NEW ZEALAND
AGRICULTURAL GREENHOUSE GAS
Research Centre

Annual Report 2011

agresearch DairyNZ Landcare Research Manaaki Whenua Lincoln University MASSEY UNIVERSITY NIWA Taihoro Nukurangi Plant & Food RESEARCH PGgRc SCION

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EXECUTIVE SUMMARY

This Annual Report of the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) provides an overview of its first full year of operation from July 2010 to June 2011.

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.

Animal derived methane currently makes up 33% of New Zealand's total estimated greenhouse gas emissions. In excess of 95% of this methane comes from enteric fermentation. Nitrous oxide from agricultural soils currently contributes about 14% of total emissions.[1] Changes in carbon stored in New Zealand agricultural soils are only poorly understood and therefore not currently included in New Zealand's emissions inventory. However, there may be significant potential to increase carbon storage, provided that robust and sustainable management practices to achieve this are identified and can be monitored and reported to international standards.

Research designed and carried out by the NZAGRC and its funding partners seeks to exploit existing, and develop new, science capacity and experience in all of these areas while also developing 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.

Science

The main aims of the NZAGRC science plan fall into four principal 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 to ensure that individual mitigation approaches are evaluated within the context of practical and profitable farming systems.

The NZAGRC's science plan is now being implemented with research in 18 specific objectives across these four components. A total of just under 24 full time equivalent research staff, mainly but not exclusively based in the NZAGRC's nine partner research organisations, have been working on those objectives in 2010/11. Below we list the significant highlights and key findings from this year's research programme. These include the opening of two major new measurement centres that support several research objectives and provide New Zealand researchers with world leading facilities.

The New Zealand Ruminant Methane Measurement Centre (NZRMMC) opened in February 2011 at the AgResearch Grasslands campus in Palmerston North. NZAGRC invested $1.2 million in the construction of new respiration chambers for sheep and cattle and the upgrading of an existing building to provide a single, purpose designed facility to house respiration chambers together with experimental facilities. The NZRMMC is the largest facility of its kind in the southern hemisphere and provides New Zealand scientists with world class facilities and equipment and significantly

[1] Based on the latest official greenhouse gas emissions inventory released in 2011 applicable for the calendar year 2009. See http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-2011/index.html

enhances the ability of scientists to test hypotheses about potential ways to reduce methane emissions from cattle and sheep.

The National Centre for Nitrous Oxide Measurement (NCNOM) was opened in April 2011 at Lincoln University. The NCNOM will treble New Zealand's capacity to measure nitrous oxide greenhouse gas emissions through a single, purpose designed facility that houses nitrous oxide measurement equipment previously distributed across multiple sites. The capacity of the NCNOM to process more than 1,000 nitrous oxide samples a day makes it one of the best specialist facilities of its type in the world. Funding of $500k for the new facility was provided by NZAGRC in response to an urgent need to increase New Zealand's nitrous oxide measurement capacity.

Research activities under each of the four principal research components are summarised in individual sections of this Annual Report, along with detailed and technical reports from each research objective. The research conducted under contract to the NZAGRC ranges from a careful, step-by-step assembly of fundamental knowledge regarding the microbial composition of the rumen and nitrogen and carbon chemistry in soils, to more applied tests of specific hypotheses and trials of specific practical mitigation options. Developing partnerships is 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 builds on existing PGgRc investment and in the Integrated Systems area the NZAGRC programme is co-funded alongside an existing SLMACC programme. As the NZAGRC science programme has been in existence for just over a year, the work is in its early stages and results are only just being obtained and analysed. However, the programme is progressing rapidly and highlights from funded research this year include:

Methane

- Identification of a microalgae that has reduced methane emissions *in vitro* when fermented with ryegrass pasture;
- A combination of modelling and experimental work has identified that there are cost-effective options to capture and utilise methane produced from anaerobic ponds. A survey has shown that manure ponds are more widespread in New Zealand than previously thought;

Nitrous Oxide

- Initial results suggest that N_2O emissions are not related to the absolute concentration of nitrate in urine over the normal range found in New Zealand. This suggests that reducing the nitrogen concentration in urine per se does little to reduce nitrous oxide emissions unless the total nitrogen quantity consumed by animals is reduced;
- Soil compaction is a critical factor in determining absolute N_2O emissions from soils. Nitrification inhibitors however seem to be effective in reducing nitrous oxide emissions under a variety of conditions including where soil is compacted by animals;

Soil Carbon

- Analyses of existing datasets and databases has improved our understanding of current soil carbon storage and the potential upper limits for soil C in New Zealand's agricultural soils. This is a critical first step in assessing the potential to increase rates of soil C storage.
- Biochar, which can increase soil carbon and reduce nitrous oxide emissions, has been produced from pine forest waste and further options for biochar production are being explored using biosolids and municipal green waste as raw material;

Integrated systems

- Models to more accurately simulate on-farm emissions of methane and nitrous oxide emissions under different management practices are being developed and key aspects that are critical for incorporation in such models are being identified.

Stakeholder engagement

The NZAGRC is governed by a Steering Group (SG) comprising a representative from each of its nine members. During 2010/11 this group has met quarterly as well as corresponding by email to see reports and respond to requests from the NZAGRC Director regarding decisions on the NZAGRC's strategic operational direction. Additionally, the NZAGRC has been 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.

A major highlight of the past year was the first annual conference of the NZAGRC held in February 2011. This three day meeting brought the leading researchers of the NZAGRC together with stakeholders from policy and industry, the International Science and Stakeholder Advisory Groups. A series of plenary presentations showcased work to date for the 150 delegates, while concurrent workshops on the following days allowed in-depth discussion of progress and opportunities for existing research objectives.

During 2010/11, the NZAGRC had a regular profile in the media and with the wider scientific community and the general public (see appendix 3). The NZAGRC also communicated its activities through the initiation of a regular newsletter 'Release', whose first issues were sent to more than 400 recipients domestically and internationally. A user friendly and comprehensive website was also developed and populated with details of the NZAGRC's science programmes and related activities.

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 the development of solutions to reduce agricultural greenhouse gas emissions globally while meeting growing food demand. It was initiated by the New Zealand Government in 2009 that also committed $45 million to support New Zealand's participation in the Alliance, in particular research into pastoral livestock emissions. This budget is administered by the Ministry of Agriculture and Forestry (MAF) and a close partnership has been developed with the NZAGRC.

New Zealand hosts the Secretariat and is co-chairing the Livestock Research Group (LRG) of the Alliance. The NZAGRC Director works alongside his counterpart from the Netherlands as the co-chairs of the LRG. The NZAGRC also provides assistance to MAF on a range of other initiatives associated with the Alliance including administering fellowship programmes, providing advice on options for targeted and strategic science and funding and the development of scientific networks, databases and guidelines, as well as ensuring strong science representation from New Zealand in the various forums set up under the Alliance.

CHAIR'S REPORT

Agriculture is pivotal to New Zealand's economic well-being: it provides more than half of New Zealand's export earnings. At the same time, agriculture is responsible for almost half of New Zealand's total greenhouse gas emissions from human activities. Cutting greenhouse gas emissions by reducing agricultural production would reduce New Zealand's economic well-being without actually reducing global greenhouse gas emissions, since other countries would fill any gap in production, driven by an increasing global demand for high-protein foods.

The success of agricultural production in New Zealand relies on its ability to produce high-quality goods at lower costs as well as higher standards than other countries. Those standards include a perception, and must reflect a reality, that the goods produced by New Zealand do not come at a high price to its local or the global environment. Nations around the world are grappling with the challenge how to decouple their economic growth from their environmental impact. Examples of such decoupling are becoming increasingly common in the energy sector, but we have yet to develop a similar ability to decouple increasing agricultural production from a commensurate increase in greenhouse gas emissions.

The NZAGRC was founded 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 the first full year of operations the NZAGRC has passed a number of important milestones. The NZAGRC has commenced its full programme of research as outlined in the agreed strategic science plan. Some areas of this research are at the stage of assembling fundamental knowledge, while others have already opened up promising leads or identified areas where further work needs to focus. The NZAGRC's first annual conference showcased this work and also demonstrated the high regard in which the NZAGRC and the scientists carrying out its research programme are held internationally. The opening of two major measurement facilities this year will further boost the capacity of the research teams to conduct high-quality and timely research that will stand up to international scrutiny. The NZAGRC's Steering Group has established itself as a collegial and effective team that ensures that the NZAGRC's strategic direction and decisions made by its Director carry the full support of the NZAGRC's nine partners.

An important addition to the many roles of the NZAGRC has been the emergence of the Global Research Alliance on Agricultural Greenhouse Gases. The Alliance has been promoted by New Zealand in the recognition that efforts to reduce emissions will have a much greater impact if nations develop and implement solutions in concert, rather than individual countries working in isolation. The expanded NZAGRC team plays an important national and international role through its work supporting the Livestock Research Group and the advice it provides on overarching science issues in developing the Alliance. This also promotes a seamless connection between our domestic research efforts and the broader, but crucial, international context.

