Proceedings of the Workshop on the Science of Atmospheric Trace Gases, 2004

Compiled by T. S. Clarkson

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INTRODUCTION

1.1 THE TRACE GAS WORKSHOP

Tom Clarkson
NIWA, Wellington

Why have a trace gas workshop?

In 1998 and 2001, NIWA hosted a Trace Gas Workshop for scientists and policymakers actively working in the trace gas/greenhouse area.

At each meeting, over 2 days, over 50 people attended and heard presentations by CRI and university researchers and government officials on trace gas research and its applications and implications. There were about 30 poster presentations and a 100-page proceedings with extended abstracts was published for each workshop.

At the end of each meeting there were expressions of the value of collaboration between the different groups represented and ideas for more formal collaborations were put forward. There was a consensus that a similar meeting should be held every one to two years. During recent years, we believe there has been improved informal or scientist-scientist collaboration for which the 1998 and 2001 Workshops could take some credit.

March 2004 was thought to be a suitable time for another such meeting. In particular, NIWA, and the Pastoral Greenhouse Gas Research Consortium were able to be fully involved in the organisation and planning of the Workshop, and the Climate Change Office was able provide financial assistance towards the costs of this publication.

There are several groups actively engaged in atmospheric trace gas research in New Zealand, supported by the Foundation for Research, Science & Technology, universities, or industry organisations such as the Pastoral Greenhouse Gas Research Consortium. The research is relevant to our understanding of climate change and New Zealand's approach to the Kyoto Protocol. Among those who have a need for the best assessments of climate change scientific information are those government ministries involved in policy development, either within New Zealand or for our interactions internationally, and industry sectors that will be directly effected by either climate change, or by government-imposed changes. Research work is now evident in the human dimensions of the buildup of atmospheric trace gases – social and economic work has introduced new aspects about.which most physical scientists may have little awareness.

Many research results are presented as specialist papers in scientific journals, often only seen and read by others working in the same field. The policy developer or industry manager is unlikely to read such papers, but needs brief and accurate information on the latest results, in plain English, to interpret and make the necessary practical applications of the research work.

Misunderstandings can arise if there is insufficient communication between and within different groups of stakeholders.

What the science users want may still not be clear to the science community and it may not be clear to science users what is available. Before research is carried out views must be exchanged so that both groups have sufficient information to be clear that the research is in the right direction.

The best scientific progress will be made, and the funders will have the best value for money, if research groups communicate and have coordination and cooperation in their planning, even where there is competitive bidding for funds.

There must always be a mechanism for bridging the gaps between the science results and the practical applications and policy development. Programmes which require scientists to interact with users help here.

Three goals for the workshop

- To provide an opportunity for scientists and science users to interact
- To make progress towards a common strategy for collaboration between science research groups and science users
- To smooth out misunderstandings and increasing the overall effectiveness of the specialist research work.

Four themes

- Pastoral greenhouse gas emission processes – microscopic and paddock scales – options for mitigation
- The New Zealand greenhouse gas emissions inventories – methods and new compilations – how good are they?
- New measurements of trace gases – concentrations and fluxes - Pacific, NZ, Antarctica.
- Human and economic dimensions of greenhouse gas issues – effects on pastoral industries - the progress of the Kyoto Protocol, within and beyond New Zealand

Some topics for discussion

For 2004, in the preliminary notices we made some suggestions of a range of topics that we could aim to cover during the Workshop.

- Identification of requirements for policy development and practical applications
- Key research results needed to advance NZ climate change policies; regional, national, and international.
- Bridging the gap between research results and information needed by users
- Interdisciplinary collaboration – climatology, chemistry, microbiology ….
- Combining ‘top-down’ and ‘bottom-up’ approaches to inventories

New work on methane and nitrous oxide – NZ agricultural emissions, southern hemisphere budgets, etc.

- The role of short lifetime species, e.g. CO, O_3, NMHC
- Complying with the Kyoto Protocol – industry and regional issues.
- Research towards mitigation

Methods of information presentation to the Workshop

- Review presentations to introduce each theme. Two of these were invited on particular issues and recent work, particularly from stakeholders in government and industry.
- Posters. Ample time during the meeting was allowed to discuss posters. This was the principal method of presenting recent scientific work. There were also about 5 minutes allowed to introduce each poster to the Workshop with a limit of three slides or transparencies.
- Facilitated discussion after each oral presentation and ample opportunities for less formal discussion, e.g., poster sessions, dinner and evening gatherings.
- Theme summing-up by facilitators.
- Abstracts. Each presenter was invited to prepare an extended abstract of up to three pages to be compiled into a proceedings volume. This publication is the result.

There were over 90 participants at the workshop, most for the full two days. A striking feature was the display of 50 posters, with standards of presentation being very high. Most of the poster presenters also prepared an ‘extended abstract’ for inclusion in these proceedings.

1.2 THE RELEVANCE OF NZ TRACE GAS RESEARCH – AN INTRODUCTION AND AN INTERNATIONAL PERSPECTIVE

David Wratt
NIWA, Wellington

New Zealand research on trace gases that have potential to influence climate is important because of two broad reasons: First, our national need for a robust scientific base for developing policies and mitigation actions, and second our national obligation under the UN Framework Convention on Climate Change to contribute internationally to knowledge.

Government policy developers need information about national greenhouse gas sources and sinks and how these are likely to change. They need science-based knowledge about options, opportunities and costs for reducing net emissions, as do policymakers and planners in local government and industry. There is a particular need for emission-reduction methods and technologies that reflect our particular greenhouse gas mix. New Zealand research is of international relevance because of our location, our unusual mix of anthropogenic greenhouse gas emissions, and our interests in forestry and land-use change as carbon dioxide sinks.

