NEW ZEALAND
AGRICULTURAL GREENHOUSE GAS
Research Centre

# Annual Report 2012

Leading Partners in Science

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## EXECUTIVE SUMMARY

This Annual Report of the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) provides an overview of activities during the financial year from July 2011 to June 2012.

The NZAGRC's mission is "To provide knowledge, technologies and practices which grow agriculture's ability to create wealth for New Zealand in a carbon-constrained world'. Through undertaking international quality research, in close cooperation with public, industry and policy stakeholders, the NZAGRC demonstrates New Zealand's commitment to finding ways to reduce agricultural greenhouse gas emissions while meeting the globally growing demand for high-protein food. The NZAGRC also aims to be a trusted and authoritative source of information on the science of agricultural greenhouse gas emissions and their mitigation.

Methane ($CH_4$) and nitrous oxide ($N_2O$) from agriculture contributed just over 47% of New Zealand's total greenhouse gas emissions in 2010 (the latest year for which inventory data are currently available). This emissions profile, which is highly unusual in the developed world, reflects New Zealand's unique national circumstances and the important role of agriculture in our economy. More than two thirds (70%) of New Zealand's agriculture emissions are in the form of methane, with almost all (more than 97%) from enteric fermentation. The remaining 30% of agricultural emissions are in the form of nitrous oxide from urine and fertiliser deposited onto agricultural soils.

Changes in carbon stored in New Zealand agricultural soils remain less well understood and therefore are not currently included in New Zealand's emissions inventory. However, the potential to increase carbon storage motivates the search for robust and sustainable management practices that can achieve and demonstrate any such increased storage to international standards.

Research designed by the NZAGRC and its funding partners, and carried out by contracted researchers, seeks to both exploit existing and develop new science capacity and experience in all of these areas, and to develop new approaches that draw on emerging technologies and insights. The NZAGRC's operations are based on comprehensive Science, Strategy and Business Plans developed following an extensive review process and adjusted in light of new findings and inputs from our international science and stakeholder advisory panels. NZAGRC science investment and operations are fully funded by the Ministry of Primary Industries (MPI) under the Primary Growth Partnership, a government-industry initiative that invests in significant programmes of research and innovation to boost the economic growth and sustainability of New Zealand's primary, forestry and food sectors.

### Science

The main aims of the NZAGRC science plan fall into four principal research components:

- Reduce emissions of methane ($CH_4$) from agricultural sources
- Reduce emissions of nitrous oxide ($N_2O$) from agricultural soils
- Increase carbon (C) sinks in agricultural soils
- Integrated solutions and modelling approaches to ensure that individual mitigation options are evaluated within the context of practical and profitable whole-farm systems.

Research activities under each of the four principal research components are summarised in individual sections of this Annual Report. Partnerships are crucial to the success of the NZAGRC and its science programme cannot be viewed in isolation from those of other funders. In the $CH_4$ area, the NZAGRC investment works with and builds on existing PGgRc investment. All areas of the NZAGRC programme, but particularly the Integrated Systems area, are also cognisant of and align with SLMACC-funded projects to ensure a comprehensive 'NZ Inc.' research portfolio without major gaps or duplication. Funding provided for initiatives in support of the Global Research

Alliance further extends and enhances international collaborative aspects of New Zealand's domestic research programme.

Some key findings from research funded/co-funded specifically by the NZAGRC include:

*Methane*

- Confirmation from an examination of calorimetry data that an extended series of short-term measurements (1 hour duration) can identify naturally low-emitting sheep, thus potentially providing a more cost effective method for screening the number of animals necessary for the successful breeding of low-emitting animals without loss of productivity.
- Advances in the genomic analysis of methanogens and key molecular interactions responsible for the formation of methane are now allowing a large-scale computer-based search for methane mitigation agents; the first anti-methanogen vaccine prototype developed by this work strand is currently being evaluated in sheep.

*Nitrous Oxide*

- Confirmation of the effectiveness of the nitrification inhibitor DCD in both trampled and highly water logged soils. This provides a basis for more robust farm management advice to reduce $N_2O$ emissions via nitrification inhibitors, and supports the targeted design of second generation inhibitors that are suitable for a wider range of weather conditions and terrains found in New Zealand.
- Improved understanding of the relative roles of soil water content and other soil properties in driving $N_2O$ emissions. The dominant influence of volumetric soil water content provides opportunities for designing simple farm management tools to help reduce $N_2O$ emissions.

*Soil Carbon*

- Reduced uncertainty in quantification of current soil carbon levels through the development of a new modelling approach; due to the relatively short history of agriculture in New Zealand, dominant predictors of soil carbon were found to be soil type, environmental variables such as rainfall and the type and density of pre-human vegetation cover. This improved understanding will allow identification of areas with the greatest potential for increased soil carbon storage and reduce the uncertainty in national estimates of soil carbon storage.
- Improved model-based understanding of the role of grazing animals on the soil carbon and nitrogen balance, in particular from intensive (dairy) systems, and improved ability to relate measurements of $CO_2$ fluxes from grazed paddocks to model-based predictions.

*Integrated systems*

- Statistical analysis of a database of $N_2O$ emissions across New Zealand farms, coupled with a whole farm model, suggests that in some circumstances better management and the adoption of specific mitigation options, such as the use of nitrification inhibitors during critical periods, stand-off pads, and timing of fertiliser and effluent application could reduce farm-scale $N_2O$ emissions by up to 30%.

As the research programmes are beginning to deliver new insights, some elements of the science plan are being revised to ensure the portfolio of research continues to be comprehensive yet sufficiently targeted to deliver the best possible value to New Zealand. Feedback from our International Science Advisory Group during this year's Annual Conference highlighted opportunities for adjustments in some Objectives. Changes will be implemented over the coming months to ensure we maintain a clear focus and appropriate balance in our research activities.

**Capability development**

Increasing the pool of researchers with skills in the agricultural greenhouse gas mitigation area is a major objective for the NZAGRC. Apart from funding embedded in science programmes,

mechanisms to attract and develop skilled students include the provision of short-term scholarships to promising undergraduate students, the provision of well-funded PhD stipends, and employment of high-quality post-doctoral fellows and early stage scientists on 2-3 year contracts. The NZAGRC is now a major funder of PhD students in agricultural sciences related to nutrition, animal and plant performance and greenhouse gas emissions in New Zealand.

The domestic capacity building measures are complemented by linking interested undergraduate and graduate students from overseas with New Zealand experts and host institutions. Such exchanges not only help expand the pool of skilled PhD students in New Zealand but also foster closer integration of research programmes in New Zealand and overseas. Additionally, the LEARN/GRASS fellowship schemes, which are supported by the NZAGRC, provide opportunities for international work placements within the NZAGRC programmes for technicians, doctoral students, post-docs, and the exchange of senior scientists.

**Stakeholder engagement**

The NZAGRC is governed by a Steering Group (SG) comprising a representative from each of its nine members. This group has met quarterly as well as corresponding by email to view and comment on reports and respond to requests from the NZAGRC Director regarding decisions on the NZAGRC's strategic direction. The NZAGRC is advised by an International Science Advisory Group (ISAG) and a Stakeholder Advisory Group (SAG). The former ensures that research carried out by the NZAGRC is internationally excellent, while the latter aims to ensure that research remains connected with practical realities of farming in New Zealand and that domestic stakeholders can both provide input to, and be informed of, the NZAGRC's research directions.

In addition, a Māori Advisory Group has been established, recognising the special role but also particular challenges that Māori may face in mitigating agricultural greenhouse gases. This group has only started its work but has already signalled its keen intent to contribute to the effective working of the Centre.

The second annual conference of the NZAGRC was held in February 2012. This meeting brought leading researchers of the NZAGRC together with stakeholders from policy and industry and the International Science and Stakeholder Advisory Groups, to provide an update of latest research findings and enable an overview of the breadth of issues tackled by the Centre's science programme. A one-day conference with plenary presentations and poster displays was followed by two days of workshops focusing in detail on the four main work strands of the NZAGRC science programme. This also allowed the International Science Advisory Group to better understand and provide feedback on the current research activities and findings to date. In 2013, the entire science programme will undergo a formal review by the International Science Advisory Group to ensure it continues to be fit for purpose and meet international standards of excellence. The workshops also allowed members of the Stakeholder Advisory Group to gain more detailed insights into the research programme, as well as providing feedback on the Centre's direction in a dedicated half-day stakeholder workshop.

The NZAGRC continued its regular profile in the media and with the wider scientific community and the general public (see appendix 3), including through its regular newsletter 'Release'. The NZAGRC website was revised to ensure easy access to the growing amount of information held by the Centre and research activities carried out under the Centre science programme by its partners.

**International dimensions – the Global Research Alliance**

The Global Research Alliance on Agricultural Greenhouse Gases (Alliance) is a major international initiative to increase international collaboration and development of solutions to reduce agricultural greenhouse gas emissions intensity globally while meeting growing food demand. New Zealand continues to host the Secretariat through MPI and, through the NZAGRC Director and supporting NZAGRC staff, is co-chairing the Livestock Research Group (LRG) of the Alliance alongside the Netherlands. NZAGRC support for the goals and objectives of the Alliance and its Livestock Research Group is covered by a separate contract with MPI. However, a high-level summary is

included in this Annual Report since the international dimension provides important context and, in many cases, an important extension of New Zealand's domestic research effort.

The NZAGRC provides assistance to MPI on a range of Alliance initiatives. In the 2011/12 year, five major targeted research projects in support of the objectives of the LRG were launched, which seek to accelerate research led by New Zealand scientists in collaboration with colleagues from around the world. NZAGRC administers the contracts for these projects on behalf of MPI and facilitates the development of dedicated research networks in specific interest areas. In addition, the past year saw the launch of the New Zealand Fund for International Partnerships in Livestock Emissions Research, which seeks to support research initiatives that may be led by New Zealand or international scientists, provided that the results are of benefit to New Zealand and there is significant participation by New Zealand scientists. Four projects were approved for funding, all led by New Zealand, and a second funding round will run in the 2012/13 financial year. NZAGRC provided strategic and scientific expert advice to MPI to the design of the fund and selection of successful projects.

Additional activities related to the Alliance include the design and operation of capacity building workshops and initiatives in Latin America and south-east Asia, which seek to increase consistency in emissions estimates and improve the ability of major livestock-producing world regions to identify and develop regionally appropriate mitigation options. These initiatives are supported by a revised awards and fellowships scheme and extension of a global network and database of experts in the area of livestock emissions and mitigation research. NZAGRC also maintains communications related to the LRG through regular newsletters and updates to the group's web pages, and ensures strong and consistent science representation from New Zealand in the other Research and Cross-Cutting Groups set up under the Alliance.

## CHAIR'S REPORT

Agriculture is part of a complex social, economic and environmental dynamic system. It feeds more than seven billion people, and underpins economic development and poverty alleviation over much of the world. It is a significant source of greenhouse gases, yet stands to be impacted, both directly and indirectly, by climate change itself. With an ever growing world population to feed, it is vital that agricultural production grows, but not its environmental impacts. New Zealand is a part of this dynamic. It is a major food exporter and has increasing opportunities to upscale food production to meet a growing international demand. However, it also needs to do this in an environmentally sustainable manner. Greenhouse gas emissions epitomise this challenge.

Nearly half of New Zealand's greenhouse gas emissions come from agriculture, and 95% of those come from the pastoral sector. In 2010, the latest year for which figures are available, the country's estimated total greenhouse gas emissions had increased by 19.8% above 1990 levels. On the back of an expanding national dairy herd and higher nitrogen fertiliser application, agricultural emissions are estimated to have increased by almost 10% above their 1990 level. New Zealand's unique emissions profile for a developed country, and the pivotal contribution of agriculture to the national economy, create an urgent need to reduce livestock emissions, if the country is to meet the goal of halving its greenhouse gas emissions by 2050. Livestock emissions are also growing in many other parts of the world. Therefore, collaborative international research to develop sustainable options to reduce emissions, whilst improving, or at least maintaining, animal productivity must be a key part of New Zealand's response.

The NZAGRC was founded in 2010 in recognition of this challenge. The NZAGRC's key role is to find ways by which New Zealand can meet its international greenhouse gas emission obligations without reducing agricultural output and thus deliver economic, environmental and social benefits to New Zealand, as well as setting an example globally.

During 2011/12 the NZAGRC research programme has continued in earnest in line with the agreed strategic science plan. The NZAGRC's second annual conference in early 2012 provided an excellent opportunity for the whole science team to come together with the NZAGRC's Steering, Stakeholder and International Science Advisory Groups to reflect on progress to date and the longer term goals of the research. Following this informal review of the programme, the Science Leadership Team has been closely looking at the science work streams to ensure that we stretch our targets for the future and deliver against our Mission. The governance of the NZAGRC was formally reviewed at the end of 2011 with a very positive outcome. The report praised the Centre Director for excellent leadership and management and the Steering Group for setting and maintaining a very high quality of governance. The Steering Group's mode of operation has ensured that the nine members maintain a clear focus on the needs and goals of the NZAGRC rather than the organisations that they individually represent.

The Global Research Alliance on Agricultural Greenhouse Gases has gained significant momentum during the past year. The NZAGRC team continues to play an important national and international role through its work supporting the LRG and providing advice on overarching science issues. The New Zealand Government (through MPI) has committed a total of NZ$45 million over five years to support the work of the Alliance, with most of this investment directly supporting collaborative research projects intended to discover and develop new ways of reducing the greenhouse gas emissions intensity of agriculture. The first projects to receive Alliance funding are now underway and the NZAGRC's input has helped to ensure that New Zealand's domestic research efforts and global collaborations are well aligned.

Through its national and international roles and responsibilities, the NZAGRC continues to build its reputation as an important source of clear and unbiased advice on the science behind agricultural greenhouse gases and their mitigation options.

**Professor Warren McNabb**
Chair of NZAGRC Steering Group
August 2012

## NZAGRC DIRECTOR'S REPORT

The 2011/12 financial year has been another busy one for the NZAGRC. I'm pleased to say that the science programmes are progressing well, milestones are being achieved and usable results, outputs and publications are emerging from the research. Our science plan was devised during 2009 and we are currently starting to prepare for its first formal review in early 2013. Following an informal review of our science conducted by the International Science Advisory Group (ISAG) in parallel with our 2012 annual conference, we have been reflecting on some of our future targets and the steps that will be required to reach them. I'd like to thank all of the scientists that have openly engaged with this process and I strongly value their input into guiding the goals of the research.

Complementary to the science plan, we have also conducted additional projects that directly support New Zealand government priorities. These include an updated 'inventory' and assessment of currently available methane and nitrous oxide mitigation practices and a comprehensive review of the nitrification inhibitor DCD. This work demonstrates the ability of NZAGRC scientists to contribute robust and unbiased information which impacts on policy level decisions. Additionally, in my role as NZAGRC Director, I have acted in technical advisory roles to the Agriculture ETS Committee and panels assessing the allocation of international research funding.

Attracting and retaining talented researchers into the agricultural greenhouse gas area remains a key goal for the NZAGRC and we have continued to build on the progress made in 2011/12. This year we have provided support to an additional 6 undergraduate, 2 Masters and 1 PhD students, bringing us to a total of 28 young and early career scientists supported to date. By all reports, the projects that these young researchers have been involved with have benefited from their enthusiasm and the aim is that they will be inspired to continue their scientific careers in this area.

The NZAGRC's input into the Global Research Alliance has grown considerably this year. In addition to co-chairing the LRG and representing New Zealand at various Alliance meetings, we have provided MPI with scientific and administrative support for a range of initiatives being funded from the Government's $45m Alliance budget. The LEARN and GRASS fellowship schemes have been actively promoted during 2011/12 and have allowed a number of researchers to visit groups outside of their own country to increase global linkages. A regional technical workshop was held in Thailand in March 2012, in which the NZAGRC team had a very active role. Further technical workshops are planned for 2012/13 in other regions following the success of the Thailand meeting. A key role this year has been to support the funding of the first targeted research projects from the Alliance budget. The funded projects are designed to increase international teamwork in the agricultural greenhouse gas research space and work so far indicates that this international collaboration will accelerate New Zealand's own efforts and allow much greater impacts than could ever be achieved in isolation.

The Governance Review that we underwent in late 2011 endorsed my view that the NZAGRC is functioning as an effective and efficient collaborative team. As in all reviews we have some things to work on but it was pleasing to receive this external confirmation. In addition to our Stakeholder and International Science Advisory Groups, this year we have established a Māori Advisory Group. This group is currently evaluating how the NZAGRC can best align with current Māori scientific, capability building and information provision initiatives to add value. I would like to express my thanks to all of our Advisory Groups, and particularly to the Steering Group, for their dedication to the NZAGRC and the knowledgeable advice that they have provided throughout the last year.

**Dr Harry Clark**
NZAGRC Director
August 2012

## THE NEW ZEALAND AGRICULTURAL GREENHOUSE GAS RESEARCH CENTRE

The NZAGRC is a partnership between the leading New Zealand research providers working in the agricultural greenhouse gas area and the Pastoral Greenhouse Gas Research Consortium (PGgRc). It is 100% government-funded by the Ministry of Primary Industries (MPI) under the Primary Growth Partnership, a government-industry initiative that invests in significant programmes of research and innovation to boost the economic growth and sustainability of New Zealand's primary, forestry and food sectors. 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.

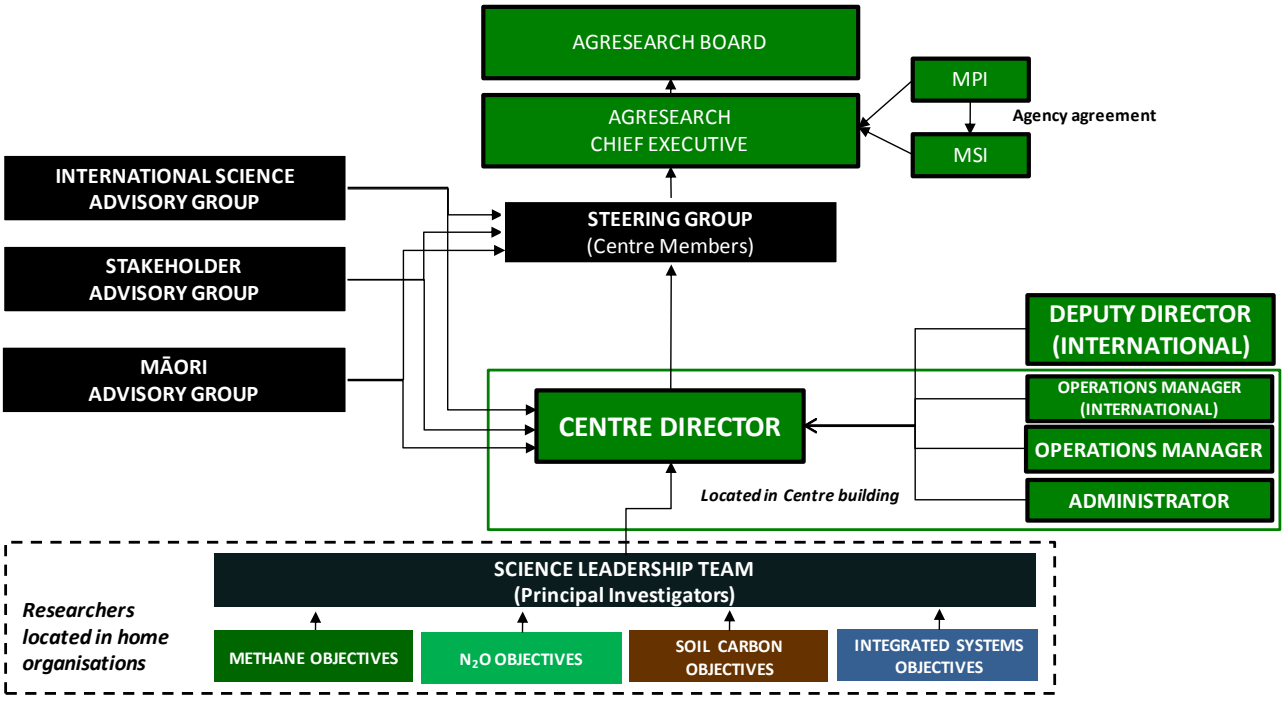
NZAGRC is not the only significant investor into agricultural greenhouse gas mitigation research in New Zealand. Much of NZAGRC $CH_4$ research builds on and continues to align with research investments made by the PGgRc, and an even closer alignment in science, contracting and reporting is envisaged for the future. 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 science programme will be formally reviewed by its International Science Advisory Panel in early 2013. For this review to be effective, an overview of the collective science investments in New Zealand is critical. To this end, NZAGRC has begun work with MPI and the PGgRc to develop a single NZ Inc science strategy and an inventory of all research being undertaken in the agricultural GHG mitigation area that will provide a more easily accessible view of the current and possible future collective effort.

The NZAGRC is physically headquartered on the AgResearch Grasslands Campus in Palmerston North. The NZAGRC Director, NZAGRC Operations Manager, Operations Manager International and NZAGRC Administrator are employed by AgResearch on behalf of the NZAGRC and are based in this building. The Deputy Director (International), also employed by AgResearch, is located in Wellington.

## NZAGRC GOVERNANCE

As the NZAGRC is set up as a unit operating within AgResearch, the Board and Chief Executive (CE) 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 CE and Board on the operation of the NZAGRC. The NZAGRC Director reports to the AgResearch CE and Board via the NZAGRC's SG. The International Science Advisory Group (ISAG) monitors, advises and reports on the NZAGRC's science quality and direction to the SG and NZAGRC Director while the Stakeholder Advisory Group (SAG) monitors, advises and reports on the alignment and performance of the NZAGRC in relation to the needs of the industries that are intended to take up its research outcomes. The roles of the ISAG and SAG are primarily in the areas of science quality, research direction and industry relevance.

A Māori Advisory Group (MAG) was established towards the end of 2011/12 to ensure that the research and development undertaken by the NZAGRC is relevant and accessible to all sectors of New Zealand society. The first responsibility of the MAG is to provide input into how: (i) the NZAGRC can best align with and draw on current Māori scientific, capability building and information provision initiatives; and (ii) identify any priority actions that would better enable the Māori farming community to engage with issues related to agricultural greenhouse gas emissions. This work is currently underway.




NZAGRC Governance Structure

### Role of the Steering Group (SG)

The NZAGRC Director reports to the Steering Group (SG) of the NZAGRC Members and via them to the AgResearch CE 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 any future alignment with the PGgRc is well considered.

During 2011/12 the SG met quarterly in Palmerston North and 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, SAG, ISAG and MAG and meetings attended during 2011/12 can be found in appendix 1.

## NZAGRC STRATEGY DEVELOPMENT AND IMPLEMENTATION IN 2011/12

### The Vision

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

*By 2015, 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 ("Alliance").*

During 2011/12 the NZAGRC has taken further steps towards realising the vision of the Centre. Scientifically, two of the initial 18 initial research objectives were completed at the end of 2010/11 and one additional objective was contracted during 2011/12. Work is progressing well and, following an informal review by the ISAG, some amendments are planned to the work programme to enhance the future goals and ensure delivery against the vision.

The NZAGRC has been communicating its role, research and achievements to a wide audience during 2011/12 via a quarterly newsletter (Release) and updated website amongst other vehicles. Three initial factsheets regarding agricultural greenhouse emissions have been prepared and will be published in early 2012/13.

NZAGRC staff and key NZAGRC-funded researchers have been working alongside MPI to advance the goals of the Global Research Alliance and have been actively promoting New Zealand's expertise and leadership in this area on the international stage.

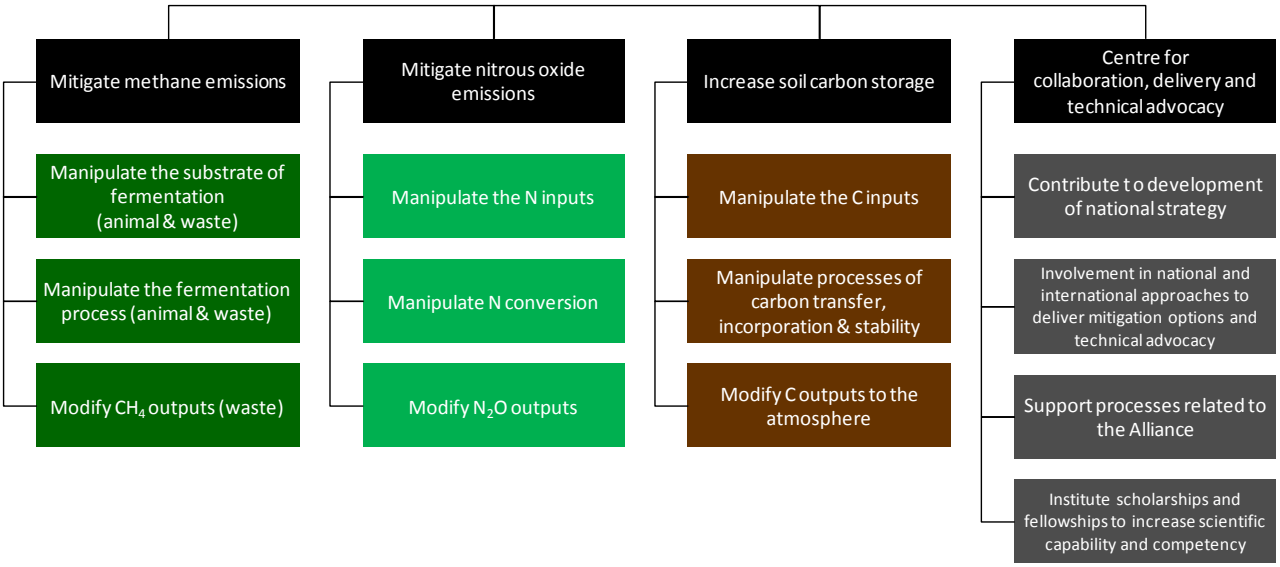
### The Mission

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

The research and development activities detailed in the NZAGRC Science Plan are now well underway. Highlights from the research programmes are provided in this Annual Report, with more detailed commentary on individual projects contained in the appendices.