The importance of the NZAGRC and its work has also been reflected in its high profile in public media, as well as by the steady stream of international and domestic visitors. The NZAGRC is recognised increasingly as an important source of clear and unbiased advice on the science behind agricultural greenhouse gases and their mitigation options.

I would like to acknowledge and thank the NZAGRC team of scientific and support staff for their efforts in coordinating an increasingly complex science strategy within a sound business plan. I wish them all the best for the coming years.

Peter Benfell
Immediate past Chair of NZAGRC Steering Group (to 30 June 2011)

NZAGRC DIRECTOR'S REPORT

First of all I would like to thank all of the scientists and support staff that have enabled the NZAGRC to make a great start to its long term science programme. Drawing up contracts, writing work schedules and agreeing milestones are not things that normally engender great enthusiasm among scientists but everyone approached the task in a highly professional manner and it was achieved with the minimum of fuss. In January we finalised contracts for the first 18 science programmes to receive long term funding through the NZAGRC, with a total initial investment of $15.5m out to June 2014.

This financial year saw some of the NZAGRC's capital investment made in early 2010 come on stream. In February the Minister of Agriculture, the Honourable David Carter, opened the National Ruminant Measurement Centre which is located in Palmerston North at AgResearch Grasslands. This facility, which allows for the simultaneous measurement of methane emissions from 24 sheep and 4 cattle, now provides New Zealand scientists with methane measurement facilities that are on a par with those found anywhere else in the world. In April, Minister Carter again demonstrated the close interest the current government has in the NZAGRC by opening the National Nitrous Oxide Measurement Centre at Lincoln University. This facility which, thankfully, came through the two earthquakes unscathed helps to avert a major problem, that of the capacity to analyse all of the nitrous oxide samples being generated across New Zealand in a timely and cost effective manner.

Developing greater human research capability is a key goal of the NZAGRC and the progress we have made this year has been particularly pleasing. The newly introduced under-graduate scholarships have received enthusiastic support from students at Lincoln and Massey Universities and NZAGRC funding has now been provided to support 5 undergraduate, 2 MSc and 9 PhD students and 4 post-doctoral fellows and early career scientists.

The NZAGRC's input into the Global Research Alliance gathered momentum as the year progressed. In addition to representing New Zealand at Alliance meetings in Canada and France we have provided MAF with scientific and administrative support for a range of initiatives being funded from the Government's $45m Alliance budget. The appointment of Dr Andy Reisinger, who now leads the NZAGRC's contribution to the Alliance, and Dr Victoria Bradley have strengthened our ability to assist MAF in making this New Zealand inspired global initiative a success.

The governance structure of the NZAGRC, which involves the Steering Group and two key advisory groups, has had a highly effective year from my perspective. The February conference and workshops, which attracted >150 participants, provided a great opportunity for the Steering Group and the Stakeholder and International Science advisory groups to become more familiar with the science programmes and to feed back their comments first hand to the scientists involved. I would like to express my thanks in particular to the Steering Group for the enthusiasm in which they have approached their role and for the sound advice they have provided throughout the year. Their contribution has been a big factor in establishing the NZAGRC as a truly collaborative venture.

Dr Harry Clark
NZAGRC Director
August 2011

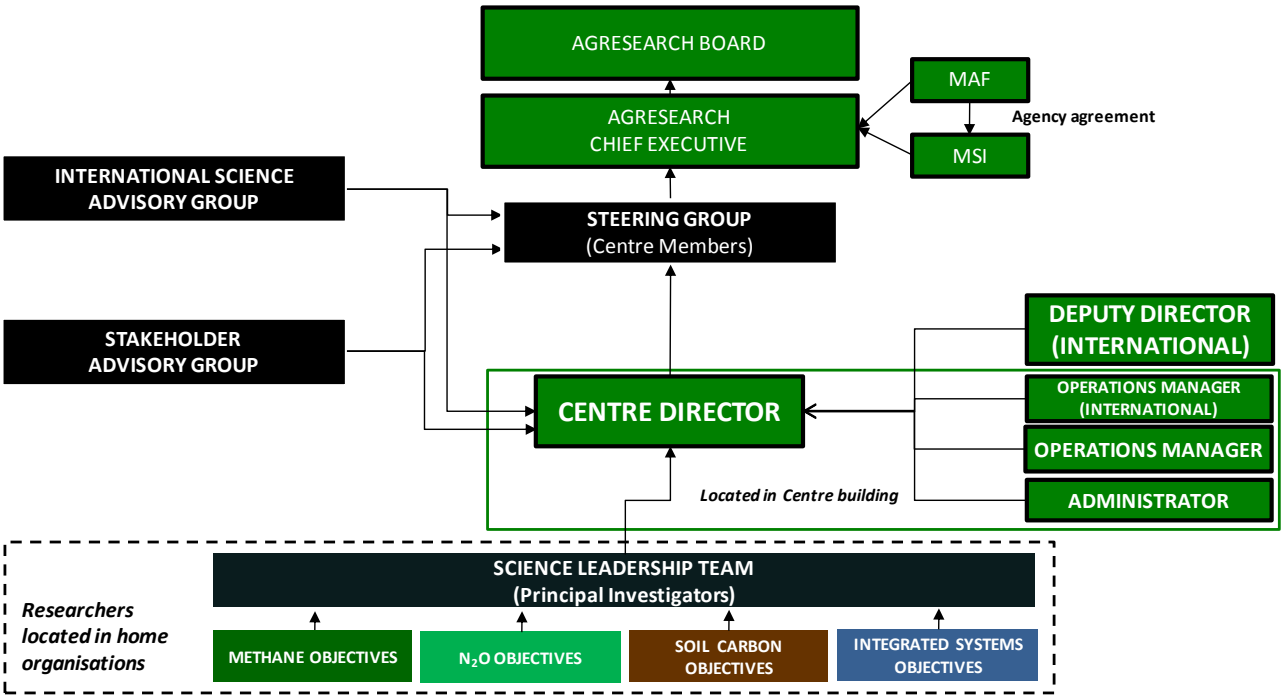
THE NEW ZEALAND AGRICULTURAL GREENHOUSE GAS RESEARCH CENTRE

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 and 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.

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, industry relevance and research direction.



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.

One of the main roles of the SG over the past financial year has been to ensure that robust plans, policies and procedures have been put in place to enable the NZAGRC to function smoothly and efficiently for its lifetime.

During 2010/11 the SG were scheduled to meet on four occasions 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. A formal Quarterly meeting could not be held in February due to the Christchurch earthquake. An informal meeting was held instead (not included in the meeting attendance table in appendix 1).

The compositions of the SG, SAG and ISAG and meetings attended during 2010/11 can be found in appendix 1.

NZAGRC STRATEGY DEVELOPMENT AND IMPLEMENTATION IN 2010/11

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 2010/11 the NZAGRC has taken a number of significant steps towards realising the vision of the Centre. Scientifically, the 18 initial research objectives have been contracted and work is progressing well. The NZAGRC has developed a communication strategy and plan and has been actively promoting its role, research and achievements during 2010/11. NZAGRC staff and key NZAGRC-funded researchers have also been working alongside MAF to establish the Alliance and promote New Zealand's leadership in this area on the international stage.

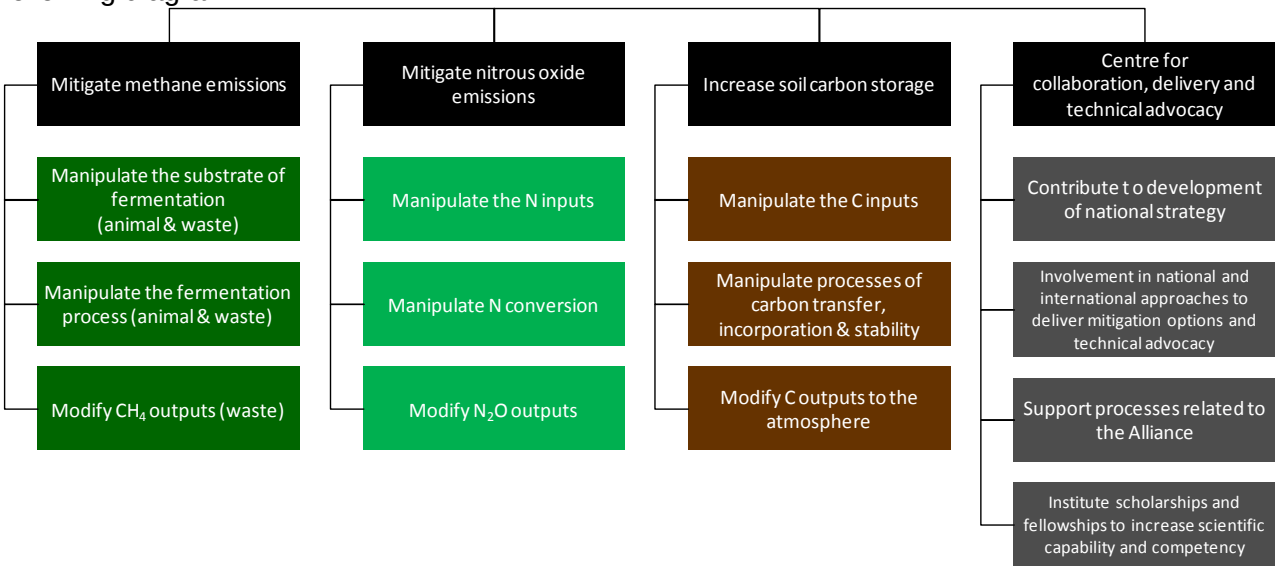
The Mission

'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 2010/11 financial year, the focus has been on establishing the science programmes whilst formalising the day-to-day strategies, policies and procedures required to run the NZAGRC in an efficient and effective manner. A number of key actions have been completed and the following strategies are either under development or finalised:

Strategy/Policy	*Description*
Communications & Media	One of the NZAGRC's overarching communications objectives is to "institute consistent communication channels by establishing effective internal and external communication systems and processes". In line with this NZAGRC staff, in conjunction with Interbrand and Green Eggs, developed a comprehensive policy which was approved by the Steering Group following their November meeting. The strategy includes policies and guidelines for dealing with media, publications and general release of information. At the core of this policy is a 'no surprises' approach with respect to all members and government departments.
Intellectual Property	The principle guiding the NZAGRC IP procedure and its research outputs is the delivery of benefit to NZ. Critical issues in this are the treatment of background IP and newly created IP. A formal procedure for the identification and handling of new IP was developed and approved by the Steering Group. This involves business managers from the NZAGRC members, the Steering Group and NZAGRC staff assessing any potential new IP and making recommendations to MAF. With regard to background IP, agreement was reached between MAF and the PGgRc regarding use of their respective background IP in each other's research programmes. All other programmes are required to register all background IP prior to the signing of research contracts.
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. AgResearch IT staff in conjunction with IT staff from Landcare Research and NIWA, have worked closely with a 'test' group of scientists and NZAGRC staff to develop a workable system. MAF, MSI and the NZAGRC Steering Group have also been involved. The system tries to maintain a balance between usability and comprehensiveness, taking into account the costs involved in maintaining any comprehensive electronic database. Basically AgResearch will store analysed and pre-analysed data in a central electronic database and raw data, laboratory books etc will be stored by the research contractor. The system design has been completed and data will start to be entered into the central database from July 2011 onwards.
Maori	The NZAGRC recognises the special nature of Maori agricultural business and has initiated the development of a specific Maori Strategy so that it can better meet these needs. A contract was given to AgResearch to develop the NZAGRC's Maori Strategy. This process was built around a consultation process with Maori individuals, organisations and groups to inform and guide the strategy development. Four groups were consulted at workshops held between March and June 2011 to provide a range of opinions and perspectives. These, along with a detailed analysis of the special nature of Maori agribusinesses, were used to write a draft strategy. Consultation on this draft strategy with workshop participants and NZAGRC partners and stakeholders, in particularly the two Maori advisers on the NAGRC Stakeholder Advisory Group, commenced in July 2011.
International	NZAGRC staff have been heavily involved in developing 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. Harry Clark has worked closely with MSI, MFAT and MAF 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.

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 2010/11. Achievements to date 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 in10/11*
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 – Scientific conference papers – Patents relating to agricultural GHG emission mitigation technologies – Practical on-farm mitigation practices and technologies identified and being promoted	9 journal submissions 15 published articles 4 reports & releases 18 conference presentations *(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 – Senior NZAGRC Staff presentations to meetings of NZ industry and policy stakeholders – NZAGRC funded scientist presentations to the farming community and general public	Active, up-to-date NZAGRC website 6 presentations to NZ industry/policy stakeholders 8 presentations to farming community/general public *(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 – Written reports prepared for government policy staff – NZAGRC's science contributions direct influence and reflection in government policy.	1 presentation on GHG mitigation to the Agricultural ETS Committee Attendance and input to a technical review of ETS emission factors 1 reports for NZ govt policy staff – background technical document on GHG mitigation for the Global Research Alliance International Fund
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 – Post-doctoral researchers completed 2-year projects – FTEs of professional researchers working on NZAGRC research programmes	9 PhD students studying 3 Post-doctoral fellows 23 FTEs working on NZAGRC programmes (including PhD & Post-docs (*nb* not all full-time on NZAGRC work))
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 – Visiting fellows from overseas research organisations hosted – Memoranda of understanding covering research collaborations agreed with research centres around the world – Confidentiality agreements with companies to discuss information related to agricultural GHG mitigation technologies – Licenses to companies to sell agricultural	Active NZAGRC input into Alliance during year 1 visiting fellow (C Martin) 1 MOU with India NZAGRC science programme fully aligned with PGgRc and SLMACC programmes

		GHG emission mitigation technologies that the NZAGRC or its partners have developed or imported and implemented to suit NZ requirements	

SCIENCE FUNDING REPORT

Funding

In accordance with the NZAGRC's Business, Strategy and Science Plans, $3.76 million was allocated to Research Programmes in the 2010/11 financial year. The distribution of funding between Programmes is reported in detail later in this section. All figures are exclusive of GST.

Infrastructure Update 2010/11

In the previous (2009/10) financial year, which was the first year of operation for the NZAGRC, $2.3 million was allocated to infrastructure spending. The two largest contracts were for buildings to increase the capacity to measure emissions; areas that were deemed to be constraining the research effort. These projects were completed in the 2010/11 financial year.

In February 2011, the New Zealand Ruminant Methane Measurement Centre (at the AgResearch Grasslands campus in Palmerston North) was opened by the Minister of Agriculture, David Carter. This facility allows scientists to measure methane from 24 sheep and 4 cattle in a purpose designed facility that is the largest of its type in the world.

In April 2011, the New Zealand Nitrous Oxide Measurement Centre, situated at Lincoln, was also opened by Minister Carter. This facility, thankfully, came through the two major earthquakes intact. The facility has, along with investment at Landcare Research in Palmerston North, more than doubled the New Zealand nitrous oxide measurement capacity and removed a critical bottleneck for a wide range of research programmes that rely on routine and rapid emissions measurements.

No new contracts for infrastructure were executed in 2010/11.

Capability Development Funding 2010/11

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 when high quality students are projects are identified. In the 2010/11 financial year this additional funding totalled $245,000. 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 undergraduate
3. Employing high quality post doctoral fellows and early stage scientists on 2-3 year contracts

In 2010/11 pilot undergraduate "pipeline" scholarship schemes were established with Massey and Lincoln Universities. These are scheduled to initially run for three years and then be reviewed. If deemed to be successful, the scheme may be extended to other Universities in following years. Additionally, new NZAGRC PhD and post doctoral fellow positions in the core NZAGRC-funded Research Programmes were advertised both nationally and internationally.

Type of Capability Development	# funded in 2010/11
Undergraduate - Summer student	4
Undergraduate - Honours student	1
Masters	2
PhD	9
Post doctoral fellow	3
Early career scientist	1

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.

Research Programmes 2010/11

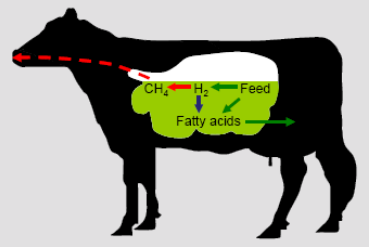
The Science Plan consists of 18 Research Objectives which align under four key areas: (i) methane; (ii) nitrous oxide; (iii) soil carbon and; (iv) integrated systems. In 2010/11 all of the 18 Research Objectives received funding. Those programmes marked with a dagger (‡) are co-funded with the PGgRc and/or PGgRc/MAF and those marked with a diamond (◊) are co-funded with SLMACC (MAF).

Area	Research Objective	Objective Title	Objective Leader	Objective Leader Organisation	2010/11 Research FTE**	2010/11 $NZ (GST excl)*
Methane	1.1	Feeding Microalgae	David Pacheco	AgResearch	0.33	82,000
	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	275,000
	1.4‡	Enhanced discovery of methanogen-specific inhibitors	Ron Ronimus	AgResearch	0.60	155,000
	1.5‡	Expression of vaccine target proteins	Bryce Buddle	AgResearch	0.60	150,000
	1.6‡	Identifying alternative hydrogen utilisers	Gemma Henderson	AgResearch	0.90	170,000
	1.7	Methane capture and utilisation from dairy effluent	Rupert Craggs	NIWA	0.28	60,000
Nitrous Oxide	2.1	Manipulating N inputs	Cecile de Klein	AgResearch	1.55	420,000
	2.2	Manipulating nitrification processes	HJ Di	Lincoln University	4.00	400,000
	2.3	Manipulating denitrification processes	Surinder Saggar	Landcare Research	2.88	200,000
	2.4	N_2O emissions and soil water status	Steve Thomas	Plant & Food	0.45	125,000
Soil Carbon	3.1	Limits of soil carbon storage in New Zealand soils	Mike Beare	Plant & Food	0.59	150,000
	3.2	Quantifying the carbon currently stored in New Zealand soils	Allan Hewitt	Landcare Research	0.35	80,000
	3.3	Process-based modelling of drivers of soil carbon change	Tony Parsons	AgResearch	1.45	200,000
	3.4	Manipulation of carbon inputs, incorporation and retention to protect and enhance soil carbon	David Whitehead	Landcare Research	3.57	425,000
	3.5	Improved soil carbon measurements	Frank Kelliher	AgResearch	0.45	140,000
Integrated Systems	4.1◊	Mechanistic modelling of enteric CH_4 production	David Pacheco	AgResearch	1.74	280,000
	4.2◊	Improved N_2O Component Modelling	Iris Vogeler	AgResearch	0.90	200,000
				Total	23.14**	3,762,000

*N.B. 2010/11 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 - 2010/11

Principal Investigators: Dr Graeme Attwood and Dr Peter Janssen



The underlying aim of the NZAGRC CH_4 programme is to reduce emissions by manipulating the processes responsible for producing methane. This essentially involves a two pronged approach; directly manipulating the activities of methanogens through such things as small molecule inhibitors or vaccines and indirectly manipulating the activities of methanogens through feeding and changes in animal phenotype. The NZAGRC investment in these areas is highly aligned with existing programmes already being funded by the PGgRc and/or PGgRc/MAF.