Relevance of Trace Gas Research to National Policy Development

Although New Zealand produces only a small fraction of the total global anthropogenic greenhouse gas emissions (around 0.2%), our per capita emissions are relatively high compared to many other countries. In 1999 our per capita annual net emissions (taking into account sinks from land-use change and forestry as well as sources) were 14.4 tons of carbon dioxide equivalent[1] (Turton and Hamilton 2002). This was the seventh highest value for countries listed in Annex B of the Kyoto Protocol. If the Kyoto Protocol is ratified, New Zealand's commitment is to reduce aggregate anthropogenic carbon dioxide equivalent net emissions for 2008 – 2012 to 1990 values.

In order for New Zealand to demonstrably meet this Kyoto target, and for our representatives to be well informed for negotiating future agreements, our policymakers need robust estimates of national emissions and sinks of greenhouse gases. Information on options for reducing emissions and increasing sinks is needed as a base for actions. New Zealand's mix of greenhouse gas emissions (Ministry for the Environment, 2003) is unusual, in that less than half (45%) of the estimated contribution to radiative forcing[1] comes from carbon dioxide. The remainder is predominantly from methane (37%) and nitrous oxide (17%). In comparison, the global numbers in 1990 were (Pew Centre, 2003): Carbon dioxide 69%; methane 20%; nitrous oxide, 10%.

Hence research on sources and sinks of methane and nitrous oxide and on reducing emissions of these gases is important for New Zealand. Most of our methane emissions come from enteric fermentation in cattle and sheep. Research to develop ways to reduce these emissions is particularly relevant.

The International Contribution of New Zealand Research and Observations

New Zealand scientists are making important contributions to international understanding of sources and sinks of greenhouse gases, and the chemistry that influences their atmospheric concentration. This is aided by New Zealand's remote location in the South Pacific, the skills our scientists have developed in isotopic measurements which help tease out the sources of

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[1] 100 year greenhouse warming potentials were used to calculate CO_2 equivalents of non-CO_2 gases.

greenhouse gases, and our long time series of background atmospheric concentrations of trace gases (including measurements from ships crossing the Pacific and flights to Antarctica).

New Zealand research on agricultural greenhouse gas emissions and their mitigation, on forestry, soils and land use change as sinks of greenhouse gases, and on ocean processes which influence atmospheric greenhouse gas and aerosol concentrations is also of international relevance. New Zealand scientists undertaking such work have acted as lead and contributing authors for many of the assessments carried out by the IPCC (Intergovernmental Panel on Climate Change). International collaboration also benefits New Zealand by bringing important skills and resources here.

Are There Really "Reasons for Concern" Regarding Greenhouse Gas Emissions?

The goal of the United Nations Framework Convention on Climate Change is "stabilization of greenhouse gases in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". However, some articles in the media and magazines have suggested that risks arising from greenhouse gas emissions have been grossly exaggerated, and that there is little need to constrain such emissions. De Freitas (2003) summarises several of the arguments used to support this position. If confirmed, such assertions would raise significant questions about whether substantial investment in greenhouse gas research remains relevant and justified. Issues often raised include:

Was the late 20th Century really unusually warm? The IPCC Third Assessment Report (Watson et al, 2001) concluded that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". This conclusion drew on published evidence, such as estimates of northern hemisphere temperatures through the last millennium inferred from paleoclimate evidence (e.g. Mann et al, 1999) indicating the last 50 years of the twentieth century were unusually warm. However, there have been some challenges to this view. For example Soon and Balliunas (2003) argue that this late 20th Century warming was not unusual in the context of the past millennium, and McIntyre and McKitrick (2003) claim the 15th Century was warmer than the 20th. Mann and his colleagues (Mann et al 2003a, 2003b) have provided strong rebuttals to these challenges. The IPCC's interpretation is still supported by the scientific evidence.

Are measured surface warming trends through the 20th century flawed? Some have argued that apparent warming trends measured near the surface of the earth have been contaminated by urban heat island effects, and that satellite measurements in the lower atmosphere (uncontaminated by such processes) indicate any warming trend has been very small (e.g. de Freitas, 2003). But satellite measurements have their own set of problems, with some recent reanalyses inferring greater warming than was previously thought, and leading to the conclusion that data uncertainties can explain observed differences (Santer et al, 2003). Much work has been done on homogenising surface temperature series and removing or correcting doubtful records. Also warming trends are observed over oceans where there are no urban effects (Watson et al, 2001). A study of North American surface observations (Peterson 2003) concludes that: "Contrary to generally accepted wisdom, no statistically significant impact of urbanization could be found in annual temperatures".

Are greenhouse gas emission scenarios used by the IPCC incorrect? Climate model predictions of future climate change depend on the future concentrations of greenhouse gases in the atmosphere, which in turn depend on the assumed emission scenarios. Castles and Henderson (2003) argue that many of the emissions scenarios used in the IPCC's Third

Assessment are too high, because market exchange rates (MER) rather than purchasing power parity (PPP) were used in many of them to calculate future economic growth. Specialists involved in preparing these IPCC scenarios strongly disagree with these criticisms (Nakicenovic et al, 2003). This debate will doubtless continue, perhaps from the perspective of whether some of the IPCC scenarios are more probable than others. Nevertheless, it is worth noting that even if greenhouse gas emissions were immediately cut drastically, to the level where atmospheric concentrations of these gases remained constant, there would still be significant warming of the atmosphere and sea level increase over coming centuries, because of lags in the ocean-atmosphere system (see Watson et al, 2001).