### The Objectives

The NZAGRC is working with its partner organisations – particularly the PGgRc as a joint venture of industry and government – to deliver science that is innovative, practical, credible and able to stand up to international peer review. Its activities have been designed to be transparent and effectively communicated to its stakeholders. The NZAGRC's objectives are summarised in the following diagram:




NZAGRC Objectives

During the 2011/12 financial year, the focus has been on management of the science programmes whilst finalising and effectively implementing the strategies, policies and day-to-day procedures required to run the NZAGRC in an efficient manner. A number of key actions have been completed and the following strategies have now been finalised:

| *Strategy/Policy* | *Description* |
|---|---|
| Communications & Media | A comprehensive policy was signed off by the Steering Group in 2010/11. During 2011/12, the NZAGRC website was substantially updated, a quarterly NZAGRC "Release" newsletter was produced and circulated widely, and a series of fact sheets was initiated. The first three factsheets are due for release in the spring of 2012. The communications plan will be updated in 2012/13 to ensure that the NZAGRC continues to actively promote its vision. |
| Intellectual Property | Following the Governance Review at the end of 2011, minor changes were proposed to the NZAGRC IP procedure. Changes were made to ensure alignment with MPI's position that achieving benefit to New Zealand is of greater priority than achieving commercial returns on the NZAGRC research investment. These were signed off by the Steering Group in May 2012. |
| Knowledge Management | The NZAGRC is required to store data generated by its research programmes in line with best research practice. This requires data to be stored in a safe, readily retrievable and comprehensively described form. After consultation with a wide number of parties a workable system was developed which tries to maintain a balance between usability and comprehensiveness, taking into account the costs involved in maintaining any comprehensive electronic database. Basically AgResearch (on behalf of the NZAGRC) stores pre-analysed and post-analysed data in a central electronic repository and raw data, laboratory books etc are stored by the research contractor. The Data Storage Policy, Processes and User Guide documentation were distributed to the science teams in November 2011. A review of the repository to date was conducted in May 2012 by an independent contractor. Feedback from the review was disseminated to the science teams prior to data upload being conducted at the 2011/12 year end. |

| | |
|---|---|
| Māori | The NZAGRC recognises the special nature of Māori agricultural business and has developed a specific Māori Strategy so that it can better meet these needs. A draft strategy document was developed under contract by AgResearch during 2011. Following this, a short, targeted strategy that extracted key elements of the draft report was finalised and approved by the SG in early 2012 following input from the Māori SAG members and relevant business managers at the partner organisations. The key action areas of the strategy are: (i) engagement; (ii) science; (iii) capability; and (iv) information. In order to actively engage, a Māori Advisory Group was established in April 2012. This involves the two SAG Māori representatives, a representative involved in Māori engagement from each NZAGRC organisation and, it is envisaged, senior representatives from the Māori agricultural / agribusiness sector. The MAG's role is to advise on relevant science needs, capability development and information requirements. The MAG met twice during 2011/12 and their first action was to commission a stock take of existing Māori related work being conducted by the NZAGRC members. This report will be discussed by the MAG in early 2012/13 and advice regarding potential NZAGRC actions to address identified gaps in the science, capability and information areas prepared accordingly. |
| International | NZAGRC staff have been heavily involved in advising and supporting MPI regarding the Global Research Alliance (*See separate section on Global Research Alliance*). In addition Drs Andy Reisinger and Harry Clark have contributed to the forthcoming IPCC 5th Assessment Report through their work as Coordinating Lead Author and Lead Author respectively, and Andy Reisinger also as member of the Core Writing Team for the IPCC Synthesis Report. Harry Clark has worked closely with MBIE, MFAT and MPI in promoting linkages between the New Zealand science effort and the European, Canadian and Australian science effort through membership of Knowledge Based Bioeconomy (KBBE) forum. This forum has adopted agricultural GHG mitigation as a priority area for cooperation. Harry Clark also leads the New Zealand input into the EU framework 7 programme Animal Change and has been instrumental in aligning New Zealand efforts with those of this EU initiative on agricultural GHG mitigation and adaptation. Andy Reisinger is also the New Zealand representative on the Scientific Programming Group of the Asia-Pacific Network for Global Change Research (APN). |
| NZAGRC/PGgRc alignment | The PGgRc's co-funding through MBIE ceased on the 30th June 2012, subject to a re-bidding process. Discussions regarding much closer alignment between the NZAGRC and the PGgRc have been ongoing during 2011/12. The NZAGRC Director and PGgRc Consortium Manager have been working closely to develop a single research strategy for the two organisations to inform future investment. A draft strategy and proposed new operating model have been prepared and circulated to the PGgRc Board and NZAGRC SG and SAG for their approval and feedback. The areas in which closer alignment between the NZAGRC and PGgRc could prove valuable and offer greater efficiency include: (i) full alignment of science funding; (ii) joint contracting and reporting; (iii) joint meetings; and (iv) joint IP decision making. |

**The Goals**

The NZAGRC has five major goals for the first five years of its life. These have been defined and quantified in order to be consistent, realistic and achievable and detailed targets are included in the NZAGRC Strategic Plan. The high level goals are shown below alongside the progress towards these goals in 2011/12. Achievements so far focus on papers and presentations, rather than patents and licensing, given the current early point in the NZAGRC research programmes.

| *Title* | *Goal by 2015* | *Measurement criteria* | *Progress in 11/12* |
|---|---|---|---|
| 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 | – Peer-reviewed scientific journal papers<br>– Scientific conference papers<br>– Patents relating to agricultural GHG emission mitigation technologies<br>– Practical on-farm mitigation practices and technologies identified and being promoted | 3 journal paper submissions<br>13 published journal papers<br>10 other publications<br>53 conference presentations<br>*(see appendix 3)* |
| 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 | – Page views of NZAGRC website<br>– Senior NZAGRC staff presentations to meetings of NZ industry and policy stakeholders<br>– NZAGRC funded scientist presentations to the farming community and general public | Upgraded, up-to-date NZAGRC website. 8,436 page views.<br>9 presentations to NZ industry/policy stakeholders by NZAGRC staff<br>13 presentations to farming community/general public<br>*(see appendix 3)* |
| 3: Contribute to policy | The NZAGRC will be the authoritative source of information for the New Zealand government on agricultural GHG emission mitigation | – Senior NZAGRC Staff presentations to meetings of NZ government policy staff<br>– Written reports prepared for government policy staff<br>– NZAGRC's science contributions direct influence and reflection in government policy. | 3 presentations to meetings of NZ govt policy staff<br>Attendance and input to a technical review of ETS emission factors<br>2 reports prepared for govt policy staff<br>Additional technical advisory roles |
| 4: Develop science capability | The NZAGRC will be a major source of new capability in the field of agricultural GHG emission mitigation | – PhD students studying and graduated<br>– Post-doctoral researchers completed 2-year projects<br>– FTEs of professional researchers working on NZAGRC research programmes | 10 PhD students studying<br>3 Post-doctoral fellows<br>78 researchers are contributing to the NZAGRC research programmes (including PhD & Post-docs). This equates to 24 FTEs. |
| 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 | – Leadership of science input into Global Research Alliance and coordination of Livestock Research Group with the Netherlands<br>– Visiting fellows from overseas research organisations hosted<br>– Memoranda of understanding covering research collaborations agreed with research centres around the world<br>– Confidentiality agreements with companies to discuss information related to agricultural GHG mitigation technologies | Active NZAGRC input into Alliance during year<br>LEARN/GRASS Fellowships actively promoted<br>NZAGRC science programme fully aligned with Alliance, PGgRc and SLMACC programmes |

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|---|---|---|---|
| | | – Licenses to companies to sell agricultural GHG emission mitigation technologies that the NZAGRC or its partners have developed or imported and implemented to suit NZ requirements | |

## NZAGRC IMPACTS IN 2011/12

In addition to the goals listed previously, it is important that the new knowledge developed in NZAGRC funded/co-funded research programmes is utilised in order to have a practical impact, wherever possible, on the greenhouse gas emissions resulting from New Zealand agriculture.

| *NZAGRC output* | *Impact to date* |
|---|---|
| Methane suppression activity of microalgae:<br>• NZ microalgae from fresh water and marine origin too low in lipid content to reduce emissions<br>• Red marine algae from Australia showed promising *in vitro* results | NZAGRC work on using algal biomass for enteric methane emission identified an Australian supplied marine alga that completely reduced emissions in a batch culture.<br>Further assessment of this marine alga will be carried out under the MITIGAS component of an AgResearch SLMACC funded programme once further material has been sourced from Australian collaborators. Australian researchers have received funding to expand work on micro algae and discussions are under way to define the New Zealand contribution to this work; |
| *Methanobrevibacter* sp. AbM4 genome sequenced | This is the second ruminant methanogen genome sequenced in New Zealand. So far only one ruminant methanogen sequence has been published. The AbM4 gene complement is very similar to that of M1, suggesting that both organisms are likely to be amenable to inhibition by the same small molecule inhibitors and vaccine-based methane mitigation technologies as the targets are conserved features common to more than a single methanogen species. |
| Potential protein identified with anti-methanogen activity that looks promising as a vaccine target | The first NZ prototype vaccine based on this protein has been developed and is being evaluated in sheep. |
| Evaluation of repeatability and consistency of series of short-term (one hour) methane measurements to identify and rank low-emitting sheep | Study confirmed that it is feasible to identify low and high emitting animals using a series of short-term (one hour) measurements, opening the opportunity for cost-effective identification and testing of the large numbers of animals needed for the successful breeding of low emitting phenotypes. |
| Preliminary study assessing anaerobic digestion technologies to capture and utilize methane emissions from dairy farm effluent | Study showed that it may be cost-effective to use bio-digesters in New Zealand. The key need identified was for better quantification of emissions from waste ponds so that these modelled findings can be confirmed. These data are being collected from a project funded by MPI as part of its inventory improvement programme. |
| Field work results showing that $N_2O$ mitigation strategies that reduce the urine N concentration below typical (8-10 gN/L) concentrations, but don't reduce the total amount of urine N excreted, may have limited impact on reducing direct $N_2O$ emissions. | Results demonstrate that the current constant emission factor for $N_2O$ emissions from urine used in the national inventory is appropriate. This is a key piece of work that will be used to justify our approach to international reviewers. It also rules out some proposed mitigation technologies, e.g. diuretics to reduce urine concentration. |

| | |
|---|---|
| Trial application of gibberellin showed significant growth increase in ryegrass under low N availability | This study suggests that a possible route for $N_2O$ mitigation is to apply gibberellins rather than nitrogen as this would give high DM production without emissions from N fertiliser. This opens up a new mitigation possibility. |
| Field work results showing that $N_2O$ emissions are significantly affected by animal treading of wet soils which causes soil compaction, affecting soil air permeability and air-filled pore space. DCD was shown to be highly effective in reducing $N_2O$ emissions and the efficacy was not affected by trampling. | Study confirms effectiveness of DCD as mitigation tool under a variety of situations. It also clearly highlights that water logged soils and trampling are a recipe for high $N_2O$ emissions and should be avoided. . |
| Experiments show that the soil water content threshold before nitrous oxide emissions rapidly increased (approx. 54% v/v) is the same across a variety of sedimentary and volcanic soil types. | If confirmed by further studies, this finding can provide the basis for robust and simple guidance for farm management to reduce $N_2O$ emissions. |
| Modelling of current carbon stocks over the NZ landscape has produced a soil map of the 0-30 cm layer at a 1km spatial resolution. The strongest explanatory input variables were the LENZ environmental classification layers, and the pre-human vegetation layers. | The statistical uncertainty in this map is half that present in the current soil carbon model used by MfE (24.4t/ha vs. 40.7t/ha), thus potentially offering a significant reduction in uncertainty in GHG inventory calculations. In conjunction with improved estimates of maximum soil C storage across New Zealand, this map will allow us to identify how and where soil carbon levels could be potentially be increased. Further funding has been allocated to this project for the writing of a peer reviewed paper so that the methods, results and conclusions can be independently scrutinised. |
| The Grassland Ecosystem Dynamics model (HPM) has undergone major revision, and initial results demonstrate that the off-take of N in intensive, notably dairy, systems, leads to a reduction in C and N sequestered in soil. | These modelled results are consistent with long term measurements from dairy farms and suggest that it will be difficult for many NZ farmers to increase soil C storage. |

## SCIENCE FUNDING REPORT

### *Funding*

In accordance with the NZAGRC's Business, Strategy and Science Plans, and with the approval of the SG, $3.87 million was allocated to core Research Programmes in the 2011/12 financial year. The distribution of funding between Programmes is reported in detail later in this section. All figures are exclusive of GST.

### Infrastructure Update 2011/12

All spending 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 new contracts for infrastructure were executed in 2011/12 and none are planned for the remainder of the NZAGRC contract.

### Capability Development Funding 2011/12

Increasing the pool of researchers with skills in the agricultural greenhouse gas mitigation area is a major objective for the NZAGRC, due to an aging science population and the need for increase capacity and capability. To achieve this objective the NZAGRC has commenced a programme of strategically funding students to build capability for the future. Some of this funding is embedded within the funding of the science programme, with additional funding being available on a discretionary basis when high quality students are projects are identified. In the 2011/12 financial year this additional funding totalled $125,909. The funding plan has a number of elements:

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 2011/12 the undergraduate "pipeline" scholarship schemes continued with Massey and Lincoln Universities. These have now completed their second year and will be reviewed following the completion of the third intake of summer/Honours student scholarships. If deemed successful, the scheme may be extended to other Universities in following years. No new PhD or post doctoral positions have been established in the core-NZAGRC science programmes this year. This is due to the initial recipients of the positions created at the start of the programmes now being part way through their contracts. Two core science programmes have, however, accommodated short term Masters project students from overseas. These help to build international linkages and may lead to high calibre PhD students who remain in the agricultural greenhouse gas emissions field in future. Additionally, one new PhD position has been established in the methane area and will be supervised and financially supported by both the NZAGRC and TEAGASC in Ireland. Funding for international students under the LEARN fellowship scheme (under separate contract with MPI; see below, 'Engagement with Policymakers & External Parties') provides further international dimensions to NZAGRC's overall capacity building efforts.

| Type of Capability Development | # new in 2011/12 | Total funded to date* |
|---|---|---|
| Undergraduate - Summer student | 5 | 9 |
| Undergraduate - Honours student | 1 | 2 |
| Masters Project | 2 | 2 |
| Masters | | 1 |
| PhD | 1 | 10 |
| Post doctoral fellow | | 3 |
| Early career scientist | | 1 |
| | 9 | 28 |

*Including new 11/12 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.

**Research Programmes 2011/12**

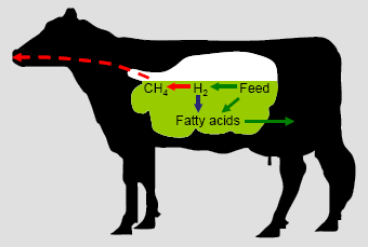
The Science Plan consists of 19 Research Objectives which align under four key areas: (i) methane; (ii) nitrous oxide; (iii) soil carbon and; (iv) integrated systems. In 2011/12 17 of the 19 Research Objectives received funding, with 2 projects having been completed at the end of 2010/11. Those programmes marked with a dagger (‡) are co-funded with the PGgRc and/or PGgRc/MPI and those marked with a diamond (◊) are co-funded with SLMACC (MPI).

| Area | Research Objective | Objective Title | Objective Leader | Objective Leader Organisation | 2011/12 Research FTE** | 2011/12 $NZ (GST excl)* |
|---|---|---|---|---|---|---|
| Methane | 1.1 | Feeding Microalgae | David Pacheco | AgResearch | 0 | 0 |
| | 1.2‡ | Low methane producing animals | John McEwan | AgResearch | 0.65 | 250,000 |
| | 1.3‡ | Genomic identification of universal targets for methanogen inhibition | Sinead Leahy | AgResearch | 1.85 | 243,269 |
| | 1.4‡ | Enhanced discovery of methanogen-specific inhibitors | Ron Ronimus | AgResearch | 0.85 | 235,000 |
| | 1.5‡ | Expression of vaccine target proteins | Bryce Buddle | AgResearch | 0.60 | 150,000 |
| | 1.6‡ | Identifying alternative hydrogen utilisers | Gemma Henderson | AgResearch | 1.25 | 145,000 |
| | 1.7 | Methane capture and utilisation from dairy effluent | Rupert Craggs | NIWA | 0 | 0 |
| Nitrous Oxide | 2.1 | Manipulating N inputs | Cecile de Klein | AgResearch | 2.21 | 470,000 |
| | 2.2 | Manipulating nitrification processes | HJ Di | Lincoln University | 4.00 | 450,000 |
| | 2.3 | Manipulating denitrification processes | Surinder Saggar | Landcare Research | 3.05 | 250,000 |
| | 2.4 | $N_2O$ emissions and soil water status | Steve Thomas | Plant & Food | 0.45 | 125,000 |
| | 2.5 | Influence of anecic earthworms on nitrous oxide emissions | Alec Mackay | AgResearch | 0.11 | 31,114 |
| Soil Carbon | 3.1 | Limits of soil carbon storage in New Zealand soils | Mike Beare | Plant & Food | 0.56 | 150,000 |
| | 3.2 | Quantifying the carbon currently stored in New Zealand soils | Allan Hewitt | Landcare Research | 0.35 | 110,000 |
| | 3.3 | Process-based modelling of drivers of soil carbon change | Tony Parsons | AgResearch | 1.43 | 200,000 |
| | 3.4 | Manipulation of carbon inputs, incorporation and retention to protect and enhance soil carbon | David Whitehead | Landcare Research | 3.47 | 445,000 |
| | 3.5 | Improved soil carbon measurements | Frank Kelliher | AgResearch | 0.43 | 140,000 |
| Integrated Systems | 4.1◊ | Mechanistic modelling of enteric $CH_4$ production | David Pacheco | AgResearch | 1.69 | 280,000 |
| | 4.2◊ | Improved $N_2O$ Component Modelling | Iris Vogeler | AgResearch | 0.73 | 200,000 |
| | | | | Total | 23.68** | 3,874,383 |

*N.B. 2011/12 funding includes personnel costs, consumables and in certain cases, significant expenditure on travel, items such as SNP chips or services such as DNA sequencing. **NZAGRC PhD students and post-doctoral researchers time is included.

**Methane Research Programme Report - 2011/12**

***Principal Investigators: Dr Graeme Attwood and Dr Peter Janssen***




The NZAGRC $CH_4$ programme is coordinated with existing PGgRc and/or MPI programmes and aims to reduce emissions by directly targeting the $CH_4$-producing methanogens through small molecule inhibitors and vaccines and indirectly through feeding and changes in animal phenotype. The current objectives within the NZAGRC $CH_4$ programme have made significant progress this year and remain on track to deliver their contracted milestones.

The inhibition of ruminant methane emissions, without compromising the normal digestive functions of the rumen, requires the targeting of methanogen-specific features. These are being identified by a rumen methanogen genome sequencing strategy coordinated across the NZAGRC and PGgRc programmes. This year the genome sequence of the rumen methanogen, *Methanobrevibacter* sp. AbM4, has been completed and its gene sequence information has been added to a growing rumen methanogen gene database. This database adds value to the $CH_4$ mitigation programmes by confirming current targets for inhibitor and vaccine development and by identifying new targets for further investigation.

This information also adds significant value to the inhibitor discovery objective, where key methanogen enzyme targets have been cloned, expressed, crystallised and their three dimensional structures solved using data collected at the Australian Synchrotron facility. These enzyme structures are helping to elucidate the molecular interactions required for the key metabolic steps of methanogens, while assays of their enzymatic activity enable screening of large chemical compound libraries to accelerate discovery of valuable new methanogen inhibitors.

In the vaccine development pipeline, important work continues in the identification and testing of vaccine targets. A promising protein candidate, with potential usefulness as an antigen for a prototype anti-methanogen vaccine, is currently being evaluated in sheep. A further seven vaccine targets have been identified, five of which have been used to immunise sheep; the antisera produced against these five new targets will be tested *in vitro* against pure cultures of methanogens to test their ability to inhibit growth and $CH_4$ production.

A consequence of inhibition of methane production in the rumen is likely to be the accumulation of $H_2$; it is vital that $H_2$ is removed or it will inhibit rumen function. It is thought that homoacetogens (a group of organisms that use $H_2$ and $CO_2$ to form acetate) will use this accumulated $H_2$, but this is an unproven assumption. The objective identifying alternative $H_2$ users is measuring homoacetogen activity using isotopically labelled $CO_2$ when methanogens are inhibited, and aims to isolate and study rumen homoacetogens, so that we can better understand their role in the rumen and encourage their establishment in the absence of methanogens. The work is also expanding the set of experimental inhibitors for each of the different processes to provide better evidence of their significance in normal and low-methane rumens.

In the animal variation objective, sheep screened in the allied PGgRc programme for high or low methane emitters are being genotyped to find genetic markers associated with these contrasting phenotypes. Such genetic markers in sheep will be most valuable as they will allow a rapid and cheap way of identifying and selecting for the low methane phenotype in animal breeding programmes.

Last year's observation that repeated one hour measurements of methane emissions at a specific time after feeding was sufficient to 'rank' animals in terms of their overall emissions has been further investigated and analysed, by estimation of the heritabilities, repeatabilities and genetic correlations of these short chamber methane measurements with standard 24 hour measurements.

The results indicate that under controlled conditions, brief measurements (of 15 minutes to 1 hour) can have significant value to estimate individual animal methane emissions either on a total emission ($gCH_4$/day) or intake ($gCH_4$/kg DMI) basis. However, four to five hourly measurements separated by several weeks are required to achieve the same breeding value accuracy that is currently generated by two 24 hour measurements. It was also found that the repeatability over longer periods between measurements is stable, even though it is not as high as for measurements between adjacent days. This suggests that $CH_4$ measurements of shorter duration will be good predictors of long term $CH_4$ emissions, and therefore worthy of further investigation for screening larger numbers of animals as this could considerably lower the cost of measurements.

**Nitrous Oxide Research Programme Report - 2011/12**

***Principal Investigators: Dr Cecile de Klein and Prof Hong Di***

A principal focus of the nitrous oxide mitigation programme is the optimisation and improved performance of nitrification inhibitors. In the second year of the programme, the work has shown that animal treading of wet soils significantly increased $N_2O$ emissions and more than doubled the $N_2O$ emission factor. Nonetheless, DCD was shown to be highly effective in reducing $N_2O$ emissions and its relative efficacy was not affected by trampling. Lysimeter studies of $N_2O$ emissions in winter runoff grazing systems showed that DCD was also highly effective in reducing $N_2O$ emissions and nitrate ($NO_3^-$) leaching (indirect source of $N_2O$) in these winter runoff grazing systems. Collectively, these results confirm the potential for the use of DCD as a mitigation tool for $N_2O$ emissions in winter runoff systems which have high potential for $N_2O$ emissions due to wet conditions and high animal density and large urine inputs.

Another strand of the work has looked at whether diluting the concentration of nitrogen in the urine (e.g. by feeding a diuretic) could reduce emissions. Field trials have all been completed and showed that diluting the urine N concentrations below a typical concentration did not reduce the $N_2O$ emission factor. Therefore, we conclude that $N_2O$ mitigation strategies that reduce the urine N concentration but don't reduce the total amount of urine N excreted would have limited impact on reducing direct $N_2O$ emissions. This is an important piece of evidence to underpin the current national inventory approach.

Water is another area of focus, with one project aiming to better quantify how soil water content and soil physical conditions influence nitrous oxide emissions. The work includes a combination of a specifically designed laboratory experiment and the analysis of existing data for sedimentary and volcanic soils. A key finding from these experiments was that the soil water content threshold before nitrous oxide emissions rapidly increased was the same for each soil, providing crucial information for refinement of models and development of mitigation management decisions.

At a more strategic level, the programme focuses on exploring the genetic mechanisms underlying grass growth. This knowledge will be used to ascertain whether nitrogen supply does really limit growth, as a common strategy to increase pasture production is to increase N supply. However, the high N content in grasses cannot be utilised by animals and is thus excreted, resulting in increased $N_2O$ emissions. The research to-date shows that at low N supply, addition of a group of plant hormones called gibberellins significantly increased above and below-ground biomass production. This demonstrated that ryegrass growth can be stimulated without the need for additional nutrient and in particular N resources, and thus that breeding highly productive grasses with a nitrogen content closer to those required by grazing animals could be a possibility

Another novel component of the programme focused on nitrous oxide emissions from plants and showed that leaves of common New Zealand grass species emit $N_2O$. There was a variation in emission between species, and negative fluxes occurred in the dark. The results show that $N_2O$ can be absorbed by plants at night. We also found emissions from cut leaf surfaces due to a strong conduit effect, indicating that transpiration is important in leaf $N_2O$ emissions and emissions may be affected by defoliation management.

Finally, one programme addresses the question whether it is possible to manipulate the denitrification process to achieve a similar result that can be obtained by manipulating the nitrification process. The work to-date has shown that New Zealand dairy-grazed pasture soils have wide variations in denitrification enzyme activity (DEA), denitrification rate (DR), microbial biomass carbon (MBC) and $N_2O/N_2$ ratio. The key soil factors contributing to the differences in the amount of $N_2O$ produced, DR and DEA as well as $N_2O/N_2$ ratio were the nitrate, Olsen P, soil

moisture, soil microbial biomass and soil C status. On-going research will focus on understanding how soil, climatic and or microbial parameters affect the microbial denitrifier communities and the denitrifying enzymes that could accelerate the reduction of $N_2O$ into $N_2$.

**Soil Carbon Research Programme Report - 2011/12**

***Principal Investigators: Prof Frank Kelliher***
***and Dr David Whitehead***

Increasing the quantity of carbon stored in agricultural soils has the potential to offset emissions of greenhouse gases to the atmosphere. However, realising this potential is technically challenging when soil carbon stocks are already high as they are in New Zealand, potential changes in soil carbon are small and spatial variability is high. The NZAGRC's programme has three distinct components (1) assessing the potential to store carbon across the range of physical and climatic conditions found in New Zealand, (2) devising management practices that can increase the long term soil carbon store and (3) development of tools for verifying that soil carbon stocks have in fact been changed.

Determining the potential to store additional carbon (C) in New Zealand's agricultural soils depends on understanding the current stocks of soil C under existing land uses and the upper limits of soil C storage under existing climatic conditions. The difference between the upper limits and the current stocks represent the potential for additional C storage. Data mining and modelling approaches have been used to quantify both of these estimates of soil C. Our analyses indicate that current stocks of soil C are strongly affected by soil classification, climate and land use. Whereas overseas research suggests that the clay and silt content of soils is an important determinant of soil C storage, our results for New Zealand soils indicate that other more specific soil properties (e.g. mineral surface area) are involved in the stabilisation of soil C that determines the upper limits of soil C storage.

To estimate the current stocks of soil C across New Zealand under existing land uses, a regression model has been developed to predict logarithm of the C storage to a depth of 0.3 m from a set of national environmental covariate layers. The model's uncertainty, quantified by the residual standard error, is 26 tonnes C/ha, ~16% of the value for most soils. For context, uncertainty of the regression model used for NZ's land use and carbon monitoring system (LUCAS) is 41 tonnes C/ha. The NZAGRC model has been used to produce a soil map across NZ at 1 km spatial resolution.

Experimental approaches to assess the potential of three practical farm management practices that will lead to increasing carbon storage in soil are established. These comprise re-grassing to convert conventional ryegrass pasture into a high diversity sward (carbon input), introduction of exotic earthworms into pastures (carbon incorporation with depth) and addition of biochar to soil (retention of carbon). We are using different methodologies at each experimental site to address the challenge of our ability to measure small changes in carbon storage. We have made considerable progress in developing existing models to simulate the effects of the experimental treatments. Our expectation is that the data will inform the models and the models will allow forecasting of the long-term impacts of the experimental treatments at larger spatial scales.

We have demonstrated the precision of a paddock-scale, micrometeorological technique incorporating measurements from chambers and farm records to determine small changes in soil carbon associated with a pasture cultivation event and the establishment of a new sward. Despite large losses of soil carbon associated with cultivation, increased carbon uptake from the re-established sward exceeds the loss. We conclude that cultivation and re-establishment of pasture is an effective management option to increase long-term carbon storage.

We have estimated that anecic earthworms are absent from about 7 million hectares and their introduction as a mitigation option for increasing soil carbon storage is feasible. Using stable isotopes of carbon in mesocosm experiments, we have demonstrated that introducing earth worms

results in the transfer to carbon from the soil surface to depth in the soil profile. However, our preliminary data from mesocosm and field plot studies suggest that further research needs to be done before we can recommend the large-scale introduction of earth worms as a tool to increase soil carbon storage because results for two contrasting soil types are contradictory.

By incorporating biochar into soil, our preliminary findings demonstrate that most of the biochar particles remained in the coarse and fine free particulate soil organic matter. Biochar produced from a biosolids and a mixture of biosolids and Eucalyptus wood residues stimulated root elongation on poor sandy soil thus contributing potentially to the increase of the soil carbon sink.

We are using two complimentary modelling approaches, both employing process-based understanding of the mechanisms regulated changes in soil carbon storage. The Hurley Pasture Model (HPM) accounts for changes in soil carbon in relation to farm management with a strong focus on grazing, inputs of carbon and nitrogen from grazing animals and addition of nitrogen fertiliser. We are using this model to explore long-term effects of farm management practices on soil carbon storage and retention. Initial modelling results demonstrate that the off-take of N in intensive, notably dairy, systems, leads to a reduction in C and N sequestered in soil. The focus of the CenW model is the partitioning the fractions of soil carbon and carbon to nitrogen ratios that drive pasture growth. We have demonstrated the success and validated the CenW model for simulating seasonal and annual changes in soil carbon in relation to the effects of cultivation and re-establishment of pasture. We intend to develop and test the model further to simulate the effects of establishing deep-rooting pasture species, introducing exotic earthworms and addition of biochar on changes in soil carbon. Together, these two models provide important theoretical support and tools to understand results from experiments, and allow the up-scaling of results from individual field plots to larger regions.

