integrated Farm Systems presentations' - Onetai Station Field day - 20 November, 2016
- Susanna Rutledge, Louis Schipper, Aaron Wall, Paul Mudge & Dave Campbell, 'Increasing carbon balance of temperate grasslands through increased species diversity' - seminar - 15 March, 2017
- Rashad Syed, Thilak Palmada, Surinder Saggar, Kevin Tate & Peter Berben, 'Dairy housing methane mitigation using pasture soils' - MPI annual Methanet/NzOnet/Soil carbon Workshop -2017 - 08 May, 2017
- Cecile de Klein and Hong Ji Di, 'Role of plants in reducing N2O emissions from grazed pastures' - MPI annual Methanet/NzOnet/Soil carbon Workshop -2017 - 08 May, 2017
- Coby Hoogendoorn, Surinder Saggar, Neha Jha, Donna Giltrap, Jiafa Luo, Peter Bishop, Stuart Lindsey, Peter Berben, Thilak Palmada, Bert Quin, Geoff Bates & Mike Hedley, 'Efficacy of three nitrogen transformation process inhibitors for reducing nitrogrn losses from urine applied to well-drained dairy soils in autumn/winter' - MPI annual Methanet/NzOnet/Soil carbon Workshop -2017 - 08 May, 2017
- Marta Camps Arbestain, 'Providing an in-depth understanding of how organic matter (quantity and quality) respond to management practices' - MPI annual Methanet/NzOnet/Soil carbon Workshop -2017 - 08 May, 2017
- Robyn Dynes & IFT team, 'Integrated Farm Systems presentations' - Highlands Farm Field day - 18 May, 2017
- Maori project team, 'Hui during year' - Maori project focus farms - 30 June, 2017

NZAGRC Meetings and Presentations (International)

- Meeting: IPCC Scoping and Bureau: 15-19 August, 2016 - Geneva
- Presentation: AAAP Satellite Workshop : 22-23 August, 2016 - Fukuyoka
- Meeting: IPCC Panel: 17-21 October, 2016 - Bangkok
- Meeting: FAO scientific advisory panel for land-use meeting: 20 October, 2016 - Telecon
- Meeting: scientific steering committee for IPCC land-use report: 25 October, 2016 - Telecon
- Meeting: discussion of MRV work with CCAFS: 26 October, 2016 - Telecon
- Meeting: Amy Dickie re use of algae as mitigation option: 17 November, 2016 - Telecon
- Meeting: input to Vivid report: 28 November, 2016 - Telecon
- Meeting: FACCE-JPI meeting: 28-30 November, 2016 - Berlin
- Meeting: Vivid report feedback on first draft: 7 December, 2016 - Wellington
- Meeting: steering group for the IPCC land-use report: 16 December, 2016 - Telecon
- Meeting: IPCC land-use report scoping meeting: 13-17 February, 2017 - Dublin
- Meeting: MRV workshop & white paper discussion: 20-23 February, 2017 - Rome
- Meeting: IPCC panel and bureau meeting: 25-31 March, 2017 - Mexico
- Meeting: IPCC bureau: 20 April, 2017 - Telecon
- Meeting: FACCE-SAB: 26-28 April, 2017 - Brussels
- Meeting: IPCC AR6 scoping meeting: 1-5 May, 2017 - Ethiopia
- Meeting: LRG co-chairs team: 23 May, 2017 - Telecon
- Meeting: IPCC author selection for report on land-use issues: 8 June, 2017 - Telecon
- Meeting: IPCC bureau: 15 June, 2017 - Telecon
- Meeting: MRV follow-up work discussion with CCAFS: 21 June, 2017 - Telecon
- Meeting: IPCC author selection for report on land-use issues: 27 June, 2017 - Telecon

International Visitors and Groups

- Visit: Sri Lanka study tour: 13 July, 2016 - Palmerston North
- Visit: Carolyn Opio - FAO: 17-24 November, 2016 - Palmerston North
- Visit: World Federated Farmers: 30 November, 2016 - Palmerston North
- Meeting: Australia's Ambassador for the Environment meeting: 8 February, 2017 - Wellington
- Visit: China Vice Chair of National Development and Reform Commission: 16 February, 2017 - Palmerston North
- Visit: BMEL - Germany: 8 March, 2017 - Palmerston North
- Visit: Argentinian Ambassador : 16 March, 2017 - Palmerston North
- Visit: Vanuatu delegation: 25 May, 2017 - Palmerston North