In summary, despite challenges put forward since 2001, key findings from the IPCC's Third Assessment Report remain valid, including the "reasons for concern" summarised in Figure SPM3 of the Synthesis Report (Watson et al, 2001). These indicate that for most of the IPCC scenario range over the coming century there will be risks to unique and threatened systems and risks from extreme climate events will increase. If emissions follow the higher IPCC scenarios, impacts by the end of the century are expected to be negative for most regions of the world, and aggregate impacts to be negative.

The Next IPCC Assessments

Given the often intense debate about climate change, the IPCC assessments performed by top climate scientists from around the world and subjected to extensive review are a very important source of authoritative science information for policymakers. New Zealand scientists, including trace gas researchers, made important contributions to the third assessment report. They also contributed to recent IPCC assessments on land use, land use change and forestry issues. Work is now starting on the fourth assessment report (due out in mid-2007). Several New Zealanders are likely to be lead authors, others will be contributing authors, and there will be opportunities for many to submit technical review comments.

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1.3 THE STATE OF PLAY” – UNFCCC AND THE KYOTO PROTOCOL

Helen Plume
New Zealand Climate Change Office

The United Nations Framework Convention on Climate Change (UNFCCC) entered into force on 21 March 1994, almost exactly ten years ago. It has gained almost universal acceptance in that it has been ratified by 188 countries. The UNFCCC contains commitments and obligations for all Parties (taking into account their common but differentiated responsibilities) including to:
mitigate climate change;
undertake research into climate change and undertake systematic observation of the climate system including reporting on contributions to the Global Climate Observing System (GCOS);
provide regular greenhouse gas inventory reports and national communications. (For Annex I Parties2 the 4th national communication is due to be reported by 1 January 2006).

The UNFCCC provides the basis for action on climate change. In addition to the more general commitments outlined above, this action includes for Annex I Parties the limiting of greenhouse gas emissions, and protecting and enhancing greenhouse gas sinks and reservoirs. In addition, Annex II Parties3 have commitments relating to financial assistance to developing countries.

The first Conference of the Parties to the UNFCCC (COP1) met in 1995 agreed the “Berlin Mandate” which guided negotiations on what became the Kyoto Protocol. The Berlin Mandate clearly stated that the negotiations would provide quantified emission limitation and reduction objectives for Annex I Parties but no new commitments for developing countries. The Kyoto Protocol was agreed in December 1997 at COP3. New Zealand signed the Protocol in May 1998, and ratified it in December 2002. The first commitment period of the Protocol is from 2008 to 2012 for which Annex I Parties have legally binding emission targets.

To enter into force the Kyoto Protocol requires ratification by *fifty five Parties to the Convention, incorporating enough Annex I Parties to account for 55 percent of the total Annex I carbon dioxide emissions in 1990.* Currently there are 121 ratifications representing 44.2% of Annex I 1990 CO_2 emissions. This means there is a deficit of 10.8% needed before entry-into-force can occur. The following table shows the percentage of 1990 CO_2 emissions of three major emitters that have not yet ratified.

Annex I Party	Percentage of 1990 CO2 emissions
Australia	2.1%
Russian Federation	17.4%
United States	36.1%

There is considerable discussion going on in a number of fora regarding the prospects for entry-into-force of the Kyoto Protocol. In this context it is worth remembering that the general trend is for international treaties to enter into force eventually, that there are examples where treaties may not enter into force for some time (e.g. the Law of the

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[2] Annex I Parties are developed countries and countries with economies in transition (or EITs).
[3] Annex II Parties are developed countries (core OECD members).

Sea that took several decades to enter into force), and that it is still a relatively short time since COP7 (November 2001) when most of the Kyoto rules were finalized.

Of the countries listed in the table above, both the United States and Australia have stated that they will not ratify the Kyoto Protocol. This then leaves the question of Russia, and there are several scenarios, almost all of which lead to a period of uncertainty which may last through to the end of 2004, or possibly longer. There is no consensus view on how long the international community will wait and how it might react if Russia decides not to ratify the Protocol. However, most countries agree it is too soon to abandon the Kyoto Protocol.

The question of what happens next is already being discussed in a number of fora, including in the margins of UNFCCC meetings. If there is no entry-into-force by COP10 (December 2004), and if Russia has not named a date by which it will ratify, then the discussion of "what next?" becomes more mainstream.

2005 is a key year for the Kyoto Protocol. This is the year by which Annex I Parties are expected to have made "demonstrable progress in achieving its commitments" under the Protocol (Article 3, paragraph 2 of the Protocol refers) and Annex I Parties are also due to report on demonstrable progress by 1 January 2006. Also, 2005 is the year by which negotiations for the second commitment period are scheduled to begin (Article 3, paragraph 9 refers). Negotiations can only occur under the Kyoto Protocol if it has entered into force. However, it may make more sense to conduct the negotiations for future commitments under the UNFCCC as this would mean the United States could fully participate as a Party.

There are a large number of COP decisions on the operational rules and procedures for the Kyoto Protocol. These decisions have been prepared in advance so that once the Kyoto Protocol enters into force, the decisions are ready for adoption by the first Meeting of the Parties under the Protocol (COP/MOP1). These rules and procedures include those relating to the reporting and review of greenhouse gas inventory information under Articles 5, 7 and 8 of the Kyoto Protocol, most of which were agreed at COP7 and COP8. Procedures and methodologies for adjustments under Article 5, paragraph 2 were agreed at COP9[4]. These Kyoto Protocol rules and procedures build upon the systems already in place for greenhouse gas inventory reporting and review under the UNFCCC.

