NEW ZEALAND AGRICULTURAL GREENHOUSE GAS Research Centre

Annual Report 2018

Leading Partners in Science

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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 it is a long term goal. Successfully reducing greenhouse gas (GHG) emissions below a historical baseline 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 has a practical impact on the greenhouse gas emissions emitted from New Zealand agriculture. The table below highlights key some key outputs from 2017/18 and their envisaged impacts.

NZAGRC/PGgRc output	*Expected impact*
The animal breeding work has found: • Differences in methane (CH_4) emissions between sheep selection lines continue to persist with continued breeding. • The low CH_4 sheep appear leaner. VFA meat quality analyses, however, show that intra-muscular fat doesn't differ but branched chain fatty acids are higher in the low lines. • Prediction using molecular breeding values appears to be sufficiently accurate that, given a well-chosen training population, predictions could be made available to breeders. • Breeding sheep for low methane will neither increase nor decrease nitrogen excreta-related greenhouse gas emissions. • Some parts of the rumen microbial communities have been identified that appear predictive of methane yield. • Higher economic value in favour of the low lines appears to be an on-going trend.	Direct breeding for low emissions and selection via genomic markers or rumen microbial community analysis has the potential to reduce from the sheep sector by up to 1% pa. The indication of leaner low emitting lines could be important for milk composition and for early life nutrition. B+LNZ Genetics Ltd are now testing the impact of the low emitting trait with elite breeders.
Plantain appears to have a direct effect on nitrous oxide (N_2O) emissions. Results from detailed animal studies with cattle show that at equal total N intake the quantity of urinary N excreted declines as the proportion of plantain in the diet increases above 15%. Preliminary results suggest that the lower N_2O emission factors recorded with increasing proportions of plantain in the sward is most likely due to an effect of plantain itself on soil processes. An initial cattle trial suggest that plantain may also reduce CH_4 emissions, but the unusually high emissions recorded in control animals fed silage only suggest that this may be associated more with a dilution of the silage component rather than plantain having properties that would reduce emissions below the values usually recorded for pasture dominated diets.	There is a growing weight of evidence from individual that plantain can have a positive impact on N processes in animals and soils. The challenge now will be to integrate plantain into farming systems.
Analysis has shown that mid-infrared (MIR) spectroscopy can be used to identify the soil carbon stabilisation capacity and saturation deficit of different New Zealand grassland soils.	This technique may allow soil carbon measurements to be made from whole soil samples more quickly and more cost-effectively.

The key finding from an assessment of the effects on soil carbon from high levels of supplementary feeding on a dairy farm (approximately 5.3 t carbon imported per ha) was that 13% of the imported carbon (about 710 kg/ha/y) was stored as additional soil carbon during the three years of the study. Once soil carbon losses from growing these supplementary feeds using current practices is taken into account the net impact on soil carbon may be minor.	Net carbon changes arising from supplementary feeding (e.g. maize) on dairy farms using existing management practices may be minor.
Successful demonstration that the urine from sheep consuming a novel compound delivered through a slow release device reduced N_2O emissions in a controlled laboratory study.	Work is at an initial stage and more comprehensive trials are being planned.
Modelling farm system change on multi-enterprise Māori farming entities resulted in +/- 5-10% changes in GHG emissions, similar to previous modelling work. Land use change into forestry or horticulture had a much higher impact.	Mixing and matching the farm system and land use change at the whole business level has the potential to significantly reduce GHG emissions, while maintaining or enhancing business profitability.

CHAIR'S REPORT

Over the past year the focus on environmental issues in both domestic and international arenas has continued to grow. Following the Paris meeting in December 2015, governments around the world began fast tracking climate change issues and ratifying the global agreement much earlier than anticipated and it came into force on 4th November 2016. New Zealand ratified the agreement in October 2016. Currently 179 Parties have ratified the Paris Agreement, out of 197 Parties to the convention.

Domestically, climate change policy is being revised. At the end of 2017, the new Minister for Climate Change announced an intention to consult widely on a proposed Zero Carbon Act, with the aim of a Zero Carbon Bill being introduced in 2019. The cabinet has agreed a framework for the whole of Government which will drive New Zealand's climate change policy towards low emissions and climate resilience. This framework supports the existing target for New Zealand to reduce greenhouse gas emissions by 30% per cent below 2005 levels by 2030. It also plans to set a new emissions reduction target for 2050 and to establish an independent Climate Change Commission.

There is increasing urgency at all levels and within all major industries to address climate change. Whilst the Zero Carbon Bill is under development, a domestic Interim Climate Change Committee along with a supporting secretariat has been established, which involves both Harry Clark and Andy Reisinger from the NZAGRC. One of the two key issues for the Committee to develop evidence and analysis on is "if a decision is made to bring agriculture into an emissions trading scheme, how should this be done?" It is now widely accepted that the agricultural sector will have to play its part in achieving the Paris target and longer term goals. As a sector which contributes 49% to the country's GHG emissions, changes will need to be made to the way New Zealand farms in the future.

When contemplating agricultural GHG strategies however, there are a number of science and policy challenges to be considered. Globally, large technical questions remain about how to mitigate agriculture's emissions whilst still producing food in sufficient quantities to supply an expanding population. General national economic impacts and impacts on farmers and rural communities also need to be considered carefully. This is especially important when considering whether changes in land use, for example a move away from livestock into trees (in some areas) are the most cost-effective mitigation solution.

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. 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. New, practical, cost-effective mitigation technologies and practices will make a valuable contribution to government strategies and subsequent action plans. There is also a need to consider international collaborations and alliances in order to find lasting global solutions.

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. The NZAGRC is also working with the Biological Emissions Reference Group (BERG) and industry-led initiatives such as the Dairy Action for Climate Change plan to ensure that the science-based strategies developed are fully aligned with the industry and policy makers needs.

A number of key science results in 2017/18 demonstrate that the science teams are getting closer to viable solutions to reduce agricultural GHGs. 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 2018

NZAGRC DIRECTOR'S REPORT

Interest in mitigating GHG emissions from New Zealand agriculture has never been stronger. Reports from the Parliamentary Commissioner for the Environment and the Productivity Commission, and the planned introduction of a Zero Carbon Act with the possibility of agriculture entering the Emissions Trading Scheme, have brought emissions from agriculture to the forefront of the national debate. The work of the NZAGRC has never been more relevant or topical and NZAGRC staff and researchers are playing key roles as new policy and industry-led initiatives to reduce agriculture's environmental footprint are being developed and launched. The NZAGRC-funded research programme continues to contribute to what we envisage will be globally applicable mitigation solutions which will help countries to meet their emissions reduction targets.

Working alongside MPI, the PGgRc, and increasingly with industry, 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 and, in some areas, this is already happening at a pilot scale. For example, the impact of the low emitting sheep is currently being validated with elite breeders. This is an exciting development as it will enable commercialisation of the programme and allow decisions to be made by breeders to select lower methane sheep at farm level.

New work plans have been developed for the nitrous oxide, soil carbon, integrated farm systems and Māori programmes over the past year and work is now underway. Recommendations from the reviews of these programmes during 2016/17 were taken into account at the planning stages. A new programme, "Plants and GHGs", brings together the nitrous oxide and soil carbon research in a fully coordinated fashion out to June 2019. Additionally, the new integrated farm systems and Māori work plans involve working alongside the relevant industry organisations and aligning strongly with their goals.

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 provides opportunities for undergraduates to gain experience in a research environment and provides post-graduates with top-up funding to accelerate their work. In addition, we also provide direct support to PhD students linked to NZAGRC research programmes. We are proud that a number of past recipients of NZAGRC funding as students have now gone on to research careers in the agricultural GHG space, both in New Zealand and overseas.

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 my appointment to the Interim Climate Change Committee and Andy Reisinger's role as an Inquiry Director for the Committee's Secretariat. We also completed a comprehensive piece of work for the Government's Biological Emissions Reference Group summarising what farmers can do now to reduce emissions. The increasing demand for impartial science advice around the science of greenhouse gases from a broad range of companies and organisations has meant that there has been no shortage of things to do. At an operational level, we welcomed a new administrator, Trina Bishop, to the team after Tania Brown moved to a more senior role within AgResearch.

The Centre's original contract was planned to end on 30 June 2019. A one year extension has been agreed with MPI for the NZAGRC to continue in its current form and at the same level of funding to June 2020. Centre partners and stakeholders have started to work with government and industry to develop priority research and technology actions to support the agriculture sector to reduce their GHG emissions over the next decade.

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

Dr Harry Clark
NZAGRC Director
August 2018

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.

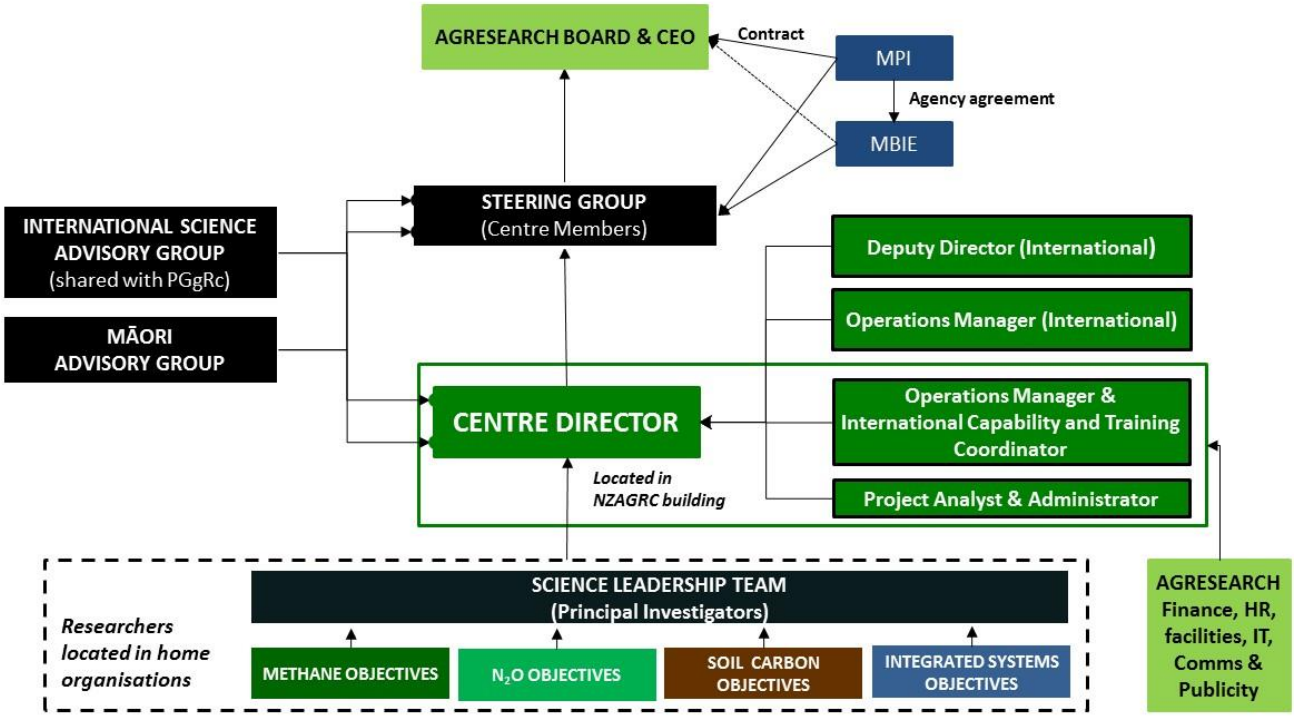
NZAGRC is not the only significant investor into agricultural GHG mitigation research in New Zealand. Much of NZAGRC methane research builds on research investments made by the PGgRc, and since 2013 the NZAGRC and PGgRc investments have been formally aligned. This involves a single research strategy 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 Operations Manager (International) is also employed by AgResearch and works remotely but with a routine presence in both Wellington and Palmerston North. The Deputy Director (International), is located in Wellington and was fully employed by AgResearch until late 2017/18. In May 2018 the Deputy Director accepted a senior, part time, position in the Secretariat supporting the Government's newly appointed Interim Climate Change Committee. The NZAGRC has retained a small part of the Deputy Director's time and a replacement is being sought.

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. An International Science Advisory Group (ISAG) is convened regularly 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. Additionally, the SG have contributed to strategic, high level thinking about the involvement of science in supporting the agriculture sector to reduce their GHG emissions post 30 June 2019.

During 2017/18 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 2017/18 can be found in Appendix 1.

2017/18 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 for the first five years of were included in the NZAGRC Strategic Plan. The targets were updated in 2017 in agreement with MPI. 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 2017/18 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 number of factors have brought agricultural emissions to the forefront of the national debate in the past year and the NZAGRC has been heavily involved in this discussion. NZAGRC staff and researchers are playing key roles as new policy and industry-led initiatives to reduce agriculture's environmental footprint are being developed and launched.
- 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 vaccines.

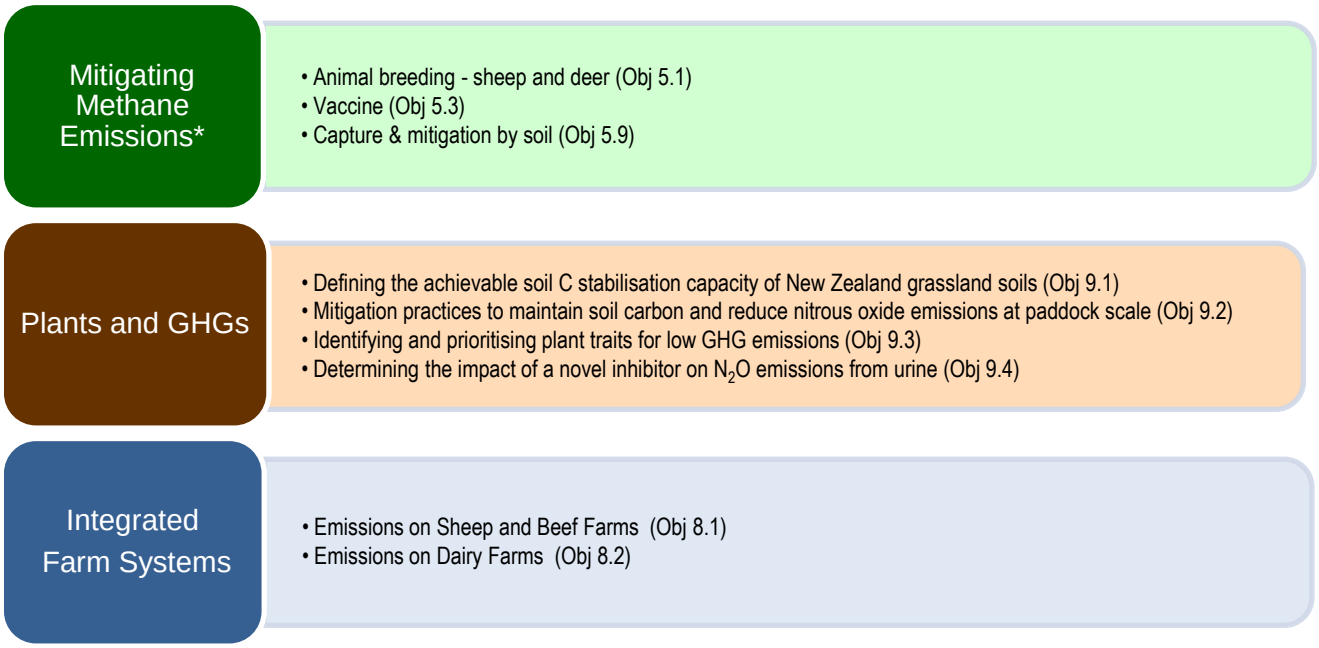
- Further building of relationships and engagement with the Māori sector, including holding a number of hui and on-farm field days with new focus farms as part of the next stage of the Māori-focussed research programme.
- Continued efforts to communicate our science and how it fits into the bigger picture 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. NZAGRC works closely with key GRA partners such as the FAO, World Bank and CCAFS (the CGIAR's Research Program on Climate Change, Agriculture and Food Security) to deliver international and regional projects on behalf of the GRA and to raise awareness of the opportunities associated with low emissions livestock production.
- Extensive engagement with New Zealand policymakers including active scientific input into the Biological Emissions Reference Group and Harry Clark's appointment to the Interim Climate Change Committee. The demand for impartial science advice around the science of greenhouse gases from policymakers has increased over the past year.
- 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 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 three Science Programmes in alignment with other agencies and private investors.



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

Formal alignment with the PGgRc led to a joint science plan and subsequent joint contracting in the Methane programme being implemented from 1 July 2013. Since this time, contracts have had an annual review clause in them to ensure that the research remains solution-focussed. In 2017/18 updated work plans were negotiated for the breeding and vaccine work out to 31 December 2018 and 30 June 2018 respectively. These plans were agreed with the PGgRc Board, based on progress and results in the recent year. New work plans are currently being finalised.

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 would enable more fundamental studies on understanding the ruminant immune system to be undertaken. This funding covered two dedicated post-doctoral fellows. One post-doctoral fellow was appointed in late 2016/17 and the other in early 2017/18. The input of the post-doctoral fellows has been very valuable to moving the programme forwards at an increased rate.

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 were accepted by the Steering Group and taken into consideration for planning the next stage of the research. A strong recommendation was to combine the N_2O and Soil C work streams together to work under one overall conceptual framework with an integrated view of the Centre's objective and outcomes. This has been done under the new 'Plants and GHGs' programme.

An extensive amount of strategic thinking, industry engagement and planning has been put into developing new work plans for the Integrated Farms Systems programme over the past year. B+LNZ

and DairyNZ are integrally involved, respectively, in the new work for the sheep and beef sector and the dairy sector. The goal is that the outcomes of this work will be rolled straight out to NZ farmers via existing, and potentially new, extension networks.

Descriptions of the Objectives outlined above, and their progress during 2017/18, are contained in Appendix 2.

In 2017/18, key science achievements included:

- Demonstration that differences in methane emissions between sheep selection lines continue to persist and diverge. Additionally, higher economic value in favour of the low CH_4 selection line was seen again this year and this appears to be an on-going trend.
- Identification of some microbial communities that appear predictive of methane yield.
- Further study of plantain and contribution to the growing weight of evidence that plantain can have a positive impact on N processes in animals and soils. An initial cattle trial suggests that plantain may also reduce CH_4 emissions, but this result needs further examination.
- Analysis to show that mid-infrared (MIR) spectroscopy can be used to identify the soil carbon stabilisation capacity and saturation deficit of different New Zealand grassland soils.
- Assessment of the effects on soil carbon of high levels of supplementary feed has shown that net carbon changes arising from supplementary feeding on dairy farms are likely to be minor.
- Successful demonstration that the urine from sheep consuming a novel compound reduced N_2O emissions in a controlled laboratory study.