NZAGRC Global Research Alliance related interactions

- Workshop: Sri Lanka - New Zealand Agricultural Cooperation : 11 July, 2016 - Wellington
- Meeting: GPLER pre proposal assessment meeting: 4 August, 2016 - Wellington
- Workshop: Inventory development: 11-19 August, 2016 - Bali
- Meeting: MPI/NZAGRC quarterly meeting: 7 September, 2016 - Paraparaumu
- Meeting: Climate Leaders - session 2 : 15 September, 2016 - Wellington
- Meeting: ERA-GAS meeting: 27-29 September, 2016 - Dublin
- Meeting: GRA Research Group Co-Chairs meeting: 9 October, 2016 - Mexico
- Meeting: GRA Council meeting : 10-11 October, 2016 - Mexico
- Meeting: IP Council meeting: 12 October, 2016 - Telecon
- Meeting: GRA co-chairs meeting: 9 November, 2016 - Telecon
- Meeting: Stakeholder Advisory Board: 1 December, 2016 - Berlin
- Meeting: ERA-GAS full proposal assessment meeting: 8 December, 2016 - Wellington
- Meeting: MPI/NZAGRC quarterly meeting: 13 December, 2016 - Palmerston North
- Meeting: GRA-LRG co-chairs meeting: 15 December, 2016 - Telecon
- Meeting: IRG meeting: 18-20 January, 2017 - Rome
- Meeting: IPCC FAO GRA Symposium: 23-27 January, 2017 - Rome
- Meeting: GRA-LRG co-chairs meeting: 8 February, 2017 - Telecon
- Meeting: GPLER panel meeting: 9-10 February, 2017 - Wellington
- Meeting: GRA co-chairs : 7 March, 2017 - Telecon
- Meeting: CCAC Panel Expert Workshop & Science Panel: 13-17 March, 2017 - Canada
- Meeting: MPI/NZAGRC quarterly meeting: 22 March, 2017 - Paraparaumu
- Meeting: GRA-LRG : 10-14 April, 2017 - Washington
- Meeting: SAP: 24-25 April, 2017 - Santiago
- Meeting: GRA Co-chairs: 15 June, 2017 - Telecon
- Meeting: CCAC: 29 June, 2017 - Telecon

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.

- 'NZAGRC welcomes stocktake of New Zealand's action on climate change' - Media release - 23 September, 2016 (Andy Reisinger - NZAGRC)
- 'NZ making good progress in climate change' - Meat Export - 28 September, 2016 (Andy Reisinger - NZAGRC)
- 'One Quick Question for 10 October 2016' - RNZ - 10 October, 2016 (Surinder Saggar - NZAGRC)
- 'Dr Andy Reisinger: livestock impact on climate change set to rise' - RNZ - 14 October, 2016 (Andy Reisinger - NZAGRC)
- Media interview (Eloise Gibson) supporting an article in NZ Listener on soil carbon – 14 October, 2016 (Andy Reisinger - NZAGRC)
- 'NZAGRC welcomes PCE report on agricultural GHG mitigation' - Media release - 19 October, 2016 (Harry Clark - NZAGRC)

- 'Cooperation needed over agricultural emissions - Experts' - Media release - 19 October, 2016 (Harry Clark - NZAGRC)
- 'Low biological emissions future for NZ red meat sector ' - Meat Export - 20 October, 2016 (Harry Clark - NZAGRC)
- 'Black Gold: Can soil save the climate?' - The Listener - 11 November, 2016 (Louis Schipper - NZAGRC)
- 'Hill country farming produces fewer emissions than previously thought' - NZ Farmer - 28 November, 2016 (Robyn Dynes - NZAGRC)
- 'Translating climate change science into practical solutions' - Meat Export - 02 December, 2016 (Harry Clark - NZAGRC)
- 'Emission reductions will have costs' - Rural News - 11 January, 2017 (NZAGRC - NZAGRC)
- 'Federated Farmers Climate Change Policy' - Fed Farmers - 08 March, 2017 (Andy Reisinger - NZAGRC)
- Media: Kristin Lin: 15 March, 2017 – Telecon (Andy Reisinger – NZAGRC)
- 'Science: Louis Schipper' - RNZ - 20 March, 2017 (Louis Schipper - NZAGRC)
- 'Greenhouse gas awareness of livestock's contribution to emissions rises among farmers' - NZ Farmer - 29 March, 2017 (Harry Clark - NZAGRC)
- 'Strong environmental gains on farm show opportunities' - Media release - 29 March, 2017 (Ina Pinxterhuis - NZAGRC)
- 'Comment: Good progress in GHG mitigation and meat research' - Meat Export - 03 April, 2017 (Andy Reisinger - NZAGRC)
- 'Dr Andy Reisinger: livestock impact on climate change set to rise ' - NZ Farmer - 03 April, 2017 (Andy Reisinger - NZAGRC)
- 'Profitable and environmental go hand in hand on South Canterbury farm' - NZ Farmer - 13 April, 2017 (Robyn Dynes - NZAGRC)
- Robyn Dynes & IFT team, 'Discussions with media' - Highlands Farm Field day - 18 May, 2017
- Robyn Dynes, David Scobie, Ray Moss & Anna Taylor, 'GHG emissions on monitor farm' - Television - Rural Delivery - 23 May, 2017
- 'Searching deep within for methane battlers' - NZ Farmer - 23 May, 2017 (Sinead Leahy - NZAGRC)
- 'Nights' Science - Soils' - RNZ - 12 June, 2017 (Louis Schipper - NZAGRC)
- 'RE: Gas emissions - farmer reaction.' - Tracey Jourdain - 13 June, 2017 (Andy Reisinger - NZAGRC)
- 'Author argues against link between ruminants and global warming' - NZ Farmer - 26 June, 2017 (Andy Reisinger - NZAGRC)