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[4] Adjustments can be applied to greenhouse gas inventory data if it is deemed by expert reviewers to have been compiled using inappropriate methodologies.

2 PRESENTATIONS FROM MINISTRIES

2.1 THE NEW ZEALAND AGRICULTURAL INVENTORY RESEARCH PROGRAMME FOR NON-CO2 GREENHOUSE GASES

Gerald Rys[1], Helen Plume[2], Keith Lassey[3], and members of NzOnet and Methanet Expert Groups
[1]Ministry of Agriculture and Forestry
[2]New Zealand Climate Change Office
[3]NIWA, Wellington

Projections of Agricultural Greenhouse Gases to 2010 in New Zealand.

Year	Nitrous Oxide (kt)	Methane (kt)	Total (kt)
1990	9,890	21,320	31,210
2001	12,060	23,080	35,140 (13%)
2010 projected	12,990 (31%)	24,250 (13.7%)	37,240 (19%)

The Impact of Excess Emissions during the Commitment Period

Excess emissions over 1990 levels are projected to be 6 million tonnes carbon dioxide equivalents
Uncertainty estimates give a value between 3 to 10 million tonnes
The value an excess of 6 million tonnes over the Commitment Period (2008 -02012) at 25$ tonne is $750 million dollars.

Uncertainties - Monte Carlo Analysis of the 2001 Inventory

Methane (all SF_6-tracer based experiments to date):
    mean 1099 Gg: 95% confidence limits 593–1606 Gg
    methane per unit intake accounts for 90% of variance
Nitrous Oxide:
    median 37.7 Gg: 95% confidence limits 22.4–67.5 Gg
    EF3 accounts for 89% of variance

The International Context for Agricultural Inventories

Few countries are devoting significant resources to agricultural inventory improvement. Agricultural emissions are 9% for Annex 1 parties (2001) and 28% on Non-Annex 1 parties total emissions.
Inventories are becoming more important with the prospect of Kyoto coming into force. They are being subjected to closer international scrutiny.
Inventories will also be influenced by the upcoming review of the IPCC Inventory Good Practice Guidance.

Overview of the Inventory Research Programme

The programme commenced in July 2001
It is four year programme with NZ$2.75m funding
It is supported through two expert groups — NzOnet and Methanet comprising Climate Change policy officials, government and private sector scientists
The groups identify the strategy and projects at a science level.

Scope of Programme Activities

Field research activities
Desktop studies
Decision support tools
Programme broadly split between methane and nitrous oxide activities
Focussed on IPCC methodologies
Recognises the need for capacity building

Nitrous Oxide

Field studies for emission factor EF3 – emission from urine onto pasture.
EF3 values assessed to date, in various combinations:
Three locations (flatland) Waikato, Lincoln, Otago
Up to three soil drainage classes at each location
Both dung and urine from both sheep and cattle
Seasonal time-slots: summer, autumn, winter, spring
Methane from deposits as well as nitrous oxide

Evaluation of Process-based Models

Three models were assessed using emissions data from the national series:
NZ-DNDC, DAYCENT and NOPAS
All models performed poorly in predicting nitrous oxide emissions and other key drivers such as soil nitrate levels. Possible reasons are:
poor input data
poor model specifications for NZ conditions (e.g, grazing)
Models are being re assessed.

The Future — Nitrous Oxide

Emissions from hill country pastures have not been assessed yet — 30% of livestock (sheep, beef cattle) graze such pastures.
Upscaling: chamber → paddock → region → country
Dietary N varies seasonally ⇒ impact on emissions?
The impacts of soil compaction due to grazing?
Which models should be developed further?
Improving national inventory back to 1990 is difficult as some data is not available.

Methane

New measurements (SF_6-tracer technique):
dairy calves and mature beef cows

NZ ‘Tier 2’ enteric methane inventory methodology

Emission factors (kgCH_4/hd/yr) averaged over all stock in the national herd as at 30 June.

	1990	2001
Sheep	8.9	10.6
Dairy cattle	70.2	74.7
Beef cattle	50.8	56.0
Deer	19.7	20.9

Characterizing Herbage Quality through Remote Sensing

Real-time satellite imagery using Spot 4 VEGETATION sensor — daily passage provides monthly means on spatial grid based on 10 retrievals/month

Correlation between ground-truth values and spectral proxies (spatial variation):

Digestibility proxy: 5.6% SE, R2 = 0.53
ME proxy: 0.74 MJ/kg SE, R2 = 0.48

Goal to construct monthly herbage characterization over a geographic grid based on satellite retrievals

Decision Support Tools

Improvement of the OVERSEER nutrient budget model to incorporate methane and nitrous oxide emissions. Freely WWW available.

Development of a relational database for SF_6 tracer studies with all associated animal data, to enable CH_4 emission relationships — data welcome!

Construction of a user-friendly National Inventory Calculation model.