More detailed information regarding science progress during 2017/18 can be found in Appendix 2 which includes the submitted annual reports from the NZAGRC-funded Objectives.

Goal 1 metrics:

Measure	*Progress in 2017/18*
Peer-reviewed scientific journal papers	12 papers published plus 15 papers submitted
Scientific conference papers	30
Valuable pieces of IP produced or contributed to	Methane breeding values, vaccine programme and novel compound which reduces N_2O emissions
Practical on-farm mitigation practices and technologies identified and being promoted	Comprehensive report prepared for the Government's Biological Emissions Reference Group summarising what farmers can do now to 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. The PGgRc is an unicorporated joint venture involving: AgResearch, Beef + Lamb New Zealand, DairyNZ, DEEResearch, Fertiliser Association, Fonterra, Landcorp Farming (Pāmu) and PGG Wrightson. 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 2017/18 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 2018 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 range of co-branded factsheets and proactive media engagement.
- NZAGRC support for PGgRc-led activity and engagement to progress commercialisation.

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 2017/18 that included:

- Meetings with farmer groups, individual companies and organisations and giving presentations at stakeholder forums (e.g. NZAGRC planning workshops, Federated Farmers, Fonterra, LIC and CRV Ambreed, DairyNZ board and farmer climate change workshops, on-farm field days at research farms).
- Presenting at outreach events and giving expert lectures in New Zealand and internationally (e.g. IPCC public outreach events, FAO workshops, Massey University course, OECD Climate Change Experts Group).
- Dedicated publications (e.g. annual Highlights document, factsheets and e-newsletter) and articles in farming and general press and interviews on television and radio.
- Appointment of Harry Clark to the Interim Climate Change Committee.
- 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, Parlimentary Commisioner for the Environment, Productivity Commission).

- Hosting international visitors and showcasing New Zealand agricultural GHG science, including 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, B+LNZ and DairyNZ) and Māori programme (2 new Māori agri-business entities).
- Increasing presence on social media.

Māori Engagement

The first stage of a focussed Māori research programme ran from 1 July 2014 to 30 June 2017. The "Low emission farm systems for the Māori sector" project was led by AgFirst and Scion and involved developing a network of 29 farms, with in-depth modelling studies carried out on four focus 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 was required to better understand barriers and risks to their adoption. The project was well received and feedback from the MAG was positive. The project was independently reviewed in November 2017 and recommendations from the review were incorporated into the new contract.

The "Farm Systems Mitigation Modelling for GHG Reduction on Māori Farms" project started in December 2017 and finishes 30 June 2019. This project builds on the previous Māori project and extends it further by working with 2 Māori Agri-Businesses entities (involving dairy, sheep & beef, forestry and potentially horticulture) to model greenhouse gas emissions from the various enterprises, and how these can be balanced at a business level. In addition, the project will (i) discuss and outline decision making criteria and issues around GHG mitigation strategies; and (ii) discuss and analyse barriers to the uptake of GHG mitigation strategies.

In 2017/18 the project team identified 2 multi-enterprise Māori operations, incorporating dairy farms, sheep & beef farms, and forestry operations that were willing to allow modelling to identify impacts of reducing GHG emissions. Following discussions with the Trustees, a range of scenarios have been modelled involving a variety of farm system changes and also changes in land use. The proposed changes are being discussed in detail with Trustees. Engagment from across the sector has been very positive for the research. The project involves a Reference Group made up of representatives from Dairy NZ, Beef + Lamb NZ, FOMA, and Te Tumu Paeroa, to ensure that results from the project can be shared across the wider agricultural industry.

Communications and media

In August 2017 the NZAGRC Steering Group endorsed a new Communications Strategy intended to help build the profile of the New Zealand Agricultural Greenhouse Gas Research Centre. It was felt that the Centre should put more priority on communications, with the aim of the strategy being to showcase the Centre's work and to broadcast the contribution it makes to the science around mitigation of agricultural greenhouse gases in New Zealand and globally. Six communications objectives were established, namely to:

- Promote the NZAGRC and its key staff and lead scientists as the country's most important and trusted source of information on agricultural greenhouse gas emission mitigation;

- Drive traffic to the NZAGRC website (KPI target is five percent increase year on year);
- Positively engage stakeholders and members of the public to ensure they understand the purpose and value of the NZAGRC;
- Help ensure stakeholders understand what solutions might be in the pipeline;
- Increase media engagement; and
- Develop and maintain an active social media presence.

In the year since, the main objectives of the strategy have been met and the focus has been on promoting the NZAGRC as a knowledge hub, cementing the Centre's role as New Zealand's foremost authority on livestock greenhouse gas mitigation.

However, subsequent to the creation of the 2017 Communications Strategy, the change of Government and the consultation on the introduction of a Zero Carbon Bill has required the Centre to strategically review its communications approach in order to ensure the NZAGRC is understood to be neutral, and purely scientifically-focused. In particular, the objective of "increasing media engagement" could have been counter-productive in the short-term unless the focus on science was underlined.

Some requests for engagement from media and the public have assumed that the Centre would be an advocate for a particular GHG mitigation strategy. The danger for the Centre was in being drawn in debate with lobbyists on the merits of particular strategies. A further consideration has been the appointment of Centre Director Harry Clark and Deputy Director Andy Reisinger to positions with the Interim Climate Change Committee. The Government's brief to the committee is to begin work on how New Zealand transitions to a net zero emissions economy by 2050, and how agriculture might enter into the New Zealand Emissions Trading Scheme (NZETS), prior to the setting up of the independent Climate Change Commission. It has been important therefore not to compromise the Director and Deputy Director by actively seeking media opportunities when they could be asked to comment on Government policy, as opposed to science.

While bearing in mind the above, we have still continued to promote the NZAGRC and its key staff and lead scientists as the country's most important and trusted source of information on the science of agricultural greenhouse gas emission mitigation.

Communication highlights from 2017/18:

- An active presence has been initiated and maintained on Facebook, Twitter and LinkedIn, with the key goal of driving traffic to the NZAGRC website. The engagement on Twitter to date continues to be the most active and engaged.
- Regular content added to the NZAGRC website and redevelopment of navigation to enable information from our factsheets to be repackaged into web content.
- Stories written and disseminated profiling NZAGRC-funded researchers, in particular graduating PhD students and new publications.
- Engagement with New Zealand journalists and the international media including options for NZ farmers to reduce emissions and the impact of livestock on climate change.
- Proactive media comment including clarifying the interpretation of national and international research reports related to methane in the atmosphere, explaining what the impact of climate change on NZ might be by 2100 and providing information about IPCC meetings

Additionally, during 2017/18 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 2017/18
Meetings and Presentations (New Zealand)	104
Meetings and Presentations (International)	15
International Visitors and Groups	11
Global Research Alliance related interactions	26
Media interactions	21
Conference presentations	30
Journal articles in press	15
Journal articles published	12
Other interactions/publications	42

Goal 2 metrics:

Measure	*Progress in 2017/18*
Increase in page views of Centre's website	+36% versus 2016/17
Senior Centre staff presentations to meetings of New Zealand industry and policy stakeholders and contributions to news articles	26 presentations with NZ industry/policy stakeholders 7 direct contributions to news articles
Centre funded scientist presentations / news articles / factsheets for the farming community and general public	16 presentations for farming community and/or general public 18 direct contributions to news articles / factsheets
Senior Centre staff representation on international bodies	- Climate and Clean Air Coalition Science Advisory Board - FACCE-JPI Science Advisory Board - Global Research Alliance on Agricultural Greenhouse Gases - Intergovernmental Panel on Climate Change - Livestock Environmental Assessment and Performance partnership

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 and strengthen in 2017/18, reflecting in part the rapidly changing international and domestic context and New Zealand's goal to introduce a Zero Carbon Bill in 2019.

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 an assessment of the national impact of currently available mitigation practices and technologies. NZAGRC staff have also advised the Productivity Commission and the Parlimentary Commissioner for the Environment.

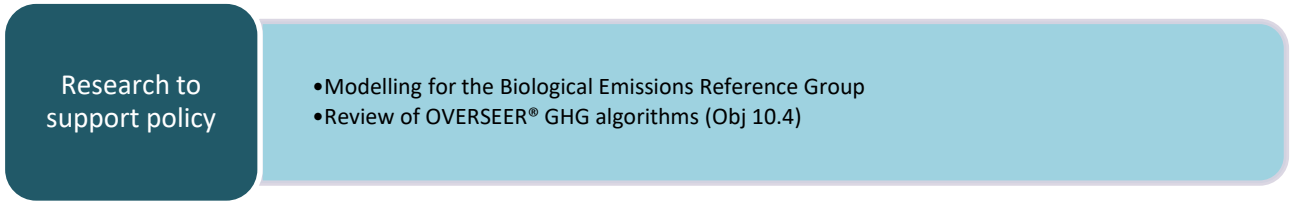
The Centre's on-going inputs into the GRA and other international initiatives, as well as technical advice to government agencies and industry stakeholders to support domestic policy development, are prime examples of activities that the Centre engaged in during 2017/18 related to this goal.

Other activities by the Centre in 2017/18 include:

- Director has been appointed to the Interim Climate Change Committee (0.4 FTE) and Deputy Director has a senior role in the Secretariat to the committee (0.5 FTE).
- 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 Climate and Clean Air Coalition Science Advisory Board.
- Deputy Director is a member of the FACCE-JPI Science Advisory Board.
- Deputy Director is vice-chair of the Bureau of Working Group III of the Intergovernmental Panel on Climate Change (IPCC). This focuses on options to reduce greenhouse gas emissions. The NZAGRC was involved with organising an IPCC expert meeting in Christchurch in March 2018.
- The Director and Deputy Director have both been selected as Lead Authors of the IPCC 6th Assessment Report.
- NZAGRC hosted a number of international, as well as senior-level domestic, visitors.

Research to support policy

In addition to the activities outlined above, in alignment with MPI, the NZAGRC funds research to specifically support policy.



In 2017/18, NZAGRC senior staff conducted and commissioned modelling work for the Biological Emissions Reference Group. A review of the OVERSEER® GHG algorithms was also funded.

Goal 3 metrics:

Measure	*Progress in 2017/18*
Senior Centre staff presentations to meetings of New Zealand government policy staff and Ministers	20 - Including some meetings with the Parliamentary Commissioner for the Environment and Prime Minister's Chief Science Advisor's offices, plus visits from international Ministers and Ambassadors accompanied by NZ policy staff
Written reports prepared for government policy staff as requested by MPI	4 reports requested and prepared. 2 reports prepared for the BERG, 1 report on OVERSEER® and 1 for the Parliamentary Commissioner for the Environment

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 2017/18 the dedicated undergraduate "pipeline" scholarship continued with Massey, Lincoln and Waikato Universities each receiving funding to allocate as required to encourage high achieving students to continue their study and assist with their career development. The NZAGRC also contributed funding to maintain two dedicated post-doctoral researchers to support the vaccine programme.

Type of Capability Development	# active in 2017/18	Total funded to date*
Undergraduate - Summer student	1	23
Undergraduate - Honours student	1	12
Undergraduate - Intern	2	4
Masters Project	0	3
Masters	3	9
PhD	10	20
Post-doctoral fellow	4	8
Early career scientist	0	2
	21	81

*Including active 17/18 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 2017/18*
PhD students graduated	6 PhD students graduated during 2017/18
Undergraduate, masters and PhD students currently studying under NZAGRC funding	4 undergraduate, 3 masters & 4 PhD students
Post-doctoral researchers completed projects under NZAGRC or GRA funding	3 active NZAGRC-funded post-doctoral researchers, 1 completed NZAGRC-funded project at end of 2017/18 3 active GRA-funded post-doctoral researchers, 1 completed GRA-funded project during 2017/18
Centre is maintaining a balanced funding portfolio to ensure that capability is maintained and research programmes are sufficiently resourced	Proportion of science spending: - Methane 29% - Nitrous Oxide 33% - Soil Carbon 26% - Integrated Farm Systems 12%

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 New Zealand Government started the Global Research Alliance on Agricultural Greenhouse Gases (GRA) in 2009 to increase international cooperation and investment in agricultural research activities that mitigate the effect of greenhouse gas emissions. Nearly a decade on, 50 countries and 16 international and regional partners are now working together in the pursuit of this goal. It remains a key plank in New Zealand's work on climate change and agriculture, offering significant opportunities to build global research and commercial partnerships and strengthen domestic capability.

NZAGRC has played a critical science leadership role in the GRA since 2009, including continuing to co-chair the GRA's Livestock Research Group and providing strategic advice and support to MPI (which administers the GRA Secretariat and the Government's dedicated multi-million GRA budget). NZAGRC works closely with key GRA partners such as the FAO, World Bank and CCAFS (the CGIAR's Research Program on Climate Change, Agriculture and Food Security) to deliver international and regional projects on behalf of the GRA and to raise awareness of the opportunities associated with low emissions livestock production. NZAGRC advises on the strategic direction of the GRA, helps link its activities internationally and ensures that the New Zealand science community is well engaged. It also promotes the work of the GRA more broadly via a range of communication channels, including the press, social media, a regularly updated website, newsletters and presentations at scientific conferences and expert meetings.

NZAGRC led or supported a wide range of GRA activities during 2017/18 as well as continuing to negotiate and manage GRA research contracts on behalf of MPI. NZAGRC's GRA work now involves the Centre Director, Operations Manager (International), International Capability and Training Coordinator and Project Analyst, along with external contractors. A dedicated GRA post-doctoral position will be created at the start of 2018/19. The Centre's Deputy Director has also played a lead role, however moved on in May 2018 to take up a senior position in the Secretariat supporting the Government's newly appointed Interim Climate Change Committee.

NZAGRC organised and co-chaired the annual meeting of the LRG in mid-May 2018 in Ho Chi Minh City, Vietnam. Representatives from 26 countries attended the meeting, along with the LRG's research networks and four international partners (FAO, CCAFS, the Climate & Clean Air Coalition (CCAC) and CATIE (Latin American regional research institute)). The LRG meeting identified countries' shared challenges and opportunities in research to reduce livestock greenhouse gas emissions, reviewed progress with the GRA's newly established flagships (see Research Activities section below) and discussed ways that the group, and the wider GRA, could engage more actively internationally. This included opportunities to inform the work of the Intergovernmental Panel on Climate Change (IPCC) and the UN climate change negotiations, which is establishing a work programme on agriculture.

Research Activities

A new research partnership opportunity emerged during 2017/18 with the GRA Council's establishment of flagship programmes on enteric fermentation, inventories, and soil carbon (a rice flagship was also set up, and further flagships on nitrous oxide and 'circular agriculture' are also being explored). These flagships represent the GRA's top priorities for research and capability building, aiming to advance global knowledge through collaboration at the same time as supporting countries to develop and implement nationally appropriate solutions. NZAGRC's leadership of the enteric fermentation flagship has resulted in the establishment of two major global projects during 2017/18 – both involving New Zealand providers.

As well as supporting the GRA flagships, NZAGRC provided extensive support to MPI on other collaborative research investment opportunities –signing a total of 23 new contracts during 2017/18 (the negotiation of some of these took place in 2016/17). This included eight contracts from the fourth round of the New Zealand Fund for Global Partnerships in Livestock Emissions Research (GPLER) and five contracts supporting New Zealand's involvement in 'ERA-GAS', a European co-fund for monitoring and mitigation of greenhouse gases from agri- and silvi-culture. NZAGRC also provided support with the contracting of a further 10 priority projects for MPI, valued at nearly $5.5 million. Details of these projects can be found in the separate NZAGRC annual report for services relating to the GRA.

The NZAGRC in partnership with the Food and Agricultural Organisation of the United Nations (FAO) submitted a successful bid to the Climate and Clean Air Coalition for work in Asia, East Africa and Latin America. This work, which is focussed on improved national GHG inventories, is co-funded by the New Zealand GRA fund.

2017/18 also saw 10 GRA-funded projects completed. A number of these have delivered outcomes of relevance to NZAGRC's domestic programmes, with highlights including:

- *Deep sequencing the rumen microbiome* (2013-2017): advancing our understanding of the interaction between low-emitting animals and the differences observed in their rumen microbiome.
- *Using naturally produced lovastatin to reduce methane emissions* (2015-2018): testing the methane mitigation effects of lovastatin produced in palm kernel cake and fed to goats. The project found that naturally produced lovastatin, at 4 mg/kg body weight, can effectively mitigate enteric methane emissions by 20% in goats without negatively affecting animal productivity, although higher dosages did not achieve additional reductions and may lead to possible myotoxicity.
- *Do animals selected for reduced feed intake produce less methane?* (2017-2018): concluded that selecting dairy heifers for low residual feed intake is unlikely to affect daily methane production, but may increase methane yield on a high forage diet.
- *Discovery of new nitrification inhibitors* (2015-2018): identified 17 compounds that showed significant nitrification inhibition, which are now being evaluated as part of a follow-on contract.

A further and significant achievement for a GRA research partnership in 2017/18 was a publication in *Nature*. The project – a global collaboration known as Hungate1000 – generated a reference catalogue of over 500 rumen microbial genomes, where before just 15 genomes were available to the scientific community. The work was completed in 2016/17 (and reported in that Annual Report), however the publication was not announced until March 2018.

Capability building

Provision of capability building services to the GRA was another major area of effort for NZAGRC during 2017/18. Key achievements included:

- Working with CCAFS to develop much-needed resources for countries to use in strengthening their national greenhouse gas inventories for livestock emissions. These build on the influential white paper published in 2016/17 that assessed the extent of countries' systems for measuring, reporting and verifying (MRV) livestock greenhouse gas emissions. The new resources will be available in 2018/19.
- Working with FAO, drawing on CCAC funding, to deliver the second phase of a multi-country project on reducing enteric methane for food security and livelihoods; and securing CCAC funding for a third phase.

- Launching a major project with Indonesia to develop and implement a Tier 2 inventory for the beef sector that will have benefits to the wider region in terms of training opportunities and development of regionally relevant methane emission factors.
- Outreach in Africa to better understand countries' needs regarding MRV of livestock greenhouse gas emissions, including via post-doctoral research being carried out in West Africa and organisation of a technical workshop in Kenya in late 2017/18 and a high profile East African regional engagement workshop that will take place in Ethiopia in July 2018.
- Ongoing administration of the LEARN/GRASS fellowship scheme, with five awards issued this year, four via the traditional application process and a fifth tagged to a GRA priority project.