Conference Presentations

- 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 - 07 July, 2016
- AGE Ausseil, K Bodmin, A Daigneault, E Teixeira, ED Keller, MUF Kirschbaum, L Timar, A Dunningham, C Zammit, S Stephens, M Cameron, P Blackett, G Harmsworth, B Frame, A Reisinger, A Tait, D Rutledge, 'Climate change impacts and implications: an integrated assessment in a lowland environment of New Zealand' - International Environmental Modelling and Software Society (iEMSs) 8th International Congress on Environmental Modelling and Software - 10 July, 2016
- Tanira Kingi, 'International Rangelands GHG Presentation' - International Rangelands Congress 2016, Saskatoon, Canada - 21 July, 2016
- Supatsak Subharat, Neil Wedlock, Sarah Hook, Eric Altermann, Sinead Leahy & Peter Janssen, 'Vaccination of ruminants to reduce methane emissions' - Internatinal Veterinary Immunology Symposium 2016 - 29 July, 2016
- Sandeep Kumar, Gemma Henderson, Sandra Kittelmann, Mark L. Patchett, Arjan Jonker, Sinead Leahy, Graeme Attwood, Sinead M. Waters & Peter H. Janssen, 'Quinella: low-methane associated bacteria in the sheep rumen' - 16th International Symposium on Microbial Ecology - 22 August, 2016
- Phil Journeaux, 'Modelling GHG Emissions from Maori Farms Presentation' - 2016 NZ Agricultural & Resource Economics Society conference - 26 August, 2016
- Sinead Leahy, 'Methane mitigation in ruminants - a microbes perspective' - Sanfeed Animal Nutrition and Feeding Workshop - 16 September, 2016
- John McEwan, Ken Dodds, Suzanne Rowe, Rudi Brauning & Shannon Clarke, 'Genomic selection in sheep; Where to now' - EAAP conference website - 07 October, 2016
- Andy Reisinger, 'Panel discussion on the role of agriculture in the NZ-ETS' - Climate Change and Business Conference - 11 October, 2016
- Ron Ronimus, Carrie Sang & Linley Schofield, 'High-throughput screening to identity inhibitors for reducing ruminant methane emissions' - The annual New Zealand Microbiology conference - 07 November, 2016