Conclusions - Future Issues

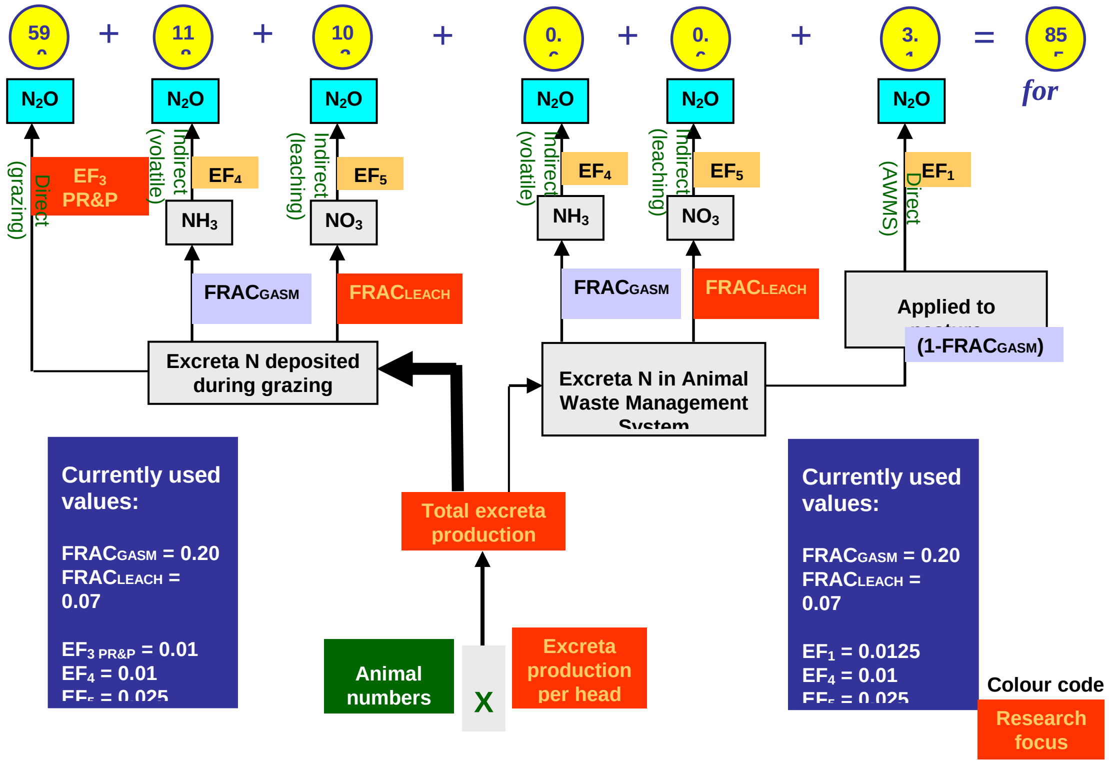
How do we incorporate mitigation technologies/management practice impacts into the national inventory particularly with simultaneous use of more than one technology?

What are the best approaches to narrow/reduce/control the uncertainties in the agricultural inventory?

Are we using the “right” methodologies and models?

Do we have the correct sampling frames for animal number statistics?

Livestock-sourced N_2O: IPCC emission pathways


59 + 11 + 10 + 0. + 0. + 3. = 85

for

N_2O N_2O N_2O N_2O N_2O N_2O

Direct (grazing)

EF_3 PR&P

Indirect (volatile)

EF_4

NH_3

Indirect (leaching)

EF_5

NO_3

$FRAC_{GASM}$

$FRAC_{LEACH}$

Excreta N deposited during grazing

Indirect (volatile)

EF_4

NH_3

Indirect (leaching)

EF_5

NO_3

$FRAC_{GASM}$

$FRAC_{LEACH}$

Excreta N in Animal Waste Management System

Direct (AWMS)

EF_1

Applied to

$(1-FRAC_{GASM})$

Currently used values:

$FRAC_{GASM} = 0.20$
$FRAC_{LEACH} = 0.07$

$EF_{3\ PR\&P} = 0.01$
$EF_4 = 0.01$
$EF_5 = 0.025$

Total excreta production

Animal numbers

X

Excreta production per head

Currently used values:

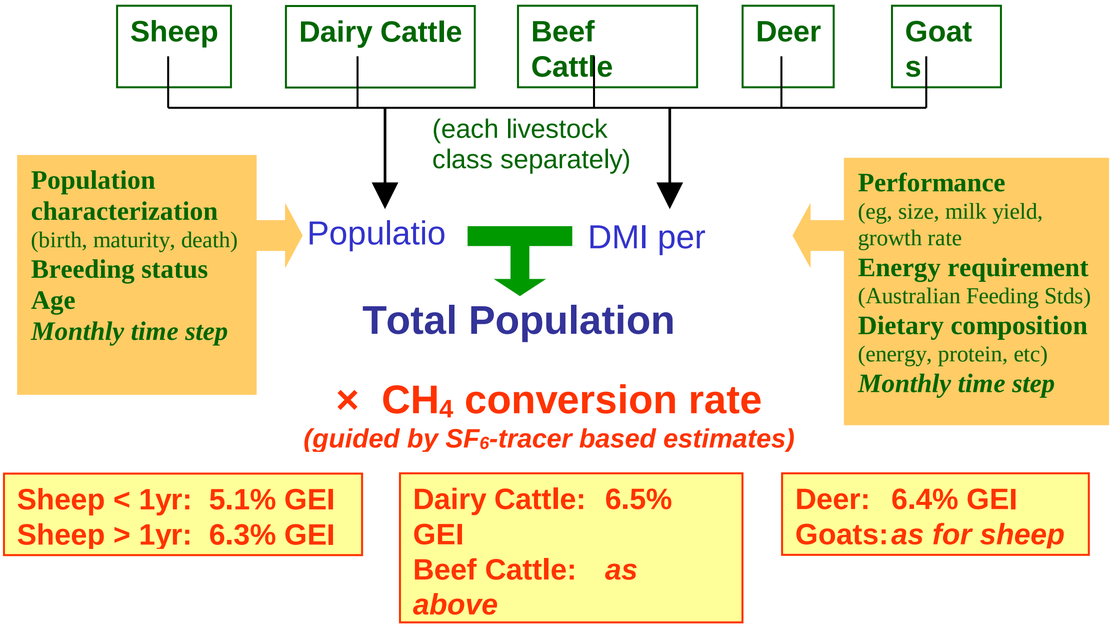
$FRAC_{GASM} = 0.20$
$FRAC_{LEACH} = 0.07$