The final focus area is to develop improved methods to verify temporal changes in soil carbon storage and accounting rules suitable for a national inventory of agricultural soils. Initial focus has been on data of long-term changes in irrigated grassland at the Winchmore site. A method to integrate changes in the vertical profile of carbon storage from soil samples has been developed. Initial findings are that 60 years of seasonal irrigation using border dykes resulted in a 32% reduction in soil carbon storage to a depth of 1 m. Most of the effect of irrigation on soil carbon storage happened below a sampling depth of 0.25 m.

**Integrated Systems Research Programme Report - 2011/12**

***Principal Investigators: Mr Dave Clark and Dr Robyn Dynes***

This work area is the NZAGRC contribution to a SLMACC funded programme looking at developing profitable, practical low emitting farming systems. The NZAGRC component of the work is to develop better predictive mechanistic models whose insights can be incorporated into simpler farm systems models. This work comprises two areas: modelling enteric methane emissions and modelling nitrous oxide emissions from soils.

Existing models that aim to predict methane yield from chemical composition have been shown to have poor predictive ability for diets based on temperate fresh forages. New equations for predicting molar proportions of volatile fatty acids (VFA) in the rumen of sheep fed fresh forages were derived by meta-analysis of previous NZ experiments. The prediction of VFA is important not only because they are key intermediates in the process leading to methane production, but also because they supply nutrients for the animal and therefore influence animal productivity. Thus, these improved equations represent an important advance to improve both the methane emissions and productivity in ruminants.

The importance of rumen sampling time relative to feeding time, highlighted that the diurnal kinetics of rumen fermentation must be considered when modelling rumen fermentation. A literature review has identified the importance of passage rate of feed and methanogens from the rumen, and an improved characterisation of this factor for fresh forage diets will be a key component of future models for a variety of ruminant species and feeding strategies. A final highlight in this area has been the development of a mechanistic model of the interactions between $H_2$ concentrations and methanogen growth. Concentrations of $H_2$ in the rumen are critical for methanogen growth, methane and VFA production. The future assessment of mitigation strategies such as vaccines and chemical inhibitors will be greatly dependent on having a defensible mechanistic model with an explicit methanogen population. Furthermore, the model of $H_2$ dynamics sets the basis for representing thermodynamic feedback that modulates VFA production in the rumen. The future assessment of farm changes in ruminant species, feeding level and feed type is contingent on accurate rumen sub-models within a whole farm framework.

This year further data from NZ monitoring and research sites for $N_2O$ emissions have been included in the compiled $N_2O$ database. The $N_2O$ emissions from a dairy farm using a whole farm model with the relevant soil and climate data from the database have been estimated based on statistical analysis of measured $N_2O$ emissions. These analyses suggest that in some circumstances better management and the adoption of specific mitigation options, such as the use of nitrification inhibitors during critical periods, stand-off pads, and timing of fertiliser and effluent application could reduce farm-scale $N_2O$ emissions by up to 30%.

Two conceptually different models for estimating $N_2O$ emissions, APSIM and DNDC have been compared for their ability to respond to different environmental conditions. These two models have also been used to compare emissions from urine patches in various experiments from Waikato and Southland regions. The datasets from the Waikato region were also compared with other models that predict nitrification, denitrification and $N_2O$ emissions, namely, DayCent, Nemis and WNMM by linking them to the SoilN module of APSIM. The fact that none of these models proved suitable in all circumstances highlighted the need to do further sensitivity analysis using all available data.

Urine patches will remain the major source of $N_2O$ emissions whenever pasture is grazed. Accurate monitoring of emissions is prohibitively expensive, so future assessment of on–farm nitrogen management strategies will require defensible predictive models that take account of soil and climate variation at the farm scale.

## ENGAGEMENT WITH POLICYMAKERS & EXTERNAL PARTIES

**Policymakers and the global science community**
Policymakers are a key end-user of the science and scientific advice generated by the NZAGRC. In addition, scientific research conducted by the NZAGRC relies on and interacts with activities carried out by research groups all around the world. Consistent with these key links, the NZAGRC greatly increased both the scope and level of its activities related to the Global Research Alliance in 2011/12, and the LEARN network and fellowship scheme were fully integrated into the wider activities under the Global Research Alliance (see below).

As previously described, NZAGRC staff are heavily involved as lead authors for various parts of the IPCC 5$^{th}$ Assessment Report and in supporting the KBBE initiative.

Harry Clark leads the New Zealand input into the EU framework 7 programme Animal Change, and has recently been invited onto the Scientific Advisory Board of the EU Joint Programming Initiative on Agriculture, Food Security and Climate Change. He also maintains close links with other research institutions such as TEAGASC in Ireland to explore better alignment of research programmes and sharing of expertise. With respect to coordination with Australian Researchers, Harry is a member of the Expert Assessment Panel for the Australian Filling the Research Gaps GHG Programme.

Andy Reisinger participated, at the invitation of MPI, in an UNFCCC workshop on alternative metrics for comparing emissions of non-$CO_2$ greenhouse gases with carbon dioxide, which is a key issue for agriculture. Andy also is the New Zealand representative for the Scientific Programming Group of the Asia-Pacific Network on Global Change Research (APN).

***Global Research Alliance on Agricultural Greenhouse Gases***
The Alliance aims to better coordinate global research to reduce the emissions intensity of agriculture and to promote the importance of a collaborative research approach in the global policy community. NZAGRC support for the goals and objectives of the Alliance and its Livestock Research Group is covered by a separate contract with MPI. However, a high-level summary is included in this Annual Report since the international dimension provides important context and, in many cases, an important extension of New Zealand's domestic research effort and collaborations.

The past year saw a significant expansion of activities in the various Research and Cross-Cutting Groups of the Alliance, as well as the consolidation of the governance of the Alliance through its Council. The most important achievements of the Alliance as a whole during 2011/12 include:

- Formal meetings of its Research and Cross-Cutting Groups to expand their range of activities including a stocktake of current research, additional research projects, formation of dedicated research networks, capacity building activities, and engagement with other organisations that align with the objectives of the Alliance
- The second formal meeting of the Alliance Council, 4-7 June 2012 in Saskatoon, Canada, which agreed the Alliance's communications policy and further discussed expectations and established a regular reporting schedule from the Research Groups to the Council
- Expansion of the Alliance membership to 33 member countries.

The NZAGRC has contributed significantly to the development and coordination of activities within the Alliance through multiple roles:

- New Zealand co-chairs, together with the Netherlands, the Livestock Research Group (LRG) of the Alliance, with the NZAGRC Director holding the formal position of co-chair of the group, as well as co-leading the ruminant sub-group with Uruguay. The LRG held its

third formal meeting 5-6 November 2011 in Amsterdam, the Netherlands. The group expanded its work plan to encompass actions related to:

- Stocktake of existing expertise and activities
- Capacity and capability building through workshops, projects, and fellowships/awards
- Information and technology transfer through technical manuals and best practice guides
- Establishment of and support for dedicated research networks
- Collaborative research projects to test and improve measurement techniques and identify novel mitigation options
- Identification of ways to align research funding, and to enhance collaboration with other organisations and institutions that share the goals of the Livestock Research Group

NZAGRC (Director, Deputy Director (International) and Operations Manager (International)) together with their Dutch colleagues monitor and oversee implementation of the group's work plan.

- The NZAGRC acts as primary point of contact for New Zealand's science input into the development and operation of research projects undertaken or facilitated by the LRG and activities of the Alliance overall, and to provide advice to MPI on collaborative research and funding opportunities. Highlights from the past year include:
  - Scoping and funding of five additional priority projects to support the goals of the LRG. These include completion of a best practice guide for chamber $N_2O$ measurements; formation and administrative support for two research networks on animal selection, genetics and genomics, and on rumen microbial genomics; targeted research to advance measurement options and trait identification to assist with targeted breeding of low-emitting animals; and establishing a taxonomy and undertaken a comprehensive genomic analysis of rumen microbes that can assist the development of dedicated vaccines or inhibitors to reduce methane production in ruminants. NZAGRC administered contracts to fund those activities on behalf of MPI, with scientific leadership in each of these projects provided by NZAGRC partners within international collaborations.
  - The first round of the New Zealand International Partnership Fund for Livestock Emissions Research was launched in September 2011, with 4 successful projects announced in June 2012. NZAGRC provided advice on the design of the fund and its criteria, and the NZAGRC Director Harry Clark acted as scientific expert adviser to the fund's Technical Advisory Panel. A second round of the fund will open early in 2012/13, taking into account lessons from the first round of the fund and based on additional advice from NZAGRC to maximise international collaboration while ensuring direct benefits to New Zealand.
  - NZAGRC continues to act as a scientific partner in the FONTAGRO project, which aims to accelerate and improve development of greenhouse gas inventories and identification of mitigation options for grazing livestock in several Latin American countries including Uruguay, Chile, Argentina, Colombia and the Dominican Republic). Dr David Pacheco (AgResearch) attended a FONTAGRO project meeting as New Zealand expert in March 2012.
  - The New Zealand and Thai governments jointly hosted a south-east Asia capacity building workshop in Bangkok, 13-15 March 2012. NZAGRC provided scientific planning, chaired the workshop and manages follow-up. The workshop brought together experts from Thailand, Indonesia, Vietnam and Malaysia, with the goal of identifying opportunities for collaborative research projects that would help build capacity and increasing consistency in approaches to estimation and mitigation of greenhouse gas emissions from livestock in the region. Following the development

of initial concept notes, a pilot project is now being planned with financial support from the New Zealand government out of its Alliance budget.

- NZAGRC manages appropriate New Zealand science representation in other Alliance Research and Cross-Cutting Groups and maintains coordination between groups. Dr Mike Beare (Plant and Food Research) attended the second meeting of the Croplands Group in San Antonio, Texas, 20 October 2011, as New Zealand's representative, and also a workshop of the Soil C/N Cycling Cross-Cutting Group 13-14 July 2011 in Leuven, Belgium. Dr Frank Kelliher, in his role as New Zealand representative on that group, attended the joint Croplands and Soil C/N Group meetings during 4-7 July 2012 in Bari, Italy. Harry Clark attended on behalf of New Zealand the first meeting of the Inventory and Measurement Cross-Cutting Group, 8-10 November 2011, in Ottawa, Canada. The comprehensive and coordinated input from New Zealand science experts ensures that projects and activities considered and undertaken by those groups are well aligned and address, where appropriate, New Zealand's science needs and interests. Key activities of potential relevance to New Zealand undertaken by those groups include:
    - A stocktake of data and models for changes in soil C and N content under a variety of land-uses, including grazing lands
    - The possible development of a best practice guide for measuring soil C content across different land-uses
    - Improving the sharing of emissions data and factors
    - Targeted measures to build capacity for estimation of emissions
- NZAGRC provides regular and accessible information on the LRG activities through maintaining the group's web pages and issuing a quarterly newsletter.

***LEARN***

LEARN is a New Zealand initiative to develop an international network of scientists, industry leaders and government officials interested in working together in livestock emissions abatement research. LEARN also offers a fellowship programme to provide training opportunities for individuals from developing countries to work alongside some of the best New Zealand scientists. Both the fellowship scheme and the network are administered by NZAGRC on behalf of MPI under a separate contract to support the goals and objectives of the Global Research Alliance.

The year 2011/12 saw a substantial revision of the fellowship scheme to ensure it addresses training needs as well as capacities of providers within New Zealand. The revised LEARN/GRASS scheme provides four categories of awards, for technicians, doctoral students, post-docs, and the exchange of senior scientists. While the first three are only for individuals from developing countries to come to New Zealand, the Global Research Alliance Senior Scientist (GRASS) award provides for extended visits and collaborations between senior scientists between New Zealand and any Alliance member country. LEARN and GRASS awards totalling $448,000 were given out during 2011/12, including two work trainee awards, three postdoctoral fellowships, one PhD scholarship and seven senior scientist awards.

The network and website of LEARN were substantially revised, following endorsement by the LRG that it should act as the prime vehicle to facilitate and stimulate researcher-to-researcher contacts within the Group. The revision resulted in an update and refreshment of the LEARN membership, with currently 170 members from 26 countries.

***Advice to New Zealand policymakers***

The NZAGRC Director Harry Clark is a member of the Agricultural Emissions Trading Scheme Advisory Committee and MPI's Research, Technology and Technical Transfer Working Group. In the year to 30 June 2011 he attended three Advisory Committee meetings, a meeting of the full Emissions Trading Scheme Review Panel and a science workshop reviewing the agriculture ETS emission factor methodologies. Harry also chairs MethNet, the body that assists MAF in identifying inventory research priorities.

Andy Reisinger is a member of the Agricultural Greenhouse Gas Inventory Advisory Panel, which provides scientific advice and quality control to MPI regarding any revisions of New Zealand's agricultural greenhouse gas inventory. Andy also acted on the request of MBIE as chair of the assessment panel to evaluate funding proposals under the Sustainable Land Management and Adaptation to Climate Change (SLMACC) 2012 funding round operated by MPI.

NZAGRC funding also supported a MPI requested review of the currently available methods for mitigating $CH_4$ and $N_2O$ and their current and future mitigation potential.

## External Parties

### *NZAGRC 2nd Annual Conference*

- Attended by approximately one hundred and fifty scientists, policy makers and industry bodies.
- The annual conference is an essential element of the NZAGRC's visibility and supports its vision "to be an internationally renowned centre for research and development into agricultural greenhouse gas mitigation solutions".
- Excellent opportunity to reflect on the international context in which New Zealand's agricultural GHG emissions research programme resides.
- Day included a wide range of presentations and posters covering research underway and how this may be applied on-farm in the future.
- Introduction by Dr Andy Reisinger (NZAGRC Deputy Director (International)), followed by four science sessions covering methane, nitrous oxide, soil carbon and integrated systems research. Four speakers, including one leading international scientist, presented in each session. This provided an opportunity for delegates to hear the latest developments in areas outside of their regular sphere of interest. Closing address provided by John Hutchings (General Manager (Sustainability Policy and Carbon) at Fonterra).

### *Meetings, Media, Presentations and Publications*

During 2011/12 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 2011/12 |
|---|---|
| Meetings and Presentations (New Zealand) | 71 |
| Meetings and Presentations (International) | 11 |
| International Visitors and Groups | 9 |
| Global Research Alliance related interactions | 15 |
| Media interactions | 8 |
| Conference presentations | 53 |
| Journal articles in press | 3 |
| Journal articles published | 13 |
| Other interactions/publications | 10 |

## FINANCIAL SUMMARY

| | $ |
|---|---|
| ***EXPENDITURE*** | |
| **Core research spending** | |
| Methane | 1,023,269 |
| Nitrous Oxide | 1,326,114 |
| Soil Carbon | 1,045,000 |
| Integrated Systems | 480,000 |
| **Research Total** | **3,874,383** |
| **Other research costs** | |
| Additional Fellowships and Studentships | 125,909 |
| NZAGRC Conference | 86,800 |
| Policy support | 105,000 |
| Targeted Workshop and Conference Support | 47,113 |
| Māori Stocktake Exercise | 35,000 |
| **Total** | **399,822** |
| **Administration** | **502,284** |
| ***Total Expenditure (actual)*** | ***4,776,489*** |
| ***REVENUE**** | ***4,876,234*** |
| ***Balance unspent carried over*** | ***99,745*** ** |

*Includes $26,234 carried over from 2010/11

**NZAGRC contract provides for a formal science review after two years. In 2011/12 the science programmes had been running for < two years and the formal review was delayed until 2013. This unspent money will fund the delayed science review which will take place in February 2013.

## DIRECTORY

### NZAGRC STAFF

**Dr Harry Clark**
NZAGRC Director

**Dr Heather Went**
NZAGRC Operations Manager

**Kate Parlane**
NZAGRC Administrator

**Dr Andy Reisinger**
Deputy Director (International)

**Dr Victoria Bradley**
Operations Manager (International)

### NZAGRC STEERING GROUP

**Professor Warren McNabb**
Chair
Research Director
AgResearch

**Dr David Johns**
Investment Policy Manager
DairyNZ

**Dr Richard Gordon**
General Manager, Environment & Society
*(until 31/12/11)*
**Dr Peter Millard**
General Manager, Science & Industry
*(from 01/01/12)*
Landcare Research

**Dr Peter John**
Director of Research & Commercialisation
Lincoln University

**Professor Mike Hedley**
Professor Soil and Earth Sciences
Massey University

**Dr Murray Poulter**
Chief Scientist, Atmosphere, Natural Hazards & Energy
NIWA

**Warrick Nelson**
Portfolio Manager - Sustainable Production
Plant & Food Research

**Mark Aspin**
Consortium Manager
PGgRc

**Dr Trevor Stuthridge**
Group Manager Sustainable Design
Scion

### STEERING GROUP OBSERVERS

**James Palmer**
Director Strategy, Systems and Science Policy
Ministry for Primary Industries

**Dr Gerald Rys**
Senior Scientist
Ministry for Primary Industries

**Dr Marc Lubbers**
Senior Sector Advisor, Biological Industries
Ministry of Business, Innovation & Employment

**Dr Andrea Pickering**
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## APPENDIX 1 – COMPOSITION OF NZAGRC SG, SAG, ISAG and MAG

**Compositions of the SG, SAG, ISAG and MAG**

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

| Steering Group (SG) | | Meetings attended | Proxy attended |
|---|---|---|---|
| Prof. Warren McNabb | AgResearch (Chair) | 5 | 0 |
| Dr David Johns | DairyNZ | 4 | 1 |
| Dr Richard Gordon | Landcare Research | 2 | 0 |
| Dr Peter Millard | Landcare Research | 3 | 0 |
| Dr Peter John | Lincoln University (Deputy Chair) | 5 | 0 |
| Prof. Mike Hedley | Massey University | 4 | 1 |
| Dr Murray Poulter | NIWA | 5 | 0 |
| Mr Warrick Nelson | Plant & Food Research | 5 | 0 |
| Mr Mark Aspin | PGgRc | 4 | 0 |
| Dr Trevor Stuthridge | Scion | 3 | 0 |
| Dr Gerald Rys | MAF/MPI (Observer**) | 5 | 0 |
| Dr Mike Jebson | MAF/MPI (Observer**) | 1 | 0 |
| Dr Max Kennedy | MSI/MBIE (Observer**) | 1 | 0 |
| Dr Marc Lubbers | MSI/MBIE (Observer**) | 2 | 0 |
| Dr Andrea Pickering | MAF/MPI (Observer***) | 1 | 0 |
| *Number of meetings held* | | *5** | |

*Four Quarterly meetings held in Wellington (18 August 2011) and Palmerston North (17 November 2011, 2 February 2012 and 16th May 2012). Plus one teleconference (8 March 2012).

**In addition to representatives of MPI, MBIE and MFAT sitting on the Stakeholder Advisory Group, MPI and MBIE hold Observer (non-voting) positions on the Steering Group.

***Dr Andrea Pickering was invited to attend SG meetings from 16 May onwards following recommendation from MPI that an Alliance representative attend SG meetings to ensure coordination.

| Stakeholder Advisory Group (SAG) | | Meetings attended | Proxy attended |
|---|---|---|---|
| Mr Richard Wakelin | B+LNZ | 1 | 1 |
| Dr Rick Pridmore | DairyNZ | 2 | 0 |
| Mr Simon Tucker | DCANZ | 1 | 0 |
| Dr Nick Pyke | FAR | 2 | 0 |
| Dr Philip Mladenov | Fert Research | 2 | 0 |
| To be advised | HortNZ | 0 | 0 |
| Mr Paul Stocks | MAF | 0 | 2 |
| Mr Jamie Tuuta | Maori | 1 | 0 |
| Ms Lorraine Stephenson | Maori | 2 | 0 |
| Ms Jo Tyndall | MFAT | 2 | 0 |
| Mr Dan Coup | MIA | 1 | 0 |
| Dr Marc Lubbers | MSI/MBIE | 2 | 0 |
| Mr Sam McIvor | NZ Pork | 1 | 1 |
| Mr Mark Leslie | PGgRc | 1 | 1 |
| *Number of meetings held* | | *2** | |

*Annual meeting held in Wellington (11 October 2011) and SAG session held with key scientists as part of Annual Workshops in Palmerston North (1 February 2012).

| International Science Advisory Group (SAG) | | Meetings attended | Proxy attended |
|---|---|---|---|
| Dr Richard Eckard | Melbourne University | 1 | 0 |
| Prof Keith Goulding | Rothamsted | 1 | 0 |
| Dr Peter Kuikman | Alterra | 1 | 0 |
| Dr Tim McAllister | AgCanada | 1 | 0 |
| Dr Mark Morrison | CSIRO | 1 | 0 |
| Prof Jamie Newbold | Aberystwyth University | 1 | 0 |
| Dr Frank O'Mara | Teagasc | 1 | 0 |
| Prof Johan Six | California University | 0 | 0 |
| Prof Keith Smith | Edinburgh University | 1 | 0 |
| Prof Pete Smith | Aberdeen University | 1 | 0 |
| Dr Jean-Francois Soussana | INRA | 0 | 0 |
| *Number of meetings held* | | *1** | |

*Annual meeting held in parallel with Annual Workshops in Palmerston North (1-2 February 2012).

The members of the NZAGRC's ISAG are partially shared with the PGgRc in order to aid alignment of scientific advice and direction between the NZAGRC and the PGgRc.

| Māori Advisory Group (MAG) | | Meetings attended | Proxy attended |
|---|---|---|---|
| Lorraine Stephenson | NZAGRC SAG | 2 | 0 |
| Jamie Tuuta | NZAGRC SAG | 1 | 0 |
| Dr Tanira Kingi | AgResearch | 1 | 0 |
| Geoff Taylor | DairyNZ | 1 | 0 |
| Marino Tahi | Landcare Research | 2 | 0 |
| Prof. Hirini Matunga | Lincoln University | 0 | 0 |
| Dr Nick Roskruge | Massey University | 1 | 0 |
| Dr Charlotte Severne | NIWA | 2 | 0 |
| Alby Marsh | Plant & Food Research | 0 | 0 |
| Peter Bennett | Scion | 2 | 0 |
| Erica Gregory | MPI | 2 | 0 |
| *Number of meetings held* | | *2** | |

*Introductory teleconference (5 April 2012) and first face to face meeting held in Palmerston North (2 May 2012).

The second NZAGRC Annual Conference and Workshops, held in January/February 2012, provided an opportunity for the SG, SAG and ISAG to meet in person, to interact closely with NZAGRC researchers and staff, and to give feedback on the research programmes underway. (The MAG had not been formally established at this time). The ISAG were asked to informally review each science work stream during the workshops and high level feedback was provided to the NZAGRC Director, Steering Group and Science Leadership Team. Following the feedback, additional one day workshops were held for the Nitrous Oxide programme (18 April 2012) and Soil Carbon programme (19 April 2012) in Palmerston North.

## APPENDIX 2 – ANNUAL OBJECTIVE SUMMARY SCIENCE REPORT

**DISCLAIMER: The following reports have not been peer reviewed and report interim results only. Therefore, they may be subject to change.**

## Objective Level Summary - 2011/12

Key:

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

Those programmes marked with a dagger (‡) are co-funded with the PGgRc and/or PGgRc/MAF and those marked with a diamond (◊) are co-funded with SLMACC (MAF).

| Area | # | Objective Title | Objective Leader | Objective Leader Organisation | 2011/12 $NZ (GST excl) | Status End 2011/12 |
|---|---|---|---|---|---|---|
| **Methane** | 1.1 | Feeding Microalgae | David Pacheco | AgResearch | 0 | Completed 10/11 |
| | 1.2‡ | Low methane producing animals | John McEwan | AgResearch | 250,000 | On track |
| | 1.3‡ | Genomic identification of universal targets for methanogen inhibition | Sinead Leahy | AgResearch | 243,269 | On track |
| | 1.4‡ | Enhanced discovery of methanogen-specific inhibitors | Ron Ronimus | AgResearch | 235,000 | On track |
| | 1.5‡ | Expression of vaccine target proteins | Bryce Buddle | AgResearch | 150,000 | On track |
| | 1.6‡ | Identifying alternative hydrogen utilisers | Gemma Henderson | AgResearch | 145,000 | On track |
| | 1.7 | Methane capture and utilisation from dairy effluent | Rupert Craggs | NIWA | 0 | Completed 10/11 |
| **Nitrous Oxide** | 2.1 | Manipulating N inputs | Cecile de Klein | AgResearch | 470,000 | V. minor delays re paper submission/ publication |
| | 2.2 | Manipulating nitrification processes | HJ Di | Lincoln University | 450,000 | On track |
| | 2.3 | Manipulating denitrification processes | Surinder Saggar | Landcare Research | 250,000 | V. minor delays re paper submission |
| | 2.4 | $N_2O$ emissions and soil water status | Steve Thomas | Plant & Food | 125,000 | On track |
| | 2.5 | Influence of anecic earthworms on nitrous oxide emissions | Alec Mackay | AgResearch | 31,114 | Exp work complete, awaiting analysis & final report |
| **Soil Carbon** | 3.1 | Limits of soil carbon storage in New Zealand soils | Mike Beare | Plant & Food | 150,000 | V. minor delays re paper submission |
| | 3.2 | Quantifying the carbon currently stored in New Zealand soils | Allan Hewitt | Landcare Research | 110,000* | On track with additional milestone added |
| | 3.3 | Process-based modelling of drivers of soil carbon change | Tony Parsons | AgResearch/ Massey University | 200,000 | Delays re paper submission |
| | 3.4 | Manipulation of carbon inputs, incorporation and retention to protect and enhance soil carbon | David Whitehead | Landcare Research | 445,000** | On track |
| | 3.5 | Improved soil carbon measurements | Frank Kelliher | AgResearch | 140,000 | On track |
| **Integrated Systems** | 4.1◊ | Mechanistic modelling of enteric $CH_4$ production | David Pacheco | AgResearch | 280,000 | On track with agreed revisions |
| | 4.2◊ | Improved $N_2O$ Component Modelling | Iris Vogeler | AgResearch | 200,000 | On track |

* Additional $30k approved in Q4 for extra milestone. **Extra $20k approved in Q4 to cover re-grassing costs

### *1.1 - Feeding Microalgae – Completed 10/11*

***Objective Leader – Dr David Pacheco (AgResearch)***

Practical strategies to reduce agricultural greenhouse gas emissions are urgently sought, particularly for ruminant enteric methane, which forms 31% of New Zealand's total greenhouse gas inventory (Pinares-Patino *et al*, 2009). The most successful strategies will be those that lead to a profitable increase in animal productivity, as well as reducing net greenhouse gas emissions, not just those of enteric methane alone.

Dietary fat supplements, especially those containing unsaturated fatty acids, can reduce enteric methane emissions, but oil production for animal feed is usually associated with increased net greenhouse gas emissions (Beauchemin *et al*, 2008, 2009; Grainger *et al*, 2010). Eicosahexanoic acid (EPA or C20:5) and Docosahexanoic acid (DHA or C22:6) are the major bioactive unsaturated fatty acids found in fish oil and marine algae (Givens *et al*, 2000). *In-vitro* studies suggest that EPA and DHA may reduce methane emissions by up to 80% (Fievez *et al*, 2003) and marine algae by greater than 92% (Bozic *et al*, 2009).

A commercial DHA microalgae supplement has been shown to reduce dry matter intake and increase milk yield of dairy cows (Boeckaert *et al*, 2008). Seaweeds and algae are more digestible than many terrestrial plants, due to less cellulose and more starch. However, *in-vivo* trials feeding algae or algae products where methane emissions have been measured have not yet appeared in the peer-reviewed literature, although it is understood these are underway in Australia (Chris Grainger, pers comm., Tony Parker, pers comm.).