- Sandeep Kumar, Gemma Henderson, Sandra Kittelmann, Mark L. Patchett, Arjan Jonker, Sinead Leahy, Graeme Attwood, Sinead M. Waters & Peter H. Janssen, 'Quinella: A diagnostic rumen bacterium in low-methane-emitting sheep' - Joint meeting of the New Zealand Microbiological Society and the New Zealand Society for Biochemistry - 14 November, 2016
- Arjan Jonker, David Scobie, Robyn Dynes, Grant Edwards, Cecile de Klein, Russel McAuliffe,Anna Taylor, Terry Knight & Garry Waghorn, 'Reduced CH4 emissions from dairy cows fed fodder beet' - Australasian Dairy Science Symposium, short conference presentation - 15 November, 2016
- Andy Reisinger, 'Use of national-scale socio-economic scenarios to reduce ‘presentist-bias’ in climate change adaptation decision making' - Decision Making Under Uncertainty Society - 16 November, 2016
- Arjan Jonker, Edgar Sandoval, Paul Boma, Sarah MacLean, Sharon Hickey, John McEwan, Peter Janssen & Suzanne Rowe, 'Progeny from lucerne pellets based low methane yield selection line sheep also express low methane yield on fresh pasture in three repeated periods in respiration chambers' - Proceedings British Society of Animal Science - 01 December, 2016
- Camilla Gardiner, Tim Clough, Keith Cameron, Hong Di, Grant Edwards & Cecile de Klein, 'Potential for non-urea urine nitrogen compounds to mitigate ruminant urine-derived nitrous oxide emissions' - NZ Soil Science Society Conference, Queenstown, December 2016 - 06 December, 2016
- Sheree Balvert, Jiafa Luo & Louis Schipper, 'Naturally occurring compounds in animal urine that may inhibit nitrous oxide emissions from soils' - NZASSS Conference - 12 December, 2016
- Camilla Gardiner, Tim Clough, Keith Cameron, Hong Di, Grant Edwards & Cecile de Klein, 'Can non-urea urine nitrogen compounds mitigate ruminant urine-derived nitrous oxide emissions?' - New Zealand and Australian Soil Science Symposium - 12 December, 2016
- Qinhua Shen, Marta Camps-Arbestain, Manuel Suarez-Abelenda, Stanislav A. Garbuz & Roberto Calvelo Pereira, 'Seeking Evidence of Preservation and Accumulation of Soil Organic Matter' - The joint conference of the New Zealand Society of Soil Science and Soil Science Australia - 12 December, 2016
- Mike Beare, Sam McNally, Denis Curtin, Frank Kelliher, Qinhua Shen, Roberto Calvelo-Pereira, Jeff Baldock & Esther Meenken, 'The Carbon Sequestration Potential of New ZealandÃ¢??s Agricultural Soils' - New Zealand / Australia Soil Science Society Conference - 12 December, 2016
- Louis Schipper, Jack Pronger, Dave Campbell, Susanna Rutledge, Michael Clearwater, Aaron Wall & Paul Mudge, 'Carbon isotope discrimination as an indicator of pastoral water use efficiency' - New Zealand Society of Soil Science Annual meeting - 13 December, 2016
- Louis Schipper, Aaron Wall, Susanna Rutledge, Ben Trougton, Paul Mudge, Jack Pronger & C Joshi, 'Do Soils Gain Carbon Following Conversion of Ryegrass/Clover to a Moderately Diverse Pasture?' - New Zealand Society of Soil Science Annual conference joint with Australia - 15 December, 2016
- Vince Carbone, Linley Schofield, Yanli Zhang, Carrie Sang, Renee Atua, Andrew Sutherland-Smith & Ron Ronimus, 'X-ray Crystallography, a Tool for High-Throughput Screening Inhibitors of Rumen Methanogens' - The 42nd Lorne Conference on Protein Structure and Function - 23 December, 2016
- Coby Hoogendoorn, Surinder Saggar, Neha Jha, Donna Giltrap, Peter Bishop, Jiafa Luo, Peter Berben, Thilak Palmada, Stuart Lindsey, Geoff Bates, Bert Quin & Mike Hedley, 'FLRC poster Hoogendoorn et al 26-01-17' - FLRC 30th Annual Workshop - Massey University - 31 January, 2017
- Ron Ronimus, Vince Carbone & Linley Schofield, 'Crystal structure of an UDP-aminosugar 4-epimerase from Methanothermobacter thermautotrophicus ?H' - Thermophiles 2017 conference; South Africa - 01 February, 2017
- Ron Ronimus, 'Structural Biology of Methanobacterial Enzymes for Fun and Profit' - 2017 Congress on gastrointestinal function - 24 February, 2017
- Coby Hoogendoorn, Surinder Saggar, Neha Jha, Donna Giltrap, Peter Bishop, Jiafa Luo, Peter Berben, Thilak Palmada, Stuart Lindsey, Geoff Bates, Bert Quin & Mike Hedley, 'Efficiency of Spikey®-applied nitrogen transformation inhibitors for reducing nitrogen losse from urine applied to well drained dairy soils in autumn/winter in New Zealand'- Fertiliser and Lime Research Centre Occasional Report No. 30. - 28 February, 2017
- Andy Reisinger, 'Agricultural emissions and their role in climate change: past, present and future' - New Zealand Agricultural GHG Mitigation Conference - 28 March, 2017
- Cecile de Klein and Hong Ji Di, 'New Zealand’s nitrous oxide research: plant and animal interventions' - NZ Agricultural Greenhouse Gas Mitigation Conference 28 April 2015 - 28 March, 2017
- Ron Ronimus, Vince Carbone & Linley Schofield, 'Chicago gut conference invited talk' - 2017 Chicago Congress on Gastrointestinal Function - 03 April, 2017
- Arjan Jonker, Edgar Sandoval, Sarah Maclean, Sharon Hickey, John McEwan & Suzanne Rowe, 'Sheep selected for divergent CH4 yield on lucerne pellets also express the same trait when fed fresh pasture' - British Society of Animal Science Conference - 21 April, 2017
- Rashad Syed, Surinder Saggar, Kevin Tate, Thilak Palmada & Peter Berben, 'Dairy Housing Methane Mitigation Using Pasture Soils' - FLRC 2017 - 21 April, 2017