NZAGRC also continued to facilitate New Zealand input to the IPCC, including via the Deputy Director's role in the IPCC Bureau. Several major IPCC reports are due out in the next few years and this input will help ensure more comprehensive coverage of mitigation options that response to the challenges of enhancing food security, reducing emissions and increasing the climate-resilience of food systems.

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 2017/18, the NZAGRC has supported the PGgRc in its engagements with industry partners to move these research areas closer to commercial reality. At the end of 2016/17 the inhibitior programme reached a point where the NZAGRC stopped funding to allow a clearer route to market via the PGgRc and a commercialisation partner. The focus is now on getting the vaccine programme to a point where this can occur.

Goal 5 metrics:

Measure	*Progress in 2017/18*
Leadership of science input into Global Research Alliance and coordination of Livestock Research Group with the Netherlands	26 activities*
Visiting scientists from overseas research organisations hosted	2 exchanges funded by LEARN/GRASS Fellowships
New research collaborations agreed with national and international research organisations, programmes or centres	New research collaboration in Kenya established in 2017/18

* Activities include attendance at international meetings and conferences, training and development, and collaboration with other research funds.

SCIENCE FUNDING REPORT

Funding

In accordance with the NZAGRC's Business, Strategy and Science Plans, and with the approval of the SG, $4.30 million was allocated to research and ancillary activities in the 2017/18 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 2017/18

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 2017/18

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 2017/18

The current Science Plan consists of 11 active Research Objectives which align under five key areas: (i) methane; (ii) plants and GHGs; (iii) integrated farm systems; (iv) Māori; and (v) policy support. Those programmes marked with a dagger ([†]) are co-funded with the PGgRc, AgResearch and/or PGgRc/MPI. 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 2017/18

Programmes marked with a dagger (‡) are co-funded with the PGgRc, AgResearch and/or PGgRc/MPI. Those left unmarked are solely funded by the NZAGRC.

Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2017/18 $NZ NZAGRC (GST excl)	2017/18 $NZ TOTAL (GST excl)
Methane	5.1‡	Animal Breeding – Sheep and deer	S Rowe & A Jonker	AgResearch	300,000	800,000
	5.3‡	Vaccine	N Wedlock	AgResearch	600,000	2,155,000
	5.9	Dairy housing methane capture and mitigation by soil	S Saggar	Manaaki whenua (LCR)	0	0
Plants and GHGs	9.1	Defining the achievable soil C stabilisation capacity of New Zealand grassland soils	M Beare	Plant & Food Research	205,000	205,000
	9.2	Mitigation practices to maintain soil carbon and reduce nitrous oxide emissions at paddock scale	L Schipper	Waikato University	713,718	713,718
	9.3	Identifying and prioritising plant traits for low GHG emissions	C de Klein	AgResearch	878,000	878,000
	9.4	Determining the impact of a novel inhibitor on N_2O emissions from urine	P Newton	AgResearch	93,743	93,743
Integrated Farm Systems	8.1	GHG Emissions on Sheep and Beef Farms	R Dynes & K Hutchinson	AgResearch	166,150	166,150
	8.2	GHG Emissions from Dairy Systems	R Dynes & K Hutchinson	AgResearch	0	0
Māori	20.2	Farm Systems Mitigation Modelling for GHG Reduction on Māori Farms	P Journeaux	AgFirst	230,700	230,700
Policy Support	10.4	Review of OVERSEER® GHG algorithms	C de Klein	AgResearch	130,000	130,000
				Totall	3,317,311	5,372,311

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

Notes:

- 2017/18 funding includes personnel costs, consumables and in certain cases, items such as SNP chips or services such as DNA sequencing.
- Total funding is shown for jointly contracted objectives.

Methane Research Programme Report - 2017/18

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, with the sheep breeding programme getting closer to delivering breeding values to the national flock.

The sheep breeding programme continued to build on developments in earlier years in 2017/18. The aim is to deliver solutions on the ground, whilst still monitoring the divergent methane selection lines for any unintended effects. The high/low sheep lines continue to diverge and are currently on average 10% different for methane yield. The lines continue to segregate on maternal breeding worth with the low line favourable by ~$10 gross margin per mated ewe. However, breed proportion may play some role in the observed differences in maternal breeding worth. This requires validation in other flocks with greater genetic diversity.

A trial with low and high CH_4 yield selection line sheep fed cut pasture indicated consistent differences in CH_4 per unit of intake of across all four seasons. In addition, excretion of faecal and urinary nitrogen were similar for low and high CH_4 yield selection line sheep in two seasons, suggesting that breeding sheep for low methane will neither increase nor decrease excreta greenhouse gas emissions.

Analyses of rumen microbial communities in ewe lambs measured multiple times on cut pasture and lucerne pellets suggest that rumen microbial community composition has the potential to be used to rank animals for prediction of methane. This holds out the prospect that direct measurements of methane emissions are not necessary for identifying low emitting phenotypes. This work is being developed further with funding from the New Zealand Global Research Alliance Fund.

Preliminary analysis of CT scans from 96 ewe lambs measured through the feed intake facility show that there are differences between the lines in fat and lean proportions of carcass. Additional detailed meat quality measures on a subset of the ram lambs, however, show that the low methane animals had no difference in intra-muscular fat but significantly higher branched chain fatty acids. This has potential positive implications not only for meat quality but also for milk quality and even for subsequent lamb growth in the low emitting sheep.

Breeding values were estimated for PAC traits using both pedigree (eBV) and molecular or genomic information (mBV). A module to automate estimation of breeding values for the national flock has been developed in collaboration with Beef and Lamb New Zealand genetics (B+LNZG). This work was presented to breeders at a forum in June. Additionally, a Radio NZ article on methane mitigation in New Zealand sparked global media interest, in particular from educational press wanting to inform students of ways to mitigate greenhouse gas production.

During 2017/18, a sheep vaccination trial, including measurement of methane emissions in respiration chambers, was conducted to test experimental vaccines consisting of a mix of recombinant proteins or a mix of methanogen strains. All vaccinated animals produced antibodies

against each of the 19 protein/protein fusions present in the mix of recombinant proteins. This is an important finding as anti-methanogen vaccines are very likely to contain multiple antigens.

The issues that arose with assay repeatabily in the vaccine programme in 2016/17 have been addressed over the past year. The methanogen growth assay has been refined in order to ensure reliable testing of antibodies against candidate vaccine targets. New auxiliary assays (ELISA, Western blotting, flow cytometry) for measuring 'effectiveness' of antibodies produced against specific targets have been developed. Additionally, new methods and protocols for quality control of recombinant proteins used in experimental vaccines have been established.

After promising results in the inhibitor programme in 2016/17, with three compounds showing sustained activity of greater than 20% over 16-day and 28-days, the NZAGRC involvement in this programme did not continue in 2017/18. The project is now solely funded by the PGgRc as the lead commercialising partner.

A feasibility study of a novel mechanism for capturing and breaking down CH_4 was completed at the start of 2017/18. The aim of this study was 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 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 >6 months found 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%). NZAGRC funding is not continuing in this area. However Manaaki Whenua - Landcare Research and Callaghan Innovation have agreed to work together to create biofilters that can oxidise methane produced from dairy effluent ponds and/or herd-homes (where the amount and concentration of methane is not suitable for energy capture).

Plants and GHGs Research Programme Report - 2017/18

Principal Investigators: Dr Cecile de Klein,
Prof Hong Di,
Dr David Whitehead and
Professor Louis Schipper

Based on the recommendations of a review of the NZAGRC nitrous oxide, soil carbon and integrated farm systems programmes in March 2017, the former nitrous oxide and soil carbon work streams were combined at the start of 2017/18. This ensures a strong overall conceptual framework, closer communication and full GHG analyses across the programme as appropriate. The Plants and GHGs programme focusses on three key areas:

1. Identifying and prioritising plant traits for low GHG emissions;
2. Mitigation practices to maintain soil carbon and reduce nitrous oxide emissions at paddock scale; and
3. Defining the achievable soil C stabilisation capacity of New Zealand grassland soils.

An animal feeding trial conducted in association with the Forages for Reduced Nitrate Leaching programme, investigating the ability of plantain to modify N processes in animals and soils, was a major focus this year. The aim of this trial was to assess the impact of increasing proportions of plantain in the diet on CH_4 yield, nitrogen excretion in urine and dung, and N_2O emissions. Preliminary findings include:

- a reduction in urinary N concentration with increasing proportions of plantain and associated reductions in N_2O emissions from urine patches.
- differences in CH_4 per kg dry matter intake between the treatment groups, but as methane emissions were unusually high for the control group these data need careful interpretation.
- N_2O emission factors reduced with increasing proportions of plantain in the sward, most likely due to an effect of plantain plants on soil processes.

To further study the effects of plantain, a sward containing 60% plantain has been established at a Waikato farm. Carbon balances and nitrous oxide emissions have been continuously measured in comparison to a ryegrass/clover sward. Part of this field research utilises a novel nitrous oxide measurement technique using micro-meteorological approaches to quantify emissions at the paddock scale and experiments have commenced to compare these results to traditional chamber measurements at the plot scale.

Parallel work at a nearby farm calculated carbon balances for three years for a farm with very high feed imports (about 12 t dry matter or 5.3 t of carbon per hectare per year). It has been demonstrated that about 13% or 710 kg per hectare of this imported carbon accumulated in the farm. The majority of the imported feed was converted back to carbon dioxide by cow respiration or decomposition of dung. Some of the imported carbon was also exported in increased milk production. While these gains are important they may be offset by losses of carbon from sites where feed is produced and carbon balance measurements over maize are continuing at the site so that the carbon balance of feed production and importation can be completed.

An initial study to determine the impact of a novel inhibitor was conducted in 2017/18. After 36 days urine from treated animals had 50% lower N_2O emissions than untreated animals. This work will be expanded in 2018/19.

The CenW model developed for Waikato farms was compared against three years of eddy-covariance data from an irrigated grazed pasture in the Canterbury region. The comparison showed good agreement across a range of measures of the site carbon and water exchange. Following that

comparison, CenW was then used to compare three irrigation management scenarios: no irrigation (dairy grazed), real life irrigation (dairy grazed), and sheep grazing (no irrigation or fertiliser). This initial modelling demonstrated that carbon accumulation was maximised with about 1100 mm of combined rainfall and irrigation.

In 2017/18 an experiment was designed and conducted using a novel ^{13}C stable isotope method to determine how the stabilisation capacity and saturation deficit of different soils affects their ability to store more carbon. Research was also completed describing a rapid, non-destructive method based on mid-infrared (MIR) spectroscopy to identify the soil C stabilisation capacity and saturation deficit of different New Zealand grassland soils.

Integrated Farm Systems Research Programme Report - 2017/18

Principal Investigator: Dr Robyn Dynes

During 2017/18 new work plans have been developed for both the sheep and beef and dairy components of the Integrated Farm Systems research programme out to mid 2019. These have been co-developed with significant input from Beef + Lamb New Zealand (B+LNZ) and DairyNZ respectively to ensure alignment with relevant industry investment, initiatives and extension programmes. Work is now underway on the research outlined below.

The sheep and beef part of the programme is designed to provide new insights into GHG emissions from the sheep and beef sector by assessing the drivers of GHG emissions for at least 100 real sheep and beef farms, representing all 8 Beef + Lamb New Zealand (B+LNZ) farm classes, to identify characteristics for reducing GHG outputs. The data set generated will be relevant to all sheep and beef farmers and will be used to develop a diversity of recommendations and pathways for the sector that are beyond 'averages'. Data and analysis from this programme will be used for development of extension material/processes that enable sheep and beef farmers to understand which mitigation approaches are most effective across a range of farm classes. Individual farmers will be able to identify with one or more of the modelled real farms to see how they got from A to B with their GHG emissions and use these strategies to develop their own pathway to a lower emissions future.

The new programme is also extending the work to date on two existing monitor farms – Highlands and Onetai Station. Aspirational mitigation options (e.g. GHG at a collective level, carbon-neutral, integrated catchment management) will be investigated following a line of enquiry agreed upon with the farm owners.

The dairy part of the programme involves the design of a cohesive and targeted communications and extension programme that provides the dairy industry with the information required to begin addressing its GHG emissions. The programme will build off and interlink with existing industry and Government initiatives, such as the Dairy Industry Action for Climate Change (DACC), a partnership between DairyNZ and Fonterra and supported by MfE and MPI, launched in mid-2017. The NZAGRC has the capacity to build off the DACC, and other existing initiatives and extension networks and provide dairy farmers, rural professionals, and the wider dairy industry with a more comprehensive set of targeted resources to enable the industry to begin addressing its GHG emissions. Building awareness, knowledge and confidence will position the industry well to respond to the incoming policy framework under development.

In addition to co-development of new work programmes with industry, results from previously funded Integrated Farm Systems research has been widely presented and reported in the rural media over the past year.

Māori-focussed Research Programme Report - 2017/18

Project Leaders: Phil Journeaux
Dr Tanira Kingi

This project will improve the capacity of Māori farmers to improve their efficiency and productivity while lowering greenhouse gas emissions. It will achieve this by utilising previous research funded by the Centre, via working with 2 Māori Agri-Businesses entities (involving dairy, sheep & beef, forestry and potentially horticulture) to model greenhouse gas emissions from the various enterprises, and how these can be balanced at a business level. In addition, the project will: (i) discuss and outline decision making criteria and issues around GHG mitigation strategies; and (ii) discuss and analyse barriers to the uptake of GHG mitigation strategies.

During 2017/18 the project has:

- Identified 2 multi-enterprise Māori operations, incorporating dairy farms, sheep & beef farms, and forestry operations willing to allow modelling of farm system change and land use change to identify impacts of reducing GHG emissions.
- Following discussions with the Trustees of the enterprises, carried out a range of modelling involving a range of farm system changes on both the dairy and S&B farms, incorporating improving productivity measures as well as changes in stocking rate and animal production levels.
- Modelling has also incorporated change in land use, particularly increases in forestry development, as well as possible horticulture enterprises, and change in pastoral land uses, e.g. finishing deer, and dairy sheep.

The results of the modelling reinforced previous modelling work in that changes in farm systems generally have a limited impact on reducing GHG emissions; +/-5-10%, while having a variable impact on farm profitability; while a number reduced farm profitability, those that concentrated on lifting animal performance, often resulted in an improvement in farm profitability.

The largest impact on reducing GHG emissions was achieved via land use change into forestry; both enterprises had targeted increased areas of forestry planting on their sheep & beef farms. Both enterprises also have an issue in that they have large areas of pre-1990 production forest, which cannot be claimed as an offset.

The horticultural enterprise considered (chestnuts) had a significant impact on both the GHG emissions (negative) and profit levels (positive), albeit restricted to the relatively small size of the proposed plantings; 10 & 40ha respectively.

Part of the aim of the project is to consider the impact of any changes at a whole enterprise level. Mixing and matching the various scenarios modelled would indicate that significant gains in reducing GHG emissions (largely due to land use change) and some improvement in profitability, is possible at the whole enterprise level. There is some variation around this however, with no “magic bullet” answer.

Research to Support Policy - 2017/18

NZAGRC staff and key researchers completed a comprehensive piece of work for the Government's Biological Emissions Reference Group summarising what farmers can do now to reduce emissions.

During 2017/18 an NZAGRC-funded project reviewed the GHG algorithms in the OVERSEER® Nutrient budget model. This model has been recommended as the tool of choice for on-farm reporting of CH_4 and N_2O emissions. However, on-farm GHG reporting is reliant on full confidence in the GHG estimates being produced by the model.

The current algorithms and approachs for estimating on-farm CH_4 and N_2O emissions in OVERSEER® have been evaluated and the existing code has been systematically checked. Recommendations from the project team have been documented and reported to a MPI/OVERSEER®/NZAGRC steering group. The objective leader met twice with the steering group during 2017/18 to discuss issues relating to GHG estimates, project progress and agree on next steps. A meeting is planned for early 2018/19 to agree on the steps to address the recommendations of this project.

FINANCIAL SUMMARY

	$
EXPENDITURE	
Core research spending	
Methane	925,000
Nitrous Oxide	1,071,743
Soil Carbon	818,718
Integrated Farm Systems/industry engagement	166,150
Māori	230,700
Research Total	**3,212,311**
Other research costs	
Additional Fellowships and Studentships	97,930
Science planning and support	30,078
Policy support	239,440
Special IT and communications	35,801
Other Total	**403,249**
Administration	**682,340**
Total Expenditure (actual)	***4,297,900***
REVENUE*	***5,246,948***
Balance unspent carried over **	***949,048***

*Includes $396,948 carried over from 2016/17.
**Not contracting proposed work on cattle breeding, some vaccine research, dairy farm systems work and some sheep & beef farm systems work in 2017/18 has contributed to the under spend. This underspend will be allocated in 2018/19.

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NZAGRC Director

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NZAGRC Operations Manager

Dr Andy Reisinger
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International Capability & Training Coordinator

Kate Parlane
Project Analyst

Tania Brown (until Dec 2017)
NZAGRC Administrator

Trina Bishop (from Mar 2018)
NZAGRC Administrator

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Senior Scientist
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Prof Mike Hedley / Prof Peter Kemp
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Dr Sam Dean
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Plant & Food Research

Mark Aspin
Consortium Manager
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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 2017/18 (23rd August 2017, 15th November 2017, 28th February 2018 and 30th May 2018).

Name	Organisation
Dr Greg Murison	AgResearch
Dr David Burger	DairyNZ
Dr Peter Millard	Manaaki Whenua - Landcare Research (Chair)
Kevin Hurren	Lincoln University
Prof. Mike Hedley	Massey University (to Feb 2018)
Prof. Peter Kemp	Massey University (from Mar 2018)
Dr Sam Dean	NIWA
Warrick Nelson	Plant & Food Research
Mark Aspin	PGgRc
Dr Tim Payn	Scion (to Nov 2017)
Dr Steve Wakelin	Scion (from Nov 2017)
Neil Williams	MPI (Observer*)
George Strachen	MPI (Observer*)
Dr Gerald Rys	MPI (Observer*)
Dr Marc Lubbers / Vacant	MBIE (Observer*)

*MPI and MBIE hold Observer (non-voting) positions on the Steering Group.
The MBIE position has been vacant since Marc Lubbers left MBIE in early 2017/18.

International Science Advisory Group

The ISAG did not meet in 2017/18. A review of the Māori programmes was conducted in November 2017 by the specialist panel named below. The panel was chaired by Andy Reisinger of the NZAGRC.