Microalgae offer a means of supplementing animals with a source of unsaturated fatty acids with believed potent methane mitigation potential that will reduce net greenhouse gas emissions. Microalgae of freshwater and marine origin can be cultivated to treat wastewaters of human, agricultural and industrial origin e.g. from sewage and effluents from dairy farms, piggeries, aquaculture facilities and fossil fuel fired power stations.

New Zealand research by NIWA has developed wastewater treatment high rate algal ponds and there are several demonstration facilities that could provide sufficient biomass for harvest and potential use as a methane-mitigating animal feed supplement. Meanwhile, in Australia, researchers at James Cook University (T. Parker and R. de Nys) have been attempting to feed marine macroalgae cultivated in the University algal farm to cattle to reduce methane emissions. However, they have recently moved to producing freshwater microalgae to avoid suspected iodine toxicity in cattle initially fed algae of marine origin. These researchers are also to test a microalgal meal, a bi-product from microalgal oil production from a bio-sequestration 'algal synthesiser' farm associated with a coal-fired power station, for methane mitigation potential in cattle (T. St Clair and T. Parker, pers comm.).

This project capitalises on these very recent developments to keep New Zealand at the forefront of enteric methane mitigation research. Microalgal supplements of NZ and Australian origin will be evaluated for methane mitigation potential in sheep using the 'gold-standard' calorimetry facility at AgResearch. If successful, we may have a nutrition supplement capable of both reducing methane emissions and enhancing animal production, at a reduction in net greenhouse gas emissions.

### *1.1 - Progress in 2009/2010*

An international review of the literature of the potential of micro- and macro-algae or algae bi-products such as oil or meal as feed supplements for reducing ruminant enteric methane emissions has been initiated. This has included sourcing information on algae of fresh water and marine origin. The review will include the chemical composition of algal biomass for enteric methane emission reduction and the risks to animal health from feeding wastewater-grown algae.

Initial samples of algal biomass grown in NIWA's domestic wastewater treatment ponds at Ruakura have been shown to contain 20-30% total lipid, with results for individual fatty acids pending. Further sampling over the next 4 months will also include the algae from NIWA designed ponds at DairyNZ, Hamilton and Christchurch wastewater treatment plant and will also be analysed for polyunsaturated fatty acid composition of the total lipid, in addition to all other aspects of chemical composition and toxicology (Massey University). From this, the three NZ sources of microalgae can be compared and any risks to animal health from feeding these sources of algae can be identified. In October, the best source of algae for feeding to sheep will be identified so that the required quantities can be collected before the animal trial commences in January 2011.

Initial discussions have been held with Australian researchers (James Cook University) on similar trials that they have already conducted supplementing the diet of cattle with macroalgae harvested from a coastal lagoon.

### *1.1 - Progress in 2010/2011*

The objectives of this programme have been fully achieved after some modifications to the original milestones. Microalgae from two waste water ponds and two marine algae of NZ origin were grown, collected, and analysed for fatty acid and lipid composition. The two samples with the highest lipid concentrations were then tested in the laboratory for their ability to reduce $CH_4$ emissions. No reduction in emissions was recorded, probably because the level of lipids in these samples was too low to reproduce the results from other studies demonstrating that feeds with a high lipid content can decrease $CH_4$ emissions. This work was therefore discontinued. A red marine algae sourced from Australia (*Asparagopsis taxiformis*) was incubated with ryegrass in an in-vitro batch test and this reduced $CH_4$ production. A proposed mechanism is that these marine algae naturally produce compounds (halogens) that are toxic to methanogens. The next stage of this work will be to repeat the work under the more realistic conditions of a continuous culture test and to further assess the practicalities of using marine algae like this as $CH_4$ mitigation agents. The next stage of this work will be carried out under the MITIGAS component of an AgResearch SLMACC funded programme.

***COMPLETED***

### *1.2 - Low methane producing animals*

***Jointly supported programme***

***Objective Leader – Dr John McEwan (AgResearch)***

**Key science question to be addressed**
Quantification of the role of ruminant host genomics on methane emission in sheep, coupled with development of technologies to breed sheep with reduced emissions.

An existing PGgRc project is measuring methane emissions, via calorimetry chambers, in 1080 hoggets that are the progeny of 100 sires to estimate the genetic variation in this trait and its relationship with other production related traits. The project will use animals generated and comprehensively measured for production traits from Ovita and Meat & Wool progeny test flocks that are representative of New Zealand maternal breeds. A pilot trial using 100 sheep from the same resource has already shown that the trait ($gCH_4$/kgDM) displays animal to animal variation that is moderately repeatable. Sire variation was also present indicating that the trait is heritable.

However, it is clear that if breeding for reduced emissions is shown to be scientifically feasible, several key ancillary technologies are required for widespread industry adoption. These are:

- An optimised methane emission measurement system that minimises cost
- Genomic prediction equations that allow estimation of accurate breeding values for methane emission in animals that have not been measured.
- An industry genetic evaluation system that includes costs of greenhouse gases and can transparently integrate these breeding values into selection indices.

This project addresses these three components in such a way that we would envision initial industry implementation for reduced emissions, if the project is successful, in 2013 with the first component implemented in 2011. The final 2 years of the project would be evaluation of commercial industry animals using the technology developed coupled with extension to ensure uptake.

The project work will provide a significant extension of current knowledge into the nature of the host genome's control over ruminant green house gas emission. Currently there is only sparse information available and this knowledge could lead to novel mechanisms to control emissions. However, the current work is primarily directed towards rapid industry adoption via traditional breeding methodologies and genomic selection.

***Optimised methane emission measurement system***. The current experimental measurement system involved the animal being recorded in a calorimetry chamber for 2 days with cumulative daily estimates of methane production and this process is subsequently repeated several weeks later. While this has been demonstrated to provide accurate measurements for research it is both expensive and not optimised for high throughput industry evaluation. The key constraints are the number of available chambers and the operating cost of each chamber. The proposed work is for a "rapid" but slightly less accurate methodology to be developed that preferably can be undertaken based on a single 4 hour measurement. This would allow an 8 fold increase in the number of animals that could be measured.

***Genomic prediction.*** Genomic selection is where high density SNP chip genotype results are "trained" on animals that have estimates of the breeding value for the desired trait and then subsequently used to estimate the breeding value in animals that have not been measured. In this regard they can accelerate genetic progress in two ways: first they allow increased genetic selection intensity where previously few animals were measured, and secondly they can shorten the generation interval if the trait is measured after the animals become reproductively mature. In the current case both are relevant because measurement costs would be much lower, with the incremental cost near zero when genotyping is already being undertaken for other traits. We

expect the number of animals "tested" could be amplified by at least 10 fold. Potentially the average generation interval in males could also be reduced from ~2.5 years to 1.5 years, reducing the overall generation interval when females are included from 3 to 2.5 years providing another potential 20% gain.

However, the accuracy of the genomic predictions depends on many variables including the number of animals evaluated, the heritability of the trait, the effective population size of the breed and the degree of relatedness of the evaluated animals with the animals in the training set. While this can be quantified, in the current context usable accuracies will require at least 1000 measured animals and preferably more than 4000. The latter are only possible if a "rapid" protocol is developed and preferably results from equivalent overseas work are also combined.

In the current context we propose that the available animals already measured and their sires are genotyped (n = 450) with the existing 50K SNP chip and also additional animals in subsequent years. In years 4 and 5 commercial industry animals would be evaluated to further increase animal numbers and prediction accuracy while working with key industry breeders.

***Modify the SIL selection indices to include green house gas emission costs.*** Industry implementation of genetic selection for reduction of methane emissions requires that the various measurements and breeding objectives are accurately weighted. In Sheep Improvement Limited this is undertaken on the basis of an economic model that does not include green house emissions. A recent analysis has shown these historic weightings have reduced GHG emission intensity and could be worth over $93 million over the next decade. However, they are not optimised for GHG emission costs, nor can changes in the costs of these emissions be rapidly updated, and finally they do not allow for direct selection on this trait. The proposed work would address all these issues, but more importantly would have an immediate direct benefit by reweighting selection on current traits to better reduce GHG emission intensity per unit product.

### *1.2 - Progress in 2009/2010*

In the first year of this project we have genotyped all available sheep (n=441) that have been or will shortly be measured for methane production with the Illumina OvineSNP50 Beadchip and sourced genotypes for their sires (n~40) as well.

In separate work AbacusBio, as part of a subcontract, has produced an extensive series of reports examining how current SIL selection indices are changing methane production in sheep and what is the potential to enhance the gains being made. This work is currently being reviewed by NZAGRC before being released more widely. Key results include:

- Genetic gains in sheep between 2000-2006 were a 0.9kg increase in carcass weight and 5% increase in the number of lambs born
- Gains in genetic merit for growth rate in terminal breeds of sheep have caused a 3.2kg $CO_2$e reduction in GHG emissions per ewe (from 500.1 to 496.9 kg $CO_2$e/breeding ewe) and a 0.2 kg $CO_2$e reduction per kilogram of lamb carcase (from 31.31 to 31.11 kg $CO_2$e). This is equivalent to a 0.09% annual reduction in GHG emissions per kilogram of lamb.
- The 5 percentage point NLB increase made total GHG emissions per breeding ewe increase from 500.1 to 506.1 kg $CO_2$e/breeding ewe. However, on a per kilogram of lamb carcase weight basis, increasing NLB reduced GHG emissions from 31.31 to 30.32 kg $CO_2$e/kg lamb carcase, due to more lamb being produced per ewe. On an annualised basis over the period 2000 to 2006, the improvement in NLB reduced emissions by 0.14 kg $CO_2$e/kg lamb pa; equivalent to a 0.45% pa reduction in emissions.

An incentivisation meeting was held with key sheep breeders and industry stakeholders in May 2010. An invited review paper has been submitted to the 9th World Congress of Genetics Applied

to Livestock Production titled: Genetic Opportunities to Reduce Enteric Methane Emissions from Ruminant Livestock R.S. Hegarty and J.C. McEwan

### *1.2 - Progress in 2010/2011*

Genotyping animals being screened to identify high and low emitters in a companion PGgRc/SLMACC programme has continued. A further 360 were sampled in this financial year making a total of 720 to date. These data will be analysed to try to find a 'genetic' marker that can be used to cheaply and rapidly identify low emitting phenotypes. Data analyses will commence in the 2012 year once data are available from the final cohort.

An analysis of data from $CH_4$ emissions studies has indicated that it may also be possible to accurately identify low and high emitting animals from much shorter term measurements of emissions. Emissions data collected for 1 hour, between 2 and 7 hours after feeding, can rank animals in terms of their emissions just as accurately as a 24 hour measurement. However, this is for animals that have already been adjusted to the diet and level of feeding for approximately 10 days. Further work is needed to verify whether the same is true of animals taken directly off pasture. If the latter is found to be true then considerable savings in time and cost of identifying desirable phenotypes can be made.

An updated sheep improvement economic model indicates that genetic selection for reduced emissions intensity can be achieved with minimal impact on overall economic gain in sheep farming operations. Based on a $25 tonne carbon cost a 0.62% annual reduction in GHG emission efficiency (kg $CO_2$e/kg lamb CWT pa) can be achieved with little impact on farm profit by reweighting the existing industry index and trait measurements.

### *1.2 - Progress in 2011/2012*

The key results of the current years work are twofold. Firstly taking brief measurements of methane emissions (15 minutes to 1hr vs the standard 24 hrs) whilst animals are held in feed intake facilities have been extensively investigated and analysed after last year's encouraging report. This includes estimation of heritabilities, repeatabilities and genetic correlations with standard 24 hour chamber methane measurements. These results indicate that under suitable conditions, brief measurements (15 minutes to 1 hour) can have significant value to estimate individual animal methane emissions whether measured on a gross emission ($gCH_4$/day) or intensity (gCH4/kgDMI) basis. However, multiple measurements are required to achieve the same breeding value accuracy with 4 to 5 separate hourly measurements spaced out by several weeks required to be equivalent to 2 separate 24 hour measurements also spaced out by several weeks. Such measurements can be implemented relatively cheaply in a feed intake facility.

The second key result is that while the repeatability of brief methane measurements between adjacent days is higher than measurements spaced out by longer time periods, our emerging evidence is the repeatability of measurements taken >1 day apart, while lower, is stable after that time regardless of time between measurements. This suggests that brief measurements will be good predictors of long term emissions.

### *1.3 - Genomic identification of universal targets for methanogen inhibition*

***Jointly supported programme***

***Objective Leader – Dr Sinead Leahy (AgResearch)***

Methanogens in the rumen form part of a complex microbial community, the function of which is to degrade plant material to compounds that can be used by the ruminant animal for energy and growth. Reducing the activity of methanogens in the rumen, while allowing the digestive functions of the remaining rumen microbes to continue, requires specific intervention against methanogens only. Furthermore, all rumen methanogens should be targeted as any remaining methanogens are likely to expand to fill the vacated niche. The most promising avenues for inhibiting rumen methanogens is via small molecule inhibitors or vaccines. To be successful, these approaches require knowledge of the enzymes and cellular structures that are the targets of the inhibitors and antibodies. Genome sequencing is a particularly effective way of gaining this information and genome-wide comparisons enable identification of targets that are universally present in rumen methanogens and also those that are not present, or are different, in other organisms.

The genomes of several rumen methanogens have been sequenced or are under way, but these sequences do not represent the full phylogenetic diversity of methanogens found in the rumen (estimated at some 20 different species). Also, these sequences do not address the intra-species (strain-level) variations that may exist and which are important to understand to ensure efficacy of interventions against methanogens. When the range and frequency of occurrence of methanogens in the rumen is considered, representatives from the genus *Methanobrevibacter* and the Rumen Cluster C (RCC) group are under-represented in current sequencing projects. This objective aims to obtain a better representation of rumen methanogen genomes by sequencing two additional *Methanobrevibacter* species as part of a *Methanobrevibacter* 'pan-genome' and attempting retrieval of complete genome sequences from "previously uncultured" methanogens by sequencing metagenomic DNA from a RCC enrichment culture.

This research is complementary to, and extends, current methanogen genomics projects in PGgRc- and SLMACC-funded programmes, and also fits well with on-going research to isolate a wider variety of rumen methanogens. The intention is to combine the new sequences from this objective with those from current sequencing projects to obtain a complete set of methanogen genomes which will inform programs developing small molecule inhibitor and vaccines to control rumen methane emissions. This work is essential to allow effective development of inhibitors and vaccines with broad efficacy that will work on farm. The objective will involve the development of research capability in methanogen genomics by recruiting and training a PhD student.

### *1.3 – Progress in 2009/2010*

A *Methanobrevibacter* strain (ABM4) was selected from the available methanogen cultures, its purity checked by fluorescence microscopy and strain identity was confirmed by partial small subunit ribosomal RNA gene sequencing.

A Rumen Cluster C (RCC) enrichment culture yielded a pure culture of a fluorescent, methane-forming organism identified as a *Methanosphaera* sp. which was designated strain 3F5. The 3F5 strain represents a previously uncultured rumen methanogen and is suitable for genome sequencing.

Intact genomic DNAs from ABM4 and 3F5 were extracted, purified, quality checked and delivered to Macrogen Corporation for paired end pyrosequencing.

### *1.3 – Progress in 2010/2011*

Work on sequencing the genome of *Methanobrevibacter* ABM4 is nearing completion. The genome is the smallest in size of any rumen methanogen sequenced to date. The small size of this genome is very useful as it will assist in efforts to identify a core set of genes that must be targeted by any $CH_4$ inhibitor if it is to have universal applicability. Both the ABM4 and the *Methanosphaera* 3F5 genome sequences have given new insight into key biochemical pathways relevant to rumen methanogenesis and continued re-evaluation of the latest literature has allowed us to identify additional targets for the chemogenomic (1.4) and vaccine (1.5) components of NZAGRC and PGgRc research programmes.

Invited international presentations in Canada, USA and Australia by scientists in this objective have increased the exposure of the NZAGRC program of work.

### *1.3 – Progress in 2011/2012*

The completed *Methanobrevibacter* sp. AbM4 is a representative of the *Methanobrevibacter wolinii* clade and at 1.99 Mb in size it is smaller than *M. ruminantium* M1 (2.93 Mb) and encodes fewer ORFs (1702 vs 2217). Overall the AbM4 gene complement is very similar to that of M1 suggesting that the methanogenesis pathway and central metabolism of these strains are highly similar, and both organisms are likely to be amenable to inhibition by small molecule inhibitors and vaccine-based methane mitigation technologies targeting these conserved features. *AbM4* has a much fewer genes encoding adhesin-like proteins, clusters of genes predicted to encode exopolysaccharides, transcriptional regulators and transporters which suggests it occupies a ruminal niche different from that of M1.

### *1.4 - Enhanced discovery of methanogen-specific inhibitors*


***Jointly supported programme***

***Objective Leader – Dr Ron Ronimus (AgResearch)***

Small molecule inhibitors have great potential to provide sustained and complete knockdown of methane emissions from ruminants by the targeting of multiple essential enzymes, while minimising the development of resistance. Currently, however, the partners of NZAGRC are limited in their capacity for throughput to discover methane mitigation tools.

Numerous studies have demonstrated the 'proof of principle' of small molecule inhibitors, especially in shorter term animal experiments, but unfortunately, the inhibitors are either unacceptable due to environmental or toxicology concerns, or become less effective over time. There are two proven scientific cost- and time-effective strategies to find novel inhibitors that overcome the problems relating to toxicity and resistance development. These are (1) the *in silico* use of enzyme structure data combined with advanced computer software modelling to guide the selection and testing of compounds from larger chemical compound libraries or the *de novo* design of novel compounds; and (2) the *in vitro* screening of large scale diverse chemical compound libraries using enzyme assays (e.g. high-throughput screening). The combined use of these two strategies is widely recognised as the best overall approach to identifying and developing novel inhibitors.

These two strategies require the identification of suitable target enzymes using genome sequence data and metabolic pathway analysis followed by the cloning, expression and purification of target enzymes. The purified recombinant enzymes are used for (1) identifying optimal crystal formation conditions to aid their subsequent structural determination, and (2), development of assays compatible with high-throughput screening.

In this Objective, which builds on an existing PGgRc funded initiative, the rate at which new target enzyme structures is determined, and the rate at which assays for high-throughput screening can be developed will be accelerated. These are currently key steps in the chemogenomic pipeline used by NZAGRC partners to discover small molecule inhibitors of methanogens. This will increase the likelihood of discovering a solution, and decrease the time taken to do so.

Successful expression in *E. coli* and crystal formation is enzyme-dependent and it is therefore impossible to predict which targets will ultimately end up being utilised. In addition, the requirement for targeting enzymes with methanogen-specific features potentially limits the development of high-throughput screening-compatible assays, due in some cases, to the difficulty in obtaining substrates for the enzyme assays and/or the monitoring of reaction products. In these cases inhibitors can still be tested against pure cultures of methanogens. This project aims to add an additional 10 targets for finding novel inhibitors, with the goal of obtaining two enzymes suitable for screening inhibitors.

The approach now being taken by partners within the NZAGRC is based on these two strategies and is modular, with prioritised target enzymes being introduced into a functional and structural analysis pipeline. This allows a simple increase in throughput. All the necessary expertise is available or can be readily recruited.

### *1.4 – Progress in 2009/2010*

Objective 1.4 seeks to accelerate the discovery of novel enzyme-based inhibitors for controlling ruminant methane emissions. Analysis of the rumen methanogen *Methanobrevibacter ruminantium* strain 1093 genome, a genome sequenced with PGgRc funding, and comparison of

its genome with other methanogens and ruminal microbes has enabled the identification of target enzymes to be included into our 'chemogenomics pipeline'. A total of ten target enzymes from *M. ruminantium* have been selected after prioritisation and assigned to NZAGRC Objective 1.4. The enzymes catalyse important reactions in five separate metabolic pathways including aromatic amino acid synthesis, methanopterin synthesis (an essential methanogen cofactor), F420 synthesis (an essential methanogen cofactor), polyamine synthesis (involved in redox balance control) and gluconeogenesis (an essential central pathway for synthesis of cellular components including some amino acids, cell wall components, DNA and RNA).

The above described genes have been synthesised and cloned into a plasmid vector. Cloning represents the first laboratory-based step in the 'chemogenomics pipeline'. The genes have been synthesised to minimise potential problems with expression in *E. coli*.

### *1.4 – Progress in 2010/2011*

The most significant advance this year has been the further determination of the structure for GTP cyclohydrolase enzyme, a potential methane inhibition target which has been identified from genomic and biochemical studies. We now have three structures of the enzyme, including one with the substrate GTP bound which provides key data relating to the important molecular interactions required for binding and catalysis, a crucial step for methanogen inhibition.

A second enzyme (PPDK) has also been expressed. This is a very large enzyme (~1000 kDa) and expression was technically difficult as multiple clones were needed to obtain expression. This enzyme will be used to assay other NZAGRC target enzymes (MptA and GTP cyclohydrolase).

Three other potential target enzymes (mru 0383, mru 1696 and mru 0229) have been identified and work has commenced on determining their structure as no structures for these novel archaeal enzymes currently exist.

### *1.4 – Progress in 2011/2012*

High resolution crystals of a key enzyme target have been grown and their structures solved to high resolution with data collected at the Australian Synchrotron. These new structures have the substrate for the enzyme bound and help to elucidate the key molecular interactions required for catalysis. This new structural data will form the basis of our attempts to derive new inhibitors in our methane mitigation work and *in silico* screening process. Methanogen-specific enzyme assays are being developed that will enable screening of large compound libraries to accelerate discovery of methane mitigation agents.

### *1.5 - Expression of vaccine target proteins*

***Jointly supported programme***

***Objective Leader – Dr Bryce Buddle (AgResearch)***

Vaccination of ruminants has the potential to be a very cost-effective means of mitigating methane emissions by preventing or reducing the growth of methanogens in the rumen and impairing their ability to produce methane. Ruminant methanogens are difficult organisms to culture *in vitro*; therefore, in order to produce an affordable anti-methane vaccine, it is necessary to identify critical antigenic components of the methanogens that are amendable for large scale vaccine production and express them as recombinant proteins. Recent advice from the Scientific Advisory Group which evaluates the science conducted within the PGgRc and the NZAGRC programmes was to produce as broad a range of potential targets as possible. Two approaches have been used to date to identify candidate proteins in the PGgRc (METH0701) and SLMACC (METH0802) programmes; an immunological approach (Western blotting) and bioinformatics (functional protein sequence comparison among sequenced methanogens). A list of more than 70 potential vaccine candidate proteins has been generated, principally from bioinformatics. To date only six potential targets proteins have been produced as recombinant proteins, two of these proteins having been produced by our collaborator, Greg Cook. Some of the methanogen proteins have proven difficult to express and produce in *Escherichia coli*, particularly in sufficient amounts needed to vaccinate sheep to raise antisera for testing. This has contributed towards the creation of a bottleneck in the process of evaluating vaccine candidate antigens. In order to substantially progress the development of a methanogen vaccine, the process of producing and testing recombinant proteins needs to be greatly accelerated and to achieve this, considerably more resources need to be utilised in this area. Funding from the NZAGRC being used to prioritise the list of candidate proteins and accelerate the expression of candidate proteins.

The first milestone of this project will be to shortlist candidate vaccines for expression in consultation with scientists working on methanogen genomics and drawing on their bioinformatics expertise. Vaccine candidates are likely to be those that are shared among different methanogens and are cell surface located. In general, it is difficult to express membrane proteins and rather than expressing the entire protein, we may consider expressing part of the protein such as extracellular domains. Bioinformatics will assist in selecting which parts of the protein to express. The second milestone will involve making the constructs for expression of recombinant proteins or domains in *E. coli* or yeast (*Pichia pastoris* and *Saccharomyces cerevisiae*), and producing and purifying sufficient quantities of proteins for immunising sheep to raise antisera for evaluation in *in vitro* assays. The third milestone will involve a reprioritisation of vaccine targets and markedly expanding the number of proteins expression, while the fourth milestone (planned for 13/14) will determine whether improvements in the antigenicity of the proteins can be enhanced by expression in insect cells which would allow optimal glycolysation and folding of proteins.

### *1.5 – Progress in 2010/2011*

A pipeline has been established to identify and select potential vaccine targets in the rumen methanogen, *Methanobrevibactor ruminatium* M1. Once identified and selected these targets can be produced as recombinant proteins in *E. coli* for further evaluation.

Initial analysis of the genomic sequence of *M. ruminatium* M1 identified 71 methanogen-specific vaccine targets. These membrane associated proteins were predicted to be involved in energy metabolism, protein fate, transport, biosynthesis of cell wall components, or in the case or one protein, the function remained to be determined. This initial list has now been reduced to ten.

Sheep antisera have been raised against peptides from each of the 10 targets and will be used to help identify and characterise the recombinant proteins. Four of the ten short-listed targets, BtcC, CbiN2, GT2 and OT have been produced as recombinant proteins in *E. coli*. In the next phase of the work sheep will be vaccinated with each of the four proteins to produce antisera which will be tested for the ability of target-specific antibodies to inhibit growth/production of methane in *in vitro* pure cultures of methanogens.

### *1.5 – Progress in 2011/2012*

A pipeline has been used to identify and select potential vaccine targets in the rumen methanogen, *Methanobrevibacter ruminantium* M1 and produce them as recombinant proteins in *Escherichia coli* for evaluation as antigens for an anti-methanogen vaccine.

Analysis of the genomic sequence of *M. ruminantium* M1 has identified membrane associated proteins with potential as vaccine targets. We previously reported that four of these targets had been expressed as recombinant proteins in *E. coli*. The proteins have been evaluated by producing sheep antisera (antibodies) to the proteins. These antibodies have been tested for anti-methanogen activity in *in vitro* pure cultures of methanogens. One of these proteins looks promising as a vaccine target and was selected as an antigen for a prototype vaccine that is currently being evaluated in sheep.

Seven more potential vaccine targets were selected from a further analysis of the *M. ruminantium* M1 genome. These targets have been produced as recombinant proteins in *E. coli*. Sheep have been immunised with five of these proteins and the antisera produced against the targets will be tested for the ability of target-specific antibodies to inhibit growth/production of methane in *in vitro* pure cultures of methanogens.

### *1.6 - Identifying alternative hydrogen utilisers*

***Jointly supported programme***

***Objective Leader – Dr Gemma Henderson (AgResearch)***

Proposed methane mitigation strategies include eliminating rumen methanogens by means of an inhibitor or a vaccine. The inhibition of methanogens will result in the accumulation of hydrogen that is formed during the fermentation of feed. This hydrogen is expected to slow the rate of feed conversion, and so may affect animal productivity. However, this hydrogen may also be used by alternative hydrogen utilisers such as homoacetogens. Knowing which organisms will use the hydrogen and understanding how best to encourage their growth and manage the transition from a methane-producing rumen to an equally (or perhaps even more) productive system that doesn't produce methane is important for on-farm application of methane control technologies.

Recently, a PGgRc funded programme detected many new potential homoacetogens in New Zealand ruminants (Henderson, Naylor, Leahy, Janssen, Appl Environ Microbiol 76:2058-66 (2010)). It is not known if these homoacetogens will respond to increased hydrogen concentrations in the rumen and grow up to take over the niche vacated by methanogens when the latter are displaced with an inhibitor or vaccine. To build up knowledge on the best ways to manage such a transition in the rumen microbial community, and at the same time gain further information on alternative hydrogen utilising bacteria, we will investigate the bacteria with formyl-tertrahydrofolate synthetase (FTHFS) genes indicative of an ability to utilise hydrogen in the rumen.

Building on knowledge generated in an existing PGgRc programme we will identify candidate alternative hydrogen utilisers in a range of different rumen samples by analysis of sequences of the FTHFS gene (a marker gene indicative of the homoacetogenic Wood-Ljungdahl pathway) using existing (Henderson, Naylor, Leahy, Janssen, Appl Environ Microbiol 76:2058-66 (2010)) and newly developed tools for identification of these bacteria. We will identify alternative pathways of ruminal hydrogen utilisation by means of a stable isotope tracer technique that measures the incorporation of the $^{13}CO_2$ into acetic acid and other fermentation end products. We will then use stable isotope probing to link the bacteria to the hydrogen-utilising activity, and then isolate and study bacteria involved in alternative ruminal hydrogen utilisation pathways to better understand their characteristics and requirements.