NZAGRC support has been provided to existing PGgRc and/or MAF programmes to find ways of directly inhibiting the activities of rumen methanogens, the micro-organism responsible for the production of methane in the digestive tract of ruminants. NZAGRC funding has allowed two more methanogen genomes to be sequenced and this information will in turn be used to identify more/better vaccine targets and to 'design'/identify small molecules which can inhibit methanogen growth. NZAGRC funding has already enabled a further 10 candidate enzyme 'targets' to be studied in detail so that their structure can be determined. This is the first stage in the identification of inhibitors that can bind to and suppress the activity of these key enzymes. Both of these programmes are still at the stage where testing is in the laboratory not the animal.

Second, animals that are being screened to identify as 'low' or 'high' emitters under existing PGgRc and MAF programmes are now being genotyped to ascertain if a genetic marker can be found which could rapidly identify these contrasting phenotypes (i.e. the properties of the animals as a whole, including their observed methane emissions). Rapid and cheap identification of the phenotype is an essential pre-requisite if animal breeding approaches are going to be used to mitigate methane emissions. Analysis of existing methane emissions data has also revealed that it is possible to robustly 'rank' animals in terms of their emissions just from repeated one hour measurements as opposed to the standard two days of measurements used now. However, this is for animals that have had considerable pre-conditioning (e.g. three weeks adjustment to the diet and individual feeding and housing for five days). Further work will now look at whether short duration measurements are still accurate when animals are taken directly from the field with no pre-conditioning. A NZAGRC funded study has also theorised that if a price were placed on carbon then emissions intensity can be cost effectively reduced in the sheep sector using traditional animal breeding approaches to shift flocks towards low-emitting animals with almost no loss of productivity.

A further small programme has concentrated on the development and validation of a model that can be used by farmers to estimate the economics of installing methane bio-digesters. The model suggests that the installation of bio-digesters on farms having as few as 400 cows can be economic, with a payback period on the investment of 3-5 years. Further work is being undertaken using MAF funding from the Sustainable Land Management and Climate Change Fund (SLMCC) to confirm these initial findings prior to the model being promoted and released.

A promising novel approach to the mitigation of methane has been that of feeding algal species to ruminants. The original hypothesis that high lipid algae could reduce emissions proved to be incorrect, because the amount of lipids was not high enough to have an appreciable effect. However, an algal species obtained from Australia had a dramatic effect on methane production in a laboratory experiment. The algal species will be studied further to see if it is also successful in live animals.

Nitrous Oxide Research Programme Report - 2010/11

Principal Investigators: Dr Cecile de Klein and Prof Hong Di

A principle focus of the nitrous oxide mitigation programme is the optimisation and improved performance of nitrification inhibitors. Nitrification inhibitors are proven to reduce nitrous oxide emissions but their performance is uneven across the country and also varies with season. The NZAGRC's programme of work is aimed at understanding why performance varies and finding ways of improving efficacy. In the first year, field trials have been established and some laboratory studies undertaken. Initial results indicate that animal trampling has a critical impact on the absolute quantity of nitrous oxide emitted but that nitrification inhibitors work effectively on both trampled and non-trampled soils. Some laboratory work has been delayed due to the Canterbury earthquakes.

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. Early results suggest that the concentration of nitrogen in the urine over the normal range does not affect emissions and that it is the total amount of nitrogen excreted that is important, not how much water it is associated with.

Water is another area of focus, but in a slightly different context: one project aims to better quantify how soil water content and soil physical conditions influence nitrous oxide emissions. Field trials have been established and data are being collected. Both of these programmes provide crucial field data needed by farm systems modellers to validate their model predictions.

Three programmes, which are much more basic in nature, have also started.

Breeding highly productive grasses with nitrogen content closer to those required by grazing animals would have a substantial impact on nitrous oxide emissions as animals generally eat more nitrogen than they require for their own growth. However, high production in grasses themselves is normally associated with high nitrogen content. *Can this link be broken?* A NZAGRC programme is exploring the genetic mechanisms underlying grass growth and using this knowledge to ascertain whether nitrogen supply does really limit growth. Evidence so far has identified gibberellins (a group of plant hormones) as important regulators of growth, independently of nitrogen supply.

Another novel programme is looking at nitrous oxide emissions from plant leaves. Conventional knowledge is that nitrous oxide emissions in grazed pastures are soil derived but in some circumstances emissions seem to arise from plants themselves. *Is this important and can it be manipulated?* The initial stage of this project has centred on developing equipment that can allow emissions from plants to be measured.

Finally, one programme addresses the issue that although inhibiting nitrification processes (the process by which ammonium is converted to nitrate) does reduce emissions, *is it possible that a similar result can be obtained by manipulating the de-nitrification process (the breakdown of nitrate)?*

Initial studies at a range of sites clearly show that the rates of denitrification vary substantially in both space and time, and research is underway to better understand the microbial and chemical processes that cause this variability.

Soil Carbon Research Programme Report - 2010/11

Principal Investigators: Prof Frank Kelliher and Dr David Whitehead

Increasing the quantity of C stored in agricultural soils has the potential to offset emissions of greenhouse gases to the atmosphere. However, realising this potential is technically challenging, especially when soil carbon stocks are already high as they are in New Zealand. 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 practises that can increase the long term soil carbon store and (3) methods for verifying that soil carbon stocks have been changed.

Assessing maximum soil carbon storage potential involves a data mining and modelling approach to quantify what is there now and what is the absolute maximum amount that can be stored; the difference represents the true potential for additional carbon storage. The exhaustive literature review undertaken suggests that the principle determinants of the what is stored is a balance between carbon inputs and outputs while maximum storage potential when carbon supply is not limiting is regulated by climate and soil characteristics.

Devising management practices to increase soil carbon storage requires a mix of modelling and experimental approaches. The modelling approaches offer the advantage of being able to assess multiple options in ways that would never be possible experimentally. The experimental approach, guided by (and informing) the models are the true test of what happens in the real world. Work in the first year of the programme has concentrated on developing two models so that they can be used to predict the consequences of management actions; in particular the role of nitrogen supply and stocking rate. Three high priority areas for the experimental manipulation of carbon input, incorporation and retention in soils have been identified; 1) the replacement of conventional grassland with deep-rooting species, 2) the introduction of earthworms and 3) production and addition of biochar. Three long-term experimental projects to test these options have been set up and measurements of the effects are underway. Two farms in Waikato will use micrometeorological measurements of carbon balance at paired sites using conventional ryegrass and alternative deep-rooting species. In Palmerston North, we have set up a series of replicated microcosms in which we have introduced worms and dung labelled with a detectable carbon isotope signature to follow its incorporation into the soil profile. We have also completed measurements of the vertical distribution of soil carbon at field sites where worms were introduced 23 years earlier. Also in Palmerston North, biochar made from biosolids and green waste in a pilot pyrolysis plant at Palmerston North have been applied to soil at two field sites with contrasting soil types.

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 soil carbon from soil samples collected from field sites at different times has been developed and tested on this data set

Integrated Systems Research Programme Report - 2010/11

Principal Investigators: Mr Dave Clark and Dr Robyn Dynes

This work area is the NZAGRC contribution to a SLMCC 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 system models. The work comprises two areas: modelling enteric methane emissions and modelling nitrous oxide emissions from soils.

Thermodynamic principles are critical for mechanistic understanding of the processes of fermentation (e.g. Volatile Fatty Acid (VFA) production) and subsequent methanogenesis in the rumen. A literature review of the key metabolic processes underpinning a multi-species mechanistic model of methane production was completed and then used to evaluate two published models for prediction of volatile fatty acid concentrations in forage-fed sheep. Neither model was able to satisfactorily predict the observed proportions of all three major VFA from the assembled database of NZ studies ($r^2 < 0.30$). Further work will now concentrate focus on how to better estimation of pool sizes (e.g.: liquid pool, solid pool) and substrate concentrations in the rumen, which in turn are affected by the outflow of solid and liquid material from the rumen.