Name	Organisation
Dave Clark	Independent Consultant
Lance Iwikau	Ministry for Primary Industries

Māori Advisory Group

The current membership of the Māori Advisory Group is detailed below. The group met twice by teleconference in 2017/18.

Name	Organisation
Lorraine Stephenson	Independent
Jamie Tuuta	Māori Trustee
Ariana Hemara Wahanui	AgResearch
Kate Sargeant / Kara Lok	DairyNZ
Holden Hohaia	Manaaki Whenua - 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
Marian Horan	MPI

APPENDIX 2 – ANNUAL OBJECTIVE SUMMARY SCIENCE REPORTS (AS SUBMITTED)

Objective Level Summary – 2017/18

Key:

Objective completed
Objective on-going

Those programmes marked with a dagger (‡) are co-funded with the PGgRc, AgResearch and/or PGgRc/MPI.

Area	#	Objective Title	Objective Leader	Objective Leader Organisation	2017/18 $NZ NZAGRC (GST excl)	Status End 2017/18
Methane	5.1‡	Animal Breeding – Sheep and deer	S Rowe & A Jonker	AgResearch	300,000	Manuscripts delayed
	5.3‡	Vaccine	N Wedlock	AgResearch	300,000 +300,000	Minor delay to one milestone (additional funding to support two post docs)
	5.8	Modelling rumen methane production	D Pacheco	AgResearch	0	Completed
	5.9	Dairy housing methane capture and mitigation by soil	S Saggar	Manaaki whenua (LCR)	0	Completed
Plants and GHGs	6.3	Feed management options for mitigating N_2O emissions from grazed systems	C de Klein	AgResearch	0	Completed.
	6.7	Review of the current understanding of the effects of plant species and animal forages on N_2O emissions	C de Klein	AgResearch	0	Completed
	7.1	Manipulation of carbon inputs to stabilise and enhance soil carbon stocks	D Whitehead	Manaaki whenua (LCR)	0	Delayed manuscript
	7.3	Modelling management manipulations using the HPM	T Parsons	Massey University	0	Completed
	9.1	Defining the achievable soil C stabilisation capacity of New Zealand grassland soils	M Beare	Plant & Food Research	205,000	Minor delay to manuscript
	9.2	Mitigation practices to maintain soil carbon and reduce nitrous oxide emissions at paddock scale	L Schipper	Waikato University	713,718	On track
	9.3	Identifying and prioritising plant traits for low GHG emissions	C de Klein	AgResearch	878,000	Minor delay to final trial report
	9.4	Determining the impact of a novel inhibitor on N_2O emissions from urine	P Newton	AgResearch	93,743	Delay due to key member of analytical staff on maternity leave.
Integrated Farm Systems	8.1	GHG Emissions on Sheep and Beef Farms	R Dynes & K Hutchinson	AgResearch	166,150	New contract on track. Delayed manuscript from previous contract.
	8.2	GHG Emissions from Dairy Systems	R Dynes & K Hutchinson	AgResearch	0	New contract started at end of 2017/18. First payment in 2018/19. Delayed manuscript from previous contract.
Māori	20.2	Farm Systems Mitigation Modelling for GHG Reduction on Māori Farms	P Journeaux	AgFirst	230,700	On track
Policy Support	10.4	Review of OVERSEER® GHG algorithms	C de Klein	AgResearch	130,000	Completed

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 2017/18

Summary

As the program matures, objectives for the 2017/18 year were to build on developments in earlier years to deliver solutions on the ground whilst still monitoring the divergent methane selection lines for unintended effects of selection. Measurements performed during 2017/18 included: a cohort of 72 ram lambs from the selection lines measured several times through respiration chambers over the course of a year, with measures of nitrogen excretion in two periods; 379 ewe lambs measured for feed intake on lucerne pellets were also measured for methane and CO_2 through portable accumulation (PAC) chambers, which included a second cohort of 96 selection line ewe lambs; over 1000 methane measures were taken through PAC from grazing animals with a rumen sample was collected and stored from every animal measured. Additional fatty acid measures and CT scanning data together with papillae counts are yielding interesting results for physiological differences between the lines.

Breeding values were estimated for PAC traits using both pedigree (eBV) and molecular or genomic information (mBV). A module to automate estimation of breeding values for the national flock has been developed in collaboration with Beef and Lamb New Zealand genetics (BLNZG). This work was presented to breeders at a forum in June.

Finally a Radio NZ article on methane mitigation in New Zealand sparked global media interest, in particular from educational press wanting to inform students of ways to mitigate greenhouse gas production.

Selection Lines

The lines continue to diverge and are currently on average 10% different for methane yield. Average breeding values (expectation of offspring phenotype relative to the population mean) for methane yield for the two lines were +0.81 and -0.91 g CH_4/kg DMI for retained ewes and +1.27 and -1.5 for retained rams for high and low lines respectively. For the born 2017 lamb crop BVs, the average ram lambs were +1.0 and -1.15. The highest and lowest rams differed by over 20% with the best rams predicted at +1.5 and -1.8 g/kg DMI for high and low lines respectively. The lines continue to segregate on maternal breeding worth with the low line favourable by ~$10 gross margin per mated ewe. This is potentially a founder effect and difficult to predict in the general population without using low methane rams in other flocks. Average breed proportions of the lines differ slightly. Both lines are on average 50% Coopworth and 10% Perendale, but the high line averages 30% Romney versus 15% in the low line, and Texel 9% versus 25%, respectively. Therefore, breed proportion may play

some role in observed differences in maternal breeding worth. This requires validation in other flocks with greater genetic diversity.

A trial with low and high CH_4 yield selection line sheep fed cut pasture indicated consistent differences in CH_4 per unit of intake of across all four seasons. In addition, excretion of faecal matter and nitrogen were similar for low and high CH_4 yield selection line sheep in two seasons, suggesting that breeding sheep for low methane will neither increase nor decrease excreta greenhouse gas emissions.

Analyses of rumen microbial communities in ewe lambs measured multiple times on cut pasture and lucerne pellets suggest that rumen microbial community composition has the potential to be used to rank for prediction of methane. This work needs to be completed, and written up for publication.

Preliminary analysis of CT scans from 96 ewe lambs measured through the feed intake facility show that there are differences between the lines in fat and lean proportions of carcass. Additional detailed meat quality measures on a subset of the ram lambs described in 5.1.20, however, show that the low methane animals had no difference in intra-muscular fat but significantly higher branch chain fatty acids. This has potential positive implications not only for meat quality but also for milk quality and for subsequent lamb growth in the low emitting sheep.

Methane measures

PAC measures were taken on 224 males and 233 females from flock 3633, 328 from 2638 and 304 from 4640 totalling 1089 measures from grazing animals added plus 397 ewe lambs measured through RFI. A journal article and conference proceedings on genetic parameters for PAC measures have been published. The heritability for the equivalent PAC trait for methane yield is 0.19 +/- 0.03 and the correlation between animals younger than 15 months and adult sheep is 0.99 +/- 0.01. Given these results, recommendations are that only young sheep need to be measured through PAC and PAC can be used as a suitable proxy for respiration chamber measurements. The new SIL module will be based on prediction of PAC phenotypes.

Feed Intake Traits

A large feed intake trial on young lambs funded by BLNZG is now complete. In total 989 animals have been measured for 42 days through a feed intake facility, with 192 from the methane selection lines. All animals have been measured through PAC chambers and had a rumen sample taken. Genetic parameters have been estimated and summarised. Heritability of feed intake was moderate to high at 0.39 (+/- 0.11). Results suggest that feeding behaviour is correlated with methane emissions. Animals that ate fewer larger meals tended to emit more methane than those that ate less meals more frequently. A negative correlation was found between residual feed intake and methane of -0.37 (+/-0.15). This indicates that breeding for one of these traits will not automatically bring improvements in the other. Each must be actively selected for and included in a selection index.

Breeding values.

Breeding values for PAC and respiration traits were estimated for all flocks that have had methane measures. Genomic information for these flocks was collated. A total of 16,400 animals have been genotyped to date. The number of genetic markers genotyped per individual varies from 5,000 to 600,000. Individuals were imputed to a common set of 50,000 before molecular breeding values were estimated. Accuracies (correlation between measured phenotype and predicted phenotype using genomics) were ~0.5 for PAC methane traits and ~0.6 for PAC CO_2. This means that breeders using only molecular breeding values, i.e., not measuring animals, could potentially make 50-60% of the total genetic gain possible if animals were measured. Recommendations for objective traits to add to the current national selection index for maternal worth (measured in additional gross margin per ewe per year over the average flock) are to incorporate feed intake, absolute methane emissions and liveweight as separate component traits, and not to use derived traits such as methane yield or residual feed intake. This will enable complete flexibility and traits can be weighted according to economic importance. Under selection index theory, even if traits are negatively correlated, correct weighting will ensure progress in both.

Two formal workshops and multiple meetings have been held throughout the year to confirm statistical models for automation of methane breeding values. The first stage of this will be delivery of research breeding values to a small number of breeders, after further roll out, the ultimate objective is inclusion of methane emissions in the national selection index.

Impact

As the program gets closer to delivering breeding values to the national flock, discussions are being held with key stakeholders. A PGgRc workshop at the 2018 BLNZG forum enabled direct discussion with over 100 breeders. In general, breeders felt that the selection lines should continue to be monitored, and many expressed concern around performance of the low line under conditions of very poor feed quality given the smaller rumens. Almost unanimously, breeders would be happy to use a methane breeding value to choose a low methane animal, provided that the animals maintained other performance indicators. A description of the program was also presented at a conference held in Wellington (July 9th 2018) by AgResearch on climate change. The audience included government officials, funders and key stakeholders. Again, the mood was positive with a desire to continue to monitor selection lines. Concerns were voiced around leaner carcasses affecting eating quality and survival traits.

There is considerable global interest in the program from educational providers and producers. Given the success of the NZ program, a unit including 12 PAC chambers mounted on a trailer has been purchased from Teagasc in Ireland where researchers plan to begin monitoring the Irish national flock.

Key achievements for 2017/18:

- Jonker A, Hickey S, Rowe SJ, Janssen PH, Bain WE, Wing J, Greer GJ, Bryson B, MacLean S, Dodds KG, Pinares-Patiño CS, Young EA, Knowler K, Pickering N, McEwan JC. 2018. Genetic parameters of methane emissions determined using portable accumulation chambers in lambs and ewes grazing pasture and genetic correlations with emissions determined in respiration chambers. Journal of Animal Science (doi:10.1093/jas/sky187).B
- Hickey SM, Rowe SJ, Jonker A, Wing J, Bryson B, Dodds KG, Young EA, Knowler K, McEwan JC. 2018. Effective short-term measures of enteric methane emissions. Proceedings of the 11th world congress on genetics applied to livestock production. Auckland. February 11-16th 2018.
- Suzanne Rowe was invited to attend a Methagene meeting (Casserta, Italy October 11-13, 2017) to present a new program of work on the relationship between methane and rumen microbial communities. No new information was presented but a summary of the methane program was given to an international audience to put this work into context.
- Correlations have been estimated for feed intake and feeding behaviour. A Sheep Improvement Module has been written and is currently being validated. This is an exciting development as it will enable commercialisation of the program and enable decisions to be made by breeders to select lower methane sheep at farm level.
- Seventy-two ram lambs (36 high and 36 low) were followed for an entire year and measured in different seasons through respiration chambers. The work showed that the differences between the lines were consistent throughout the year and in a subset of 30 lambs that nitrogen excretion did not differ between lines.

5.3 – Vaccine

Jointly supported programme

Objective Leader – Dr Neil Wedlock (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 antigens selected by bioinformatics analysis of genomes from the most rumen-abundant methanogens, and formulated with current 'best' adjuvants will be administered to sheep. Alternatively, experimental adjuvants may be tested with agreed reporter antigens. Depending on the aims of the particular trial, the readouts will be from: A. antibody responses to the antigens, B. anti-methanogen activity measured in *in vitro* assays, C. rumen microbial profiling undertaken to determine antibody induced changes in microbial populations in the rumen and D. methane emissions measured in respiration chambers.

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.

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 routine 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 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 – Progress in 2017/18

Review of methane vaccine programme

- The vaccine programme was reviewed in October 2017 by Prof. Dick Strugnell and Dr Paul Wood. Documentation was prepared for the review and the review was attended by Darren Pegram (chair), Peter Janssen (PI), Neil Wedlock (Objective leader), Harry Clark (NZAGRC), and Mark Aspin (PGgRc).
- Recommendations from the review report were incorporated into the programme of work, e.g., refinement of growth assay with an SOP, quality control of antigens, a protocol for high throughput qPCR of methanogens in cultures.

Animal trials to test experimental vaccine and measure impact on methane emissions

Antigen Trial 1 (2018-1)

- 10 antigens were identified from previous screening to develop for multivalent application. These were analysed bioinformatically to confirm their orientation in the membrane of the methanogen cells.
- A minimal set of proteins of eight of these antigens was devised for multi-species coverage with the intention that five or six antigens will be selected for the first five antigen trial. A total of 34 proteins covered these antigens for multispecies variation and produced for use by GenScript.
- Six antigens were selected for the trial. These proteins have known or predicted essential functions in methanogen metabolism and disruption of their activity by antibody binding would be expected to impair the growth and survival of methanogens in the rumen.
- Three groups of 9 sheep were vaccinated. 1. mixture of recombinant proteins (19 proteins covering the 6 antigenic targets); 2. mixture of 4 methanogens (M1, D5, SM9, AbM4) or); 3, control group given Montanide ISA61 adjuvant alone.
- At 3 weeks after the boosting vaccination, methane emissions were measured in respiration chambers.
- There was no significant difference in methane emissions between the groups of sheep.
- DNA has been prepared from rumen contents samples taken immediately the animals were removed from the chambers. This is being sequenced for analysis of rumen microbial communities. The results are expected in mid-August. This is to determine if there was only a partial impact on methanogen communities, such that some species were affected but others replaced these.
- Antibody responses to each of the different methanogen strains and the 19 different protein/protein fusions in the vaccines were determined by ELISA. All the animals produced strong serum and salivary IgG antibody responses to the range of vaccine antigens (recombinant proteins or methanogen cells) present in the vaccines.
- These serum samples are available for further studies, including: (a) testing in the growth assay, (b) testing in rumen *in vitro* assays, and (c) used to determine if the recombinant proteins used for the vaccination sufficiently mimic the native methanogen proteins to elicit antibodies that are effective against methanogens. The last point is a critical next step for this programme.

Antigen trial 2

- Bioinformatics has been performed and 5 antigens selected for a 2nd antigen trial.
- A total of 18 proteins were produced by GenScript and will be shipped in early July.
- The trial is scheduled to start end of July (assuming proteins from GenScript arrive in time). Respiration chambers have been booked for 24 sheep on 17th and 18th September 2018.

Refinement of the growth assay and auxiliary assays

This work was undertaken to identify why the methanogen growth assay has not been reproducible and to improve the assay.

Lab-based work conducted to refine the methanogen growth assay

- Multiple experiments were performed to determine the cause of interference in the methanogen growth assay. These experiments showed that the precipitation caused by agitation of methanogen cultures was due to precipitation of antibody, and that without agitation interaction of antibody with cells was not detectable. This precipitation makes optical density measurements on cultures inaccurate.
- Shown that use of Tween-20 or Tween-80 stabilises antibodies during agitation of the methanogen cultures.
- A robust growth assay was developed and improvements in the culture assay, and is being documented in an updated and expanded SOP. This allows assessment of antibody impacts on growing cultures of *Methanobrevibacter ruminantium* M1, the model methanogen used to identify potential vaccine antigens.
- The refined culture assay can be used on stored sera from previous years' animal trials (if agreed to by PGgRc-NZAGRC). The more sensitive assay may identify antigens that were missed or inconclusive using the previous, less sensitive, assay.
- Developed a settling assay that allows easy quantification of the degree of agglutination of methanogen cells by antibody.

Lab-based work to develop auxiliary assays

- Established ELISA, Western blotting (WB) and flow cytometry protocols for determining if antibody produced against a particular antigen can cross-react with 'native' forms of the antigen.
- Western botting has shown that antisera produced against some of the targets we have tested previously can react with 'native' proteins in methanogen fractions. This provides encouragement that WB can be used (in conjunction with ELISA and Flow cytometry) as an auxiliary tool to evaluate the 'effectiveness' of target-specific antibody. Recent results from testing sera against pseudomurein suggest that to determine the effective of antibody at reacting with nature antigens, WB should be used in conjunction with ELISA and flow cytometry.
- Progress has been made developing a protocol for higher throughput qPCR.

Small scale animal trials to produce sera for assay development

- The above lab-based work was done with archived sera and also sera produced in animal trials outlined below.

  A total of 4 small-scale trials were conducted to obtain sera for assay refinement and as positive controls:

  1. Vaccination of sheep (18 animals including controls, trial 2017-4) with methanogen cells / fractions

2. Vaccination of sheep with pseudomurein (6 animals including controls, trial 2018-2)
3. Vaccination of rabbits with methanogen cells (4 animals, trial 2017-3)
4. Vaccination of rabbits with pseudomurein (1 animal, trial 2017-3a)

For each trial, sheep were vaccinated 2x (rabbits 4x) and sera collected (also saliva from sheep) pre and post-vaccination.

Methanogen strain validation, genomes re-sequenced and seed cultures established

- A new *M. ruminantium* M1 cultures was obtained from the German culture collection. This strain was shown to have an active phage. This makes it difficult to use for routine work, because cultures unexpectedly and rapidly lyse. Work will continue with a lab-adapted line of this strain that is more amenable to routine laboratoty work.
- Produced quantities of M1, SM9, D5 and AbM4 for vaccine trial (Antigen trial 1)
- Developed protocols and a SOP written for inactivation of methanogen cells for use in a vaccine.

Established quality control methods for antigens

- Preliminary work was done to establish a routine method using Circular Dichroism (CD) spectroscopy to document antigen quality was completed. This method was selected after a formal consultation with Andrew Sutherland-Smith (Associate Professor at Massey University) who is an established protein structural biologist.
- For our in-house application, CD will be used both as a method to detect batch-batch variations of the same protein antigens in the vaccine and to determine the secondary and tertiary structure of those proteins.
- Preliminary analysis of 17 of 19 proteins used in Antigen trial 1 (Milestone 5.3.16) have been completed. Two proteins were not assessed because the quantities of those proteins remaining from the vaccine trial were insufficient and below detection limits of the assay. However, sufficient stock quantities are available for all 19 proteins and reference spectra will be collected. Secondary and tertiary structures were assessed. The results indicate that the proteins are folded and the number of alpha-helixes and beta sheets assessed based on the collected spectra are similar to the structural predictions made previously from the amino acid sequences.