This line of investigation will enable us to determine whether alternative ruminal hydrogen utilisation processes are active, which alternative hydrogen utilising microorganisms are (universally) present in rumen samples, and what conditions they require to grow optimally. This will allow an assessment to be made of the potential of alternative hydrogen utilisers to take over the role of methanogens, and start to develop protocols for their enhancement in conjunction with future mitigation strategies that inhibit methanogens.

### *1.6 – Progress in 2009/2010*

A goal of this objective is to identify candidate alternative hydrogen utilisers in a range of different rumen samples by sequence analysis of formyltetrahydrofolate synthetase (FTHFS) genes, a marker gene indicative of the homoacetogenic Wood-Ljungdahl pathway) using existing (Henderson, Naylor, Leahy, Janssen, Appl Environ Microbiol 76:2058-66 (2010)) and newly developed tools for identification of these bacteria.

To date, new tools in the form of Hidden Markov Models (HMM's) have been developed for FTHFS gene PCR amplicons that are suitable for data obtained using high throughput parallel DNA pyrosequencing technology. The newly developed FTHFS HMM's have been tested on and validated against existing FTHFS sequences from databases.

FTHFS gene fragments have been amplified from 10 diverse rumen samples have been selected and submitted for pyrosequencing with Eurofins MWG GmbH.

### *1.6 – Progress in 2010/2011*

Work this year has concentrated on (a) the better identification of microorganisms which can utilise hydrogen in the rumen without producing $CH_4$ and (b) confirm that these organisms can act as alternative hydrogen 'sinks' if methanogens are inhibited under rumen-like conditions.

The better identification of alternative hydrogen utilisers has been approached using a molecular approach which examines FTHFS sequences. Although not perfect the approach has allowed for many potential alternative hydrogen user candidates to be identified in a rapid and inexpensive way. Work on refining the approach is continuing.

A series of *in vitro* studies using rumen samples incubated in the presence and absence of methane inhibitors was undertaken. As expected, the presence of methane inhibitors reduced the amount of methane formed. Tracer analysis of samples has shown that hydrogen that has not been incorporated into methane is metabolised by alternative hydrogen utilisers to produce amongst other things acetate. This demonstrates that, under these artificial conditions, the inhibition of $CH_4$ does not simply result in the accumulation of hydrogen and that some of it can be converted into an end product that a ruminant can use as energy source.

### *1.6 – Progress in 2011/2012*

Work this year has focussed on developing the methods that allow measurement of homoacetogen activity using $^{13}CO_2$ to $^{13}$C-acetate as a marker of their activity in rumen contents. In combination with the molecular biological tools already developed in the objective, we will shortly be able to measure the (hypothesised increased) activity of homoacetogens as hydrogen users when methanogens are inhibited in the rumen. We have expanded our set of experimental inhibitors so we can specifically inhibit different processes to provide better evidence of their significance in normal and low-methane rumens. We have identified a set of four inhibitors that allow us to differentiate between methanogen and homoacetogens as hydrogen users. These tools will be applied to rumen samples in 12/13 to begin understanding how best to manage the rumen when an inhibitor or vaccine is added which reduces methanogen activity. As potential inhibitor and vaccine targets emerge from other NZAGRC objectives, these tools will be available to study their impacts on rumen processes.

### *1.7 - Methane capture and utilisation from dairy effluent – Completed 10/11*

### *Objective Leader – Dr Rupert Craggs (NIWA)*

Current NZ GHG inventory calculations indicate that agricultural methane emissions are primarily (96.9%) from enteric fermentation in cattle and sheep, with emissions from animal waste contributing to the remaining 3.1%. Approximately half of the animal waste emissions are calculated to come from the dairy industry, mainly due to the release of biogas from anaerobic digestion of effluent in treatment and storage ponds.

There is limited measured data on GHG emissions from anaerobic ponds both nationally and internationally. Research by NIWA has shown that anaerobic ponds in the Waikato region emit substantial amounts of biogas methane. Overall biogas production was found to be similar to that of heated mixed digesters (0.21–0.28 $m^3CH_4$/kg VS added; Craggs et al., 2008; Heubeck et al. 2010). This data and a recent study by Landcare (Walcroft unpublished) indicate that actual methane emissions from dairy farm anaerobic ponds are likely to be significantly higher than those reported in the MfE NZ GHG inventory. With the recent trend of mandating deferred irrigation storage ponds on NZ dairy farms the GHG emissions from dairy farm waste management are likely to increase.

There is an opportunity to reduce dairy farm methane emissions by capturing biogas from effluent treatment and storage ponds for use as an on-farm energy source. Capturing the biogas emitted from digestion of all of the dairy farm effluent presently produced in New Zealand could potentially avoid GHG emissions of up to 1.4 million tonnes $CO_2$ equivalent per year. This methane has a total energy content of 3.6 PJ/y which could be used to generate up to NZ$50 million/y of electricity, and avoid a further 60,000 – 100,000 t $CO_{2equi}$/y electricity generation GHG emissions.

The aim of this research objective is to promote the uptake of technologies that mitigate methane emissions from dairy farm effluent management and provide further confirmation that methane emissions from dairy farm anaerobic ponds are higher than those currently calculated under the NZ GHG inventory. The study will include:

- An assessment of anaerobic digestion technologies to capture and utilize methane emissions from dairy farm effluent. Capital and operation costs and digestion efficiency will be compared and conceptual designs will be provided for a range of herd sizes. Appropriate on-farm biogas use options will also be compared. A simple decision support model for dairy farm effluent GHG emission abatement will be developed to assist dairy farmers to select the most efficient and cost-effective of anaerobic digestion technology and biogas use option for their farm.

- Existing data on GHG emissions from anaerobic ponds in NZ will be augmented by a one year study comparing biogas production and composition at two sites. Temperature and organic loading will be compared at each site, and the data used to calibrate NIWA's model of methane production from dairy farm effluent. A survey of number and size of NZ dairy farm anaerobic / effluent storage ponds will be conducted to enable more accurate calculation of overall GHG emissions. Further funding will be sort to extend this research to anaerobic ponds in different dairying/climatic regions of New Zealand to determine the geographic and climatic variation in GHG emissions from dairy farm waste management.

### *1.7 – Progress in 2009/2010*

Work has begun on the assessment of anaerobic digestion technologies to capture and utilize methane emissions from dairy farm effluent. These include headed mixed anaerobic digesters, plug flow digesters and covered anaerobic ponds. The assessment will compare capital and operation costs and digestion efficiency for herd sizes from 200 to 2000. The review of appropriate

on-farm biogas use options has also commenced including: heating/cooling, combined heat and power and biogas upgrading for on farm vehicle use.

### *1.7 – Progress in 2010/2011*

Measurements of methane emissions from dairy effluent ponds have been used to calibrate NIWA's model of methane production from dairy farm effluent ponds. The model was then used to construct scenarios to examine the viability of installing facilities to collect biogas from these ponds. The scenarios modelled were for dairy farms with different herd sizes (400, 800, and 1200) with or without feedpads.

The most important factors affecting financial viability are: farm size, feed pad use and presence of existing biogas use equipment (e.g. Boiler or generator). The most simple to apply and economically viable options for on-farm biogas use is either a boiler with flare to waste excess biogas, or combined heat and power (CHP) if a generator is also purchased for backup power supply.

Depending upon the biogas use option selected and farm herd sizes capital costs range from $29-132K, and payback periods of between 3 and 5 years are achievable. A survey of the number and size of NZ dairy farm anaerobic/effluent storage ponds found that there are many more anaerobic ponds in NZ than previously thought (>3,000 in the Northland, Waikato and Taranaki regions).

Additional funding was secured from the SLMACC fund to continue and extend this study at other sites and install a full-scale covered anaerobic pond at one of these sites.

Work has now begun on the assessment of anaerobic digestion technologies to capture and utilize methane emissions from dairy farm effluent. This will include headed mixed anaerobic digesters, plug flow digesters and covered anaerobic ponds. The assessment will compare capital and operation costs and digestion efficiency for herd sizes from 200 to 2000. The review of appropriate on-farm biogas use options has also commenced including: heating/cooling, combined heat and power and biogas upgrading for on farm vehicle use.

***COMPLETED***

## Nitrous Oxide Research – Objective Level Report - 2011/12

### *2.1 – Manipulating N inputs*

***Objective Leader – Dr Cecile de Klein (AgResearch)***

This objective investigates ways to manipulate the N inputs into the pastoral system though plant breeding/selection and plant management options. The plant breeding/selection component focuses on exploring the hypothesis that novel pasture grasses can produce more DM per unit N supplied than existing grass species to produce high yielding plants with low N content. This research combines molecular biology, plant physiology and ecology to alter the fundamental biology of forage plants' strategies for utilising N that has already been captured by the plants and convert it into DM.

High yielding plants with low N content will not only reduce the total N input to the system, but also alter the N concentration of animal urine deposited to pasture. Over 80% of the national $N_2O$ emissions are derived from animal urine and the effect of N concentration on $N_2O$ emissions can have a major impact on total emissions. This objective will establish the relationship between N concentration in the urine and $N_2O$ emissions, to fully assess the effectiveness of this mitigation option (and other options that will impact on the N concentration of animal urine) on reducing the agricultural $N_2O$ emissions.

The plant management component of this objective focuses on understanding and manipulating $N_2O$ emitted by leaves. Previous work has shown that plants can emit $N_2O$ in three ways: 1. $N_2O$ produced by soil micro-organisms is transported to the atmosphere through the plant. 2. $N_2O$ is produced by microorganisms (ammonia oxidizing bacteria (AOB)) on plant leaves 3. $N_2O$ is produced by the plant during photo-assimilation of nitrogen. The work in this objective will quantify the contributions from each of these pathways and screen plants for variation in their potential to emit $N_2O$.

**Key research questions:**

1. What are key gene targets that regulate plant growth?
2. Can exogenous growth stimulants be developed that promote plant growth under N limitation?
3. What is the relationship between urine N concentration and the $N_2O$ emission factor?
4. What is the relative contribution of plant canopy $N_2O$ emissions to total pasture emissions?
5. What is the relative contribution of the three different pathways to $N_2O$ emissions from plant canopy?

**Significant new knowledge:**

- Putative key molecular factors limiting plant growth under N limitation;
- The potential for developing novel pasture species that can produce more DM per unit of N supplied;
- Assessment of the impact of developing these species on N intake, milk yield, N excretion rates and $N_2O$ emissions;
- Assessment of the effectiveness of $N_2O$ mitigation strategies that alter the urine N concentration and N excretion rates;
- Assessment of the relative importance of $N_2O$ emissions through plant canopy in relation to total pasture $N_2O$ emissions;

### *2.1 – Progress in 2009/2010*

Work has been completed in three milestones, each pertaining to a separate area of work: 1) exploring the hypothesis that novel pasture grasses can produce more DM per unit N supplied than existing grass species; 2) assessing the effect of urine N concentration on the $N_2O$ emission factor, and 3) quantifying the importance of $N_2O$ emissions from the plant canopy.

1. An early career scientist has been successfully recruited and a project plan and key experiments have been designed and presented at a $N_2O$ NZAGRC meeting on 24 June 2010. Based on extensive literature review and experimental evidence we have identified as key gene targets linking plant growth to nutrient and other environmental conditions gene products which are related to the reception, synthesis, and signalling of gibberellins, which are key regulators of plant growth

2. Two field experiments have been established to determine the effect of urine N concentration on the $N_2O$ emission factors. The rates of N applied equate to 200, 400, 600, 800, 1000 and 1200 kg N/ha, and thus span the urine N deposition rates common to pastoral animals.

3. An experimental set-up to systematically quantify different pathways of $N_2O$ release from the plant canopy has been designed and presented at a $N_2O$ NZAGRC meeting on 24 June 2010. This set-up uses a hydroponic system with ammonium as an N source only to minimise any $N_2O$ emissions other than those from the plant canopy

### *2.1 – Progress in 2010/2011*

Trials to confirm the critical importance of gibberellins in regulation of growth ryegrass were undertaken. Our results clearly show that defoliation of ryegrass results in a shift from reserve carbohydrate (CHO) accumulation to CHO mobilisation and that this is regulated by endogenous levels of gibberellins. This endogenous supply of gibberellins results in the growth of tissues, which because of defoliation, are resource deprived. A second series of trials has been initiated to test the effect of an exogenous supply of gibberellins on plant growth when N is the resource limiting plant growth.

It is still an open question as to whether urinary N concentration itself influences the quantity of $N_2O$ emitted per unit of N deposited in urine patches. This has important implications both for inventory and for potential mitigation practices. Field studies undertaken this year suggest that $N_2O$ emission per unit of deposited N is relatively constant for low urine N concentrations between 2 and 8 g N/l, but tended to increase at high concentrations of 10 and 12 g N/l. Typical urinary N concentrations in New Zealand are 8g N/l. The key implications arising from the first year of these studies are (1) that $N_2O$ mitigation strategies that reduce urine N concentration from 'typical' to 'low' but don't reduce the total amount of N excreted, might have limited impact on reducing $N_2O$ emissions and (2) that the constant figure currently used in national inventory calculations is appropriate.

A prototype experimental unit consisting root and shoot chamber was constructed to test pasture canopy $N_2O$. This experimental unit allows the team to measure and quantify $N_2O$ emissions from pasture plants and to assess the contribution of this loss pathway relative to $N_2O$ losses directly from soil. A series of experiments have been conducted during 2010/11. Testing of the experimental unit identified some issues relating to air tightness of the unit, and an improved design was developed with the AgResearch engineering team. This improved unit is now being built and will be tested by 31 July 2011.

### *2.1 – Progress in 2011/2012*

Work has been completed in three milestones, each pertaining to a separate area of work: 1) exploring the hypothesis that novel pasture grasses can produce more DM per unit N supplied than existing grass species; 2) assessing the effect of urine N concentration on the $N_2O$ emission factor, and 3) quantifying the importance of $N_2O$ emissions from the plant canopy.

1. The effects of nitrogen and gibberellin on growth of more than 1000 ryegrass genotypes collected from a 4 year old dairy pasture at Massey University was assessed. The results showed that at low N supply, biomass production of blades was increased by gibberellin treatment up to 54% at low N, while root biomass increased up to 81%. This demonstrates that ryegrass growth can be stimulated without the need for additional nutrient resources.

In addition, growth stimulation achieved by increased supply of N resulted in a much lower C/N ratio in grazed tissues, potentially strongly increasing N excretion in urine by grazing animals. Growth stimulation by gibberellin on the other hand did not result in a change of C/N ratios; therefore increases in pasture production using gibberellin will not increase N excretion by grazing animals.

This work has demonstrated that there may be potential to develop novel pasture grasses that have the ability to produce more dry matter per unit of N supplied. This would result in a lower N diet for livestock with less N excreted on to agricultural soils and hence a reduction in $N_2O$ emissions.

2. All field work on the effect of urine N concentration on the $N_2O$ emission factor was completed and data fully analysed. The results showed that $N_2O$ mitigation strategies that reduce the urine N concentration below typical (8-10 gN/L) concentrations, but don't reduce the total amount of urine N excreted, may have limited impact on reducing direct $N_2O$ emissions.

These findings have important implications for the NZ GHG inventory. One component of the current $N_2O$ calculation involves estimating the emissions from livestock waste deposited during grazing. Demonstrating a linear relationship between urine concentration and direct $N_2O$ emissions means that the constant figure currently used is appropriate and uncertainty in the current calculation can be decreased.

3. This study confirmed that leaves of common grasses found in New Zealand pastures emit $N_2O$. There was a variation in emission between species. The observation of negative fluxes in the dark is significant as it shows the potential for underestimation of $N_2O$ emissions when using a chamber technique. Negative fluxes have been observed in many field studies, particularly when N is not added. The results also show that $N_2O$ can be absorbed by plants at night. We also found significant emissions from cut leaf surfaces due to a strong conduit effect, indicating that transpiration is important in leaf $N_2O$ emissions and emissions may be affected by defoliation management.

### *2.2 – Manipulating nitrification processes*

### *Objective Leader – Prof Hong Di (Lincoln University)*

Comprehensive research undertaken in NZ has already demonstrated that nitrification inhibitors (NI) can provide an effective method for reducing $N_2O$ emissions from urine patches deposited on pasture. Research funded by NZAGRC will address the challenge of optimising inhibitor use so that their effectiveness and longevity is increased.

Microbes are the engines driving nitrification in the soil. The performance of NI is affected by soil and environmental conditions. A sound understanding of the quantitative relationships between microbial, soil and environmental factors and processes is critical to improving the performance of nitrification inhibitors. Microbial communities responsible for nitrification in the soil will be studied using molecular biology techniques. Effects of key soil and environmental conditions on the performance of NI will be quantified.

Key questions that this research will address are:

1. What is the relationship between the main soil, microbial and environmental factors and processes, and the effectiveness of nitrification inhibitors in reducing nitrous oxide emissions and increasing pasture yield?
2. How can the use or the formulation of NIs be optimised to ensure increased effectiveness and longevity in the soil?

The research will generate significant new knowledge and understanding of:

- The microbial populations and processes responsible for nitrification and their relationships with nitrous oxide production;
- The effectiveness of NIs in inhibiting microbial populations and affecting processes that contribute to nitrous oxide emissions and N supply;
- Relationships between soil and environmental conditions that affect the efficiency of NI;
- New generation inhibitors and recommendations for their optimal use.

### *2.2 - Progress in 2009/2010*

Excellent progress has been made in achieving the milestones of the programme. All work is on track.

Milestone 2.2.1: A draft experimental protocol has been developed. Laboratory incubation experiments will be conducted to determine effects of animal urine and nitrification inhibitor on soil nitrifying populations (using real-time PCR) and relationships with nitrous oxide emissions as affected by soil moisture and texture conditions. The protocol will be discussed with nitrous oxide PIs and NZAGRC Director before it is finalised.

Milestone 2.2.3: Experimental protocols have been developed, and discussed with nitrous oxide PIs and at a nitrous oxide workshop.

Sixteen lysimeters (50 cm diameter and 70 cm deep) have been collected and installed at a field lysimeter facility at Lincoln University. Urine and nitrification inhibitor treatments were applied to the lysimeters in mid June and nitrous oxide emissions measurements have started.

Milestone 2.2.4: A draft protocol has been developed in discussion with our collaborator in the Scottish Agricultural College to determine how changes in soil microbial habitat and moisture content resulting from soil pugging by animal treading influence the effectiveness of nitrification inhibitors to mitigate nitrous oxide emissions from dairy pasture.

Milestone 2.2.8: Discussions have been held with AgResearch modellers on the incorporation of nitrification inhibitors in the Overseer and APSIM models to determine how nitrification inhibitors

are accounted for in these models and what further information is required in order to improve predictions.

### *2.2 - Progress in 2010/2011*

Field trials have confirmed the crucial role that animal trampling has on $N_2O$ emissions under wet conditions. Results showed that animal trampling had a significant effect on the soil's air permeability, air-filled pore space, and more than doubled the $N_2O$ emission factor in an imperfectly drained Wakanui soil. An important finding from this year's trials is that the nitrification inhibitor DCD was shown to be equally effective in reducing direct and indirect nitrous oxide emissions in both trampled and non-trampled plots.

Work on building and commissioning the National Centre for $N_2O$ Measurement located at Lincoln University was completed as planned and the was opened by the Minister of Agriculture, the Hon. David Carter, on the 1 April 2011. Presentations on nitrification inhibitor research were given to a number of visiting groups, including Fonterra executives, ECan Commissioners, Ngai Tahu, and local dairy farmers.

### *2.2 - Progress in 2011/2012*

Research so far has shown that $N_2O$ emissions are significantly affected by animal treading of wet soils which causes soil compaction, affecting soil air permeability and air-filled pore space. The $N_2O$ emission factor was more than doubled by the trampling. DCD was shown to be highly effective in reducing $N_2O$ emissions and the efficacy was not affected by trampling. Lysimeter studies of $N_2O$ emissions in winter runoff grazing systems showed that DCD was highly effective in reducing $N_2O$ emissions and nitrate ($NO_3^-$) leaching (indirect source of $N_2O$) in these winter runoff grazing systems. A paper has been published on-line in *Soil Use and Management*, and results have been presented at the NZAGRC annual conference and workshop.

### *2.3 – Manipulating denitrification processes*

### *Objective Leader – Dr Surinder Saggar (Landcare Research)*

Landcare Research
Manaaki Whenua

Denitrification is the primary process of $N_2O$ production in New Zealand pasture soils. However, we lack a comprehensive, quantitative understanding of denitrification rates and controlling factors across agrosystems. Denitrification is a facultative anaerobic microbial process producing nitric oxide, nitrous oxide and $N_2$ from nitrate and nitrite. Abiotic denitrification can occur under some conditions. Understanding those mechanisms (microorganisms; biotic processes and mineral oxide; abiotic processes) and soil & environmental factors that have the potential to reduce the production of $N_2O$ during denitrification is vital to the development of new and effective $N_2O$ mitigation technologies. This objective will test and improve the latest microbiological and tracer techniques to identify pathways to reducing $N_2O$ production during denitrification and develop mitigation technologies that reduce $N_2O$ emissions by lowering $N_2O/N_2$ ratio during denitrification, including in areas where denitrification is maximised to reduce nitrate leaching losses (e.g. riparian buffer zones). This research objective will contribute to the NZAGRC's objectives of developing novel and effective $N_2O$ mitigation technologies and provide national policy (MAF, MfE) and regional (Regional Councils) land management agencies, and the dairy industry with the ability to determine $N_2O$ mitigation potential from soil denitrification. This will assist end-users with negotiating nitrous oxide emission reductions targets to protect existing and develop new trade initiatives for New Zealand.

Key questions:

1. What is the relationship between soil, microbial and environmental parameters and processes and $N_2O/N_2$ ratio of denitrification?
2. What is the effectiveness of soil amendments for reducing nitrous oxide production during denitrification?
3. What are the optimum soil and environmental conditions required for maximum nitrous oxide mitigation using the most effective soil amendment?

Significant new knowledge:

The research will generate significant new knowledge and understanding of:

- The soil microbial populations and processes responsible for denitrification, and their relationships with nitrous oxide production;
- The pathways and microbial communities to reducing nitrous oxide production during denitrification by lowering $N_2O/N_2$ ratio;
- Relationships between soil and environmental conditions that affect the efficiency of soil amendments.

### *2.3 - Progress in 2009/2010*

Preliminary laboratory and field experiments to measure denitification rate and denitrification enzyme activity at four soil moisture levels ranging from 60% of field capacity to saturation in a Tokomaru silt loam dairy-grazed permanent pasture were conducted.

The PhD research proposal to study processes regulating nitrous oxide emissions during denitrification in grazed pasture soils has been finalised.

Some recent literatures on

- Nitrogen dynamics in temperate grasslands
- Denitification processes
- Factors affecting denitrification
- Techniques to measuring denitrification
- Modeling denitrification processes and NOx and $N_2$ emissions

- Economic and environmental impacts of denitrification
- Management practices to control denitrification

have been collected to prepare an extended review paper on denitrification.

Statement of core purpose and experimental protocol have been agreed with the key researchers, the PIs and NZAGRC Director at a meeting on 22 June 2010.

Preliminary laboratory and field studies to test soil denitrification enzyme activity and denitrification potential measurements suggested further work is needed to improve and standardise this technique.

Neha Jha PhD (Massey University) started literature review of processes regulating nitrous oxide emissions during denitrification in grazed pasture soils.

Another PhD study on biotic and abiotic soil denitrification processes including biochar (Thomas Herbin, Massey University) is established.

### *2.3 - Progress in 2010/2011*

Two important pieces of work were completed during the year, the development of analytical protocols for the measurements of Denitrification Enzyme activity (DEA) and Acetylene Inhibition (AI). These two protocols are important for interpreting data coming from field trials. Initial results from field trials suggest that potential and actual denitrification rates are higher in the top 10cm of the soil than at depths below 10cm. This indicates that in soils under pasture most of the denitrification and nitrous oxide emissions occur close to the soil surface. The research also found higher denitrification rates in intact soil cores than sieved and broken cores, indicating the important role that soil physical attributes play. A review of denitrification processes, measurements, modelling and mitigation of negative impacts was conducted and submitted for publication.

### *2.3 - Progress in 2011/2012*

- Conducted laboratory analysis for estimation of microbial biomass carbon of 10 dairy farm soils collected across North and South island in New Zealand.
- Optimised Polymerase Chain Reactions (PCR), for amplification of denitrifier enzymes encoding genes (*nos*Z, *nir*S and *nir*K), from dairy pasture soils. Estimation of community structure and abundance of denitrifier enzymes encoding genes (*nos*Z, *nir*S and *nir*K) from dairy pasture soils using PCR based technique Terminal Restriction Fragment Length Polymorphism (T-RFLP). Optimisation of quantitative PCR (qPCR) for estimation of gene copy numbers of *nos*Z, *nir*S and *nir*K genes in dairy pasture soils.
- Quantified *nos*Z, *nir*S and *rpo*B gene copy numbers in the extracted DNA samples from all the 10 soils.
- Investigated the effect of soil moisture on DR and $N_2O/N_2$ ratio in five New Zealand pasture soils of contrasting DEA and varying in soil physical and chemical characteristics at field capacity (FC) and complete saturation.
- Compared denitrification in a pasture and an adjacent riparian soil.

### *2.4 – $N_2O$ emissions and soil water status*

***Objective Leader – Dr Steve Thomas (Plant & Food Research)***

Up to 80% of total annual $N_2O$ emissions from urine patches result from a small number of large emission events. In New Zealand, denitrification occurring in anaerobic soils is the major process leading to $N_2O$ production. Soil water status is a key determinant of these emissions as it influences the amount of oxygen contained in soil pores and also regulates oxygen diffusion into and through the soil.

If we can identify a suitable descriptor of the soil water status, we may predict the extent of anaerobic conditions and the associated large $N_2O$ emissions. This knowledge could be used to reduce the risk of high $N_2O$ emission events by changing some farm management practices or the timing of these activities. Relationships between water filled pore space (WFPS) and $N_2O$ emissions have often been reported in the literature and are used in a number of models. So far, WFPS has failed to provide a consistent and widely applicable relationship across different soil types and conditions in New Zealand. A key contributing reason is that WFPS does not take into account the size, frequency, distribution and connectivity of soil pores which is a function of soil physical characteristics (e.g., texture, structure, and bulk density), and therefore, inherently influence gas and solute diffusion. Farm management practices including grazing and tillage affect soil bulk density and soil structure conditions.

The aim of this research is to develop better fundamental understanding of the role that soil physical characteristics and changing soil water conditions affect $N_2O$ emissions, and use this knowledge to produce a scientifically robust and easily measurable relationship between soil water or aeration status and $N_2O$. In turn, we will use this knowledge to help refine on-farm grazing and soil water management decision-making to minimise $N_2O$ emissions.

This research will combine soil physics, $N_2O$ measurement technologies and knowledge in targeted laboratory and field experiments. The programme will develop new capability through the inclusion of an overseas-trained soil physicist recently employed in NZ by Plant & Food Research. Alignment to other research programmes (FRST - Land Use Change & Intensification) provides an opportunity to address our research questions by combining field $N_2O$ emission measurements with soil physical measurements planned for existing or new field trials that include a range of soil physical conditions, urine treatment and changing soil moisture status in their experimental design.

We will collaborate with Dr Jeff Baldock (CSIRO) who is working in a similar research programme in Australia.

**Key research questions:**

1. What soil physical characteristics are most important for regulating the amount of air held in the soil and gaseous diffusion into and out of soil, and how are these characteristics related to $N_2O$ emissions?
2. What are the best measures of soil water and aeration status for predicting $N_2O$ emissions from urine patches?
3. How can knowledge of the relationships between soil water and aeration status and $N_2O$ emissions be applied on-farm to reduce $N_2O$ emissions?