$EF_1 = 0.0125$
$EF_4 = 0.01$
$EF_5 = 0.025$

Colour code

Research focus

NZ 'Tier 2' enteric methane inventory: methodology


Sheep

Dairy Cattle

Beef Cattle

Deer

Goats

(each livestock class separately)

Population characterization
(birth, maturity, death)
Breeding status
Age
Monthly time step

Populatio

DMI per

Total Population

× CH_4 conversion rate
(guided by SF_6-tracer based estimates)

Performance
(eg, size, milk yield, growth rate
Energy requirement
(Australian Feeding Stds)
Dietary composition
(energy, protein, etc)
Monthly time step

Sheep < 1yr: 5.1% GEI
Sheep > 1yr: 6.3% GEI

Dairy Cattle: 6.5% GEI
Beef Cattle: *as above*

Deer: 6.4% GEI
Goats: *as for sheep*

2.2 ENERGY SECTOR INVENTORY IN NEW ZEALAND'S GREENHOUSE GAS EMISSIONS

Ram SriRamaratnam
Energy & the Environment Group, Ministry of Economic Development

Energy Sector Emissions Inventory

The early work for the preparation of the energy sector greenhouse gas emissions inventory for the 1990-1992 period was carried out by an outside agency on contract to the then Ministry of Commerce (Waring & Richards, Industrial Research Limited, 1994). The subsequent annual inventory updates were prepared by the Energy and the Resources Division of the Ministry of Commerce until 1996. This was then continued within the Resources & Networks Branch from 1997 to 1999 and within the Ministry of Economic Development (MED) since 2000.

All energy sector emissions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), other oxides of nitrogen (NO_x), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC) are included in the inventory, which is augmented by CO_2 emissions from the industrial processes sector so as to give total CO_2 emission estimates. The latter consists of non-fuel emissions from the production of steel, aluminium, hydrogen, cement and lime. This is included in the annual MED publication which is published in June of each year covering the inventory from 1990 (base year) to the previous calendar year (New Zealand Energy Greenhouse Gas Emissions: 1990-2002, June 2003). This inventory update is then used as the basis for providing the necessary information for the energy sector and the industrial processes to the New Zealand Climate Change Office (NZCCO) which is responsible for the submission of the inventory to the United Nations Framework Convention on Climate Change (UNFCCC).

Energy Sector Emissions Overview

Gross CO_2 Emissions

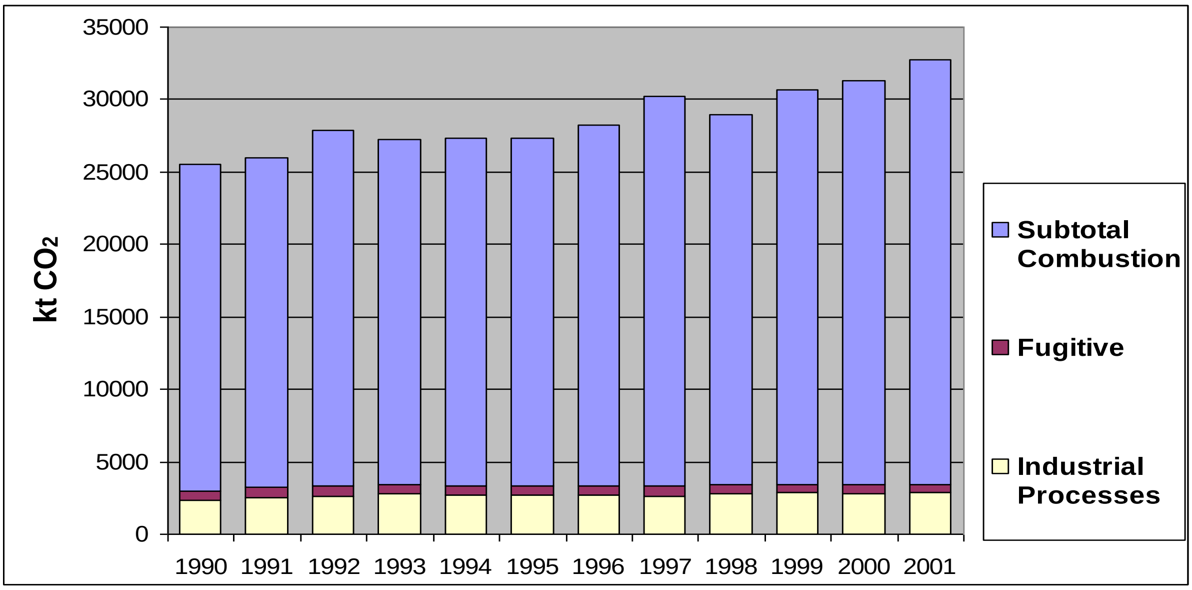


***Figure 1*: Gross CO_2 Emissions**

Gross emissions of CO_2 from the energy sector has increased from just over 25,000 Kt in 1990 to about 33,000 Kt in 2001 with combustion emissions making a significant component (about 89%) of the gross emissions and the industrial processes (about 9%) and fugitive (about 2%) emissions making up the rest. Combustion emissions have risen steadily from about 22,500 Kt of CO_2 in 1990 to the current level but have declined in some years when there has been higher emissions in the previous (dry) year when there was quite a high level of thermal generation.