A review of publicly available N_2O models has been completed so as to identify and/or develop an improved model for predicting N_2O production for NZ's pastoral systems which is:

(i) publicly available;

(ii) is mechanistically sensible;

(iii) can be tested with datasets from NZ spanning a range of soils and climates;

(iv) adequately describes NZ farming systems including urine patches; and

(v) can be used to evaluate mitigation options such as nitrification inhibitors and their effect on the whole farm system.

Various N_2O component models identified in this review have now been integrated into the Agricultural Production Systems Simulator (APSIM) modelling framework and are currently being tested for their ability to simulate results within the N cycling of the soil, which is essential for accurate predictions of N_2O emissions.

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 2010/11. The LEARN network and fellowship scheme were fully integrated into the wider activities under the Global Research Alliance. In addition, the NZAGRC Director Harry Clark is a member of the Agricultural Emissions Trading Advisory Committee, MAF's Research, Technology and Technical Transfer Working Group and the KBBE forum.

Global Research Alliance
The Global Research 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. The Alliance held its first meeting of senior officials representing members of the Global Research Alliance in April 2010, where three Research Groups and two cross-cutting Groups were established, as well as a Secretariat. The Research and Cross-Cutting Groups are the levels at which research activities and other projects are coordinated and carried out, while a governance group worked on developing a charter that formally defines the roles and responsibilities of Alliance members, partners and groups within the Alliance.

In 2010/11, the Alliance passed several important milestones, including:

- The first and second formal meetings of its Research and Cross-Cutting Groups to establish a common understanding, working relationships and define priority actions within and between the different groups, as well as developing a longer term vision for groups
- Completion of an initial stock-take of current research carried out by Alliance members to allow the identification of potential synergies and opportunities for enhanced collaboration
- The development and signing of the Alliance charter at a Ministerial Summit on 25 June 2011 in Rome, Italy, which formally brought the Alliance into existence
- Expansion of the Alliance membership to 32 member countries.

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

- New Zealand was selected together with the Netherlands as co-chairs of the Livestock Research Group (LRG) of the Alliance, with the NZAGRC Director holding the formal position of co-chair of the group. The LRG held its first two formal meetings in 2010/11, the first in October 2010 in Banff, Canada, and its second in late February/Early March 2011 in Clermont-Ferrand and Versailles, France. The NZAGRC (Director, Deputy Director (International) and Operations Manager) together with their Dutch colleagues are responsible for a work plan and a series of research-related activities in support of the goals of the group and the Alliance as a whole.
- The LRG decided at its first meeting to form two sub-groups, one focusing on ruminant issues and the other on non-ruminant issues including manure management. New Zealand through the NZAGRC was selected to co-lead the development of research-related activities specific to the ruminant sub-group together with Uruguay.
- The NZAGRC acts as New Zealand's primary point of contact for science input into the development and operation of the Alliance, and to provide advice to MAF on collaborative research and funding opportunities. Highlights from the past year include:

- Scoping and funding of priority projects identified by the LRG to develop methodological guidelines and explore the potential for a set of dedicated research networks relevant to ruminant livestock. NZAGRC administered contracts to fund those activities on behalf of MAF, with scientific leadership in each of these projects provided by NZAGRC partners within international collaborations.
- Development of a NZ$25 million competitive international fund to accelerate research into mitigation options and opportunities for ruminant livestock. NZAGRC provided advice to MAF on options and criteria for establishing the fund. The fund will be open to bids from international institutions but a significant New Zealand participation as well as substantial co-funding is mandatory. The fund was announced by the Hon. David Carter, Minister for Agriculture, at the Alliance Ministerial Summit in June 2010. It is expected to open in September 2011 with projects beginning work in July 2012.

- NZAGRC developed, coordinated and analysed the first result of the Alliance-wide stock-take of research activities currently carried out by Alliance member countries, which supported the development of initial work priorities and opportunities for enhanced collaboration in all Research and Cross-Cutting Groups of the Alliance.
- NZAGRC ensured appropriate New Zealand science representation in other Alliance Research and Cross-Cutting Groups, as appropriate, and maintains coordination between activities of the Livestock Research Group and other Alliance groups. Harry Clark, Andy Reisinger and Dr Mike Beare of Plant and Food Research attended the Croplands Group meeting in Long Beach in November 201. Andy Reisinger and Harry Clark attended a meeting of the C & N Cycling Group in France in March 2011. Harry Clark and Andy Reisinger attended a meeting of all Alliance Research Group chairs in Long Beach in November 2010.
- NZAGRC acts 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).

LEARN

LEARN is a New Zealand initiative that was established in 2007 to develop an international network of scientists, industry leaders and government officials interested in working together in livestock emissions abatement research. LEARN offers a fellowship programme to provide training opportunities for individuals from developing countries to work alongside some of the best New Zealand scientists.

Given the synergies between LEARN and the Alliance, it was decided that NZAGRC would take over administration of the LEARN fellowship scheme, and that the network would be highly aligned with the activities of the Livestock Research Group of the Alliance. The network currently has 594 members from 83 countries in its database and thus can act as an important channel for information about the work of the LRG and Alliance to a wider scientific and technical audience.

In 2010/11, the LEARN awarded four fellowships; three work trainees and one postdoctoral fellow, from Brazil, India, and China.

In late 2010/11, NZAGRC conducted a review of the LEARN fellowship programme which identified some aspects of the structure and application criteria of the programme that limited its uptake by potential candidates. Based on this review a revised programme of awards will be implemented from 2011/12 onwards.

The Global Research Alliance Senior Scientist (GRASS) Award, was recently established to compliment the LEARN fellowship programme. GRASS facilitates the exchange of senior scientists between New Zealand and Alliance member countries to work for an extended period,

between 6 weeks and 6 months on research to improve quantification of non-CO_2 greenhouse gas (GHG) emissions from animal agriculture at all scales.
The budget for the combined LEARN/GRASS fellowship scheme will be $765k from 2011/12 onwards, and will be administered by NZAGRC on behalf of MAF. In the 2010/2011 financial year four LEARN scholars were involved in programmes funded by the NZAGRC.

Advice to New Zealand policymakers
The NZAGRC Director Harry Clark is a member of the Agricultural Emissions Trading Scheme Advisory Committee. 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. As previously described, NZAGRC staff have also been heavily involved in the IPCC 5th Assessment Report and in supporting the KBBE initiative. NZAGRC funding has also supported a MAF requested review of the currently available methods for mitigating CH_4 and N_2O and their current and future mitigation potential.

External Parties

NZAGRC Inaugural Annual Conference

- Attended by 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".
- The Hon. David Carter opened the conference, followed by a speech from the Chief Scientist to the Prime Minister, Professor Sir Peter Gluckman. Sir Peter spoke about the need to globalise New Zealand science in order to strengthen the economy and protect social and environmental development. He suggested that "it is important to ensure that we (NZ) are partners in programmes that can benefit New Zealand through access to funding and infrastructure" and emphasised the role played by the NZAGRC as a facilitator for achieving this.
- Dr Harry Clark, NZAGRC Director, presented an overview of the NZAGRC's achievements in its first year including:
    - funding a 'core' set of programmes to 2014;
    - developing an NZAGRC science programme that complements and aligns with other New Zealand funding programmes;
    - the completion of large capital expenditure projects; and
    - leading New Zealand science input into the Global Research Alliance.
- Fonterra introduced their emissions reduction plan to reduce the carbon footprint of milk and spoke of their commitment to collaborative research in carbon emission mitigation measures.
- Sessions by Dr Peter Janssen (methane) and Professor Hong Di (nitrous oxide) followed by a talk by Professor Jacqueline Rowarth gave a broad overview of the three major work streams and how the NZAGRC science programme fits together and builds on other funded science programmes.
- Presentations by New Zealand Government officials included Paul Stocks, Deputy Director General: Policy, Science & Economics; Dr Gerald Rys, Sustainable Land Management and Climate Change Programme; Laura Hogg, Global Research Alliance; and Jo Tyndall, New Zealand Climate Change Ambassador.