**Significant new knowledge:**

- A soil water/soil aeration metric will be identified for predicting $N_2O$ emissions from a wide range of soil types and management conditions.
- The relationships between soil physical characteristics, soil water status and $N_2O$ emission are used to improve on-farm management decision-making to minimise $N_2O$ emissions.

### *2.4 – Progress in 2009/2010*

A key focus for the research team since 1 April has been to develop a three-year research plan for Objective 2.4. This was submitted to the PI's and NZAGRC Director at the beginning of April.

Work for Milestone 2.4.1. "Soil aeration and nitrous oxide emissions" has been initiated. A more detailed experimental protocol/plan has been developed for this Milestone following research planning meetings that were held at Lincoln and Invermay in April and June. An outline of the proposed work was presented to the PI's and other researchers in the $N_2O$ research programme in late June.

Laboratory experimental work will build on recent work conducted by Tony van der Weerden. A review and assessment of appropriate methodologies for measuring $N_2O$ fluxes from soils with different pore size distributions and air-filled volumes is progressing well. We have identified a range of key physical soil properties for measurement. Experiments will be conducted on soils representing different soil orders under a range of moisture/air content treatments.

In June, the team met with Dr Jeff Baldock from CSIRO, Adelaide to discuss research plans and approaches. This provided an excellent opportunity to exchange ideas and findings from previous research relevant to this Objective. Future collaboration opportunities with Dr Baldock's research team will be investigated in the coming year.

Dr van der Weerden will present a paper at the World Congress of Soil Science in Brisbane on soil physical properties and $N_2O$ emissions.

### *2.4 – Progress in 2010/2011*

A novel method for measuring $N_2O$ emissions from draining and rewetted soil cores using mini headspace chambers was developed and tested. This will enable emissions to be estimated in a more accurate and efficient manner.

An experiment to determine the effects of three draining cycles from saturation to field capacity (soil water tensions of 0 to -10 kPa using sand tables) on $N_2O$ emissions from urine amended re-packed soil cores was started.

Dr van der Weerden presented a paper at the World Congress of Soil Science in August on the influence of pore size distribution and soil water content and $N_2O$ emissions. A manuscript on soil water and air status and $N_2O$ emissions has been submitted to Soil Research by Dr van der Weerden.

### *2.4 – Progress in 2011/2012*

We have made progress towards identifying improved field–based soil water metric(s) for predicting $N_2O$ emissions. The work includes a combination of a specifically designed laboratory experiment and the analysis of existing data for sedimentary and volcanic soils. A key finding from the analyses of data from these experiments was that the soil water content threshold before nitrous oxide emissions rapidly increased (approx. 54% v/v) was the same for each soil. Further analysis is underway to confirm this finding for a wider range of soils and bulk densities and the transferability of this metric to the field.

Other highlights include a paper on the "Influence of pore size distribution and soil water content on nitrous oxide emissions" by Dr Tony van der Weerden et al. published in the Soil Research journal. The key results described in this paper were that $N_2O$ emissions from denitrification could be best explained by soil water matrix potential > volumetric soil water content > water-filled pore space >

relative soil gas diffusivity. It was however concluded that the most practical soil moisture metric is likely to be volumetric soil water content as it is readily measured in the field or can be modelled.

The findings that soil volumetric water content is more applicable at explaining nitrous oxide than the soil's water-filled pore space based on experiments using two sedimentary soils were presented at the World Congress of Soil Science held in Brisbane (Dr Tony van der Weerden et al.) and at the NZAGRC conference (Tina Harrison-Kirk et al) and the International Nitrogen Workshop, Wexford, Ireland (Tina Harrison-Kirk et al): based on experiments on a soil of volcanic origin.

### *2.5 – Influence of anecic earthworms on nitrous oxide emissions*

***Objective Leader – Dr Alec Mackay (AgResearch)***

New Zealand pasture soils are unique, with important soil invertebrates having been accidental exotic introductions. Consequently, diversity is low, providing an opportunity to augment their distribution to benefit the net GHG balance (Schon *et al.,* 2011). Of most interest are anecic earthworms as they incorporate surface organic matter to depth and have a limited distribution in New Zealand pasture soils (Schon *et al.,* 2011). Increasing soil C storage may offset other GHG emissions, so determining the role of these invertebrates on $N_2O$ emissions is important. Some evidence suggests a positive influence of anecic earthworms on mitigating $N_2O$ emissions in comparison to background levels when introduced alone into soils, but a negative impact when introduced with other species (Lubbers *et al*., 2011). The literature on this topic is far from comprehensive as is the mechanisms by which $N_2O$ emissions might be altered by invertebrates through their influence on soil structure, pore function and C and N turnover and distribution in the profile.

There are two elements to the proposed study:

1. Utilising a mesocosm experiment currently underway exploring the role of different earthworm (epigeic, endogeic and anecic) combinations on soil C incorporation and residence time to monitor $N_2O$ emissions following a fresh dung application.

Treatments monitored will include those with multiple dung applications

- 1.1. No earthworms multiple dung applications
- 1.2. A. longa and multiple dung applications
- 1.3. A. caliginosa + L. rubellus and multiple dung applications
- 1.4. A. longa + A. caliginosa + L. Rubellus and multiple dung applications

2. Sample *in situ* nitrous oxide emissions at two field locations (Central plateau and Hawkes Bay) will be collected where anecic earthworms where introduced 30+ years ago and adjacent areas where this species has yet to populate.

**References**

Lubbers, I.M., Brussaard, L., Otten, W.,.van Groenigen, J.W. 2011. Earthworm-induced N mineralization in fertilized grassland increases both $N_2O$ emission and crop-N uptake. *European Journal of Soil Science* 62 152–161

Schon, N.L., Mackay, A.D., Gray, R.A., Minor, M.A. 2011 Earthworms in New Zealand sheep- and dairy-grazed pastures with focus on anecic *Aporrectodea longa*. *Pedobiologia* 54S 131– 137

### *2.5 – Progress in 2011/2012*

An existing mesocosm experiment exploring the role of different earthworm (epigeic, endogeic and anecic) combinations on soil C was extended to include an examination of the influence these species have on $N_2O$ emissions. In addition in two field locations (Central plateau and Hawkes Bay) where the influence deep burrowing anecic earthworms introduced 30+ years ago have on soil C is also the subject of a current study measurement has been extended to also include an assessment of this earthworm species on $N_2O$ emissions. The field component of the study has been completed and data are currently being collated ready for analysis.

### *3.1 - Limits of soil carbon storage in New Zealand soils*

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

The NZAGRC's research programme on soil carbon is designed to move beyond quantifying the stock of carbon in New Zealand's agricultural soils to understanding the processes of soil C storage and management of those processes to conserve and, where possible, increase soil C stocks. The first steps in the research programme involve defining the upper limits of C storage in New Zealand soils and determining how close our soils are to that upper limit. This research objective seeks to address one of these first key steps, i.e. to define the upper limits of carbon storage in New Zealand agricultural soils. In addition, this objective will work in tandem with Objective 3.2 to contribute to the development of a robust methodology for estimating the potential of NZ agricultural soils to increase soil carbon storage.

The idea that soils have an upper limit of C storage is based on the concept of soil organic C saturation proposed by Hassink (1997). This concept proposed that the upper limit of soil C storage is dependent on the quantity of stable soil organic C, the upper limit of which is determined by the amount of fine mineral particles (i.e. fine silts and clay). The concept has been tested and validated for a number of situations around the world. However, research in New Zealand (Percival et al. 2000) has challenged this concept by providing evidence that clay content explains relatively little of the variation in soil C content, whereas aluminium, allophane and, to a lesser extent, Fe-oxide contents are much more important. These results suggest that chemical stabilisation of organic matter is the key to processes controlling C accumulation in New Zealand soils but this theory has not been independently verified and we lack a predictive framework in which to apply this knowledge.

Despite the work of Percival et al (2000), the state of existing knowledge and tools needed to define the limits of soil carbon storage for New Zealand soils remains relatively poor. There is a general lack of knowledge and little integrated understanding of the factors that define the C storage potential of soils. Moreover, we do not have a predictive framework for establishing the upper limits of C storage in NZ's agricultural soils. As a consequence, we do not believe that there is sufficiently rigorous existing knowledge and tools (i.e. models) to satisfactorily model and map the upper limits of soil C storage for NZ's agricultural soils at this stage.

However, the project team also agreed that there is existing component knowledge and datasets that could be used to significantly advance our understanding of the key factors that define the C storage potential of NZ's soils and to develop a first-generation empirical model that will help us to predict the upper limits of C storage and identify testable hypotheses to explain the underpinning mechanisms.

### *3.1 – Progress in 2009/2010*

The project team met to define the scope of the project and outline a research plan for the remainder of the project (July 2010 – June 2012).

The project team agreed that the research plan should encompass the following four key steps:

1) Complete a review of the scientific literature to identify the factors that may define the upper limits of soil C storage.
2) Complete a meta-analysis of NZ data to identify sites with the highest soil C stocks and factors that explain variability in stocks.
3) Develop a first generation empirical model to predict the upper limits of soil C stocks

4) Outline a hypothesis to explain the underpin mechanisms of soil C storage suitable for testing beyond 2012.

Revised milestones for the period 1 July 2010 to 30 June 2012 will be provided.

### *3.1 – Progress in 2010/2011*

A literature review entitled: *Defining upper limits of soil carbon in New Zealand agricultural soils – A review of current concepts, approaches and the state of knowledge* has been completed.

In addition, a preliminary analyses of several existing datasets (e.g. 500 Soils, NSD, LMI) to identify the upper range of soil C stocks recorded for NZ's major agricultural soils has been completed. These and other datasets are being compiled for use in completing a comprehensive analysis of the available data.

The literature and the preliminary analyses are being used to develop a first generation empirical model to predict the upper limits of soil C storage based on an improved mechanistic understanding of the soil properties that define a soils C storage capacity.

### *3.1 – Progress in 2011/2012*

#### *Environmental factors affection soil C storage*

A report describing the results and interpretations of our analyses was published (Jones et al. 2012) and the key findings are summarised in an internal NZAGRC report. The report describes the upper range of soil C stocks recorded for NZ's major agricultural soils based on an analysis of the HSD, NFS and LMI datasets. This included a breakdown based on different soil, land use, and climate classification systems used in New Zealand and for international reporting (IPCC). Our analysis of the available data showed that Organic Soils had the highest upper range ($90^{th}$ percentile) soil C stocks (309 Mg $ha^{-1}$) in the top 30 cm; significantly ($P < 0.05$) larger than that of all other orders except the Podzol Soils. Among mineral soils, Podzol Soils had the highest upper range soil C stocks (215 Mg $ha^{-1}$) followed most closely by Allophanic Soils (185 Mg $ha^{-1}$). In contrast, the soil orders with the lowest upper range values were the Raw, Semiarid, Recent, and Pallic Soils. The 90th percentile values of Semiarid Soils, and possibly also the Raw Soils, were significantly ($P < 0.05$) lower than all other orders (67 and 23 Mg $ha^{-1}$, respectively). The report also includes an exploration of a general statistical distribution of soil C, with particular reference to the applicability of the distribution to the upper extremes, and the spatial correlation between samples. A non-parametric data mining method was then used to explore the relationship between soil C and selected environmental variables. Our results indicate a strong association between mineral soil classification and the upper range of measured C stocks in New Zealand soils. The report recommended that further research focus on identifying soil properties that best explain the variability in soil C stocks and using this knowledge to develop a mechanistic model for predicting the soil C storage capacity of New Zealand soils.

#### *First-generation empirical model*

A paper describing analytical basis of the model and its application to predicting the upper limits of C stocks for key soils and locations across NZ has been drafted and is currently undergoing internal review and revisions prior to submission for publication. The paper compares the methods (models) described by Feng et al. (2011) for determining upper limits of soil C stabilisation to an alternative approach based on an analysis of critical soil factors that may contribute to soil C stabilisation. We describe the upper limits of soil C based single and multi-variable quantile regressions of the dominant explanatory variables (e.g. mineral surface area, pH, pyrophosphate extractable Al [Al-P]). We conclude that the potential to increase soil C concentrations tends decrease linearly with increases in existing soil C concentrations. On average the potential to increase soils C concentrations ranged from about 25% at 20 mg C $g^{-1}$ soil to about 2% at 100 mg C $g^{-1}$ soil based on the 90 percentile quantile regression of 0-15 cm soils.

***Future research needs***

Understanding the mechanisms that determine soil C stabilisation in soils is not only critical for defining the upper limits of soil C storage in soils but also in evaluating the likely benefits of proposed soil C sequestration practices and management to mitigate soil C losses. If we don't understand these mechanisms then we have little hope of identifying lasting approaches to improving soil C sequestration or mitigating soil C losses.

The research needed to improve and validate the first-generation model of soil C upper limits includes:

- Develop a mechanistic framework that explains the contributions of critical soil factors and their interactions to defining the upper limits of soil C storage in New Zealand soils.
- Expand the size of datasets that can be used to quantify and validate the relationships between targeted soil properties and the upper range of soil C stocks across a wide range of NZ pastoral soils and climate zones.
- Identify and fill critical gaps in data need to map the upper limits of soil C storage in NZ's agricultural soils.

***Summary***

The results from our research in Obj 3.1 in 2011/12 indicate that the upper range ($90^{th}$ percentile) of measured soil C stocks in New Zealand soils (0-30 cm) ranged from about 23 Mg C $ha^{-1}$ in Raw soils to as much as 309 Mg C $ha^{-1}$ in Organic soils, with most of the values for the major mineral soil orders (e.g. Allophanic, Brown, Granular, Gley) falling between 145 and 185 Mg C $ha^{-1}$. We compared published methods for predicting the upper limit of soil C stabilisation to a mechanistic approach based on an analysis of specific soil properties (mineral surface area, pH, aluminium concentration) that may contribute to soil C stabilisation. The mechanistic approach provided the best fit to the data. We conclude that the potential to increase soil C concentrations (0-15 cm soils) tends to decrease linearly with increases in current soil C concentrations, on average ranging from about 25% at 20 mg C $g^{-1}$ soil to about 2% at 100 mg C $g^{-1}$ soil. Additional data and further analyses are needed to confirm these findings and apply them to estimation of a sequestration potential for New Zealand soils.

### *3.2 - Quantifying the carbon currently stored in New Zealand soils*

***Objective Leader – Dr Allan Hewitt (Landcare Research)***

Landcare Research
Manaaki Whenua

The NZAGRC's research programme on soil carbon is designed to move beyond quantifying the stock of carbon in New Zealand's agricultural soils to understanding the processes of soil C storage and management of those processes to conserve and, where possible, increase soil C stocks. One of the first steps in the research programme is to determine the current status of carbon stocks in NZ agricultural soils, and this is the object of this research objective. This work complements research in Objective 3.1 on the potential upper limits of C storage in NZ soils, and the outputs are designed to be compatible with those from Objective 3.1, although they may operate in a different manner.

The current state of knowledge is such that this objective will work to develop a mechanistic understanding of factors that affect the quantity of carbon currently stored under a range of conditions. This objective will work in tandem with Objective 3.1 to contribute to the development of a robust methodology for estimating the potential of NZ agricultural soils to increase soil carbon storage.

A traditional approach to estimating soil carbon stocks, used for carbon inventory purposes, is to use a linear regression model based on soil-climate regime, with modifiers for land use intervention and a correction for erosion (slope, rainfall). While this is a simple approach, there are several objections to such a model from both a statistical and soil science viewpoint. First, the relationship between soil carbon and these covariates appears to be non-linear (McNeill et al 2009), which suggests a methodological modification. Second, there is some evidence that the relationship with soil carbon is specific to each soil type, and perhaps land use, which suggests a more complicated form of model structure. Finally, the dependence of the model only on an assessment of current land use is somewhat at odds with the likely physical soil formation process prior to agricultural development and the long-term history of land use changes at a site. These difficulties suggest that a reassessment of the basic assumptions underpinning a model for soil carbon is required.

While in-depth knowledge of land use history is available for some sites of NZ, it is difficult to obtain a comprehensive land use history for all agricultural land in the country. We believe that a physically-based model may be able to reduce its dependence on recent land use history by introducing covariates related to the soil formation process. This is a novel aspect of this proposed research.

The rationale behind the physically-based modelling approach is that an important predictor of pre-European soil carbon is defined by Land Environments of New Zealand (LENZ) environmental classifications as a primary covariate, with land use change representing a subsequent alteration process. The basis behind this modelling assumption will be tested by way of a hypothesis-driven experiment using soil data within the conservation estate that has (largely) been unaltered since European settlement. If this approach fails the alternative will be an empirical approach to covariate selection.

We will develop a new model for soil carbon that satisfies three criteria. First, it is designed to be consistent with the likely soil formation process, as noted above, while also allowing for soil-class-dependent relationships. Second, it is designed to produce statistically-consistent and physically-plausible estimates of soil carbon, with uncertainty. Finally, the model will account for the spatial relationship between the available soils data used to fit the model, and will test whether an explicit spatial model is beneficial. We will develop a model that operates over agricultural land in NZ, using readily-available covariates. The exact structure of the model is to be determined by the available soils data, readily available covariate information, and by an early data analysis phase in the first research year.

The overall goal for Objectives 3.1 and 3.2 is to use respective estimates of the upper limits and current levels of carbon storage to spatially estimate the potential for soil carbon sequestration for

productive land. Objectives 3.1 and 3.2 differ in their approach. Objective 3.1 takes a mechanistic approach based on localised clusters of sites rich in soil attributes, good measurements of soil carbon and accurate land use data. Objective 3.2 takes a statistical approach based on scattered sites of national extent that have good soil carbon measurements but generalised land use estimates based on sometimes uncertain land use information.

Despite their apparent differences Objectives 3.1 and 3.2 are mutually consistent, in two ways. First, they share a common physical soil formation model, which proposes that current soil carbon values are strongly influenced by the pre-managed native state, and that current values result from the subsequent impacts of land management. Second, both objectives contribute to each other. A starting principle for Objective 3.1 is that the upper limits of soil carbon stabilisation are defined by key soil properties (e.g. mineralogy, chemistry). The extent to which these limits are achieved is determined by the balance between carbon inputs from primary production and the losses due to decomposition, which are driven by vegetation type, climate and management. Soil carbon levels are expected to remain stable where these drivers are constant for long periods of time. Estimates of pre-European soil C levels provide the best available measure of the maximum soil carbon storage at a given site (given its soil attributes and climate), though this may be an underestimate of the carbon stabilisation potential of the soil. However this data would provide a first approximation of the upper limits of soil carbon storage, albeit with high uncertainty There will be a continuing dialogue between the two objectives that is expected to refine our understanding of current and upper soil carbon levels, and the size of the difference between these two.

**Reference:**

McNeill SJ, Forester G, Giltrap,D. 2009. *Spatial autocorrelation analysis of data for the Soils CMS model.* Landcare Research Contract Report LC0910/003 prepared for the Ministry for the Environment, Wellington, New Zealand, September 2009. 43p.

McNeill SJ. 2010. *Soil CMS model recalibration and uncertainty analysis. Landcare Research Contract Report*: LC93 prepared for the Ministry for the Environment, Wellington, New Zealand, November 2010. 14p.

### *3.2 – Progress in 2009/2010*

The milestone this year was to determine the path forward for the next two years of work including the allocation of tasks and responsibilities.

To initiate an understanding of the team's skills, knowledge and ideas for progressing the project a number of phone conversations and email discussions occurred.

Once initial conversations were held, a face-to-face meeting was held in Palmerston North (15th June) to reach agreement on approach. The outcome of this meeting was a detailed action plan for 2010-12 and associated responsibilities.

### *3.2 – Progress in 2010/2011*

A common understanding has been developed with the project team on the task timeline, responsibilities and approach, and data required to begin the work were secured.

The databases to be used in the project were listed, and the BIP was defined for the major data sets required to initiate modelling; National Soils Database, LUCAS, and SINDI.

The approach being adopted for assessing the current levels of soil carbon in New Zealand agricultural soils was discussed in detail with scientists working in Objective 3.1 so that the approaches being followed in these separate but linked objectives were coordinated. This coordination of Objectives 3.2 and 3.1 was essential so that the respective results may be used to identify possible opportunities for soil carbon sequestration potential.

The modelling approach being followed has now been finalised. A new Generalised Linear Model (GLM) has been defined for the soil carbon spatial model which is based on a Gamma-distribution basis. This new approach overcomes a number of faults inherent in the Linear Model used in the existing MfE soil carbon model.

### *3.2 – Progress in 2011/2012*

Additional input data layers were obtained from the Land Environments New Zealand (LENZ) data. They included climate and soil attributes, and a 'natural potential vegetation' derived layer, which was used to indicate the variation in major carbon soil inputs before agricultural development. One of the innovations of this study was the premise that because of the relatively short history of agricultural use in New Zealand, the pre-human vegetation would be a significant driver of contemporary soil carbon variation, and in the event the potential vegetation layer has provided a significant effect in areas strongly affected since agricultural development (e.g. dunelands, wetlands). A new explanatory input layer was an agricultural use intensity derived from land use maps and stocking rate data.

Additional topsoil carbon data was obtained by developing a statistical regression model to predict 0-15cm and 0-30cm depth samples based on 1-10cm depth samples, thus extending the spatial support of the soil data.

A spatial statistical soil carbon model was developed for all of New Zealand. The strongest explanatory input variables were the LENZ environmental classification layers, and the potential vegetation layers. This appears to support the initial proposal that carbon levels have been strongly influenced by anthropogenic influence of some environment classes since agricultural development.

The analysis reveals the median soil carbon stocks for New Zealand are 88.3 t/ha, and that the 5% and 95% quantiles of stocks are 37.5 and 153.8 t/ha respectively. Low values of soil carbon stock are typically in soils with low water storage capacity or in areas where soils have formed under low rainfall. High values of carbon are found in soils formed under high rainfall, and in soils formed in materials that have either high contents of lime or dark coloured volcanic rocks. The lowest values are in Organic Soils.

The model of soil carbon was applied over the landscape of New Zealand, to produce a soil map of the 0–30 cm layer at 1km spatial resolution. The error in this map is half that present in the current soil carbon model used by MfE (24.4t/ha vs. 40.7t/ha). This is significant because the current MfE model is used in GHG inventory calculations, and this result reduces the uncertainty. This map will allow us to identify how and where technologies to increase soil carbon levels could be potentially deployed in New Zealand.

### *3.3 - Process-based modelling of drivers of soil carbon change*

***Objective Leader – Prof Tony Parsons (Massey University)***

Our capacity to manipulate soil C (stocks and sequestration rates) depends on how well we understand the fundamental drivers of C supply, transformations and stability, in the whole of the plant, animal, and soil continuum, and so can evaluate the scope and credibility of manipulating these. The extremely long time frame for measurable changes in soil C stocks, its spatial and temporal variability, and the greater difficulty therefore in measuring changes in the rate of sequestration, means that detailed process-based dynamic models are an inescapable tool for generating insights into the drivers of soil C change. Such models are also essential to foresee what impacts strategies for changing soil C would have on emissions of methane, nitrous oxide, and on agricultural productivity.

Many grassland ecosystem models have been produced, but these differ significantly in suitability for this task. Some detailed 'soils' models lack a dynamic or responsive plant component. Others lack dynamic treatments of the grazing animals' role in C and N cycling. Some whole 'systems' models lack an explicit soil biologically active biomass. Models can differ considerably in the way different 'pools' /forms of organic matter are represented and in how these interact.

We will make progress by revisiting the scope of the few major soil C (but ecosystem wide) models, e.g. Century, (CenW), RothC, Hurley Pasture Model, and adding to a selected model (maybe a different model for different purposes) several essential new components. Of particular interest is to reconsider the enzymatic stoichiometry of different forms of soil micro-organism, notably the requirement for excess C (relative to N) in heterotrophs, compared to the reverse, a substantial requirement for N more than C in chem-autotrophs (typically nitrifiers) obtaining energy not from oxidative respiration (of C), but from their nitrogen transformations of ammonium. The modelling will progress in concert with development of molecular methods for assaying the balance of critical functions in soil, being investigated in FRST SRU C10X0903. Other examples of new components to be added are: changes in plant traits with likely impacts on the 'microbial loop' (+ve feedbacks to plants from soil micro-organisms) and e.g. Priming, and Progressive Nutrient Limitation (-ve feedbacks that may limit C sequestration). Our models include the role of animals in uncoupling, and of legumes in re-coupling, the C and N cycles (Soussana 2008; Schwinning and Parsons 1996). We will be using the original sources of insights in these areas, which are being relied on heavily in other nations (as in Soussanna 2008), to guide 'rules of thumb' for IPCC-type national C commitments.

### *3.3 – Progress in 2009/2010*

A research plan for Objective 3.3 has been identified, following meetings involving NZAGRC head, PI (Whitehead), lead scientists in this objective (Kirschbaum and Parsons) and expert input from climate change area (Newton). Discussions focussed on how modelling in this Objective has a distinctly different focus (the essential development of new concepts for above/below ground interaction in stoichiometry and the uncoupling of C and N cycles, that drives the system carbon outcomes) from work in other objectives in Theme 3, and from systems modelling of nitrous oxide and methane emissions, in Theme 4.

Access to key models, embodying two schools of approach and lead expertise in each, have been secured. The Hurley Pasture model (Thornley, Parsons) has been re-envigorated and re-tuned for NZ grassland conditions and shown to be effective in having a good balance of process detail in plant, animal and soil components of the grassland ecosystem. The model CenW (Kirschbaum) has been established as having key elements and approaches, and embodies substantial expertise, in notably soil components. Both have been used for ecosystem C sequestration issues in the past.

A visit by Thornley, to re-engage in developments to the HPM was secured (Feb/Mar 2010) funded by AGMARDT.

A substantial catalogue of farmers talks, conference talks, and press articles (most joint with Prof. Rowarth, Massey Agriculture) has established our role in science communication in soil C.

### *3.3 – Progress in 2010/2011*

The key work for 2010/11 was a critical appraisal of the approach taken by existing soil carbon models, in particular a consideration of the consequence that flow from the general dependence of soil microbial activity on plant-derived carbon supply. We tested a soil-organic matter module that explicitly included mycorrhizal fungi and free-living saprotrophic fungi and bacteria as separate functional groups within the model and found that systems with mycorrhizal fungi had more carbon than non-mycorrhizal systems. This indicates that current models lack the sophistication to accurately predict soil carbon storage across the range of conditions found in practise.

The Hurley Pasture Model is also being developed so that it can better predict the effects of N fertiliser inputs on soil C storage. In particularly routines are being added that will allow an exploration of how applied N, which can be used as an energy source by some microorganisms (eg nitrifying bacteria) changes the demand for N relative to C in the soil and so affect soil C sequestration and C and N fate.

Substantial efforts have been made to communicate issues of GHG mitigation, including the role of biosphere carbon sequestration, as an 'offset', to farmers and industry.

### *3.3 – Progress in 20011/2012*

Our Grassland Ecosystem Dynamics model (HPM) has undergone major revision, to add more realistic biological function in micro-organisms in the soil; and to fully account for how lactating (dairy) animals, compared to dry animals, alter the cycling and fate of C and N, and the longevity of these in the plant, animal, soil system. Presentations by the model demonstrate the significant role of the continual offtake of both C and N in intensive, notably dairy, systems, leads to a reduction in C and N sequestered in soil, and that there is a limit to the capacity to overcome (amend) for this using additional fertiliser (N). The model (HPM) has been used to illustrate the impacts of all possible combinations of changes in stocking rate; fertiliser input, water use, and dry vs dairy offtake animals (hence the major drivers of soil C change) in a way that matches and so provides highly plausible explanations for the long-term field based nation-wide observations of changes in soil sequestered C and N, published by Schipper et al. (Waikato). The modelling therefore answers question of what prospects there are for major mitigation of soil C (and N) changes, and for sustaining or increasing ruminant production (agri-industry) while minimising environmental impact. It also can help to assess the likely risks and opportunities arising from NZ opting to account for soil C sequestration within a land use. Ongoing work considers the prospects for increasing soil C sequestration rates by modifying plant traits and their N-use efficiency, in both a current and future climate

The model-eddy flux data comparison resulted into significant new insights into the special problems and difficulties involved in detailed matching of gas exchange rates from pastures between models and observations. Grazing events are highly episodic, localised at specific paddocks. Grazing causes $CO_2$ flux rates to change between small on-going gains during photosynthesis and growth, and large short-term $CO_2$ losses from the respiration of ingested feed by grazing animals. The fluxes can only be understood if the exact timing of grazing events can be matched with wind speeds and directions at those times. It also requires detailed compilation of the timing of grazing, harvesting and provision of supplemental feed.