Sector Trends and Shares of CO_2 Emissions

Among the components of the combustion emissions, domestic transport sector emissions make up the largest share and have increased steadily at about 4% pa with its share rising from about 38% in 1990 to 41% in 2001. Emissions from the industrial activity has accounted for about 21% of the combustion emissions and has grown at a rate of about 2% pa while emissions related to thermal generation has fluctuated between 15% ("normal years") and 25% ("dry years") contributing to the fluctuation of the overall combustion emissions.

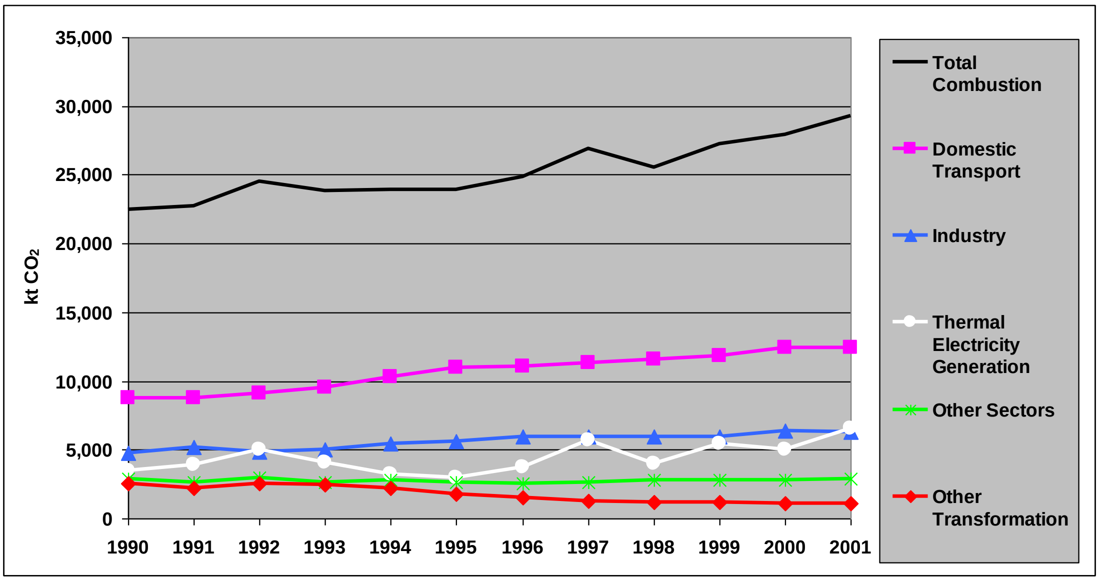


Figure 2: **CO_2 Combustion Emissions - Sector Trends**

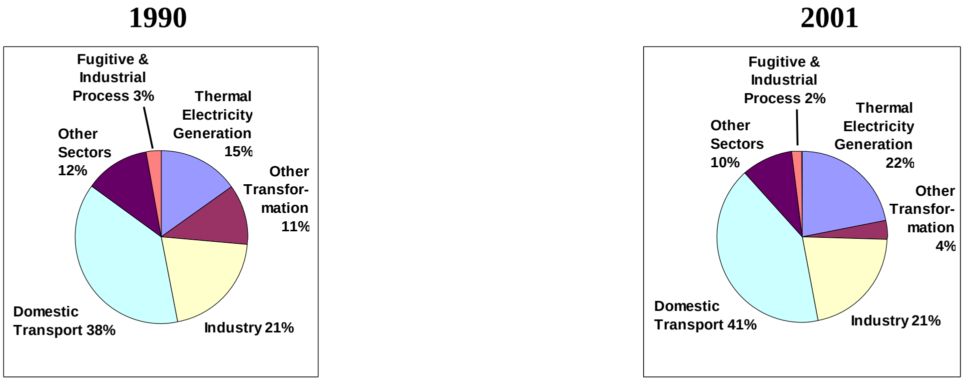


Figure 3: **Gross CO2 Emissions: Sector Shares**

Fuel Shares of CO_2 Emissions

Emissions related to liquid fuel use dominate gross CO_2 emissions accounting for about 45% of the emissions followed by gas (about 32%), coal (about 12%), and biomass (about 10%).

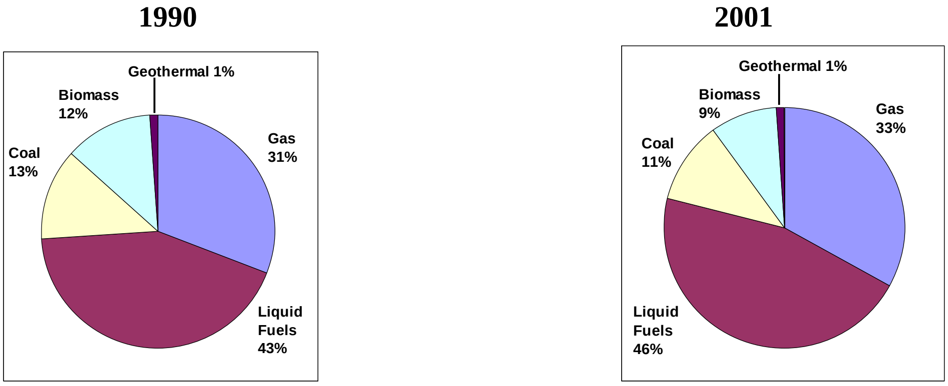


Figure 4: **Gross CO_2 Emissions: Fuel Shares**

Thermal Electricity Generation

Total CO_2 emissions from thermal electricity generation is dominated by gas (75-80%) and coal (15-17%) in New Zealand with very little liquid fuel used. The share of coal as a thermal fuel has risen in recent years at the expense of gas with declining gas availability.