- Linley Schofield, Yanli Zhang, Carrie Sang, Renee Atua, Stefan Muetzel, Kristy Lunn, Salome Molano, Amy Beattie, Debjit Dey, Greg Cook, James Cheung, Marion Weimar, Yasuo Kobayashi, William Whitman, Bill Denny, Andrew Sutherland-Smith, Vince Carbone & Ron Ronimus, 'Turning Down Global Warming by Cleaning Up Cow Belching' - ASM Microbe 2017 (American Society for Microbiology) - 05 May, 2017
- Camilla Gardiner, Tim Clough, Keith Cameron, Hong Di, Grant Edwards & Cecile de Klein, 'The fate of 15N labelled urine nitrogen compounds in pasture soil' - "Managing Global Resources for a Secure Future" - 2017 International Annual Meeting of the American Agronomy, Crop Science Society of America, and Soil Science Society of America - 09 May, 2017
- Linley Schofield, Yanli Zhang, Carrie Sang, Renee Atua, Stefan Muetzel, Kristy Lunn, Salome Molano, Amy Beattie, Debjit Dey, Greg Cook, James Cheung, Marion Weimar, Yasuo Kobayashi, William Whitman, Bill Denny, Andrew Sutherland-Smith, Vince Carbone & Ron Ronimus, 'Identifying Inhibitors of Rumen Methanogens to Mitigate Ruminant Methane Emissions' - ASM Microbe 2017 (American Society for Microbiology) - 19 May, 2017
- Andy Reisinger, 'From Paris to the NZ farm' - Intelact consultants conference 2017 - 29 June, 2017