Work has progressed significantly, and we have developed appropriate modelling structures and routines to enable that comparison. The insights gained through this work are greatly strengthening our understanding of the required methodological approach for analysing the observations of eddy-flux measurements.

### *3.4 - Manipulation of carbon inputs, incorporation and retention to protect and enhance soil carbon*

***Objective Leader – Dr David Whitehead (Landcare Research)***

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Soil carbon storage on land managed by pastoral farmers accounts for 85% of the national carbon storage for all land uses (to a depth of 0.3 m) in New Zealand, so small changes in carbon storage are important for the national inventory. Carbon storage is already high in many soils, so research to develop farm management practices that protect and retain existing soil carbon, possible leading to increases in carbon storage, is a priority for the pastoral industry. Most research so far has concentrated on methodologies to quantify the amounts of carbon stored in soils with much less emphasis on ways to manipulate the rates of carbon input, incorporation and retention in soils and, crucially, how any changes in storage can be verified.

The aim of this objective is to use measurements and models to quantify changes in soil carbon storage following experimental manipulation that could be applied as farm management practices. The research will move beyond quantification of the amounts of carbon in soils (this work is funded by other agencies outside the NZAGRC to understanding the processes driving soil carbon storage in relation to farm management with a focus on three areas identified as high priority:

- Comparison of farm practices at adjacent grazed sites (*manipulating carbon input*). The experimental variable (eg. addition of nitrogen fertiliser, selection of pasture species) and the sites will be selected following a full review of previous work and discussions with end users
- Effects of the presence or absence of invertebrate earthworms on the amount and distribution of carbon in the soil profile (*manipulating carbon incorporation*)
- Addition of biochar to grassland soils (*manipulating carbon retention*).

We will use a range of approaches and work at a range of scales from mesocosms, field plots and paddocks, employing a range of appropriate methodologies. We will make long-term, continuous measurements of carbon exchange at ecosystem scales at adjacent sites with contrasting management practices using micrometeorological instrumentation and supplementary field measurements. From estimates of seasonal changes in the components of carbon balance, we will calculate changes in soil carbon storage and reveal the processes regulating rates of storage. Our initial work with earthworms will be done using mesocosms in controlled conditions where the earthworms are introduced and this approach will later be extended to three field sites with contrasting soil types. We will use proof of concept lysimeters experiments to test the effects of and biochar addition and rooting depth using different pasture species on biochar stabilisation, then extend this work to field trials with different summer forage crops. We will also develop reflectance spectroscopy techniques to analyse for root density and black carbon concentrations in soils enriched with biochar.

Data from these three approaches will be interpreted in relation to environmental and experimental variables and used with models to inform end users of forecasted changes in soil carbon with manipulation practices.

### *3.4 – Progress in 2009/2010*

Research plans were discussed and prepared for initiating three experimental investigations involving procedures to manipulate soil carbon:

1. Management of pasture with addition of fertiliser or manipulation of species to be decided (manipulating carbon input led by Louis Schipper)
2. Effects of presence or absence of invertebrate earthworms on the amount and distribution of carbon in the soil profile (manipulating carbon incorporation led by Alec Mackay)
3. Addition of biochar (manipulating carbon retention led by Marta Camps).

A videoconference was held to discuss the most appropriate and relevant variable to be used in manipulating soil carbon input (1) and a further meeting between researchers and the dairy sector for a decision is planned for early August.

CAPEX items enabling continuous measurements of carbon exchange using (a) the ecosystem eddy covariance approach and (b) automatic soil surface chambers were purchased.

### *3.4 – Progress in 2010/2011*

An analysis of the components of ecosystem carbon balance using micrometeorological approaches at Scott farm has been completed and the results incorporated in a paper submitted for publication. In contrast to the more general finding from a range of sites that lowland soils under dairying are losing soils the results at Scott Farm indicate that the in both years carbon was being stored.

A second set of instrumentation was purchased using funding from the NZAGRC in 2010 and a third will be set up. These all use the new closed path systems for continuous estimation of carbon component fluxes, providing the benefit of fewer data gaps caused by rain interference. Preliminary data comparisons demonstrate very good agreement between the new and existing equipment.

Experimental mesocosms for investigating the effects of introducing worms on soil carbon storage have been set up successfully and the first set of samples collected for analysis. An new approach using natural abundance carbon isotopes has been developed and will be used to detect how is dung incorporation into the soil profile.

The first stage of this work has been completed with biochar being successfully produced from wood. The second stage, producing biochar from biosolids/green waste has been delayed due to delays in obtaining consent to produce and apply biochar from biosolids/green waste. Experimental facilities to test the long-term effects of biochar on soil carbon have been set up and initial sampling is underway.

### *3.4 – Progress in 2011/2012*

Two years (2008-09) of carbon balance measurements at dairy farm Scott farm have been published. The two years were climatically very different, with summer 2008 being very dry and winter 2009 being fairly cold. Despite these conditions, the site was a small sink for carbon in both years (between 600 and 900 kg $ha^{-1}$ $y^{-1}$). Analysis of 2010 and 2011 data is underway and will determine the effect of a full cultivation on the carbon balance. Initial analysis suggests that the site remained a sink for carbon on a yearly time scale despite the loss of carbon following the cultivation in 2010.

At a second farm near Waharoa, continuous measurements of carbon exchange have started late 2011 over two blocks. Both sites are scheduled to be re-grassed (one to rye grass/clover, the other to a sward with higher species richness and higher root biomass) in autumn 2013 so that the effect of the high diversity swards can be determined. We are preparing to monitor a third block that will not be re-grassed as a true control.

Anecic earthworms have a patchy distribution throughout New Zealand and it is estimated that they are absent from 7 million hectares of pasture land. Anecic earthworms feed on the organic matter on the soil surface and excrete the organic matter consumed to depth in the soil profile. Preliminary results from current mesocosm and field studies suggest that anecic earthworms are incorporating some of this organic matter into the soil. However, several decades after their introduction into hill country there was a decline in soil C at one site and no influence on soil C at another site. It would appear that their interaction with the resident earthworm communities may be important. The mesocosm and field studies currently underway will help us to understand this better.

Research has been undertaken to develop stable carbon test methodologies to estimate (i) the intrinsic stable carbon in biochar, and (ii) the stable carbon in biochar after its addition to soil. Good relationships have been found between the $H/C_{org}$ ratio and chemical aromaticity in biochar. The residual fraction of biochar after dichromate oxidation has been used as a proximate method to estimate stable carbon in biochar, although this method may not only identify the condensed aromatic C fraction of biochar but also hydrophobic aliphatic structures resistant against dichromate oxidation.

Once added to soil and during the first 100 days of incubation, biochar produced from corn stover at 350 and 550 °C induced a negative priming effect on soil organic matter decomposition in the two soils tested (Typic Fragiaqualf and Typic Hapludand). After 400 days, an important positive priming effect was evident in the Andosol soil. Physical fractionation analysis revealed that most of the biochar particles remained in the coarse and fine free particulate soil organic matter. Biochar produced from a biosolids and a mixture of biosolids and *Eucalyptus* wood residues at 550 °C stimulated root elongation on poor sandy soil (Typic Udipsamment) thus contributing potentially to the increase of the soil carbon sink.

### *3.5 - Improved soil carbon measurements*

***Objective Leader – Prof Frank Kelliher (AgResearch)***

This objective's goal is improved methods to verify temporal changes in soil carbon (C) storage and accounting rules suitable for a national inventory of agricultural soils.

Soils data in New Zealand are fragmented, geographic coverage limited and most samples have come from a depth < 0.1 m. It will be difficult to verify slow, relatively small and variable changes of C storage rate in pastoral agricultural soils. Improved methods will include the development of data analyses. This objective will begin with two foci.

Firstly, many soil properties change with depth and such relations are called vertical distributions. Analysis proceeds with a (continuous) function, optimised to fit integrated measurements made on samples excavated at discrete depth intervals. For soil C, research questions include:

1. Can C storage in soils be extrapolated from one depth interval to another (e.g., from a shallow depth interval to a deeper one) with sufficient accuracy to detect statistically significant temporal changes?
2. Is the C storage rate in soils related to the vertical distribution of C storage?
3. Do climate change and/or management (e.g., irrigation, deeper-rooted plants) sustainably affect the vertical distribution of C stored in soils?

The second foci will be analysing measurements that partition total organic C into functional fractions (distinguished by different decomposition rates) for a soil carbon cycling model. A system of automated, proxy measurements has been developed by CSIRO. As a case study, proxy measurements were recently done by CSIRO on a set of New Zealand agricultural soil samples collected by Plant and Food Research. Analysing the measurements will quantify parameters in a model to estimate C storage rate over (many) decades and sensitivity of the rate to the measurements (different fractions). Research questions include:

1. Can the partitioning of total organic C into functional fractions improve the estimation of C storage rate in soils?
2. Does the partitioning of total organic C into functional fractions reveal differences between soils that can be used to improve sustainable management of the C storage rate?
3. Can a functional fraction measurement/model system help to develop accounting rules suitable for a national inventory of agricultural soils?

The development of data analyses can improve methods to verify temporal changes in soil C storage. This can contribute to the development of soil C storage rate accounting rules for agricultural land managers. This can connect them to the national inventory of agricultural soils and improve its performance, the estimation of C storage rate in soils.

### *3.5 - Progress in 2009/2010*

Milestone 3.5.1 was for the team to agree on the required outcomes and develop a two-year achievement plan. It is understood the plan will be preliminary including the allocation of tasks and responsibilities.

To develop an understanding of the team's skills, knowledge and ideas for the work, there were a number of phone conversations and email discussions then a face-to-face meeting held in Palmerston North (26th May 2010). Notes from this meeting have been summarised in the milestone report. The key decisions included responsibilities for FY 2010/11. Kelliher will analyse samples from Winchmore to determine if sixty years of irrigation onto grazed pasture has affected soil carbon storage and submit one manuscript for publication to a peer-reviewed journal by 30 June 2011. Beare and Baldock will analyse data from a pilot study of New Zealand soil samples

that were subjected to automated, proxy measurements at CSIRO to partition total organic carbon into functional fractions for a soil carbon cycling model and complete one draft manuscript by 30 June 2011. Deurer and Clothier will analyse data from soil sampled beneath kiwifruit and apple orchards, woody and deep-rooted agricultural crops, to quantify the vertical distribution of (soil) carbon storage and extrapolation power from one depth interval to another. With Kelliher, these vertical distributions of soil carbon storage will be compared to those beneath grazed pasture.

### *3.5 - Progress in 2010/2011*

A method to analyse the vertical distribution of carbon stored in soils from existing soil cores has been developed. The method indicates that 60 years of border-dyke irrigation of sheep-grazed pasture at Winchmore reduced the soil carbon storage by 47% to a depth of 1 m. Irrigation also resulted in a significantly greater proportion of the soil's carbon located near the surface. By modelling, we also determined irrigation had induced a 36% increase in the mean annual rate of carbon inputs to the soil, mostly as litter fall but that this had been accompanied by a 97% increase in the annual soil respiration rate. These data suggest that, at this site, seasonal irrigation over 60 years would have reduced C storage by 61%, reasonably accounting for the effect determined by the soil samples.

Soil samples extracted from the Winchmore plots in 1976 and "archived" in a garage located near the plots and samples taken in 2009 have been subjected to further analyses in a laboratory to measure different size fraction, indicative of different organic matter decomposition rates. These data will be analysed during 2011/12.

A conference presentation describing the use of new methods to measure (MIR and partial least squares analyses) and model (variant of RothC) changes in total soil carbon and different-size fractions in the soil has been prepared and submitted to an International Symposium on Soil Organic Matter to be presented in July 2011.

### *3.5 - Progress in 2011/2012*

We examined the C storage in soils after 27 and 60 years of border-dyke irrigation of sheep-grazed pasture at Winchmore, to depths of 0.225 and 0.25 m, respectively. The total C storage in plots receiving irrigation was significantly less than that in plots receiving rainfall alone (5.8 ± 0.5 versus 7.6 ± 0.5 kg C $m^{-2}$ after 27 years, mean ± standard deviation, and 7.4 ± 0.4 versus 8.7 ± 0.5 kg C $m^{-2}$, after 60 years). The irrigation effects differed significantly for C storage in the three size fractions, and while the results were also significantly affected by sampling depth, alternative, equivalent mass calculations did not substantially alter the results.

Results from the analyses of the data collected under the *Land Use Change and Intensification* (LUCI) showed that the mid-infrared spectroscopy (MIR) method successfully predicted changes in total soil C and soil C fractions under changes in management and land use. The RothC model, calibrated for use with the measured soil C fraction data, successfully modelled the measured changes in soil C stocks and fractions from the LUCI data set. Although the decay constants fitted for the model were robust under a wide range of management conditions, adjustments to the constants were required to optimize the model performance where the inputs of C were substantially lower (e.g. winter or continuously fallow systems). This results suggests that one or more additional driving variable(s) (beyond temperature and soil moisture) may be important in regulating the turnover of labile soil C pools.

For an allied 1-year research project funded under the SLMACC programme (MSI contract C10X11106), a meta-analysis was done of 56 pastoral soil C profiles across NZ sampled by horizon. The uppermost A horizon averaged 0.1 m deep, and the total depth averaged 0.9 m. The soils were grouped by order, and for total C storage, allophonic > non-allophanic > pumice soil orders. By regression analysis, we developed relations between C density in the A horizon (kg

$C/m^3$) and total C storage (kg $C/m^2$) that yielded predictions with a standard error of 3 kg $C/m^2$, 19% of the mean. Thus, we were able to estimate the total C storage of pastoral soils across NZ from shallow sample data with a 19% error. While imperfect, the relation suggests the possibility of added value from shallow sample data, most commonly available from the assessment of soil fertility.

### *4.1 - Mechanistic modelling of enteric $CH_4$ production*

***Jointly supported programme: NZAGRC & SLMACC***

***Objective Leader – Dr David Pacheco (AgResearch)***

The development and evaluation of methane mitigation strategies requires a mechanistic understanding of the processes influencing methane formation in the rumen. The ability to predict responses in methane formation from NZ ruminants will improve inventory and accounting of GHG, and is fundamental to inform research and policy.

Responding to global interest in climate change and environment impact, existing mathematical models of ruminal digestion and animal metabolism have been enhanced in recent years to include prediction of methane production. The two major research efforts in mathematical modelling of methane formation[1] in the rumen have a common paradigm of methane formation. Namely, methane formation is a function of excess hydrogen resulting from reactions in which hydrogen is produced and reactions in which hydrogen is utilised. Such reactions have been more or less adequately described for dairy cattle only, with predictive models for other ruminant stock classes less well described. In addition these models have been parameterised using diets that are untypical of the forage dominant diets consumed by New Zealand ruminants.

This project will focus on two areas for improving the prediction of methane production. Firstly, we seek to identify the sensitivity of methane prediction to the digestion and metabolic processes currently represented in models of rumen metabolism, particularly in relation to forage based diets and how these processes are likely to vary among ruminant species. This step aims at improving the "top-down" approach currently used in models of methane production. Thus, the critical aspects of rumen digestion on hydrogen production and utilisation are parameterised for relevant stock classes and dietary conditions in New Zealand. Secondly, advances in the understanding of methanogen metabolism, growth and population dynamics create the opportunity for improving the prediction of methane from "the bottom up" by including a better representation of the mechanisms controlling hydrogen utilisation by methanogens. Outputs from this research will include an improved mechanistic representation of methane production across a range of ruminant species, which can be used to improve current whole-animal models.

### *4.1 – Progress in 2009/2010*

A series of workshops were organised by AgResearch researchers with key national and international researchers working in the area of methane modelling.

The first workshop was held on March 25, 2010, in Hamilton, New Zealand. This workshop established the current state of methane modelling in New Zealand and cemented the establishment of the working group for this Objective.

A second workshop was held on April 9 and 12, 2010 in Hamilton, New Zealand. This workshop included the participation of Dr. André Bannink, (Animal Science Group, Wageningen University). We identified and prioritised key processes that need to be adequately described for forage diets and animal species to achieve the goal of a multi-species mechanistic model of rumen methane formation.

[1] The Dutch-Canadian model based on the work of Bannink, France, Kebreab, Dijkstra and Mills; and the American whole-animal model "Molly" based on the work of Baldwin, and later improved by McNamara and Hanigan.

The third workshop was held on April 20, 2010 in Sydney, Australia to discuss trans-Tasman collaboration and funding opportunities with Australian researchers from NSW and Victoria.

These workshops have moved our thinking from trying to re-parameterise current models to fit New Zealand diets, towards reviewing and quantifying key processes underpinning methane formation in the rumen, which may or may not be necessarily represented in current mechanistic models.

### *4.1 – Progress in 2010/2011*

A review of the key ruminal processes involved in methanogenesis has been completed. A key finding is the identification of outflow rate as a central and influential process in all models. Thermodynamic principles are also critical for a mechanistic understanding of the processes of fermentation (e.g. VFA production) and subsequent methanogenesis in the rumen. However, their implementation in a modelling framework depends on suitable estimations of pool sizes and substrate concentrations, which in turn are affected by the outflow of solid and liquid material from the rumen. These data are not currently well estimated for forage fed ruminants.

The main goal of this exercise was to identify the processes that have a strong influence in the prediction of methanogenesis in the rumen. Now that this has been completed we are well placed to define the key areas we will concentrate on for this modelling project and undertake future experimental work based on a 'first principles' approach.

### *4.1 – Progress in 2011/2012*

We developed new equations for predicting molar proportions of volatile fatty acids (VFA) in the rumen of sheep fed fresh forages. These equations were derived by meta-analysis of data from previous NZ experiments. The new model improved predictions of VFA for sheep fed fresh temperate forages, but was not suitable to predict other types of diets. The latter could be the result of the small number of datasets available to construct the new model. The relatively poor predictive ability of chemical composition-based models for fresh forage diets suggests that that the digestive processes underpinning VFA, and hence methane, are not fully understood at least when it comes to fresh forages.

Mr James Wang obtained provisional registration as a PhD candidate at Massey University to work in this project. As part of his PhD project, Mr Wang has worked on the development of a mathematical model of the interactions between hydrogen concentrations and methanogen growth. This model has been developed from "best guess" estimates of some metabolic rates of methanogens, such as maximum $H_2$ consumption per methanogen, $H_2$ requirements for maintenance and growth. Currently the model is being tested to ensure that the modelled outcomes (methanogen population and hydrogen concentrations) are biologically sensible.

André Bannink (Wagenigen UR, The Netherlands) spent 6 weeks working with David Pacheco supported by a GRASS Award.

### *4.2 - Improved $N_2O$ Component Modelling*

***Jointly supported programme: NZAGRC & SLMACC***

***Objective Leader – Dr Iris Vogeler (AgResearch)***

Most models of soil C and N cycling include process descriptions or equations representing denitrification and some of those process descriptions include the portioning of denitrification between $N_2O$ and $N_2$. All of the models have strengths and weaknesses in different areas:

- some are highly explanatory but suffer from the inclusion of processes that are impossible to model quantitatively in a robust manner;
- some have empirical partitioning between $N_2O$ and $N_2$ that might not hold for all the required physical and chemical conditions that the model is to be applied in but have well developed and tested descriptions for the supporting soil processes; and
- most of the models do not account for the spatially heterogeneous return of urine to pastures or for the effects of the urine patches on denitrification.

This theme of work will:

- review the component models in the literature and chose the best candidate(s) for further development and testing (Milestone 4.2.1);
- source published datasets for model development and validation and seek collaboration with concurrent work funded by the NZAGRC to ensure that the improved model will represent the best emerging knowledge (Milestone 4.2.2);
- improve the $N_2O$ components of the model(s) chosen and test the improvements using the identified datasets (Milestone 4.2.3); and
- link the N2O and CH4 components into farm system model(s) to test mitigation opportunities at a systems level (Milestone 4.2.4).

### *4.2 – Progress in 2009/2010*

Val Snow was invited to attend a planning meeting for the $N_2O$ programme organised by Drs de Klein and Di. The purpose of this invitation was to ensure good coordination between the experimental and process understanding work in the $N_2O$ programme and the model development and testing work in Theme 4. Particularly interesting prospects for leveraging the two programmes were identified and collaborative work will be planned as the work streams progress.

Val Snow and Cecile de Klein visited Peter Thorburn and Jodi Biggs, CSIRO Sustainable Ecosystems in Brisbane, to discuss collaboration possibilities. Common interests were identified. CSIRO will make available a recent adaptation to the soil C-N module in APSIM that has adapted and incorporated the denitrification process descriptions in DayCent that allows the prediction of both total and N2O denitrification. A return visit is planned for July 2010.

Rogerio Cichota began updating the Tussock Creek modelling database (developed as part of the P21 Environment programme but included data relevant to leaching only) with $N_2O$ data in anticipation that this will provide an important dataset for model testing.

Iris Vogeler and Val Snow met with Donna Giltrap to plan the model review and to discuss the $N_2O$ database that Donna has been developing. Preliminary work on the review has been completed by identifying existing reviews focussing on denitrification, soil nutrient modelling and farm systems modelling.

### *4.2 – Progress in 2010/2011*

A dataset of 150 different combinations of measurements from a range of NZ climates, soils and soil drainage classes, periods, from dairying and sheep and beef on flat and hill country has been

compiled. Existing datasets for $N_2O$ model development and testing model review have been compiled. The database will regularly be updated to include new data when available. A report on the "Datasets for $N_2O$ modelling" has been written.

A number of different $N_2O$ component models, identified in the internal report on "$N_2O$ model review and selection of appropriate models" have been integrated into the APSIM modelling framework and are currently being tested against the experimental dataset for their ability to simulate N cycling of the soil, which is essential for accurate predictions of $N_2O$ emissions.

A comparison of two different modelling approaches for simulating N cycling in soils, DNDC and APSIM, has been undertaken in detail and the results will be presented at the Modsim conference in Perth, Dec 2011.

### *4.2 – Progress in 2011/2012*

Datasets for $N_2O$ modelling

Statistical analysis of the compiled $N_2O$ database has been linked with outputs from DairyNZ's Whole Farm Model to estimate Farm $N_2O$ emissions. A paper has been published on this in Soil Research: "Estimating Nitrous Oxide Emissions from a Dairy Farm based on a Mechanistic Whole Farm Model and Segregated Emission Factors for New Zealand". This paper showed that on farm $N_2O$ emissions based on the segregated Emission Factors for NZ were 5% lower than those based on NZ specific Emission Factors. Better management and mitigation options, such as the use of nitrification inhibitors during critical periods, stand-off pads, and timing of fertiliser and effluent application could further reduce farms scale $N_2O$ emissions by about 30%.

Improved $N_2O$ modelling

Different datasets comprising $N_2O$ measurements from the Otago and Waikato have been modelled with both the APSIM and DNDC model. The model simulations have been compared to measurements, including soil ammonium and nitrate concentrations to evaluate how the various N transformation processes are captured within the models. This information will be used within a sensitivity analysis to improve model parameterisation and performance.

Two different $N_2O$ component models, Nemis and WNMM, have been integrated into APSIM and are currently being evaluated as alternatives by comparing simulation outputs to various datasets dataset. Preliminary results have been presented at the NZAGRC 2nd annual conference: "Modelling nitrous oxide emissions from urine patches: Comparison of different approaches". Simulation results were compared to datasets comprising $N_2O$ emissions from urine patches. For a urine patch deposited in May in the Hamilton region the annual nitrification simulated by the various approaches was very similar. Simulated denitrification and $N_2O$ emissions, however, showed a high variability of one magnitude between these approaches.

So far none of the models could be identified as being more suitable model for estimating $N_2O$ production and mitigation strategies in NZ farm systems. The next step requires a detailed sensitivity analysis to identify and modify the model that is best suited for the many different environmental conditions inherent in NZ's farming systems.

Dr. Rogerio Cichota was invited for a two week visit to the Campinas Agronomic Institute (www.iac.sp.gov.br), hosted by Dr Chiba. During his visit he gave two seminars, including an introductory course on farm modelling using the APSIM framework. During the visit Dr Cichota established contacts with researchers studying GHG emissions from tropical pastures and the impact of land use change on the GHG inventory for Brazil.