Meetings, Media, Presentations and Publications

During 2010/11 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 2010/11
Meetings and Presentations (New Zealand)	63
Meetings and Presentations (International)	12
International Visitors and Groups	17
Global Research Alliance related interactions	15
Media interactions	11
Conference presentations	18
Journal articles in press	9
Journal articles published	15
Other interactions/publications	4

FINANCIAL SUMMARY

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EXPENDITURE	
Core research spending	
Methane	1,142,000
Nitrous Oxide	1,145,000
Soil Carbon	995,000
Farm Systems	480,000
Research Total	**3,762,000**
Other research costs	
Fellowships and Studentships	265,853
NZAGRC Conference	97,000
Short Term Projects	75,240
Workshop and Conference Support	20,304
Total	**458,397**
Administration	**477,669**
Other Expenditure	
Maori Strategy Development	52,000
Communications Strategy Development	38,500
Special IT Costs	35,200
Expenditure Total	**125,700**
Total Expenditure (actual + forecast)	***4,823,766***
REVENUE	***4,850,000***
Balance unspent carried over	***26,234***

DIRECTORY

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NZAGRC Director

Dr Heather Went
NZAGRC Operations Manager

Kate Parlane
NZAGRC Administrator

Dr Andy Reisinger
Deputy Director (International)

Dr Victoria Bradley
Operations Manager (International)

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Chair
General Manager, Agriculture & Environment
AgResearch
(Prof Warren McNabb from 1 July 2011)

Dr David Johns
Investment Policy Manager
DairyNZ

Dr Richard Gordon
General Manager, Environment & Society
Landcare Research

Dr Peter John
Director of Research & Commercialisation
Lincoln University

Prof. Mike Hedley
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APPENDIX 1 – COMPOSITION OF NZAGRC SG, SAG and ISAG

Compositions of the SG, SAG and ISAG

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

Steering Group (SG)		**Meetings attended**	**Proxy attended**
Mr Peter Benfell	AgResearch (Chair)	4	0
Dr David Johns	DairyNZ	3	0
Dr Richard Gordon	Landcare Research	1	3
Dr Peter John	Lincoln University (Deputy Chair)	3	1
Prof. Mike Hedley	Massey University	3	1
Dr Murray Poulter	NIWA	2	0
Mr Warrick Nelson	Plant & Food Research	3	1
Mr Mark Aspin	PGgRc	4	0
Dr Trevor Stuthridge	Scion	2	1
Dr Gerald Rys	MAF (Observer**)	4	0
Dr Mike Jebson	MAF (Observer**)	3	0
Dr Fraser Broom	FRST/MSI (Observer**)	0	1
Number of meetings held		*4**	

*Three Quarterly meetings held in Palmerston North (9 September 2010, 25 November 2010 and 26 May 2011) and one additional meeting by teleconference (20 July 2010). The 24 February 2011 Quarterly meeting was cancelled due to a lack of quorum as a result of the Christchurch earthquake. An informal meeting was held with the SG members able to attend.

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

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

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	0	0
Prof Johan Six	California University	1	0
Prof Keith Smith	Edinburgh University	1	0
Prof Pete Smith	Aberdeen University	0	0
Dr Jean-Francois Soussana	INRA	0	0
Number of meetings held		*1*	

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.

The first NZAGRC Annual Conference, held in February 2011, 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.

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 - 2010/11

Key:

Objective completed
Objective on track
Potential delays or revisions may be required to Objective
Current issues with Objective

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	2010/11 $NZ (GST excl)	Status End 2010/11
Methane	1.1	Feeding Microalgae	David Pacheco	AgResearch	82,000	COMPLETE
	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	275,000	On track
	1.4‡	Enhanced discovery of methanogen-specific inhibitors	Ron Ronimus	AgResearch	155,000	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	170,000	On track
	1.7	Methane capture and utilisation from dairy effluent	Rupert Craggs	NIWA	60,000	COMPLETE
Nitrous Oxide	2.1	Manipulating N inputs	Cecile de Klein	AgResearch	420,000	Delayed (delay in getting experimental unit working for one milestone)
	2.2	Manipulating nitrification processes	HJ Di	Lincoln University	400,000	On track
	2.3	Manipulating denitrification processes	Surinder Saggar	Landcare Research	200,000	On track
	2.4	N_2O emissions and soil water status	Steve Thomas	Plant & Food	125,000	On track
Soil Carbon	3.1	Limits of soil carbon storage in New Zealand soils	Mike Beare	Plant & Food	150,000	On track
	3.2	Quantifying the carbon currently stored in New Zealand soils	Allan Hewitt	Landcare Research	80,000	On track
	3.3	Process-based modelling of drivers of soil carbon change	Tony Parsons	AgResearch/ Massey University	200,000	On track
	3.4	Manipulation of carbon inputs, incorporation and retention to protect and enhance soil carbon	David Whitehead	Landcare Research	425,000	Delayed (waiting on resource consent for completion of two milestones)
	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
	4.2◊	Improved N_2O Component Modelling	Iris Vogeler	AgResearch	200,000	On track

1.1 - Feeding Microalgae

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. An alternative algal species was incubated with ryegrass in an in-vitro batch test and this reduced CH_4 production. 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 SLMCCC funded programme.

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 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 green house 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 is 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_2e reduction in GHG emissions per ewe (from 500.1 to 496.9 kg CO_2e/breeding ewe) and a 0.2 kg CO_2e reduction per kilogram of lamb carcase (from 31.31 to 31.11 kg CO_2e). 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_2e/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_2e/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_2e/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_2e/kg lamb CWT pa) can be achieved with little impact on farm profit by reweighting the existing industry index and trait measurements.

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* ABM4is 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.

1.4 - 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 metabolic pathways involved in aromatic amino acid synthesis, cofactor synthesis and gluconeogenesis (an essential central pathway for synthesis of cellular components including some amino acids, cell wall components, DNA and RNA).

1.4 – Progress in 2010/2011

Expression in *E. coli* has been obtained with a number of target constructs. The most significant advance this year has been the determination of the structure for a cofactor synthesis 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 a substrate bound which provides key data relating to the important molecular interactions required for binding and catalysis, a crucial step for advancing the discovery of methanogen inhibitors.

Another enzyme that has been expressed is a very large enzyme and was technically difficult as multiple clones were needed to obtain useful levels of expression. This enzyme is itself a direct target for development of inhibitors, but can also be used to assay other NZAGRC target enzymes and thus help the development of high-throughput assays for rapidly screening large compound libraries.

In addition, three other potential target enzymes have been identified and added to the target list. Work has commenced on expression of these targets, determining the structures of these targets is likely to be more difficult, as no structures for these novel archaeal enzymes currently exist.

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 is 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.

Sheep antisera have been raised against peptides from a number of these vaccine targets and will be used to help identify and characterise recombinant proteins. A number of the targets have been

produced as recombinant proteins in *E. coli*. Sheep will be vaccinated with these recombinant proteins to produce antisera which will be tested for the ability of target-specific antibodies to inhibit methanogen growth and 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 sequences e 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. 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

Advances have been made in the ability 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.

1.6 – Progress in 2010/2011

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

1.7 - Methane capture and utilisation from dairy effluent

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.

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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. A peer-reviewed paper on the effects of defoliation on gibberelin synthesis has been drafted.

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. Initial indications 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.

2.2 – 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 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 and the efficiency of NI.

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.

Lysimeters have been collected and installed at a field lysimeter facility at Lincoln University. Treatments were applied to the lysimeters 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 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 physical properties and this, in turn, had a significant effect on the N_2O emission factor. The nitrification inhibitor DCD was shown to have a huge potential in reducing nitrous oxide emissions in both trampled and non-trampled plots. This work is also contributing to improving our fundamental understanding of the role of soil physical characteristics and changing soil water conditions on nitrous oxide emissions which is being investigated in Objective 2.4 (see below).

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.

2.3 – 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 for 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 24 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.

2.4 – 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.

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

Laboratory experimental work will build on recent research. 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 2010, 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 Baldocks research team will be investigated in the coming year.

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.

Soil Carbon Research – Objective Level Report - 2010/11

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, allophone 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.

3.2 - 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, however, 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. The two objectives will work in tandem 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 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 complex form of model structure. Finally, the dependence of the model only on an assessment of current land use is 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 this 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 based on a Gamma-distribution. This new approach overcomes a number of faults inherent in the Linear Model used in the existing MfE soil carbon model.

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.

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

Objective Leader – Dr David Whitehead (Landcare Research)

Landcare Research
Manaaki Whenua

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.

3.5 - 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 predicts carbon storage at depths of up to 1m from soil samples taken much closer to the surface. The method has been tested against archived soil samples from Winchmore.

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.

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[2] 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.

[2] 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.

4.2 - 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.

APPENDIX 3 – NZAGRC INTERACTIONS AND OUTPUTS

Meetings and Presentations (New Zealand)