Journal Articles

Submitted

- Baldock, J., Beare, M., Curtin, D., & Hawke, B. (Submitted). Predicting the content, composition and management impacts on stocks and vulnerability of soil organic carbon using mid-infrared spectroscopy. *Soil Research*.
- Beare, M., McNally, S. R., Curtin, D., Tregurtha, C., Weiwen, Q., Kelliher, F., & Baldock, J. (Submitted). Assessing the vulnerability of organic matter to C mineralisation and loss in pasture and cropping soils. *Soil Research*.
- Calvelo Pereira, R., Camps Arbestain, M., Kelliher, F., Theng, B. K. G., Noble, A. D. L., & McNally, S. R. (Submitted). Assessing the pore structure and surface area of allophane-rich and non-allophanic soils by supercritical drying and chemical treatment. *Geoderma*.
- Clough, T., Cameron, K. C., Gardiner, C. A., Edwards, G. R., Di, H. J., & De Klein, C. (Submitted). Non-urea ruminant urine nitrogen compounds: assessing their potential effects on soil nitrous oxide emissions in a field trial. *Science of the Total Environment*.
- Frame, B., Reisinger, A., & Lawrence, J. (Submitted). Adapting shared climate policy assumptions for national and local scenarios in New Zealand. *Environmental Research Letters*.
- Jonker, A., Hickey, S., Janssen, P. H., Shackell, G., Elmes, S., Bain, W., . . . McEwan, J. C. (Submitted). Heritability and repeatability estimates of methane emissions from young and mature grazing sheep determined using portable accumulation chambers and genotypic and phenotypic correlations with emissions determined in respiration chambers. *Journal of Animal Science*.
- Jordan, O., Kuhn-Sherlock, B., Zimmerman, S., Zimmerman, P., Flay, H., Bryant, M., . . . Roche, J. R. (Submitted). Development and Validation of an Automatic Feed Intake and Methane Measurement System. *Journal of Dairy Science*.
- Kingi, T., Journeaux, P., & West, G. (Submitted). Modelling farm systems efficiencies and land use change to reduce greenhouse gas emissions: Maori case study farms from Aotearoa New Zealand *Agricultural Systems*.
- McNally, S. R., Beare, M. H., Curtin, D., Meenken, E. D., Kelliher, F. M., Calvelo Pereira, R., . . . Baldock, J. (2017). Soil carbon sequestration potential of permanent pasture and continuous cropping soils in New Zealand. [Article in Press]. *Global Change Biology*. doi: 10.1111/gcb.13720
- Reisinger, A., & Clark, H. (Submitted). How much do direct livestock emissions actually contribute to global warming? *Global Change Biology*.
- Rowe, S., Hickey, S., Bain, W., Greer, G., Elmes, S., Bryson, B., . . . McEwan, J. C. (Submitted). Effects of selecting for lowered methane yield in breeding ewes. *Journal of Animal Science*.
- Rowe, S., Hickey, S., Bain, W., Greer, G., Elmes, S., Pinares-Patino, C., . . . McEwan, J. C. (Submitted). Can we have our steak and eat it: production yield and meat quality from sheep bred for lowered environmental impact *Journal of Animal Science*.
- Shen, Q., Suarez Abelenda, M., Camps Arbestain, M., Calvelo Pereira, R., McNally, S. R., & Kelliher, F. (Submitted). New Evidences Supporting the Self-Assembly of Organic Molecular Fragments on Soil Mineral Surfaces. *Nature Communications*.
- Vetharaniam, I., Vibart, R. E., & Pacheco, D. (Submitted). Evaluation of Molly 14, a sheep rumen model, with fresh forages of diverse chemical composition. *Journal of Animal Science*.
- Weimar, M. R., Cheung, J., Dey, D., McSweeney, C., Morrison, M., Kobayashi, Y., . . . Cook, G. M. (Submitted). Development of Multiwell-Plate Methods Using Pure Cultures of Methanogens To Identify New Inhibitors for Suppressing Ruminant Methane Emissions. *Appl Environ Microbiol.* doi: 10.1128/AEM.00396-17

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- Balvert, S. F., & Luo, J. (2017). Dietary manipulation as a tool for mitigating nitrous oxide emissions. In J. Luo (Ed.), *Greenhouse Gas Emissions and Nitrogen Losses from Grazed Dairy and Animal Housing Systems*: Nova Science Publishers Inc.
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- Yang Li, 'Comparative genomics of rumen methanogens' – PhD thesis, Massey University - 29 July, 2016
- Michele Hollis, Cecile de Klein, Dave Frame, Mike Harvey, Martin Manning, Andy Reisinger, Suzi Kerr & Anna Robinson, 'Cows, Sheep and Science: A Scientific Perspective on Biological Emissions from Agriculture' - Motu Working Paper 16-17 - 31 October, 2016
- Edgar Sandoval, 'High and Low Methane Emitting Sheep' - Submiited as a research report as part of the requirements for Edgar's Diploma on Environmental Mana - 25 November, 2016
- Yuancheng Wang, 'Mechanistic modelling of enteric methane production' - Massey University for thesis examination - 21 December, 2016
- "Miko Kirschbaum, 'CenW Web Release' - Release via Landcare web site - 16 January, 2017"
- Bob Frame & Andy Reisinger, 'Climate Changes, Impacts and Implications for New Zealand to 2100. Synthesis Report: RA5. Exploring Options for New Zealand under Different Global Climates' - CCII (Climate Change Impacts and Implications) Synthesis Report - 13 February, 2017
- AGE Ausseil, K Bodmin, A Daigneault, E Teixeira, ED Keller, MUF Kirschbaum, L Timar, A Dunningham, C Zammit, S Stephens, M Cameron, P Blackett, G Harmsworth, B Frame, A Reisinger, A Tait, D Rutledge, 'Climate Changes, Impacts and Implications for New Zealand to 2100. Synthesis Report: RA2. Lowland case study' - - 13 February, 2017
- Ron Ronimus, 'Activation pathway Marsden 2017 proposal' - Marsden fund - 17 February, 2017
- Andreas Wilke, Andy Reisinger, Eva Wollenberg & Suzanne van Dijk, 'Measurement, reporting and verification of livestock GHG emissions by developing countries in the UNFCCC: current practices and opportunities for improvement' - Livestock MRV white paper - 07 June, 2017