Key achievements for 2017/18:

- A vaccination trial in sheep with measurement of methane emissions in chambers was conducted to test experimental vaccines consisting of a mix of recombinant proteins or a mix of methanogen strains. All vaccinated animals produced antibodies against each of the 19 protein/protein fusions present in the mix of recombinant proteins. This is an important finding as anti-methanogen vaccines are very likely to contain multiple antigens.
- Refined the methanogen growth assay for reliable testing of antibodies against candidate vaccine targets.
- Developed new auxiliary assays (ELISA, Western blotting, flow cytometry) for measuring ‘effectiveness’ of antibodies produced against specific targets.
- Developed methods and protocols for quality control of recombinant proteins used in experimental vaccines.

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

Manaaki Whenua
Landcare Research

Objective Leader – Dr Surinder Saggar (Manaaki whenua)

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

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

5.9 – Progress in 2017/18

The objective of priming the column soils by continuous feeding was intended to mimic the raised-bed field trial conditions, to test if fresh farm soils are fed methane how much lag time is required before these soils will start removing methane. This was being achieved by injecting the low methane-rich air into the soil for oxidation by methanotrophs, and then measuring the potential mitigation by these bacteria under the changes in soil moisture and aeration conditions. From these column studies it is evident that threshold priming levels of 60-80% removal rate could not be achieved in farm fresh soils by continuous feeding low methane concentration for 7-months with low resident time. These results suggest that to practicality capture low concentrated methane (150 ppmV) emitted by housed cattle and their waste in the barns and to mitigate these emissions by injecting it in the soil for oxidation by methanotrophs, the use of soils pre-primed with type II methanotrophs is a pre-requisite.

Future work: While further studies using RNA techniques, denaturing gradient gel electrophoresis (DGGE), terminal-restriction fragment length polymorphism (T-RFLP) and pyrosequencing over longer periods of time are likely to be warranted, to improve our better understanding of methanotroph population dynamics in a low concentrated methane environment, isolation of methanotrophs (pure/mixed cultures) from the soil and their growth in bioreactors.

Production of large quantities of high cell density cultures may provide an avenue for establishing biofilters inoculated with methanotrophs suitable for use in effluent ponds and herd-homes both in NZ and overseas. This could lead to a new approach to establishing biofilters that is applicable both nationally and globally.

Moving forward: Due to lack of future funding from NZAGRC to support this research, Landcare Research and Callaghan Innovation have agreed to work together to create biofilters that can oxidise methane produced from dairy effluent ponds and/or herd-homes (where the amount and concentration of methane is not suitable for energy capture). The strategy involves isolating methanotrophs from primed soils, multiplying them in bioreactors to produce large quantities of high cell density cultures which can then be formulated, spray dried and used as an inoculant for establishing soil biofilters for use in effluent ponds and herd-homes both in NZ and overseas. SSIF funding from both the organisations will cover the initial stage of the project, which could lead to a new approach to establishing biofilters that is applicable both nationally and globally.

9.1 – Defining the achievable soil C stabilisation capacity of New Zealand grassland soils

Objective Leader – Dr Mike Beare (Plant & Food Research)

Developing and deploying effective management practices that maximise the long-term storage of carbon in New Zealand soils depends on being able to readily identify soils with the greatest capacity to stabilise additional C and understanding the practical limitations to achieving the stabilisation capacity. The C stabilisation capacity of a soil is the maximum amount of C that the soil can hold in a form that is not readily susceptible to decomposition (loss).

We previously developed a simple empirical model (Beare et al 2014; McNally et al 2017) to predict the C stabilisation in New Zealand soils based on measurements of soil properties from long term pasture sites. The model predictions suggest that some sites have reached their soil C stabilisation capacity (i.e. they are saturated) while other sites have the capacity to stabilise additional soil C (i.e. they have a significant soil C saturation deficit). If this is true, then we predict that the achievable stabilisation of additional C in a given soil will depend on its current C stabilisation capacity and saturation deficit as well as the annual rate plant C input (e.g. dry matter production).

This project (2017-19) will take the first important steps to establishing the achievable soil C stabilisation capacity of New Zealand grassland soils by determining the role that soil C stabilisation capacity and saturation deficit play in soil C sequestration and the evaluating the importance of C input rate to the C stabilised in soil.

9.1 – Progress in 2017/18

We previously published research showing that New Zealand grassland soils differ in the maximum amount of C that they can store and that many of these soils are below their maximum. The focus of our current research is to define the achievable soil C storage capacity of New Zealand grassland soils. In 2017/18 we designed and carried out an experiment using a novel ^{13}C stable isotope method to determine how the stabilisation capacity and saturation deficit of different soils affects their ability to store more carbon. A 6 month long incubation experiment was completed, the soils have been fractionated and the ^{13}C analyses are underway. The results will be described in paper that will be submitted for publication in a scientific journal by Dec 2018.

Over the last year the project team also designed and made preparations to start an experiment aimed at evaluating how differences in dry matter production affect the rate of soil C stabilisation in soils with different saturation deficits. This experiment is expected to start in Aug/Sept 2018.

We also completed research describing a rapid, non-destructive method based on mid-infrared (MIR) spectroscopy to identify the soil C stabilisation capacity and saturation deficit of different New Zealand grassland soils. A paper has been written and is undergoing final revisions before submission to scientific journal.

Key achievements for 2017/18:

- A laboratory incubation of soils with ^{13}C-labelled ryegrass residues was completed. Soils have been fractionated to separate the silt+clay-bound C from the particulate organic matter associated with the sand fraction. Analysis of ^{13}C in soil fractions is underway.
- Journal paper published: Baldock J, Beare MH, Curtin D, Hawke B 2018. Stocks, composition and vulnerability to loss of soil organic carbon predicted using mid-infrared spectroscopy. Soil Research (doi.org/10.1071/SR17221)

- Journal paper published: McNally S, Beare M, Curtin D, Tregurtha C, Qiu W, Kelliher F, Baldock J 2018. Assessing the vulnerability of organic matter to C mineralisation in pasture and cropping soils of New Zealand. Soil Research (In press)
- Abstract submitted for invited presentation at the 21st World Congress of Soil Science: Beare MH, McNally S, Curtin D, Baldock J 2018. Defining and Predicting the Organic Carbon Sequestration Potential of Soils (invited Keynote presentation). This is a joint output with SOW14-GPLER-SP23-PFR-MB.
- Journal paper submitted for ROI approval: Baldock J, McNally, Curtin D, Beare M 2018. Predicting soil carbon saturation deficit and related properties of New Zealand soils using infrared spectroscopy. Soil Research (Under revision for ROI submission).

9.2 - Mitigation practices to maintain soil carbon and reduce nitrous oxide emissions at paddock scale

Objective Leader – Professor Louis Schipper (University of Waikato)

The production of nitrous oxide and net exchange of carbon dioxide are both strongly dependent on plant traits, soil properties and management practices. Our aim is to test and validate options for management practices to provide practical and cost effective greenhouse gas mitigation strategies. Management options need to be tested and verified at scales relevant to farmers and to avoid trade-offs where the net reduction of one greenhouse gas results in increased production of another.

This objective will investigate the efficacy of two systems based on plant traits, to maintain or increase soil carbon and reduce nitrous oxide emissions at paddock scale. Here, we focus on maize and plantain which were selected based on desirable traits (see below).

Any proposed new plant species for incorporation into the farming system will require an establishment phase. We have shown that when soils are bare there can be substantial losses of carbon, such as during pasture renewal back to ryegrass/clover or the addition of other species in the sward (e.g. plantain, chicory etc.) or establishing fodder/forage crops (e.g., maize, forage rape, Italian ryegrass etc.). The magnitude of carbon loss depends on the method and timing of renewal. It is likely that during renewal there is also nitrous oxide emitted.

<u>Maize (production, export and import)</u>
Maize grows rapidly during summer with high carbon uptake and the carbon to nitrogen ratio of the foliage is lower than that for conventional ryegrass/clover. We will quantify the losses of carbon that occur during establishment when soils are bare before harvest and also after harvest when re-establishing a pasture sward. The harvest and removal of above ground biomass also results in large loss of carbon from the paddocks in comparison to grazed pasture where some of the carbon gets returned to the pasture as dung.

Harvested maize can then be fed to animals on different paddocks or feedpads of the same farm or exported to another farm. These imports of externally grown feeds to other paddocks or farms have been predicted to increase soil carbon by increasing manure inputs to soil. We will test this prediction by determining the carbon balance of a farm with high feed imports.

<u>Plantain</u>
There is evidence that plantain slows soil nitrogen cycling, potentially reducing nitrous oxide emissions and with deeper roots may increase carbon inputs to the soil profile. We will determine the net change in carbon during and after renewal to plantain in comparison to a ryegrass/clover sward. We will also determine nitrous oxide emissions by eddy covariance during this transition and obtain preliminary evidence of whether plantain decreases nitrous oxide emissions in comparison to ryegrass/clover. Nitrous oxide emissions from ryegrass/clover sward will also be measured using a chamber technique and compared to eddy covariance measurements.

An additional effect requiring investigation is the impact of irrigation on the seasonality of carbon balance and nitrous oxide emissions.

The work programme will comprise a combination of plot and paddock-scale measurements to inform and test models that can be used to forecast the effects of management practices on greenhouse gas emissions and soil carbon stocks.

Specific research questions to be addressed will be:

1. Does the inclusion of plantain into a ryegrass/clover sward maintain or increase soil carbon stocks and potentially decrease nitrous oxide emissions?
2. What are the changes in soil carbon stocks and nitrous oxide emissions through the transition period when converting conversional swards to include plantain?
3. What is the magnitude of carbon loss from a paddock following growth of maize, its harvest and removal from the site prior to reestablishment to pasture
4. Do farms gain carbon when large amounts of feed are imported?
5. What is the impact of irrigation and its frequency of application on soil carbon stocks and nitrous oxide emissions in a ryegrass/clover sward?

9.2 – Progress in 2017/18

Our experimental and modelling efforts largely measure and model the net effects of pasture management practices on nitrous oxide and carbon dioxide emissions at paddock-to-farm and from months to annual scales. We are exploring: (i) whether incorporation plantain into the sward can decrease nitrous oxide emissions while minimising carbon losses associated with pasture renewal, (ii) whether carbon in imported feed might increase soil carbon stocks, (iii) soil physical factors that result in reductions in soil carbon stocks and nitrous oxide emissions, and (iv) whether modelling predicts that irrigation management can increase soil carbon.

Establishing plantain. This year we established a sward with 60% plantain at one of our medium-term research sites with assistance from Agricom and continuously measured carbon balances and nitrous oxide emissions in comparison to a ryegrass/clover sward. We published an article in the DairyNZ technical series that demonstrated how minimising the length of time it takes to re-establish pasture is key to constraining carbon losses particularly when soils are moist. We also presented these results at a farmer open day that was attended by ~60 farmers, agricultural consultants and media. Part of this field research utilises a novel nitrous oxide measurement technique using micro-meteorological approaches to quantify emissions at the paddock scale and we have begun experiments to compare these results to traditional chamber measurements at the plot scale.

Feed production and import. Parallel work at a nearby farm calculated carbon balances for three years for a farm with very high feed imports (about 12 t dry matter or 5.3 t of carbon per hectare per year). We demonstrated that about 13% or 710 kg per hectare of this imported carbon accumulated in the farm. The majority of the imported feed was converted back to carbon dioxide by cow respiration or decomposition of dung. Some of the imported carbon was also exported in increased milk production. While these gains are important they may be offset by losses of carbon from sites where feed is produced and we are continuing to make carbon balance measurements over maize at the site so that we can complete the carbon balance of feed production and importation.

Modelling irrigation scheduling. The CenW model developed for Waikato farms was compared against three years of eddy-covariance data from an irrigated grazed pasture in the Canterbury region. The comparison showed good agreement across a range of measures of the site carbon and water exchange. Following that comparison, CenW was then used to compare three irrigation management scenarios: no irrigation (dairy grazed), real life irrigation (dairy grazed), and sheep grazing (no irrigation or fertiliser). This initial modelling demonstrated that carbon accumulation was maximised with about 1100 mm of combined rainfall and irrigation.

Capability development. Our research includes important contributions from three PhD students who receive supervision from staff of Manaaki Whenua – Landcare Research, AgResearch, University of Waikato and Lincoln University.

Key achievements for 2017/18:

- Demonstrated that about 710 kg/ha/y was stored as additional soil carbon during the three years for a farm with very high supplemental feed imports (up to 13% of imported supplemental feed). Paper submitted: Wall, A.M.; Campbell, D.I.; Mudge, P.L.; Rutledge, S.; Schipper, L.A. Carbon budget of an intensively grazed temperate grassland with large quantities of imported supplemental feed. Agriculture Ecosystems and Environment.
- Summarised data on the need to minimise period taken to re-establish pasture and reported in a popular technical article on soil carbon published in DairyNZ technical series (December issue 2017). This work also demonstrated maintaining plant cover was more important that the form of cultivation used. These results were also presented at a farmer open day with several newspaper articles produced. https://www.dairynz.co.nz/publications/technical-series/technical-series-december-2017
- Initial modelling by CenW indicated that carbon gain was maximised when pastures received about 1100 mm of total water receipt (rainfall + irrigation) in Canterbury. With less available water, photosynthetic carbon uptake limited site carbon gain, and with more available water, greater carbon removal by grazing limited on-site carbon storage. A paper has been submitted: Giltrap, D.L.; Kirschbaum, M.U.F.; Laubach, J.; Hunt J.E. Modelling the effects of irrigation on carbon and water balances in an irrigated grazed pasture system in New Zealand. Science of the Total Environment.
- Published a review of the effects of management practices on soil carbon stocks with a focus on New Zealand grasslands. This summarises the achievements of eight years of research in soil carbon funded by NZAGRC and presents the current state of knowledge on likely changes in soil carbon stocks for New Zealand grasslands. We demonstrate that modelling is an effective approach to predicting both the impacts of management practises on carbon stocks and trade-offs with other ecosystem services. However, while the qualitative assessments are important for informing policy on net greenhouse gas emissions, lack of sufficient long-term data from field studies limits our ability to reduce uncertainty in anticipated changes in carbon stocks. We provide a list of criteria that could be used to assess the success of projects to retain or increase soil carbon stocks and conclude with a list of priorities for future research.

  Whitehead D, Schipper LA, Pronger J, Moinet GYK, Mudge PL, Calvelo Pereira R, Kirschbaum MUF, McNally SR, Beare MH, Camps-Arbestain M. Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands: New Zealand as a case study. Agriculture, Ecosystems and Environment (in press).

  This work was funded from an earlier contract with NZAGRC that was completed in June 2017 but revision and acceptance of the paper for publication has been a major achievement in the current year.

9.3 - Identifying and prioritising plant traits for low GHG emissions

Objective Leader – Dr Cecile de Klein (AgResearch)

Work to-date has shown that plants can reduce N_2O emissions through reducing urine N excretion and/or the N_2O emission factor of urine. The mechanisms of the reductions is poorly understood. The overall aim of the proposed programme is to identify and prioritise key functional plant traits for reducing N_2O emissions.

The programme is following a pipeline approach that includes i) identification of key processes that can be targeted to reduce N_2O emissions; ii) prioritisation of plant traits/attributes that could influence these processes; iii) iterative testing of promising plants and plant traits at lab, field and system level. The programme includes milestones for all these components.

The plant trait prioritisation work involves an expert workshop, scenario modelling and laboratory testing of key plant traits (MS 5-6). The aim of this work is to i) identify what key traits will be making the biggest difference in N_2O emissions; ii) understand the systems impact of the different species. This part of the programme will lead to identification of key plant attributes or key plant traits that then can be tested further in future years.

Field experimental work will focus on a key promising plant that was identified in the previous programme (and in the associated FRNL programme): plantain. The objective of the plantain work is to determine the effect of plantain in the diet on CH_4 emissions and N excretion and N_2O emissions from urine patches, and determine the mechanisms for reduced N_2O emissions (MS 1-4). This work is linking in with work proposed under FRNL, at DairyNZ Hamilton (MBIE funded), the MBIE funded Maanaki Whenua-led programme at Ashely Dene, and at Troughton farm (NZAGRC Objective 9.2) thus maximising the outcomes of the programme and the NZAGRC investment.

9.3 – Progress in 2017/18

The programme is following a pipeline approach that includes, identification of key processes that can be targeted to reduce N_2O emissions; prioritisation of plant traits/attributes that could influence these processes; iterative testing of promising plants and plant traits at lab, field and system level.

Year 1 of the programme focused on two key parts:

1. Further testing of the promising plant species plantain
2. Identifying and testing plant traits

The plantain work included an animal feeding trial in association with the Forages for Reduced Nitrate Leaching programme. The aim of this trial was to assess the impact of increasing proportions of plantain in the diet on CH_4 yield, nitrogen excretion in urine and dung, and N_2O emissions. These measurements have all been completed and results are being analysed and processed. Preliminary findings include:

- a reduction in urinary N concentration with increasing proportions of plantain and associated reductions in N_2O emissions from urine patches.
- small differences in total CH_4 between the treatment groups, but DMI data are still being calculated.
- N_2O emission factors reduced with increasing proportions of plantain in the sward, most likely due to an effect of plantain plants on soil processes.

An additional plantain trial has commenced in association with an MBIE programme at Ashley Dene in Canterbury. This trial aims to assess the effect of plantain on soil nitrification rate, functional gene abundance of soil ammonia oxidisers, and nitrous oxide emissions from urine patches. This trial will provide invaluable information on the potential mechanism(s) with which plantain reduces N_2O emissions. The trial has been established and measurements are underway.

The plant trait work included a modelling and experimental component. The modelling work was initiated by an expert workshop held in March 2018 to prioritise low-GHG plant traits and develop potential modelling scenarios. The prioritised traits include:

1. Plant compounds as nitrification inhibitors;
2. The effect of plant nitrogen concentration on N secretion in dung and urine;
3. Diuretic effect of plant compounds to affect urine N concentration and distribution of urine patches
4. Grow deep rooting plants to build soil C
5. Frequency and method of pasture renewal

The CenW model has being modified to allow scenario testing of these traits.

The plant trait experimental work focussed on the effect of canopy characteristics on N_2O emissions from urine. This work has been completed and the results to date suggest that amount of urine intercepted by the canopy does not appear likely to be an important factor in N_2O emissions. It is expected that this work will discontinue and that the resources will be redirected to focus on the effect of novel compounds on N_2O emissions.