- NZAGRC Steering Group Meeting: 01 July, 2010
- Meeting with Marc Lubbers, NZBIO regarding Global Research Alliance, ABIC and UNFCCC: 13 July, 2010
- Presentation to Massey Agricultural students regarding Professional Development and a career in science: 23 July, 2010
- Presentation to New Zealand Ministers of Parliament regarding Methane Emissions from Ruminant Animals (organised by Royal Society of New Zealand): 27 July, 2010
- Meeting with Earthwise regarding funding available from NZAGRC: 07 September, 2010
- NZAGRC Steering Group Meeting: 07 September, 2010
- NZAGRC Science Leadership Team Quarterly Meeting: 20 September, 2010
- Meeting with the PGgRc board: 22 September, 2010
- Presentation to the Massey Agricultural Systems students on "Mitigation of agricultural greenhouse gas emissions and an overview of the Emissions Trading Scheme": 24 September, 2010
- Sponsorship of the Massey University End of Year Agricultural Dinner: 08 October, 2010
- Meeting with Foundation for Arable Research regarding soil carbon and nitrous oxide emissions in/from the arable sector, research investment, and links with Australia: 13 October, 2010
- Presentation giving overview of NZAGRC and work programme "Mitigating Greenhouse Gas Emissions": 13 October, 2010
- Meeting to set up the NZAGRC Communications Forum: 18 October, 2010
- Meeting of the NZAGRC Science Leadership Team to discuss Annual workshops: 19 October, 2010
- Meeting with Landcare Research regarding their statement of corporate intent around greenhouse gas emissions inventory and mitigation: 20 October, 2010
- Meeting on photography for NZAGRC brand, Palmerston North: 20 October, 2010
- Meeting on photography for NZAGRC brand, Christchurch: 21 October, 2010
- Presentation by visiting scientist Cecile Martin on "Carbohydrates digestion in ruminants: quantitative and mechanistic approach": 28 October, 2010
- Presentation at Fonterra regarding scientific perspective of the problems and possible solutions in GHG emissions research: 02 December, 2010
- Meeting with Colin Bell to discuss using the compost barn approach for dairy cow housing/ feeding pads in reduction of methane emissions research: 07 December, 2010
- Meeting with MAF to review summary documentation on mitigation technologies: 14 January, 2011
- Second Agriculture ETS Advisory Committee Meeting: 01 February, 2011
- NZAGRC Science Leadership Team Quarterly Meeting: 07 February, 2011
- Meeting with Dorian Garrick with Mark Aspin to discuss NZAGRC: 09 February, 2011
- Meeting with Sir Peter Gluckman (led by MAF): 10 February, 2011
- Maori Technology Transfer Workshop: 15 February, 2011
- ETS Emission Factor Methodologies Workshop: 15 February, 2011
- Meeting with Alan McDermott, ANZCO Foods Limited: 18 February, 2011
- Meeting with NZAGRC ISAG: 21 February, 2011
- Opening of the New Zealand Ruminant Methane Measurement Centre: 22 February, 2011
- NZAGRC Science Workshops: 23 February, 2011
- NZAGRC combined Steering Group and Stakeholder Advisory Group: 24 February, 2011
- NZCCC meeting: 09 March, 2011
- Maori engagement workshop: 09 March, 2011
- ETS methodologies advisory meeting: 11 March, 2011
- Research and development planning meeting with PGgRc: 16 March, 2011
- Meeting with Jo Armstrong, Ministry for the Environment: 16 March, 2011
- Meeting with Vanessa Peters, University of Michigan on use of climate scenarios for education material: 17 March, 2011
- PGgRc Commercial Advisory Group and Vaccine Workshops: 29 March, 2011
- Meeting with Mike Manning, Ravendown: 01 April, 2011
- Opening of the New Zealand Centre for Nitrous Oxide Measurement: 01 April, 2011
- Poster presentation on modelling results of costs from alternative metrics and networking to support preparation of IPCC assessment: 04 April, 2011
- Presentation to general public at Te Manawa Science Cafe, "The NZAGRC: The First Year": 07 April, 2011
- Maori engagement visits to farms: 13 April, 2011
- IPCC Task Group on Scenarios for Climate Impacts Analysis: 13 April, 2011
- ETS Review Panel meeting: 20 April, 2011
- NZAGRC Science Leadership Team Quarterly Meeting: 04 May, 2011
- Discussion on inputs to IPCC assessment of climate change impacts/adaptation followed by meeting of lead authors for IPCC assessment: 05 May, 2011
- Maori engagement visits to farms: 09 May, 2011
- Agriculture ETS Advisory Committee Meeting: 11 May, 2011
- Meeting with Marta Alfaro, INIA, Chile: 11 May, 2011
- PGgRc Board meeting: 12 May, 2011

- Meeting with David Chadwick, BBSRC, UK: 12 May, 2011
- Visit from Leadership New Zealand including a NZAGRC presentation as part of field trip (36 People): 27 May, 2011
- KBBE Forum including presentation and general meeting participation as a New Zealand representative: 13 June, 2011 - 16 June, 2011
- Telephone call with Peter Davey, Dairy Solutionz - general NZAGRC discussion: 22 June, 2011
- Visit from delegation of New Zealand farmers led by Geoff Burton: "State of The Agricultural Nation" including presentation and general discussions regarding NZAGRC and New Zealand agriculture: 29 June, 2011
- Follow up discussion with Leadership New Zealand senior agriculture and climate change professionals: 01 July, 2011
- Visit from AgResearch Board including presentation regarding NZAGRC activities: 06 July, 2011
- Animal Variation Workshop with PGgRc and Vialactia: 27 July, 2011
- Fourth Agriculture ETS Advisory Committee Meeting: 04 August, 2011
- Presentation to Massey Agricultural students: 12 August, 2011
- Discussion with Irish counterpart in setting up GHG network

Meetings and Presentations (International)

- Meeting with Mr Teo Eng Dih of the National Climate Change Secretariat (NCCS), Singapore: 25 August, 2010
- Meeting with Dr Patrick Tan, Group Leader, Infectious Diseases, Genome Institute of Singapore: 26 August, 2010
- Meeting with Mr Terence Siew, Director, Special Duties, Ministry of Environment and Water Resources, Singapore: 26 August, 2010
- Meeting with Dr Neil Clark, Deputy Director and Senior Group Leader, Systems Biology, Genome Institute of Singapore: 26 August, 2010
- Meeting with HE Martin Harvey, New Zealand High Commissioner, Singapore: 26 August, 2010
- Meeting with Prof Mohan Balasubramanian, Temasek Life Sciences Laboratory, Singapore: 26 August, 2010
- Invited New Zealand representative at KBBE Forum, including presentation at plenary session: "Mitigation and adapting to climate change": 13 September, 2010 - 16 September, 2010
- Meeting in Brussels on KBBE: cooperation between NZ, Australia, EU and Australia: 15 September, 2010
- Meeting with the PGgRc Stakeholder Advisory Group: 02 October, 2010
- AnimalCHANGE kick off meeting, organised by INRA: 22 March, 2011
- IPCC Lead Author's meeting for Harry Clark in Busan, South Korea: 11 July, 2011 - 15 July, 2011
- DairyNZ presentation by Tim Mackle at China Green Dairy Summit, China, including information about the NZAGRC: 25 August, 2011

International Visitors and Groups

- Visit by Mr Modibo Tiémoko Traoré, Assistant Director-General, Agriculture and Consumer Protection Department, FAO: 21 July, 2010
- Meeting with New Zealand Climate Change Centre regarding relationship with NZAGRC: 21 July, 2010
- Meeting with Steve Thompson, British High Commission regarding United Kingdom linkages in greenhouse gas mitigation: 23 July, 2010
- Visit by Luiz Gustavo, Embrapa, Brazil regarding respiratory chambers, in vitro and SF6 technique, & measurement of enteric methane and collaborations between AgResearch, the Centre and Embrapa: 27 July, 2010 - 29 July, 2010
- Meeting with Duncan Pullar, EBLEX R&D regarding United Kingdom linkages: 30 July, 2010
- Meeting with Tom Misselbrook regarding GHG emissions from UK agriculture: inventory programme, improvements to emission factor estimates, mitigation of methane and nitrous oxide: 11 August, 2010
- Meeting with Maria Dolores Carro and Maria Jose Ranilla, University of Leon regarding ruminal physiology and reduction of methane emissions: 17 August, 2010
- Visit by Dr Junichi Takahashi to learn more about collaborative opportunities: 30 November, 2010
- Visit by Nathan Goldstein, Third Secretary, Australian High Commission: 09 December, 2010
- Meeting with NZAGRC International Science Advisory Group: 21 February, 2011
- Meeting with Wendy Gardner, Thompson Rivers University, Canada: 15 April, 2011
- Lunch with Dr James Hansen, climate change expert and public speaker: 13 May, 2011
- Visit from the Embassy of the Netherlands regarding collaborations (Global Research Alliance) and general NZAGRC update: 21 June, 2011

- Visit from delegation of leading Indian scientists regarding collaboration discussions and signing of NZ/India MOU: 22 June, 2011
- Presentation to Thai visitors, "Changes in soil carbon stocks in New Zealand pastures over the last century": 01 August, 2011
- Visit from delegation of Thailand officials including a presentation and discussion regarding NZAGRC activities: 03 August, 2011
- Visit from a delegation of Uruguan officials and agricultural professionals including a presentation (in Spanish by David Pacheco) regarding NZAGRC activities and a virtual facilities tour: 09 August, 2011

Global Research Alliance related interactions

- Meeting in Brussels, Belgium with Martin Scholten to prepare for upcoming Global Research Alliance Livestock Research Group meeting in Banff, Canada: 16 September, 2010
- Meeting and coordination of the Global Research Alliance Livestock Research Group, in Banff, Canada: Harry Clark Co-chair (with the Netherlands), and Peter Benfell and Mark Aspin as New Zealand representatives: 8 October, 2010 - 9 October, 2010
- Meeting on the Global Research Alliance, New Zealand Government budget, funding opportunities and research proposals: 15 October, 2010
- LEARN/Global Research Alliance: to discuss strategy of LEARN going forward and to update on activities in Global Research Alliance, including debrief on November trip to Long Beach: 26 November, 2010
- LEARN/Global Research Alliance: update on work to follow, update to discuss LEARN strategy and promotional ideas: 17 December, 2010
- Meetings with RFP lead scientists to discuss Global Research Alliance Initial Research Project Priorities for 2010/11 projects, budgets and timelines: 23 December, 2010
- Monthly meetings of the LRG leadership group: 1 January, 2011 - 30 June, 2011
- Monthly reporting meetings with MAF: 1 January, 2011 - 30 June, 2011
- Global Research Alliance: international research fund discussion paper - meeting with policy officials ahead of Ministerial/NZAGRC meetings: 09 February, 2011
- GRA-A2: International Rumen Microbial Genomics Network Workshop: 25 February, 2011
- Global Research Alliance Senior Officials meeting: 28 February, 2011
- GRA-A3: SF6 Tracer Technique Best Practice Manual Workshop: 08 March, 2011
- Global Research Alliance meeting with Ministry of Agriculture and Forestry: 20 April, 2011
- GRA-B7: Developing Guidelines for N2O Chamber Methodologies Workshop: 09 May, 2011
- GRA-A1: Animal Variation Workshop: 16 May, 2011 - 17 May, 2011

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 2010/11.