## APPENDIX 3 – NZAGRC INTERACTIONS AND OUTPUTS

### *Meetings and Presentations (New Zealand)*

- Meeting with social scientists working on climate change across CRIs, to discuss opportunities for input to the IPCC 5th Assessment Report, GNS Lower Hutt: 14 July, 2011
- Presentation to agriculture industry representatives and government officials on the implications of alternative GHG metrics globally and for New Zealand. Roundtable organised by the New Zealand Climate Change Centre; Federated Farmers Boardroom, Wellington: 15 July, 2011
- Keynote address on the occasion of the launch of the book “Climate Change Law and Policy in New Zealand”, edited by Alastair Cameron, LexisNexisNZ. BuddleFindlay Boardroom, Wellington.: 18 July, 2011
- Briefing on progress with IPCC WGII 5th Assessment Report with MPI officials. MPI, Wellington: 19 July, 2011
- Presentation by Peter Janssen to Massey Agriculture Student Professional Workshop - Finding ways for reducing greenhouse gas emissions without reducing agricultural output: 12 August, 2011
- NZAGRC Steering Group meeting: 18 August, 2011
- Meeting of the executive of the New Zealand Climate Change Centre - phone conference: 24 August, 2011
- Presentation by Louis Schipper at launch of the Environmental Research Institute at the University of Waikato, Hamilton - "Can we increase carbon in New Zealand pasture soils?" : 26 August, 2011
- Breeding Dairy cattle for low GHG - PGgRc collaborative workshop: 13 September, 2011
- Meeting of the planning committee of the New Zealand Climate Change Centre for the upcoming conference “Climate Change and New Zealand Coasts” - phone conference: 15 September, 2011
- NZAGRC Science Leadership Team meeting: 20 September, 2011
- Meeting with Dr Doug Cleverly, CEO of Argenta: 21 September, 2011
- PGgRc/NZAGRC meeting to work on research programme alignment: 22 September, 2011
- Meeting with Blair Stewart & Sanne Melles (Vialactia) re NZAGRC work programme: 28 September, 2011
- PGgRc Board meeting: 29 September, 2011
- Presentations on nitrification inhibitor research to the CEO and General Manager of the Tertiary Education Commission, scientists and environmental managers and farmers from Australia and France by Professor Di Hong: 30 September, 2011
- Nicole Schon contributed to several presentations to industry groups over the last three months (Beef & Lamb, DairyNZ) regarding the role of earthworms in the carbon cycle: 30 September, 2011
- Presentation to Palmerston North Lions Club - Overview of NZAGRC work programme: 04 October, 2011
- NZAGRC SAG meeting (rescheduled from 17 August): 11 October, 2011
- Agricultural Emissions Trading Scheme Advisory Committee meeting: 28 October, 2011
- Meeting of the Agriculture Inventory Science Advisory Panel; MPI, Wellington: 15 November, 2011
- NZAGRC Steering Group meeting: 17 November, 2011
- NZAGRC Science Leadership Team meeting: 28 November, 2011
- Meeting with Steve Thompson, Science and Innovation Promoter, British High Commission, Wellington: 29 November, 2011
- Meeting with David Lee, Strategic Planning Unit, Greater Wellington Regional Council, on strategic planning for climate change; Wellington: 29 November, 2011
- Presentation to the AgDialogue group hosted by Motu Economic and Policy Research; Wellington: 30 November, 2011
- MPI's Technical Advisory Panel meeting - Technical assessment of EOIs for the New Zealand Fund for Global Partnerships in Livestock Emissions research: 30 November, 2011
- Presentation to Climate Change Research Strategy for Primary Industries Forum : 08 December, 2011
- Meeting with Stephen Oakley, Statistics NZ, on compilation of environmental performance indicators; Wellington: 08 December, 2011
- Meeting with Kennedy Graham (Greens), on climate science and long-term mitigation strategies; Wellington: 08 December, 2011
- Meeting with John Newbold - Discussions re approach to methane mitigation: 22 December, 2011
- Progress report for stakeholders "Soil carbon changes from shallow samples" by Frank Kelliher: 23 December, 2011
- Reducing Emissions from Livestock Research Program Conference Planning Committee: 09 January, 2012
- Briefing for MPI officials on the implications of alternative GHG metrics; MPI, Wellington: 27 January, 2012
- NZAGRC International Advisory Group meeting: 30 January, 2012 - 2 February, 2012
- NZAGRC Annual Conference, Palmerston North: 31 January, 2012
- Keynote presentation to NZAGRC Annual Conference; Palmerston North: 31 January, 2012
- NZAGRC Science Workshops, Palmerston North: 1 February, 2012 - 2 February, 2012
- NZAGRC Stakeholder Advisory Group session: 01 February, 2012
- NZAGRC Steering Group meeting: 02 February, 2012
- Presentation on "Global GHG emissions sectors, sources & sources and sinks" to Massey University Professional Development course: 14 February, 2012
- Presentation by Ron Ronimus to Massey University Contact course - "Discovery of Methanogen-specific

Inhibitors (using chemogenomic methods)": 14 February, 2012

- Federated Farmers Manawatu Farming Tour: 62 farmers hosted: 15 February, 2012
- Presentation by Neil Wedlock to GHG contact course, Massey University - "Vaccines against rumen methanogens": 15 February, 2012
- Meeting with Alex Hannant, executive director of the Hikurangi Foundation, to discuss opportunities for engagement on climate change and agriculture; Wellington: 16 February, 2012
- Presentation by Yang Li to Dr Jasna Rakonjac student group meeting at Massey University - "Comparative genomics of rumen methanogens": 16 February, 2012
- PGgRc Board meeting: 22 February, 2012
- NZAGRC Science Leadership Team meeting: 24 February, 2012
- Presentation by Preeti Raju to Massey Universitu Helipad meeting - "Identifying alternative hydrogen utilisers in the rumen": 01 March, 2012
- PGgRc Chemigenomics progress review: 02 March, 2012
- PGgRc Vaccine Review: 06 March, 2012
- NZAGRC Steering Group meeting - teleconference: 08 March, 2012
- IPCC Lead Author's Meeting, Wellington - Harry Clark Lead Author discussions: 19 March, 2012 - 23 March, 2012
- Presentation to NZ scientists at Motu Climate Economics Research Workshop on interactions between global mitigation actions, GHG metrics, and NZ implications; Motu, Wellington: 20 March, 2012
- David Whitehead - Panel member at The Future of Food Production public debate: 29 March, 2012
- PGgRc Board meeting: 04 April, 2012
- NZAGRC Maori Advisory Group meeting - teleconference: 05 April, 2012
- Presentation to roundtable of NZ government officials and industry stakeholders on implications of GHG metrics for NZ, hosted by Victoria University Institute of Policy Studies; Wellington: 10 April, 2012
- NZAGRC Nitrous Oxide Science Programme Workshop: 18 April, 2012
- NZAGRC Soil Carbon Programme Workshop: 19 April, 2012
- Discussions with MSI re National Science Challenge policy: 23 April, 2012
- NZAGRC Science Leadership Team meeting: 27 April, 2012
- NZAGRC Maori Advisory Group meeting - Inaugural face to face korero: 02 May, 2012
- Agricultural Emissions Trading Scheme Advisory Committee meeting: 10 May, 2012
- NZAGRC Steering Group meeting: 16 May, 2012
- Inventory research discussions with MPI, Wellington: 23 May, 2012
- Annual meeting of the New Zealand Climate Change Centre; NIWA, Wellington: 29 May, 2012
- PGgRc Future Workshop and Meeting, Wellington: 26 June, 2012
- Direct methane mitigation research plans 2012+' presentation to the PGgRc board - by Bryce Buddle, Ron Ronimus, John McEwan, David Pacheco and Peter Janssen: 27 June, 2012
- Presentation by Louis Schipper to Annual Soil Organic Matter Forum VC - "Update on University of Waikato Soil Carbon Work": 27 June, 2012
- Meeting with PGgRc to plan MSI application: 29 June, 2012

### *Meetings and Presentations (International)*

- Participation in CSIRO Climate Adaptation Flagship strategic planning meeting; Melbourne, Australia: 26 July, 2011 - 27 July, 2011
- United Kingdom's Global ReseArCH4 inveN2Ory - workshop on agricultural greenhouse gas measurement methodologies and techniques: 31 October, 2011
- Participation in meeting of the Task Group on Scenarios for Climate Impact Analysis (TGICA) of the IPCC; Stanford, USA: 6 February, 2012 - 8 February, 2012
- Filling the Research Gap: DAFF research funding assessment round 1: 27 February, 2012 - 1 March, 2012
- Meeting with Thai officials to discuss opportunities for collaboration in agricultural GHG research; Bangkok, Thailand: 15 March, 2012
- Presentation by John McEwan to Teagasc researchers - "Animal variation in methane emissions": 29 March, 2012
- Presentations on N management and transformation processes, nitrification inhibitors and mitigation of nitrous oxide emissions from animal management systems by Jiafa Luo to Institute of Soil Science, Fujian Academy of Agricultural Sciences and Institute of Applied Ecology, Chinese Academy of Sciences: 31 March, 2012
- Presentations to policy officials at UNFCCC workshop on common GHG metrics; Bonn, Germany: 3 April, 2012 - 4 April, 2012
- Presentation by John McEwan to RELFP meeting in Sydney - "Animal variation in methane emissions": 15 May, 2012
- Review of Sustainable Agriculture Flagship, CSIRO, Canberra, Australia: 28 May, 2012 - 1 June, 2012
- Chairing of workshop on inputs to the IPCC 5th Assessment Report, during the Adaptation in Action Conference of the Australian National Climate Change Adaptation Research Facility; Melbourne, Australia: 27 June, 2012

### *International Visitors and Groups*

- Presentation to a delegation of scientists and policy makers from Thailand by Louis Schipper - “Changes in soil carbon stocks in New Zealand pastures over the last century”: 01 August, 2011
- Hosting of delegation of scientists and officials from Uruguay, including Uruguayan Minister of Agriculture; Palmerston North: 09 August, 2011
- Presentation re NZAGRC work and Korean collaborative ideas to Dr Lee Joo-ryang, Korean Science and Technology Policy Institute (STEPI): 23 August, 2011
- Visiting delegation from Japan (Masayuki Hojito, Yutaka Ono, Shoji Matsuura): 2 December, 2011 - 5 December, 2011
- Meeting with visiting Nuffield Scholar (PGgRc) - Discussions re reducing methane emissions from sheep production: 08 December, 2011
- Planning for Climate Action in British Columbia, Canada: Putting Agricultural Greenhouse Gas Mitigation on Local Government Agendas - Discussion with Tara Moreau re postdoctoral research: 17 February, 2012
- Surinder Saggar hosted Mr Jose Maria Peralta and Mr Francisco Tapia from INIA: 24 February, 2012
- Visit by University of Missouri - General discussions regarding NZAGRC work and tour of facilities : 07 March, 2012
- Meeting with the Scottish Agricultural College - Patricia Ricci re "Methane Emissions from Ruminants - Towards a Better Understanding of Outputs from the Laser Methane Detector": 14 June, 2012

### *Global Research Alliance related interactions*

- Monthly meetings of the Alliance LRG Leadership Group: 1 July, 2011 - 30 June, 2012
- Monthly reporting meetings on the Alliance with MAF/MPI: 1 July, 2011 - 30 June, 2012
- Presentation regarding "Carbon and the land based economy: Global Research Alliance", Climate Change and Business Conference, Wellington: 01 August, 2011
- 6th International Symposium on Non-$CO_2$ Greenhouse Gases in Amsterdam: Keynote Presentation “The initial stock-take of GHG inventory & mitigation research activities in Alliance member countries: Insights, lessons and opportunities”: 4 November, 2011
- 6th International Symposium on Non-$CO_2$ Greenhouse Gases in Amsterdam: Keynote Presentation “Global Research Alliance, overview and update”: 4 November, 2011
- Livestock Research Group meeting - Aligned with the 6th International Symposium on Non-$CO_2$ Greenhouse Gases in Amsterdam: 4 November, 2011 - 5 November, 2011
- Global Research Alliance South East Asia technical workshop: 12 March, 2012 - 16 March, 2012
- Global Agri Alliance on GHG/Pure Advantage Macroeconomic Research - work being done with the Alliance: 20 April, 2012
- TAP Meeting: Assessment of Full proposals for Alliance International Research Fund: 30 April, 2012 - 1 May, 2012
- Meeting of the Global Research Alliance Research Group co-chairs, Saskatoon, Canada: 4 June, 2012.
- Global Research Alliance Council Meeting, Saskatoon, Canada: 5 June, 2012
- Meeting of the Inventories and Measurement Research Group, Saskatoon, Canada: 6 – 7 June 2012
- The New Zealand Fund for Global Partnerships in Livestock Emissions Research: Presentation by MPI and NZAGRC, Palmerston North: 19 June, 2012
- The New Zealand Fund for Global Partnerships in Livestock Emissions Research: Presentation by MPI and NZAGRC, Hamilton: 21 June, 2012
- The New Zealand Fund for Global Partnerships in Livestock Emissions Research: Presentation by MPI and NZAGRC, Christchurch: 22 June, 2012

### *Media Interactions*

In addition to press releases and providing comment to the media on request, the NZAGRC has had a number of key interactions in 2011/12.

- Media: Farmers Weekly article following NZAGRC Conference presentation by Prof Di Hong: 30 January, 2012
- Meeting with AFP news agency (Agence France-Presse): 05 March, 2012
- David Whitehead represented the work of the NZAGRC in his appearance in the film Sky Whisperers Ranginui, a film 'exploring intimacy with our skies' directed by Kathleen Gallagher, Wickcandle, NZ: 31 March, 2012

- Contribution to 'Carbon pricing's flaws exposed' by J.S. Rowarth - National Business Review: 20 April, 2012
- Contribution to 'Pasture is New Zealand's green gold' by J.S. Rowarth - Rural News: 01 May, 2012
- Louis Schipper media interview with Susan Pepperell - "Carbon balance on farm": 15 May, 2012
- Louis Schipper radio interview with RadioNZ by Kevin Iken for Rural News: 31 May, 2012 - 1 June, 2012
- Meeting with Jill Galloway, Manawatu Standard: 15 June, 2012

### *Conference Presentations*

- Attwood, G. T., Kelly, W. J., Altermann, E., Leahy, S. C., & Janssen, P. H. (2012). *Trash or tax collectors: methanogen life at the end of the microbial food chain*. Paper presented at the INRA Gut Microbiology Conference.
- Baldock, J., Beare, M., & Curtin, D. (2011). *Modelling measureable pools of carbon in New Zealand soils: A case study*. Paper presented at the International Soil Organic Matter Symposium
- Ball, B. C., Cameron, K. C., Di, H. J., & Podolyan, A. (2012, 31/1/12). *Effects of trampling of a wet dairy pasture soil on nitrous oxide emissions and the efficacy of the nitrification inhibitor dicyandiamide.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Beare, M., Baldock, J., & Curtin, D. (2012, 31/1/12). *Modelling measurable pools of carbon in New Zealand soils: A case study.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Bowatte, S., Theobald, P., Brock, S., Hunt, C., Gebbie, S., Lieffering, M., et al. (2012, 31/1/12). *Development of an experimental system to measure plant $N_2O$ emissions.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Carbone, V., Schofield, L. R., Beattie, A. K., Sutherland-Smith, A. J., & Ronimus, R. S. (2012, 31/1/12). *The Crystal Structure of Apo- and GTP-bound GTP cyclohydrolase from Methanobrevibacter ruminantium.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Chiba, M., Cichota, R., Vogeler, I., & Hoogendoorn, C. (2012, 31/1/12). *Local and seasonal variation of nitrous oxide emissions from pastoral systems of NZ.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- De Klein, C. A. M. (2012). *Reducing $N_2O$ emissions by manipulation of nitrification and denitrification processes*. Paper presented at the NZAGRC 2nd Annual Conference.
- De Klein, C. A. M., Luo, J., Styles, T., & Wise, B. (2012, 31/1/12). *The effect of urine N concentration in animal urine on $N_2O$ emissions.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Deslippe, J. R., Jamali, H., & Saggar, S. (2012, 31/1/12). *Denitrification in pasture and riparian soils.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Di, H. J. (2012). *Manipulating nitrification processes to reduce nitrous oxide emissions*. Paper presented at the NZAGRC 2nd Annual Conference.
- Ellis, J. L., Dijkstra, J., France, J., Kebreab, E., Parsons, A. J., Rassmussen, S., et al. (2011, 6-9 September 2011). *Effect of high sugar grasses on methane emissions simulated using a dynamic model.* Paper presented at the Eighth International Symposium on the Nutrition of Herbivores, Aberystwyth, Wales.
- Harrison-Kirk, T., Thomas, S. M., Beare, M., Clough, T. J., van der Weerden, T. J., & Meeken, E. D. (2012). *Influence of soil water status and compaction on $N_2O$ and $N_2$ emissions from $^{15}N$-labelled synthetic urine.* Paper presented at the 17th International Nitrogen Workshop 2012 and Eurosoil 2012, Ireland.
- Hart, G., Chapman, R., & Reisinger, A. (2012). *Living beside the rising tide: Adapting to sea level rise in Auckland, New Zealand*. Paper presented at the Climate Adaptation in Action: Sharing Knowledge to Adapt Conference.
- Hart, G., Chapman, R., & Reisinger, A. (2012). *Stories of social innovation and change-making: Overcoming barriers to coastal adaptation*. Paper presented at the Adaptation Futures: 2012 International Conference on Climate Adaptation.
- Henderson, G., Tavendale, M., Altermann, E., Raju, P., & Janssen, P. H. (2012, 31/1/12). *Identifying alternative hydrogen utilisers in ruminants.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Janssen, P. H. (2012). *Manipulating rumen microbial processes to mitigate methane emissions in grazing systems*. Paper presented at the NZAGRC 2nd Annual Conference.
- Jha, N., Saggar, S., Tillman, R. W., & Giltrap, D. (2012). *Change in denitrification rate and $N_2O/N_2$ ratio with varying soil moisture conditions of New Zealand pasture soils.* Paper presented at the 25th Annual FLRC Workshop, Massey University, Palmerston North, NZ.
- Leahy, S. C. (2011). *Comparative genome analysis of Methanobrevibacter species.* Paper presented at the New Zealand Microbiological Society 2011 Annual Conference, Palmerston North.
- Leahy, S. C. (2012, 31/1/12). *Comparative genome analysis of Methanobrevibacter species.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.

- Li, F., Vogeler, I., & Cichota, R. (2012, 31/1/12). *Modelling nitrous oxide emissions from urine patches: Comparison of different approaches.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Luo, J., Ghani, A., Ding, W., & Saggar, S. (2011). *Effects of biochar on nitrogen transformations and denitrification enzyme activity in a grazed pasture soil - a laboratory study*. Paper presented at the Biochar Res Dev & appl.
- Luo, J., Ghani, A., & Saggar, S. (2012). *Denitrification enzyme activity in a grazed pasture soil as affected by addition of biochar - a laboratory study*. Paper presented at the 2012 Biochar Workshop.
- McEwan, J. C., & Pinares-Patino, C. (2012). *Heritability estimates for methane emissions in sheep and correlations with production traits – NZ*. Paper presented at the Australia-NZ Workshop Reducing Emissions from Livestock through Genetics and Breeding
- McNeil, S. J., Hewitt, A., & Manderson, A. (2012). *Quantifying the carbon currently stored in New Zealand soils.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Ollion, E., & Pacheco, D. (2012, 31/1/12). *Evaluation of empirical models to predict ruminal VFA proportions in sheep fed fresh temperate forages.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Ollion, E., & Pacheco, D. (2012, 31/1/12). *New equations to predict ruminal VFA proportions in sheep fed temperate forages.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Ollion, E., Pacheco, D., & Vibart, R. E. (2012). *Evaluation and improvement of empirical models to predict ruminal VFA proportions in sheep fed fresh temperate forages*. Paper presented at the Animal Science Modellers' Group (Joint Annual Meeting ADSA/ASAS).
- Pacheco, D. (2012). *(Towards) an improved model of enteric methane production*. Paper presented at the NZAGRC 2nd Annual Conference.
- Pinares-Patino, C., MacLean, S., McEwan, J. C., Hickey, S., & Dodds, K. G. (2012). *Associations between rumen characteristics and methane emissions from sheep* Paper presented at the Australia-NZ Workshop Reducing Emissions from Livestock through Genetics and Breeding.
- Pinares-Patino, C., MacLean, S., McEwan, J. C., Hickey, S., & Dodds, K. G. (2012). *Measurements of methane in NZ sheep - experimental design and repeatability of various methods*. Paper presented at the Australia-NZ Workshop Reducing Emissions from Livestock through Genetics and Breeding.
- Pinares-Patino, C., McEwan, J. C., Dodds, K. G., MacLean, S., Hunt, C., Young, E., et al. (2012). *Exploiting animal variation for mitigation of enteric methane emission: an overview of techniques in use in New Zealand*. Paper presented at the International Symposium on Emissions of Gas and Dust from Livestock.
- Rassmussen, S., Parsons, A. J., & Liu, Q. (2012, 31/1/12). *Plant growth, animal nutrition and GHG mitigation.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Reisinger, A., Collins, B., Fuglestvedt, J., Johansson, D., McGovern, F., Montgomery, H., et al. (2012). *Review of issues from the Tyndall session on metrics.* Paper presented at the Tyndall Conference 2011, EPA and Irish Royal Academy, Dublin, Ireland.
- Reisinger, A., Riahi, K., & van Vliet, O. (2012). *Cost-effectiveness and implications of GWPs and GTPs under alternative policy goals*. Paper presented at the UNFCCC Workshop on common metrics to calculate the $CO_2$ equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks.
- Reisinger, A., Stroombergen, A., Havlik, P., & van Vliet, O. (2012). *Global and National Mitigation Costs Under Alternative Metrics.* Paper presented at the Tyndall Conference 2011, EPA and Irish Royal Academy, Dublin, Ireland.
- Reisinger, A., Stroombergen, A., Riahi, K., van Vliet, O., Havlik, P., Obersteiner, M., et al. (2012). *Interactions of metrics and alternative policy settings at a country level: a case study from New Zealand*. Paper presented at the UNFCCC Workshop on common metrics to calculate the $CO_2$ equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks.
- Ronimus, R. S. (2012). *Discovery of methanogen-specific inhibitors (using chemogenomic methods)*. Paper presented at the NZAGRC 2nd Annual Conference.
- Rutledge, S., Campbell, D. I., Schipper, L. A., & Wall, A. (2012). *Net carbon exchange in grazed dairy pastures*. Paper presented at the NZAGRC 2nd Annual Conference.
- Rutledge, S., Mudge, P. L., Wallace, D. F., Campbell, D. I., & Schipper, L. A. (2011). *Effects of climate variation and management practices on the carbon balance of a Waikato dairy farm*. Paper presented at the 2011 Annual Conference of the New Zealand Ecological Society.
- Rutledge, S., Mudge, P. L., Wallace, D. F., Campbell, D. I., & Schipper, L. A. (2011). *Effects of climate variation and management practices on the carbon balance of a Waikato dairy farm*. Paper presented at the WaiBoP Soils Conference.
- Saggar, S., Jha, N., Deslippe, J. R., Luo, J., Tillman, R. W., Giltrap, D., et al. (2012, 31/1/12). *Regulation of denitrification: pathways to nitrous oxide and dinitrogen.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Schipper, L. A., Baisden, T., Dodd, M. B., Parfitt, R., Ross, C., & Sparling, G. (2011). *Changes in soil carbon stocks in New Zealand pastures over the last century*. Paper presented at the Ecology in the Heartland. Annual Conference of the New Zealand Ecological Society, and New Zealand Society of Plant Biologists.
- Schipper, L. A., Rutledge, S., Schon, N., Mackay, A., Calvelo Pereira, R., Camps Arbestain, M., et al. (2011). *Soil carbon research in New Zealand*. Paper presented at the Soil Security meeting.

- Schipper, L. A., Rutledge, S., Schon, N., Mackay, A., Calvelo Pereira, R., Camps-Arbestain, M., et al. (2011). *Managing the soil-plant system to mitigate atmospheric $CO_2$*. Paper presented at the Soils security meeting.
- Schofield, L. R., Zhang, Y., Sang, C., Beattie, A. K., Dey, D., Sutherland-Smith, A. J., et al. (2012, 31/1/12). *Utilising chemogenomics techniques to rapidly find novel rumen methanogen control agents.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Schon, N. (2012, April 2012). *Earthworm work.* Paper presented at the 4th Soil Organic Matter Forum, Palmerston North, NZ.
- Vogeler, I., Cichota, R., Giltrap, D., Luo, J., & Chiba, M. (2012, 31/1/12). *Compilation of a $N_2O$ database for NZ pastoral systems.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Vogeler, I., Cichota, R., Giltrap, D., & Snow, V. (2012, 31/1/12). *Comparison of models for simulating $N_2O$ emissions from urine patches* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Vogeler, I., Giltrap, D., Cichota, R., & Snow, V. (2012, 27-29 June 2012). *Comparison of APSIM and DNDC for simulating nitrogen transformation and $N_2O$ emissions from urine patches.* Paper presented at the 17th International Nitrogen Workshop, Wexford, Ireland.
- Wedlock, D. N. (2012). *Vaccines against rumen methanogens*. Paper presented at the NZAGRC 2nd Annual Conference.
- Wedlock, D. N., Shu, D., Zheng, T., Attwood, G. T., Janssen, P. H., & Buddle, B. M. (2012, 31/1/12). *Development of a vaccine to reduce methane emissions in ruminants.* Paper presented at the NZAGRC 2nd Annual Conference, Palmerston North, NZ.
- Wedlock, D. N., Shu, D., Zheng, T., Janssen, P. H., & Buddle, B. M. (2011). *Development of a vaccine to reduce methane emissions in ruminants*. Paper presented at the New Zealand Microbiological Society 2011 Annual Conference.

## *Journal Articles*

### *Submitted*

- Peters, G. P., Reisinger, A., Fuglestvedt, J., & Meinshausen, M. (in press). Dependence of Global Warming Potentials on constant and variable background concentrations *Environmental Research Letters*.
- Reisinger, A., Havlik, P., Riahi, K., van Vliet, O., Obersteiner, M., & Herrero, M. (in press). Implications of alternative metrics for global mitigation costs and greenhouse gas emissions from agriculture. *Climatic Change*.
- Vogeler, I., Giltrap, D., & Cichota, R. (in press). Comparison of APSIM and DNDC to simulate nitrogen transformations and $N_2O$ emissions. *Science of the Total Environment*.

### *Published*

- Ball, B. C., Cameron, K. C., Di, H. J., & Moore, S. (2012). Effects of trampling of a wet dairy pasture soil on soil porosity and on mitigation of nitrous oxide emissions by a nitrification inhibitor, dicyandiamide. *Soil Use and Management, 28*(2), 194-201.
- Calvelo Pereira, R., Kaal, J., Camps Arbestain, M., Pardo Lorenzo, R., Aitkenhead, W., Hedley, M., et al. (2011). Contribution to characterisation of biochar to estimate the labile fraction of carbon. *Organic Geochemistry, 42*(11), 1331-1342.
- Chiba, M. K., Cichota, R., & Vogeler, I. (2012). Can we improve interpolation of $N_2O$ emission measurements by using environmental factors? In L. D. Currie & C. L. Christensen (Eds.), *Advanced Nutrient Management: Gains from the Past - Goals for the Future*.
- Joos, F., Roth, R., Fuglestvedt, J. S., Peters, G. P., Enting, I. G., von Bloh, W., et al. (2012). Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis. *Atmos. Chem. Phys. Discuss., 12*(8), 19799-19869.
- Kelliher, F. M., Condron, L. M., Cook, F. J., & Black, A. (2012). Sixty years of seasonal irrigation affects carbon storage in soils beneath pasture grazed by sheep. *Agriculture, Ecosystems & Environment, 148*(0), 29-36.
- Morgavi, D. P., Kelly, W. J., Janssen, P. H., & Attwood, G. T. (2012). Rumen microbial (meta)genomics and its application to ruminant production. *Animal*.
- Mudge, P. L., Wallace, D. F., Rutledge, S., Campbell, D. I., Schipper, L. A., & Hosking, C. L. (2011). Carbon balance of an intensively grazed temperate pasture in two climatically contrasting years. *Agriculture, Ecosystems & Environment, 144*(1), 271-280.
- Orwin, K. H., Kirschbaum, M. U. F., St John, M. G., & Dickie, I. A. (2011). Organic nutrient uptake by mycorrhizal fungi enhances ecosystem carbon storage: a model-based assessment. *Ecology Letters, 14*(5), 493-502.
- Parsons, A. J., Rowarth, J. S., Thornley, J. H. M., & Newton, P. C. D. (2011). Primary production of grasslands, herbage accumulation and use, and impacts of climate change. In G. Lemaire, J. Hodgson & A. Chabbi (Eds.), *Grasslands Productivity and Ecosystems* (pp. 312): CAB International.
- Reisinger, A., Lawrence, J., Hart, G., & Chapman, R. (2012). From coping to resilience: the role of managed retreat in highly developed coastal

regions. In B. Glavovic, R. Kaye, M. Kelly & A. Travers (Eds.), *Climate Change and the Coast: Building Resilient Communities*. London, England: Taylor and Francis.

- Schon, N. L., Mackay, A. D., Gray, R. A., & Minor, M. A. (2011). Earthworms in New Zealand sheep- and dairy-grazed pastures with focus on anecic Aporrectodea longa. *Pedobiologia, 54, Supplement*(0), S131-S137.
- van der Weerden, T. J., Kelliher, F. M., & de Klein, C. A. M. (2012). Influence of pore size distribution and soil water content on nitrous oxide emissions. *Soil Research, 50*(2), 125-135.
- Vogeler, I., Beukes, P., Romera, A., & Cichota, R. (2012). Estimating nitrous oxide emissions from a dairy farm using a mechanistic, whole farm model and segregated emission factors for New Zealand. *Soil Research, 50*(3), 188-194.

### *Other interactions/publications*

- Mackay, A. (2012). Earthworm mesocosm field experiment. *NZ Soil News, April 2012*.
- Mackay, A., Gray, R. A., Schon, N., Theobald, P., Bowatte, S., & Brock, S. (2012). Current activities at Grasslands. *NZ Soil News, June 2012*.
- NZAGRC. (2011). RELEASE Newsletter #3.
- NZAGRC. (2011). RELEASE Newsletter #4.
- NZAGRC. (2012). RELEASE Newsletter #5.
- NZAGRC. (2012). RELEASE Newsletter #6.
- Ollion, E. (2011). Improving the prediction of volatile fatty acids stoichiometry in sheep fed fresh forages [Masters presentation to Animal Nutrition Group at Wageningen University, ASG].
- Ollion, E. (2011). *Improving the prediction of volatile fatty acids stoichiometry in sheep fed temperate fresh forages.* Wageningen University.
- Schon, N., & Mackay, A. (2011). A guide to beneficial pasture soil invertebrates brochure.
- Schon, N., & Mackay, A. (2011). Pasture earthworms brochure.