Key achievements for 2017/18:

- Completion of the animal feeding trial to assess the impact of increasing proportions of plantain in the diet on CH_4 yield, nitrogen excretion in urine and dung, and N_2O emissions.
- Establishment of a trial aimed at assessing the effect of plantain on soil nitrification rate, functional gene abundance of soil ammonia oxidisers, and nitrous oxide emissions from urine patches.
- Prioritisation of low-GHG plant traits and development of modelling scenarios to assess the potential of these traits
- Completion of the experimental work to assess the effect of plant canopy on N_2O emissions, and identification that the amount of urine intercepted by the canopy does not appear likely to be an important factor in N_2O emissions.
- Submission of synthesis paper of preceding ‘plant’ programme summarising the key findings of this programme.

9.4 - Determining the impact of a novel inhibitor on N_2O emissions from urine

Objective Leader – Dr Paul Newton (AgResearch)

An initial study to determine the impact of a novel inhibitor on N_2O emissions from urine was conducted in 2017/18. After 36 days urine from treated animals had 50% lower N_2O emissions than untreated animals. This work will be expanded in 2018/19.

Results of this objective are being kept confidential for commercial reasons.

8.1 - GHG Emissions on Sheep and Beef Farms

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

This programme will provide new insights into GHG emissions from the sheep and beef sector by assessing the drivers of GHG emissions for at least 100 real sheep and beef farms, representing all 8 Beef + Lamb New Zealand (B+LNZ) farm classes, to identify characteristics for reducing GHG outputs. It will facilitate a closer working relationship with B+LNZ. Teams from B+LNZ Policy and Advocacy, B+LNZ Economic Service and AgResearch Ltd will work collaboratively to meet a critical need for a deeper understanding of how diversity of farm systems affects the range of GHG emissions across S+B farms and the mitigation and offsetting opportunities that are relevant. This work will contribute to building a body of knowledge on GHGs in the S+B sector and indeed in New Zealand as well as assist B+LNZ's efforts to represent farmers' collective interests in policy development and advocacy.

This data set will be relevant to all sheep and beef farmers. We will align with industry investment and extension programmes to increase industry engagement in GHG. This programme will develop a diversity of recommendations and pathways for the sheep and beef sector that are beyond 'averages'. Data and analysis from this programme will be used for development of extension material/processes that enable S+B farmers to understand which mitigation approaches are most effective across a range of farm classes. Individual farmers will be able to identify with one or more of the modelled real farms to see how they got from A to B with their GHG emissions and use these strategies to develop their own pathway to a lower emissions future. In addition, this will help in building awareness of where the industry is now and the good news story about where the S+B sector has come from in terms of GHG emissions intensity.

This programme will extend on the investigation of future opportunities to improve the environmental footprint on two monitor farms – Highlands and Onetai Station. Aspirational mitigation options (e.g. GHG at a collective level, carbon-neutral, integrated catchment management) will be investigated following a line of enquiry agreed upon with the farm owners. The AgR and B+LNZ project team will engage with the B+LNZ staff in each region to align with their planned extension activities.

8.1 – Progress in 2017/18

The final project report was completed and submitted in July. Project staff gave a number of very successful presentations summarising aspects of the results.

- *Field day*: Grant Rennie presented at the third field day held at Onetai Station with 110 attendees the majority of which were engaged farmers along with James Parsons, B+LNZ Chairman, Martin Coup and Robyn Williamson, local farmer council member, and the new North Island General Manager Matt Ward. The feedback from all was really positive and importance of GHG to the industry was clear from the summary given by James following Grant's presentation.
- *Farmer Conference*: Dr Robyn Dynes and our monitor farmer, Bill Wright spoke at the AgInnovation 2018 conference with fantastic attendance at the session and very active participation in the question session. This presentation had associated rural media coverage providing profile to this work to the wider agricultural community. Trended on Facebook, twitter and B+LNZ video stream
- *Industry Conference*: Dr Kathryn Hutchinson gave a short presentation and poster at the Fertiliser and Lime Research Centre annual workshop in February, which generated some great interest and conversations in the poster session.

- *Media*: Rural Delivery Series 13, episode 29 aired on Saturday 23 September 7am on TVNZ1 and subsequently generated considerable interest and further rural media articles. Andrew Morrison (as B+LNZ GHG spokesperson) was consulted extensively in developing the key messages for the Rural Delivery programme. Facebook and Twitter;
- *Farmer Council*: David Scobie + Robyn Dynes provided a briefing to Northern South Island Farmer Council members on research activities in emissions to air and water.

In April/May 2017, initial meetings were held with B+LNZ (Victoria Lamb) to determine interest by B+LNZ in partnering with this project. The engagement and commitment from B+LNZ to work together and to enable access to extensive B+LNZ farm data and datasets already developed has been valuable. There is a partnership approach to the research being undertaken, including ensuring that milestones and workflows will be beneficial to the industry in having unique data available for current and future initiatives in GHG and wider environmental policy development. This partnership has included Robyn Dynes being one of the invited reviewers for B+LNZ Environmental Plan.

Key achievements for 2017/18:

- Strong engagement from B+LNZ and a collaborative project developed.
- Exposure for the work from the programme in a number of different presentations and through rural media.

8.2 - GHG Emissions from Dairy Systems

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

New programme of work (formally started 1 June 2018)

Design a cohesive and targeted communications and extension programme that provides the dairy industry with the information required to begin addressing its GHG emissions. Previous work in Integrated Systems, funded by the Centre, has built knowledge and data on New Zealand dairy farm systems GHG emissions and the key drivers of these emissions. This includes case study examples of commercial and farmlet systems with a range of management practices and divergent emissions intensity and absolute emissions.

The programme will build off and interlink with existing industry and Government initiatives, utilising existing research, communications collateral and extension networks. No new research will be commissioned in this programme.

The initiatives underway include the Dairy Industry Action for Climate Change (DACC), a partnership between DairyNZ and Fonterra and supported by MfE and MPI, launched in mid- 2017. The first stage of the DACC is focused on building awareness amongst the dairy industry on the need to address biological GHG emissions, the options that are available now and the options that may be available in the future. Workshops were presented to Rural Professionals in 2017 and will be presented to farmers in winter 2018 (by members of this programme). The second stage of the DACC, which will interlink with Commitment One of the Dairy Tomorrow Strategy, and is currently being scoped with representatives from Fonterra, MfE, MPI, Tatua, Open Country Dairy, Synlait, DairyNZ, and Miraka.

The Centre has the capacity to build off the DACC, and other existing initiatives and provide dairy farmers, rural professionals, and the wider dairy industry with a more comprehensive set of targeted resources to enable the industry to begin addressing its GHG emissions. Building awareness, knowledge and confidence will position the industry well to respond to the incoming policy framework under development.

The programme is primarily focused on GHG mitigation; however, it will be mindful of and presented in the context of the co-benefits with water quality, biodiversity, and other environmental drivers. The proposed programme recognises the need for farmers and rural professionals to understand the trade-offs of decisions, the impact of these across the farm systems and business for both tactical and strategic decision-making.

This programme will develop, establish, and implement a communication and extension framework building off existing programmes, which is intended to be active beyond the life of the contract. The overarching objective is to build awareness and knowledge amongst the farming community and acceptance that action is required. Participants from AgResearch, DairyNZ, MfE, and MPI collectively scoped the proposal and remain in the project team.

This project will involve working with the dairy companies and the wider rural professional community and linking into existing networks and programmes. Members of the programme have existing links and/or involvement with other programmes, including the Massey University GHG course, SLMACC and GRA research. It will seek to complement existing programmes where possible to avoid duplication and will develop effective links to share data and information where relevant. We will also sub-contract Perceptive and Reputation Matters as part of milestones 8.2.6 and 8.2.7, both have a proven track record of working with the industry.

8.2 – Progress in 2017/18

Project staff gave a number of very successful presentations summarising aspects of previously funded work under this Objective.

- *DairyNZ Climate Change Roadshows*: Drs Robyn Dynes, Cecile de Klein and Tony van der Weerden presented results from this work at a series of roadshows run by DairyNZ
- *Farmer Conference*: Dr Robyn Dynes along with Dr Dawn Dalley presented results of this work at the SIDE conference in June 2018 resulting in further rural media coverage.
- *Industry Conference:* Dr Kathryn Hutchinson presented a comparison of the expected GHG emissions for the P21 farmlets based on pre-experimental modelling with the actual GHG emissions for the farmlets from inventory calculations based measured and modelled data at the Fertiliser and Lime Research Centre annual workshop in February 2018.

Initial meetings were held with DairyNZ (Kara Lok) to determine interest from DairyNZ in partnering in the new project. Robyn Dynes and Kara Lok worked closely to develop a project plan. A meeting was held in December 2017 with MPI, NZAGRC and DairyNZ to discuss a useful pathway forward which build on existing investment. The proposal to develop a communications and extension programme based on both existing research outputs and the knowledge and data developed in the DACC partnership farm programme and other similar programmes A workshop was held in January 2018 with MPI, MfE, AgResearch and DairyNZ to develop a work programme. This programme was finalised after feedback from the Science Advisory Panel.

Key achievements for 2017/18:

- Strong engagement from DairyNZ and a collaborative project developed
- Exposure for the work from the programme in a number of different presentations and through rural media

20.2 - Farm systems mitigation modelling for GHG reduction on Māori farms

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

(i) Identifying the key factors and attributes of two Māori Agri-Business case studies to better understand the interaction between the enterprises within a single entity to reduce GHG emission intensity and absolute emissions on these properties, and at a business level.

(ii) Estimate GHG and nutrient emissions based on mitigation scenarios developed in consultation with the Integrated Farm Systems Programme (funded by the NZAGRC) and other programmes that are developing systems mitigation scenarios relevant to GHG reduction e.g. Forages for Reduced Nitrate Leaching (led by DairyNZ).

(iii) Build mitigation scenarios that aggregate individual mitigation strategies. This extends the previous programme (NZAGRC Objective 20.1) that limited the farm systems and land use change modelling to single mitigations. Combining mitigation options into "realistic" bundles that emerge from both farm the case study managers/governors as well as our partner programmes (e.g. IFS and FRNL) provides greater consistency with the international literature on GHG farm systems mitigation modelling.

(iv) Work with the two Māori Agri-Business case studies to

a. Analyse the impact of any changes at the whole enterprise level;

b. Discuss, outline and understand decision making criteria and issues around GHG mitigation strategies; and

c. Discuss and analyse barriers to the uptake of GHG mitigation strategies

(v) Develop a communication programme tailored to the needs of the Māori pastoral sector, and wider NZ farming community, by building on our relationships with dairy and sheep & beef industry extension services and develop new arrangements with nation-wide Māori entities such as FoMA and Te Tumu Paeroa to develop practical guidelines/recommendations and pathways for Māori pastoral farmers.

20.2 – Progress in 2017/18

This project has:

- Identified 2 multi-enterprise Maori operations, incorporating dairy farms, sheep & beef farms, and forestry operations willing to allow modelling of farm system change and land use change to identify impacts of reducing GHG emissions.
- Following discussions with the Trustees of the enterprises, carried out a range of modelling involving a range of farm system changes on both the dairy and S&B farms, incorporating improving productivity measures as well as changes in stocking rate and animal production levels.
- Modelling has also incorporated change in land use, particularly increases in forestry development, as well as possible horticulture enterprises, and change in pastoral land uses, e.g. finishing deer, and dairy sheep.

The results of the modelling reinforced previous modelling work in that changes in farm systems generally have a limited impact on reducing GHG emissions; +/-5-10%, while having a variable

impact on farm profitability; while a number reduced farm profitability, those that concentrated on lifting animal performance, often resulted in an improvement in farm profitability.

The largest impact on reducing GHG emissions was achieved via land use change into forestry; both enterprises had targeted increased areas of forestry planting on their sheep & beef farms. Both enterprises also have an issue in that they have large areas of pre-1990 production forest, which cannot be claimed as an offset.

The horticultural enterprise considered (chestnuts) had a significant impact on both the GHG emissions (negative) and profit levels (positive), albeit restricted to the relatively small size of the proposed plantings; 10 & 40ha respectively.

Part of the aim of the project is to consider the impact of any changes at a whole enterprise level. Mixing and matching the various scenarios modelled would indicate that significant gains in reducing GHG emissions (largely due to land use change) and some improvement in profitability, is possible at the whole enterprise level. There is some variation around this however, with no “magic bullet” answer.

The project also involves a Reference Group made up of representatives from Dairy NZ, Beef + Lamb NZ, FOMA, and Te Tumu Paeroa, to ensure that results from the project can be shared across the wider agricultural industry.

Key achievements for 2017/18:

- Selection of the 2 multi-enterprise operations
- Successful 1st and 2nd round of modelling, following discussions with the Enterprise Trustees
- Incorporation of different farming systems (deer, dairy sheep), + horticulture within the modelling scenarios
- A “mixing & matching” of scenarios across the whole enterprise, to give a “whole-of-business” approach
- Development of the Reference Group to compare different programmes and ensure results are spread

10.4 - Review of OVERSEER® GHG algorithms

Objective Leader – Dr Cecile de Klein (AgResearch)

The OVERSEER® Nutrient budget model has been recommended as the tool of choice for on-farm reporting of CH_4 and N_2O emissions. However, on-farm GHG reporting is reliant on full confidence in the GHG estimates and recent reviews have highlighted some issues and inconsistencies in the OVERSEER® algorithms. The purpose of this project is to recommend and implement the most appropriate algorithms contributing to the estimates of CH_4 and N_2O emissions into the OVERSEER® development version.

The key steps include:

1. Understand and confirm OVERSEER® algorithms and approaches for estimating on-farm CH_4 and N_2O emissions
2. Systematically check the existing code and implement required changes
3. Sensibility testing and reality check of implemented changes
4. Identify and document agreed procedures for changes and decision making and develop ongoing relationship with the National Inventory programme

Note: The project will closely align with two other projects that are underway:

1. An AgResearch SSIF funded project on OVERSEER®, FARMAX® and AgInform®. This SSIF project is led by Ronaldo Vibart, and aims to improve the interoperability of these models to harmonise their use. This includes a review of the animal metabolic energy (ME) sub-models. It will provide a recommendation around an agreed set of animal ME equations. We will therefore conduct step 1 above in collaboration with the SSIF project to ensure full alignment with recommendations.
2. An AgResearch SSIF funded project on the evaluation and recalibration of the N leaching outputs of OVERSEER®. This project is led by Mark Shepherd and he will be kept informed regularly of outcomes of our project (and vice versa) to ensure complete alignment.

10.4 – Progress in 2017/18

Methane and metabolisable energy algorithms

Methane estimates are reliant on an accurate assessment of the metabolisable energy (ME) requirements of the herd and two expert workshops were held to 1) map the current ME algorithms in OVERSEER® against those used in the Agricultural Inventory Model (AIM); and 2) agree on the best ME algorithms for OVERSEER®. The outcomes of the workshops are documented in reports submitted to NZAGRC and OVERSEER®; *Report 1* that details differences in methods or equations for estimating ME requirements of dairy, sheep and beef animals between the OVERSEER® and AIM, and *Report 2* with recommendations for the best ME algorims for OVERSEER®. The key recommendation from the expert panels was that OVERSEER® adopt the CSIRO (2007) methods for estimating animal ME requirements. The second report therefore also includes a discussion on issues or questions related to integrating the CSIRO (2007) model into Overseer.

Following the workshops, Rezare completed a branched version of the ME module and provided the AgResearch senior modeller access to this. AgResearch reviewed the code for consistency with the OVERSEER® ME chapter of the technical manual, while at the same time performing due diligence checks. All changes to the code to correct any inconsistencies or identified errors were carefully

recorded, and issues of concern were also noted. These changes are documented in a third report (*Report 3*) for NZAGRC and OVERSEER®.

The branched version of the ME module provided by Rezare for this project was not as 'stand-alone' as was anticipated. This meant that the ME module could not be independently run with a set of test input data, nor was it able to provide the outputs of interest (i.e. individual components of ME requirements). Instead, the branched version needed to be run with the rest of the OVERSEER® model to enable the required input data to be 'called up' from the main model. These restrictions did not allow for in-depth sensitivity or sensibleness testing, but a qualitative assessment was made that the code made sense, and that the impact of changes was considered in terms of the quantity the equation was calculating or immediately contributing to.

However, after discussions with Rezare it was agreed that the impact of the code changes could be tested by using two compiled versions of the OVERSEER® engine that were provided to AgResearch by Rezare. One of these engines was for the release version of Overseer (6.3.0), while the other incorporated changes made by Rezare based on the notes made by AgResearch. Over 5000 farm files were run through both these OVERSEER® engine versions and predictions for enteric methane compared graphically. The difference in predictions between the two engine versions ranged from a 13% reduction to a 4% increase, with a mean reduction of 6% in predicted enteric methane. The results of the testing are included in *Report 3*.

Nitrous oxide algorithms

To review and summarise the current OVERSEER® approaches to estimating N_2O emissions, a meeting was held with key N_2O and OVERSEER® experts. The outcomes from this meeting have been summarised in a draft report and will be used as starting point of a second N_2O expert panel workshop that has been agreed as an extension of the current contract. A final report with recommendations will be prepared following this upcoming workshop (to be held on 31 July 2018).

Procedures for ensuring alignment between OVERSEER® and AIM

A meeting was held with OVERSEER® Ltd and MPI to discuss procedures and relationships for ensuring ongoing alignment between OVERSEER® and AIM (*Report 4*). The key steps include:

1. MPI share their inventory procurement plan with OVERSEER® Ltd
2. MPI invites OVERSEER® Ltd to any presentations by researchers no research projects
3. MPI to send draft reports to OVERSEER® Ltd
4. Continue to invite OVERSEER® Ltd to AIAP meetings (suggestion was made to change the ToR of AIAP to permanently include OVERSEER® Ltd as an observer to the meetings).
5. OVERSEER® Ltd to provide an updated to MPI the AIAP on current and planned work
6. OVERSEER® Ltd to provide the inventory team with any changes recommended from its technical expert groups

A MPI/OVERSEER®/NZAGRC steering group to be established and to meet regularly to discuss changes and issues relating to GHG estimates. The objective leader (Cecile de Klein) has met twice with the current members of the steering group: Phil Wiles (MPI), Caroline Read (OVERSEER® Ltd) and Harry Clark (NZAGRC) to discuss progress and agree on next steps.

The steering group and the objective leader will meet again on 20 August to discuss the outcomes of this project and to agree on the steps to address the recommendations.

Key achievements for 2017/18:

- Held three expert meetings (two on ME and one on N_2O) and prepared a fourth one (on N_2O).
- Completion of report on comparison of ME algorithms in OVERSEER® and AIM (*Report 1*).