- Television interview for "Ever Wondered" (TVNZ 7) for episode 8 on climate change. Focus on New Zealand's agricultural sector and our biggest greenhouse gas challenges.: 25 September, 2010
- Our Changing World interview with Veronika Meduna, Radio New Zealand on research to reduce greenhouse gases: 09 December, 2010
- Interview with Kevin Ikin, Rural News: 21 January, 2011
- Interview with Morning Report, Radio New Zealand: 21 January, 2011
- Interview with AgResearch Inside Story: 21 January, 2011
- Interview with On the Field farming, Radio New Zealand: 21 January, 2011
- New Zealand Herald article regarding New Zealand Ruminant Methane Measurement Centre (NZRMMC): 18 February, 2011
- Interview with Kevin Ikin, Rural News: 21 February, 2011
- Media conference for the opening of the New Zealand Centre for Nitrous Oxide Measurement: 01 April, 2011
- Interview with Country Life with Carol Stiles, Radio New Zealand: 11 August, 2011
- Newspaper interview (Rodney Times) regarding the effects of climate change on farm production and reducing the impacts of climate change on-farm - two Centre Principal Investigators provided information

Conference Presentations

- 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.
- Clark, H. (2010). Animal vs. measurement technique variability in enteric methane production - is the measurement resolution sufficient? Paper presented at the Greenhouse Gas and Animal Agriculture Conference.
- Clark, H. (2010). Environmentally sustainable dairy production - Mitigating methane in a systems context. Paper presented at the Australasian Dairy Science Symposium.
- Clark, H. (2010). International collaboration and technology transfer: The Global Research Alliance. Paper presented at the IDF World Dairy Summit.
- Clark, H. (2010). Methane emissions from grazing animals. Paper presented at the 2010 AAAP Nutrition Forum.
- Clark, H. (2010). Modifying the cow and the rumen to reduce enteric methane emissions from dairy cows; challenges and opportunities. Paper presented at the IDF World Dairy Summit.
- Clark, H. (2010). Platinum sponsor presentation. Focus on New Zealand and the New Zealand Agricultural Greenhouse Gas Research Centre. Paper presented at the Greenhouse Gas and Animal Agriculture Conference.
- Clark, H. (2011). Carbon and the land based economy: Global Research Alliance. Paper presented at the Climate Change and Business Conference.
- Clark, H., Parsons, A. J., Kelliher, F., Rowarth, J. S., & Newton, P. C. D. (2010). Greenhouse Gas Fluxes in Grazed Pastures. Paper presented at the NZ Grasslands Association Conference.
- James, A. (2010). Communicating Greenhouse Gas Research through Cooperation and Collaboration. Paper presented at The National Science Communication Officers' Forum 2010.
- Leahy, S. C. (2011). Rumen methanogen genomics - Reducing Emissions from Livestock Research Program. Paper presented at the Metagenomics CSIRO workshop/meeting.
- Leahy, S. C. (2011). Use of microbial genomics to understand fiber degradation and methanogenesis in the rumen environment. Paper presented at the Congress on Gastrointestinal function.
- Ludemann, C. I., Byrne, T. J., Sise, J. A., & Amer, P. R. (2011). Potential for NZ farmers to reduce Greenhouse Gas emissions through genetic selection tools. Paper presented at the International Farm Management Association Congress.
- Ludemann, C. I., Byrne, T. J., Sise, J. A., & Amer, P. R. (2011). The role of breeding in reducing sheep GHG emissions. Paper presented at the New Zealand Society of Animal Production.
- Reisinger, A. (2011). Alternative metrics to value mitigation of non-CO_2 greenhouse gases. Paper presented at Greenhouse 2011.
- Reisinger, A., P., H., & K., R. (2011). Economic and social implications of alternative metrics for agricultural greenhouse gases in multi-gas mitigation strategies. Paper presented at the 6th International Symposium on non-CO2 Greenhouse Gases.
- Reisinger, A., Stroombergen, A., & Havlik, P. (2011). Global and National Mitigation Costs Under Alternative Metrics. Paper presented at the Tyndall Conference 2011.
- Vogeler, I., Giltrap, D., Li, F., & Snow, V. (2011). Comparison of models for predicting nitrification and denitrification in pastoral systems. Paper presented at the ModSIM conference.

Journal Articles

Submitted

- Ball, B. C., Cameron, K. C., Di, H. J., & Moore, S. (in press). 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.
- Calvelo Pereira, R., Kaal, J., Camps-Arbestain, M., Pardo Lorenzo, R., Aitkenhead, W., Hedley, M., et al. (in press). Contribution to characterisation of biochar to predict carbon lability. Organic Geochemistry.
- Kelliher, F. M., Condron, L. M., Cook, F. J., & Black, A. (in press). Sixty years of seasonal irrigation affects carbon storage in soils beneath pasture grazed by sheep. Agriculture, Ecosystems and Environment.
- Ludemann, C., Byrne, T., Sise, J., & Amer, P. (in press). Potential for NZ farmers to reduce Greenhouse Gas emissions through genetic selection tools. International Journal of Agricultural Management
- Mudge, P. L., Wallace, D. F., Rutledge, S., Campbell, D. I., Schipper, L. A., & Hosking, C. L. (in press). Carbon balance of an intensively grazed temperate pasture in two climatically contrasting years. Agriculture, Ecosystems and Environment.
- Orwin, K. H., Kirschbaum, M. U. F., St John, M. G., & Dickie, I. A. (in press). Organic nutrient uptake by mycorrhizal fungi enhances ecosystem carbon storage: a model-based assessment. Ecology Letters.
- Reisinger, A., Lawrence, J., & Hart, G. (in press). From coping to resilience: the role of managed retreat in highly developed coastal regions. In B.

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

- Saggar, S., Tillman, R. W., Jha, N., Bolan, N. S., Luo, J., Giltrap, D. L., et al. (in press). Denitrification in temperate grasslands; processes, measurements, modelling and mitigating. Soil Biology and Biochemistry.
- Stockmann, U., Adams, M., Crawford, J., Field, D., Henakaarchchi, N., Jenkins, M., et al. (in press). Managing the soil-plant system to mitigate atmospheric CO2. Agriculture, Ecosystems and Environment.

Published

- Attwood, G. T., Altermann, E., Kelly, W. J., Leahy, S. C., Zhang, L., & Morrison, M. (2011). Exploring rumen methanogen genomes to identify targets for methane mitigation strategies. Animal Feed Science and Technology, 166-167, 65-75.
- Buddle, B. M., Denis, M., Attwood, G. T., Altermann, E. H., Janssen, P. H., Ronimus, R. S., et al. (2011). Strategies to reduce methane emissions from farmed ruminants grazing on pasture. The Veterinary Journal, 188, 11-17.
- Clark, H., Kelliher, F. M., & Pinares-Patiño, C. S. (2011). Reducing CH4 emissions from grazing ruminants in New Zealand: challenges and opportunities. Asian-Australasian Journal of Animal Science, 24, 295-302.
- de Klein, C. A. M., Cameron, K. C., Di, H. J., Rys, G., Monaghan, R. M., & Sherlock, R. R. (2011). Repeated annual use of the nitrification inhibitor dicyandiamide (DCD) does not alter its effectiveness in reducing N2O emissions from cow urine. Animal Feed Science and Technology, 166-167, 480-491.
- Kelliher, F. M., & Clark, H. (2010). Methane emissions from bison-An historic herd estimate for the North American Great Plains. Agricultural and Forest Meteorology, 150(3), 473-477.
- Manning, M., & Reisinger, A. (2011a). Broader perspectives for comparing different greenhouse gases. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 369(1943), 1891-1905.
- Manning, M., & Reisinger, A. (2011b). The Science of Climate Change, its Potential Impacts and Global Response Options. In A. Cameron (Ed.), Climate Change Law and Policy in New Zealand. Wellington, NZ: LexisNexis.
- 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: CAB International.
- Pinares-Patiño, C. S., McEwan, J. C., Dodds, K. G., Cárdenas, E. A., Hegarty, R. S., Koolaard, J. P., et al. (2011b). Repeatability of methane emissions from sheep. Animal Feed Science and Technology, 166-167(Greenhouse Gas Special Issue), 210-218.
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