  Wheeler et al. (2018) Comparison of OVERSEER® and AIM methodologies

- Completion of recommendations on the most appropriate ME equations for OVERSEER® (*Report 2*).

  Wheeler (2018) Proposed changes to the animal metabolisable energy requirements model in OVERSEER®

- Completion of code checking and impact of any changes on CH_4 estimates (*Report 3*).

  Vetharaniam and Rollo (2018) Checking C# code for OVERSEER® ME predictions

- Established steering group and agreed procedures for ensuring ongoing alignment between OVERSEER® and Aim (*Report 4*).

  de Klein (2018) Short report on agreed procedures and relationships for ensuring ongoing alignment between the GHG module of OVERSEER® Nutrient Budgets and the Agricultural Inventory Model.

APPENDIX 3 – NZAGRC INTERACTIONS AND OUTPUTS

NZAGRC Meetings and Presentations (New Zealand)

- Meeting: BERG: 26 July, 2017 - Wellington
- Meeting: PGgRC board meeting: 3 August, 2017 - Wellington
- Meeting: NZAGRC MAG meeting: 7 August, 2017 - Telecon
- Meeting: RFI-Methane workshop: 11 August, 2017 - Wellington
- Meeting: NZAGRC/PGgRc vaccine research programme meeting: 18 August, 2017 - Wellington
- Meeting: BERG: 22 August, 2017 - Wellington
- Meeting: NZAGRC Steering Group: 23 August, 2017 - Palmerston North
- Meeting: PCE: 31 August, 2017 - Wellington
- Workshop: Plantain and GHGs: 8 September, 2017 - Christchurch
- Lecture: Parliamentary Commissioner for the Environment: 6 October, 2017 - Wellington
- Meeting: Greenhouse gas projections: 13 October, 2017 - Wellington
- Meeting: NZAGRC & MFE linkages: 25 October, 2017 - Wellington
- Meeting: Productivity Commission: 27 October, 2017 - Wellington
- Workshop: New Zealand Soil carbon research: 3 November, 2017 - Palmerston North
- Workshop: Transition Hub Agricultural Emissions Workshop: 6 November, 2017 - Wellington
- Workshop: NZAGRC and DairyNZ dairy mitigation options comparison: 6 November, 2017 - Wellington
- Meeting: BERG: 7 November, 2017 - Wellington
- Meeting: Ag Inventory Panel: 8 November, 2017 - Wellington
- Workshop: Inventory training module: 9 November, 2017 - Palmerston North
- Meeting: NZAGRC Maori research review: 13 November, 2017 - Wellington
- Meeting: Parliamentary Commissioner for the Environment: 14 November, 2017 - Wellington
- Meeting: NZAGRC Steering Group: 15 November, 2017 - Palmerston North
- Workshop: Sustainable Nutrition Workshop: 20 November, 2017 - Massey University
- Workshop: Dairy NZ - Strategy Refresh: 21 November, 2017 - Wellington
- Workshop: FRNL Plantain trial GHG measurement: 22 November, 2017 - Telecon
- Workshop: GHG Modelling Comparisons: 24 November, 2017 - Hamilton
- Presentation: E-Mission Possible Roundtable 2: 29 November, 2017 - Wellington
- Presentation: Intro to NZ Ag GHG Emissions & Management: 5 December, 2017 - Massey University
- Presentation: E-Mission Possible Roundtable 2: 8 December, 2017 - Wellington
- Meeting: BERG: 11 December, 2017 - Wellington
- Meeting: Dairy NZ: 12 December, 2017 - Wellington
- Meeting: NZ Submission to UNFCCC: 12 December, 2017 - Wellington
- Meeting: COP23 Outcomes: 13 December, 2017 - Wellington
- Meeting: MBIE & NZAGRC: 13 December, 2017 - Wellington
- Workshop: NZAGRC/PGgRc sheep genetic research programme: 14 December, 2017 - Dunedin
- Meeting: MFAT re COP23: 15 December, 2017 - Wellington
- Meeting: PMCSA Agricultural GHG Report: 25 January, 2018 - Wellington
- Meeting: NZ Productivity Commission: 25 January, 2018 - Wellington
- Meeting: Overseer: 25 January, 2018 - Telecon
- Presentation: Fonterra Climate Science and mitigation options: 13 February, 2018 - Hamilton
- Meeting: Inventory Course : 14 February, 2018 - Palmerston North
- Meeting: Animal Nutrition Company: 15 February, 2018 - Wellington
- Meeting BERG: 20 February, 2018 - Wellington
- Presentation: Federated Farmers: 21 February, 2018 - Wellington
- Meeting: PGGRC Board: 23 February, 2018 - Wellington
- Meeting: NZAGRC Steering Group: 28 February, 2018 - Palmerston North
- Workshop: NZAGRC Plant Traits: 7 March, 2018 - Lincoln
- Meeting: Ngai Tahu: 8 March, 2018 - Christchurch
- Meeting: New Zealand Institute of Primary Industry Management: 8 March, 2018 - Christchurch
- Workshop: MPI Red Meat Sector Supply Chain Programme / Sustainability and Capability and Research and Development - Lead workshop on Sustainability and Research Partnerships: 15 March, 2018 - Fielding
- Meeting: Fonterra Board: 20 March, 2018 - Hamilton
- Conference: 2018 Agriculture Greenhouse Gas Inventory : 21-22 March, 2018 - Wellington
- Meeting: PCE: - Wellington
- Meeting: BERG: Overseers and future mitigation potentials: 22 March, 2018 - Wellington

- Meeting: MPI re ideas for Joint GMI Biogas Subcommittee/ CCAC Ag Initiative: 22 March, 2018 - Wellington
- Meeting: Animal Nutrition Company: 22 March, 2018 - Wellington
- Presentation: MRV work: 23 March, 2018 - Wellington
- Visit: National MPs Todd Mueller, Scott Simpson and Nathan Guy: 26 March, 2018 - Palmerston North
- Presentation: panel discussion on land-use and GHG emissions for IPCC: 28 March, 2018 - Christchurch
- Visit: David Horne - discuss the formation of a CORE on climate change mitigation in agriculture: 29 March, 2018 - Palmerston North
- Visit: Minister Honourable James Shaw and others - update on research that is underway that specifically looks at managing climate change adaptation and mitigation.: 6 April, 2018 - Palmerston North
- Meeting: Parliamentary Commissioner for the Environment officers: 10 April, 2018 - Wellington
- Meeting: ICCC (Interim Climate Change Committee) Announcement: 17 April, 2018 - Wellington
- Workshop: Carbon Foot-printing Tool for NZ Farms: 19 April, 2018 - Wellington
- Workshop: MPI strategic review of GRA: 23 April, 2018 - Wellington
- Meeting: GIF and agriculture sector: 23 April, 2018 - Wellington
- Meeting: NZAGRC / MPI: 24 April, 2018 - Wellington
- Meeting: ICCC: 30 April, 2018 - Wellington
- Workshop: Land use and climate change modelling: 30 April, 2018 - Wellington
- Workshop: Cross-sectoral climate change mitigation modelling: 1 May, 2018 - Wellington
- Meeting: Dairy company visit to NZAGRC to discuss on-farm GHG initiatives and targets : 3 May, 2018 - Wellington
- Meeting: Kelsey Serjeant PCE Overseer Investigation: 3 May, 2018 - Wellington
- Meeting: PGgRc Board: 3 May, 2018 - Wellington
- Meeting: Don Syme on NZAGRC programme, LRG activities and activities and capability building and site tour: 4 May, 2018 - Palmerston North
- Meeting: ICCC: 7 May, 2018 - Wellington
- Meeting: ICCC on agriculture report draft: 7 May, 2018 - Wellington
- Meeting: Inventory Research Focus Group: 9 May, 2018 - Wellington
- Meeting: Geoff Bates - on NitroStop™, scientific results and information behind recent press release: 10 May, 2018 - Palmerston North
- Meeting: LIC science seminar on mitigating agricultural greenhouse gases in NZ, an update on research progress: 11 May, 2018 - Hamilton
- Meeting: LIC on low emitting animals : 11 May, 2018 - Hamilton
- Meeting: DairyNZ/MPI/NZAGRC: 11 May, 2018 - Hamilton
- Meeting: ICCC: 21 May, 2018 - Wellington
- Workshop: Methane RFI: 21 May, 2018 - Telecon
- Lecture: GHG training course: 22 May, 2018 - Palmerston North
- Meeting: PMCSA Agricultural GHG Emission project - OVERSEER: 23 May, 2018 - Auckland
- Meeting: MBIE/PGgRc/NZAGRC: 24 May, 2018 - Palmerston North
- Workshop: Short life time of methane and implications: 1 June, 2018 - Telecon
- Meeting: ICCC: 5-6 June, 2018 - Wellington
- Meeting: NZAGRC-PGGRC Breeding - Work Plan Review: 6 June, 2018 - Palmerston North
- Meeting: Maori project: 7 June, 2018 - Telecon
- Meeting: Minister Damien O'Connor: 11 June, 2018 - Wellington
- Meeting: Presentation to Dairy NZ board on issues around methane as a short lived GHG: 12 June, 2018 - Wellington
- Meeting: ICCC: 18 June, 2018 - Wellington
- Meeting: B+LNZ re Climate Change: 19 June, 2018 - Wellington
- Workshop: NZ Dairy Genetics Research And Implementation Programme: 20 June, 2018 - Telecon
- Meeting: Riddet Institute re KPMG modelling GHGs: 21 June, 2018 - Palmerston North
- Workshop: ACRE Winter Forum - Getting To Grips With Climate Change In Agriculture : 27 June, 2018 - Palmerston North

Meetings and Presentations (New Zealand)

- Louis Schipper, Liyin Liang, Dave Campbell & Aaron Wall, 'Continuous measurements of N_2O emissions and controls at paddock to farm scales.' - DairyNZ presentation seminar - 18 July, 2017
- Sandeep Kumar & Peter H. Janssen, 'Metagenomic sequencing give insight into the physiology of Quinella, an iconic uncultured rumen bacterium' - Molecular BioSciences Plus seminar, Massey University, Palmerston North - 19 July, 2017
- Louis Schipper, Liyin Liang, Dave Campbell & Aaron Wall, 'Continuous measurements of N_2O emissions and controls at paddock to farm scales' - DairyNZ seminar - 18 August, 2017
- Miko Kirschbaum, Gabriel Moinet, Michael Beare, Sam McNally , 'How much carbon can be protected in soils?' - Public video conference seminar - 03 November, 2017
- Louis Schipper, Jack Pronger, Aaron Wall, Dave Campbell, Paul Mudge, 'Farmer open day at Troughton Farm' - 17 April, 2018
- Kathryn Hutchinson, Robyn Dynes & Grant Rennie, 'GHG monitor farms' - Taumaranui Sustainable Land Management discussion group - 16 May, 2018
- Louis Schipper, Anne Wecking, Aaron Wall, Liyin Liang, Jiafa Luo, Stuart Linsey, Dave Campbell, 'Paddock scale nitrous oxide emissions from grazed pastures: quantification and mitigation' - Presentation to DairyNZ staff in Hamilton (+VC) - 18 May, 2018

NZAGRC Meetings and Presentations (International)

- Meeting: IPCC Plenary: 10-11 September, 2017 - Montreal, Canada
- Meeting: IPCC Plenar : 16-18 October, 2017 - Oslo, Norway
- Meeting: GHG metric and emissions intensity (University of San Francisco): 31 October, 2017 - Telecon
- Meeting: A review of livestock methane emission factors: 27 November, 2017 - Telecon
- Meeting: CCAC: 19 January, 2018 - Telecon
- Meeting: IPCC Plenary : 29 January, 2018 - Geneva
- Meeting: FACCE JPI: 15 February, 2018 - Telecon
- Meeting: IPCC Bureau: 22 February, 2018 - Telecon
- Meeting: OECD climate change experts group: 8 March, 2018 - Paris
- Meeting: IPCC Plenary : 12-15 March, 2018 - Paris
- Meeting: LEAP: 8 March, 2018 - Telecon
- Meeting: IPCC SRCCL LAM2: 26-30 March, 2018 - Christchurch
- Meeting: FACCE JPI: 12-13 April, 2018 - Telecon

Meetings and Presentations (International)

- Miko Kirschbaum, 'Maximising carbon sequestration in grazed pastures. Constraints and opportunities' - Public seminar - 29 August, 2017
- Suzanne Rowe, 'Invited presentation on the relationship between methane and rumen microbial communities at Methagene meeting.' - 11 October, 2017

International Visitors and Groups

- Visit: Chinese delegation: 29 September, 2017 - Palmerston North
- Visit: Costa Rica minister: 26 October, 2017 - Palmerston North
- Visit: Australian Centre for International Agricultural Research: 2 November, 2017 - Palmerston North
- Visit: Dr Bess Tiesnamurti ICARD & Dr Yeni Widiawati IRIAP: 27 November, 2017 - NZAGRC
- Visit: British High Commissioner for NZ. NZ efforts to combat climate change and possible collaboration with UK: 14 March, 2018 - Palmerston North
- Visit: Yoji Ishii from Japan Embassy Researcher / Advisor site visit and NZ efforts on climate change: 23 March, 2018 - Palmerston North
- Visit: Jim Skea UK Climate Change Commission: 23 March, 2018 - Palmerston North
- Visit: MPI, Ministry Livestock and Fisheries Development Kenya, Ministry for the Environment and Tourism Namibia, Ministry of Agroindustry Argentina, National Institute of Agricultural Technology Costa Rica on NZAGRC purpose and role, news/updates from MPI and inventory team: 27 March, 2018 - Palmerston North
- Visit: BMGF Livestock Learning with Bill and Belinda Gates Foundation: 12 April, 2018 - Palmerston North
- Meeting: British High Commission: 19 April, 2018 - Wellington
- Visit: Netherlands ambassadors office site visit: 30 May, 2018 - Palmerston North

NZAGRC Global Research Alliance related interactions

- Meeting: NZAGRC/MPI Quarterly meeting: 5 July, 2017 - Paraparaumu
- Meeting: GRA Council Meeting: 28-30 August, 2017 - Tsukuba, Japan
- Workshop: Improving GHG inventories from livestock in south & south-east Asia: 11-12 September, 2017 - Bangkok, Thailand
- Workshop: Quality Assurance/Quality Control for GHG emission inventories from livestock systems in south-east Asia: 13-14 September, 2017 - Bangkok, Thailand
- Presentation: LEAP annual meeting: 21 September, 2017 - Rome
- Presentation: CCAC annual meeting: 28 September, 2017 - Paris
- Meeting: GRA partner linkages with ICAT and GRA, CCAFS, CCAC: 11 October, 2017 - Telecon
- Presentation: GASL side event at the World Food Security: 12 October, 2017 - Rome
- Meeting: GRA Quarterly Meeting: 1 November, 2017 - Paraparaumu
- Meeting: NZAGRC and CCAFS: 3 November, 2017 - Telecon
- Meeting: NZAGRC and World Bank: 16 November, 2017 - Telecon
- Meeting: GRA Coordinators: 29 November, 2017 - Telecon
- Meeting: International guidance on MRV: 30 November, 2017 - Telecon
- Meeting: GRA Co-chairs call: 1 December, 2017 - Telecon
- Meeting: GRA IRG : 15 January, 2018 - Paris
- Meeting: GHG Inventories: 23 January, 2018 - Nairobi, Kenya
- Meeting: GRA Co-chairs call: 13 February, 2018 - Telecon
- Meeting: GRA Quarterly Meeting: 21 February, 2018 - Wellington
- Meeting: MRV priority research: 4 March, 2018 - Telecon
- Workshop: Bilateral technical training workshop for manure GHG inventory development in Thailand: 6-8 March, 2018 - Bangkok, Thailand
- Meeting: GRA LRG Co-chairs: 13 March, 2018 - Telecon
- Meeting: GRA funding for next two years: 5 April, 2018 - Wellington
- Workshop: Regional Techical Training Workshops on construction and use of reprisation chambers for small ruminant studies: 9-13 April, 2018 - Kuala Lumpur, Malaysia
- Meeting: Peter Ettema - GRA East African initiative: 7 May, 2018 - Wellington
- Meeting: GRA LRG: 14-17 May, 2018 - Ho Chi Minh
- Workshop: Improving GHG Inventories for the livestock sector in Kenya: 27-29 June, 2018 - Nairobi, Kenya

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.

- 'OPINION: Farmers advocate takes wrong message from climate reports' - NZ Herald - 23 August, 2017 (Andy Reisinger)
- 'Low methane producing sheep could be way forward for NZ' - NZ Farmer - 30 August, 2017 (Suzanne Rowe)
- 'PAC chambers for measuring sheep CH4 emissions' - RNZ - 13 September, 2017 (Suzanne Rowe)
- 'Methane inhibitors starting to take shape' - Rural News group - 22 September, 2017
- 'The re-designing of a farm system to reduce greenhouse gas emissions' - Rural Delivery - 25 September, 2017 (Robyn Dynes)
- 'Agriculture's methane figures solid, scientists say' - NZ Herald - 04 October, 2017 (Andy Reisinger)
- 'Cutting Down on Cow Burps to Ease Climate Change' - Bloomberg Businessweek - 30 November, 2017 (Andy Reisinger)
- 'Meeting with media' - ODT - 04 December, 2017 (Andy Reisinger)
- 'What Generation 2100 will see' - ODT - 17 January, 2018 (Andy Reisinger)
- 'World's top climate scientists deliver warning for Kiwi farmers' - Newshub - 26 March, 2018 (Andy Reisinger)
- 'Plantain shows potential for reducing greenhouse gas emissions' - Stuff.co.nz - 29 March, 2018 (Jiafa Luo)
- 'Retaining soil carbon the answer to managing agricultural GHG emissions' - Stuff.co.nz - 20 April, 2018 (Louis Schipper & team)
- 'Reducing greenhouse gas emissions a priority' - Stuff.co.nz - 03 May, 2018 (Cecile de Klein)
- 'Meeting with RNZ re half-hour documentary and online feature for RNZ's Insight programme on agricultural greenhouse gases and efforts to mitigate emissions' - RNZ - 09 May, 2018 (Harry Clark et al)
- 'Insight: Farming and the Fight Against Climate Change' - RNZ - 20 May, 2018 (Harry Clark et al)
- 'Kiwi scientists leading world in reducing livestock methane emissions' - Stuff.co.nz - 03 June, 2018 (Peter Janssen)
- 'New Zealand scientists are breeding sheep to fart and burp less' - ABC Rural radio (Australia) - 07 June, 2018 (Suzanne Rowe)
- 'Interview about sheep breeding programme' - Ferrari Press Agency (UK) - 08 June, 2018 (Suzanne Rowe)
- 'Interview about sheep breeding programme' - Sustainability Zero website (India) - 15 June, 2018 (Suzanne Rowe)
- 'Interview about sheep breeding programme' - Thomson Reuters Foundation (Italy) - 21 June, 2018 (Suzanne Rowe)
- 'Interview about sheep breeding programme' - Scholastic Math magazine (USA) - 21 June, 2018 (Suzanne Rowe)

Conference Presentations (Abstracts, Posters & Oral Presentations)

- Camilla Gardiner, Tim Clough, Keith Cameron, Hong Di, Grant Edwards, 'Effect of application rate of aucubin, a secondary metabolite in Plantago lanceolata and potential nitrification inhibitor, on ruminant urine patch nitrous oxide emissions' - American Geophysical Union Fall Meeting - 26 July, 2017
- Louis Schipper, Liyin Liang & Dave Campbell, 'Continuous eddy covariance measurements of N2O emissions and controls from an Intensively Grazed Dairy Farm ' - American Geophysics Union annual meeting - 31 July, 2017
- Ron Ronimus, Vince Carbone & Linley Schofield, 'Crystal structure of an UDP-aminosugar 4-epimerase from Methanothermobacter thermautotrophicus ' - Poster for Thermophiles Conference, South Africa - 11 August, 2017
- Ron Ronimus, Vince Carbone & Linley Schofield, 'Conference presentation' - SAADC - The Sixth International Conference on Sustainable Animal Agriculture for Developing Countries, Indonesia - 24 August, 2017
- Arjan Jonker, Sharon Hickey, John McEwan, Suzanne Rowe, Yoav Aharoni, German Molano, Edgar Sandoval, Cesar Pinares-Patino, 'Rumen characteristics and total tract digestibility in low and high methane yield selection line sheep offered fresh good or low quality pasture' - World Congress on Genetics Applied to Livestock Production - 29 September, 2017
- Suzanne Rowe, Sharon Hickey, Arjan Jonker, Janine Wing, Brooke Bryson, Ken Dodds, Emily Young, Kevin Knowler, Sara Elmes, John McEwan, 'Effective Short-term measures of enteric methane emissions' - World congress in genetics applied to livestock genetics - 01 November, 2017
- Melanie Hess, Suzanne Rowe, Tracey Van Stijn, Rudiger Brauning, Andrew Hess, Michelle Kirk, Graeme Attwood, Peter Janssen, John McEwan, 'Using genotyping-by-sequencing for high-throughput rumen microbial profiling' - MapNet - 06 November, 2017

- Louis Schipper, Dave Campbell, Liyin Liang, Aaron Wall, 'Insights into N_2O and CH_4 fluxes from a NZ dairy farm using a QCL-based EC system' - OzFlux conference joint NZ Australian eddy covariance flux network - 14 November, 2017
- Mike Beare, Sam McNally, Denis Curtin, Frank Kelliher, Roberto Calvelo-Pereira, Jeff Baldock, Qinhua Shen, Esther Meenken, 'The Carbon Sequestration Potential and vulnerability to C loss of New Zealand's Agricultural Soils' - International Soil Organic Matter Symposium - 17 November, 2017
- Louis Schipper, Aaron Wall, Dave Campbell, Paul Mudge, 'Does the Import of Supplement Feed to a Dairy Farm result in an Increase in Soil Carbon?' - WaiBOP Waikato Bay of Plenty Soils conference - 05 December, 2017
- Louis Schipper, Dave Campbell, Liyin Liang, Aaron Wall, 'Continuous Eddy Covariance Measurements of N_2O Emissions and Controls from an Intensively Grazed Dairy Farm' - American Geophysics Union annual fall meeting - 11 December, 2017
- Camilla Gardiner, Tim Clough, Keith Cameron, Hong Di, Grant Edwards, 'Biological nitrification inhibition as a method to reduce nitrous oxide emissions from grazed pasture soils: a New Zealand perspective' - 21st World Congress of Soil Science - 19 January, 2018
- Linley Schofield, Vince Carbone, Yanli Zhang, Carrie Sang, Andrew Sutherland-Smith & Ron Ronimus, 'Using Enzyme Assays and Structures for High-Throughput Screening to Discover Inhibitors of Rumen Methanogens' - The 43rd Lorne Conference on Protein Structure and Function - 26 January, 2018
- Kathryn Hutchinson, Robyn Dynes, Grant Rennie, David Scobie, Anna Taylor, Ray Moss, 'Monitoring GHG emissions from a real farm - changes in the red meat sector over 25 years' - FLRC workshop - 07 February, 2018
- Arjan Jonker, Sharon Hickey, John McEwan, Suzanne Rowe, Yoay Arahoni, German Molano, Edgar Sandoval, Wendy Bain, Sarah Elmes, Ken Dodds, Sarah MacLean, Kevin Knowler, Brooke Bryson, Cesar Pinares-Patino, 'Rumen characteristics and total tract digestibility in low and high methane yield selection line sheep offered fresh good or poor quality pasture' - World Congress on Genetics Applied Livestock Production - 08 February, 2018
- Kathryn Hutchinson, Robyn Dynes, Grant Rennie, David Scobie, Anna Taylor, Ray Moss, Bill Wright & Shirley Wright, 'Monitoring GHG emissions from a real farm - changes in the red meat sector over 25 years' - FLRC workshop - 08 February, 2018
- John Roche, Holly Flay, Danny Donaghy, Nicolas Lopez-Villalobos, Mark Camara, Kevin Macdonald, 'Relationship between residual feed intake and methane production in dairy heifers' - International Symposium on the Nutrition of the Herbivore - 09 February, 2018
- Sharon Hickey, Suzanne Rowe, Arjan Jonker, John McEwan, Janine Wing, Brooke Bryson, Emily Young, Ken Dodds, Kevin Knowler, 'Effective short-term measures of enteric methane emissions' - World Congress on Genetics Applied to Livestock Production - 09 February, 2018
- Kathryn Hutchinson, Tony van der Weerden, Pierre Beukes, Cecile de Klein, Robyn Dynes, 'Can we prove modelled mitigation strategies work on farm' - FLRC workshop - 09 February, 2018
- Rowe, S.J., 'Planned work in Methane and Microbiomes' - ASGGN workshop held at the 11th world congress on genetics applied to livestock production. Auckland - 11 February, 2018
- John Roche, Holly Flay, Kevin Macdonald, Mark Camara, Danny Donaghy, Nicolas Lopez-Villalobos, Barbara Kuhn-Sherlock, 'Relationship between residual feed intake and CH4 production in dairy heifers' - Annual Conference of the American Dairy Science Association - 20 February, 2018
- Qinhua Shen, Manuel Suarez-Abelenda, Marta Camps-Arbestain, Roberto Calvelo Pereira,Samuel R McNally, Francis M. Kelliher, 'An Investigation of Organic Matter Quality and Quantity in Acid Soils as Influenced by Soil Type and Land Use' - 21st World Congress of Soil Science (WCSS) - 28 February, 2018
- Anne Wecking, Dave Campbell, Liyin Liang, Aaron Wall, Louis Schipper, Jiafa Luo & Stuart Linsey, 'From points to paddocks: measuring N_2O fluxes by static chambers and eddy covariance' - Agricultural GHG inventory research conference Wellington MPI/MfE - 21 March, 2018
- Louis Schipper, Dave Campbell, Liyin Liang & Aaron Wall, 'Nitrous Oxide (N_2O) Emissions from Grazed Pasture using Eddy Covariance Measurements' - Agricultural GHG inventory research conference Wellington MPI/MfE - 21 March, 2018
- David Whitehead, 'Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands in New Zealand' - Agricultural GHG inventory research conference Wellington MPI/MfE - 21 March, 2018
- Louis Schipper, Aaron Wall, Dave Campbell & Paul Mudge, 'Does the Import of Supplement Feed to a Dairy Farm result in an Increase in Soil Carbon?' - Agricultural GHG inventory research conference Wellington MPI/MfE - 21 March, 2018
- Miko Kirschbaum, 'Optimising carbon sequestration and milk production in grazed pastures. From measurements to scenario modelling.' - Agricultural GHG inventory research conference Wellington MPI/MfE - 22 March, 2018
- David Pacheco & Arjan Jonker, 'Methane emissions from sheep and dairy cattle fed fodder beet' - Agricultural GHG inventory

research conference Wellington MPI/MfE - 22 March, 2018

- Robyn Dynes & Bill Wright, 'Emissions to air and water: learning from Sheep and Beef monitor farms and farmers' - Beef + Lamb New Zealand AgInnovation Conference - 02 May, 2018

- Ron Ronimus, Vince Carbone, Linley Schofield & Andrew Sutherland-Smith, 'Conference poster - methanogen enzyme structures' - INRA-ROWETT Conference - 11 June, 2018

Journal Articles

Submitted

- Balvert, S. F., Luo, J., & Schipper, L. A. (Submitted). Can incorporating brassica tissues into soil reduce nitrification rates and nitrous oxide emissions? Journal of Environmental Quality.
- Cradock-Henry, N. A., Frame, B., Preston, B. L., Reisinger, A., & Rothman, D. S. (2018). Dynamic adaptive pathways in downscaled climate change scenarios. [journal article]. Climatic Change. doi: 10.1007/s10584-018-2270-7
- de Klein, C. A. M., van der Weerden, T. J., Luo, J., Cameron, K. C., Di, H. J., & Vibart, R. E. (Submitted). Plant options for mitigating nitrous oxide emissions from pasture-based dairy systems - a review and modelling assessment. NZ Journal of Agricultural Research.
- Jonker, A., Hickey, S., McEwan, J. C., Rowe, S., Janssen, P. H., MacLean, S., . . . Pinares-Patino, C. (Submitted). Heritability and repeatability for plasma and ruminal volatile fatty acids in sheep fed alfalfa pellets and genetic and phenotypic correlations with enteric methane emissions. Journal of Animal Science.
- Journeaux, P., Kingi, T., & West, G. (Submitted). Modelling and communicating greenhouse gas mitigation strategies on farms in New Zealand. Agricultural Systems.
- Kumar, S., Treloar, B. P., Teh, K. H., McKenzie, C. M., Henderson, G., Attwood, G. T., . . . Janssen, P. H. (2018). Sharpea and Kandleria are lactic acid producing rumen bacteria that do not change their fermentation products when co-cultured with a methanogen. Anaerobe, 54, 31-38. doi: https://doi.org/10.1016/j.anaerobe.2018.07.008
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- Reay, D. S., Smith, P., Christensen, T. R., James, R. H., & Clark, H. (2018). Methane and Global Environmental Change. Annual Review of Environment and Resources. doi: 10.1146/annurev-environ-102017-030154
- Ronimus, R. S., Carbone, V., Schofield, L. R., & Sutherland-Smith, A. J. (Submitted). The crystal structure of 2,5-diamino-6-(ribosylamino)-4(3H)-pyrimidinone 5'-phosphate reductase (MthRED) from Methanothermobacter thermautotrophicus ΔH. Proteins; Structure and Function.
- Schipper, L. A., Liang, L., Wall, A., & Campbell, D. I. (Submitted). Pattern and Regulation of N2O Fluxes from Grazed Pasture using Eddy Covariance Measurements. Agriculture, Ecosystems and Environment.
- Schipper, L. A., Wall, A., Mudge, P. L., Rutledge, S., & Campbell, D. I. (Submitted). Carbon budget of an intensively grazed temperate grassland with large quantities of imported supplemental feed. Agriculture, Ecosystems and Environment.
- van der Weerden, T., Beukes, P., de Klein, C. A. M., Farrell, L., Stormink, T., Romera, A. J., . . . Dynes, R. (Submitted). The effects of system changes in grazed dairy farmlet trials on greenhouse gas emissions. Agricultural Systems.
- Waite, S. J., Zhang, J., Cater, J. E., Waghorn, G. C., Bain, W. E., McEwan, J. C., & Suresh, V. (2018). Development of an in situ procedure to evaluate the reticulo-rumen morphology of sheep selected for divergent methane emissions. Animal, 1-7. doi: 10.1017/S1751731118001854
- Whitehead, D., Schipper, L. A., Pronger, J., Moinet, G. Y. K., Mudge, P. L., Calvelo Pereira, R., . . . Camps-Arbestain, M. (2018). Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands: New Zealand as a case study. [Review]. Agriculture, Ecosystems and Environment, 265, 432-443. doi: 10.1016/j.agee.2018.06.022
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Other interactions/publications

Media related

- 'OPINION: Farmers advocate takes wrong message from climate reports' - Media Release - 23 August, 2017 (Andy Reisinger)
- 'Support for award winning technology via the science programme (Spikey)' - NZAGRC website - 03 September, 2017
- 'Support for Suzanne Rowe's work on low methane sheep' - NZAGRC Twitter - 13 September, 2017
- 'Congratulations to Dr Jack Pronger' - NZAGRC website - 14 September, 2017
- 'Laser has bright future in nitrous oxide emissions measurement' - NZAGRC website - 21 September, 2017
- 'Support for Robyn Dynes work on sheep and cattle farm profiled on Rural Delivery ' - NZAGRC Twitter - 25 September, 2017
- 'NZAGRC: Global methane emissions discrepancy not applicable to NZ' - Media Release - 04 October, 2017
- 'Further international recognition for Andy Reisinger' - NZAGRC website - 19 October, 2017
- 'New research shows significant impact from livestock on actual warming' - NZAGRC website - 10 November, 2017 (Andy Reisinger)
- 'Support for John McEwan's Science NZ Lifetime Achievement award ' - NZAGRC Twitter - 14 November, 2017

- 'Support for Louis Schipper's RNZ Nights commentary on soils ' - NZAGRC Twitter - 20 November, 2017
- 'Infographic on how livestock affect the carbon cycle ' - NZAGRC website - 30 November, 2017
- 'Support and promotion of the Aotearoa New Zealand Science Journalism Fund's 2018 application round ' - NZAGRC Twitter - 30 November, 2017
- 'NZAGRC scholarship forges future international collaboration' - NZAGRC website - 15 December, 2017
- 'NZAGRC Highlights 2017 ' - NZAGRC website - 15 December, 2017
- 'Watching CO2 exchange and maize growth' - NZAGRC website - 17 January, 2018
- 'NZAGRC leaders to contribute to next IPCC report' - Media Release - 14 March, 2018
- 'NZ-led rumen microbial genome work published in prestigious journal ' - Media Release - 20 March, 2018 (Sinead Leahy)
- 'NZAGRC Director to take key role in Government' - Media Release - 17 April, 2018
- 'Getting to the bottom of a beneficial bacterium' - NZAGRC website - 04 May, 2018
- 'Applying maths to methane' - NZAGRC website - 14 May, 2018
- 'Groundbreaking trial seeks links to agricultural GHG emissions ' - Media Release - 14 May, 2018
- 'Maori project profile in Te Uranga B2 Incorporation's Autumn 2018 newsletter ' - Newsletter - 21 May, 2018 (Phil Journeaux & Tanira Kingi)

From Release of Information system

- Graeme Attwood, 'Permission to use rumen and buccal samples, and methane emission data' - Request to access sheep rumen and buccal samples, and methane emission data - 23 August, 2017
- Graeme Attwood, 'Use of sheep rumen samples for metagenome and metatranscriptome sequencing ' - Request to access sheep rumen samples, and methane emission data - 23 August, 2017
- Sandeep Kumar, 'Physiology of rumen bacteria associated with low methane emitting sheep' - Ph.D. thesis submitted to Massey University - 08 September, 2017
- Stephen McNeill & Allan Hewitt, 'SOC C map to FAO GSOC17' – Request to access data for FAO Global Soil Partnership (GSP) Global Soil Organic Carbon Map (GSOC17) - 06 October, 2017
- Louis Schipper, Dave Campbell & Aaron Wall, 'Looking after your soil carbon - what are the benefits?' - DairyNZ Technical series - 01 December, 2017
- Kirsty Hammond & David Pacheco, 'Methane Production by Ruminants: its synthesis and ways to mitigate it' - Workshop "An introduction to New Zealand's Agricultural Greenhouse Gas Emissions and Management" - 05 December, 2017
- Sinead Leahy, Peter Janssen, Graeme Attwood, Sandra Kittelmann, Christina Moon, 'Rumen Microbial Diversity' - State of the World's Biodiversity for Food and Agriculture report - 05 December, 2017
- Mariana Garcia Rendon Calzada, 'Internship report - National Autonomous University of Mexico' - Internship report to be presented to the Faculty of Veterinary Medicine and Zootechnics - 06 February, 2018
- Miko Kirschbaum, 'Maximising carbon sequestration in grazed pastures. From measurements to scenario modelling.' - Public seminar at Landcare Research, Palmerston North - 19 February, 2018
- Louis Schipper, Jack Pronger, Aaron Wall, Dave Campbell, Paul Mudge, 'Managing greenhouse gases – lessons learnt and where to from here? An On-Farm Field Day' - Flyer for open day at Troughton farm - 06 March, 2018
- Rogerio Cichota & Iris Vogeler, 'Soil Moisture Measurements' – Request to access data for Soil Research - 14 March, 2018
- Grant Rennie, Robyn Dynes & Kathryn Hutchinson, 'Greenhouse gas emissions & environmental modelling at Onetai station' - Practical solutions for sheep and beef farming in 2025 - Onetai Station environmental focus farm field day - 15 March, 2018
- Wanjie Yu, 'Internship report: Effect of seasonal pasture quality on methane emissions and nitrogen partitioning in methane yield selection line sheep' - Internship report to Aarhus Universtiy and Wageningen University - 06 April, 2018
- Phil Journeaux & Tanira Kingi, 'Meeting held with Reference Group (Dairy NZ, B+L NZ, TPP, FOMA) to discuss progress to date, and potential extension activities in 2018/19.' - 11 April, 2018
- Sheree Balvert, 'Can naturally occurring glucosinolate related compounds from brassica crops act as biological nitrification inhibitors and reduce nitrous oxide emissions?' - Thesis submission to the University of Waikato - 16 May, 2018
- John Roche & Holly Flay, 'Facility a world first in methane measurement' - InSide Dairy - 21 May, 2018
- Kirsty Hammond & David Pacheco, 'Methane Production by Ruminants: its synthesis and ways to mitigate it ' - Presentation as invited speaker at the Rutherford U3A Club in Christchurch - 22 June, 2018
- Angela Schipper & Louis Schipper, 'Measuring gases using eddy covariance' - Science Learning Hub website article - 29 June, 2018f