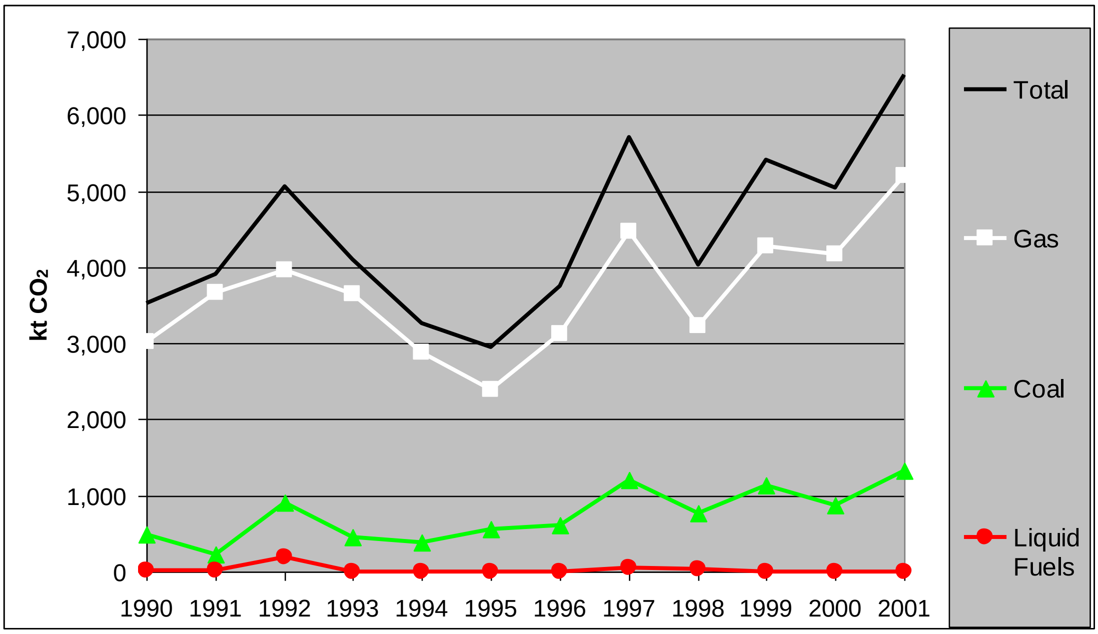


Figure 5: Thermal Electricity Generation - CO_2 Emissions by Fuel

CH_4 Emissions from Energy

Total CH_4 emissions from the energy sector is dominated by fugitive emissions (about 80%) with fuel combustion (mainly related to the transport sector) making up the rest. Fugitive CH_4 emissions is made up of emissions arising from coal mining and post-mining activities, those related to gas transmission and distribution, geothermal electricity generation as well as some related to oil & gas processing and flaring and oil transportation and refining.

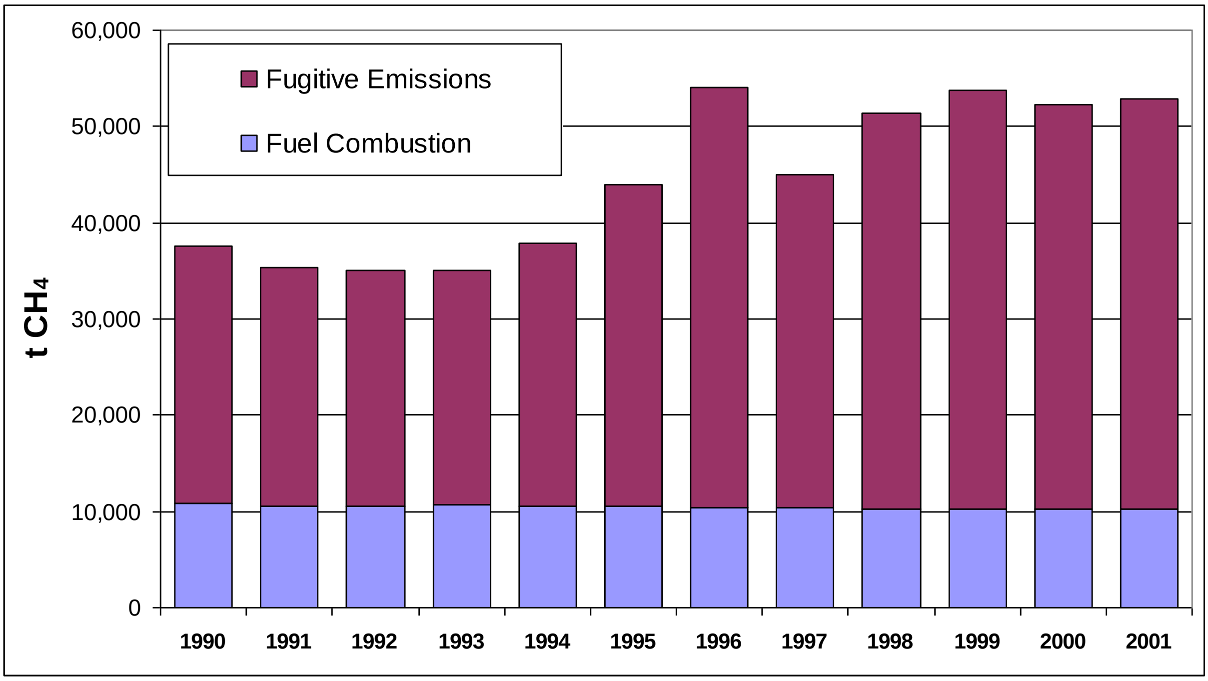


Figure 6: **CH4 Emissions from Energy**

Energy Emissions Inventory Reviews

Scope of the Reviews:

The New Zealand energy sector, particularly energy-related CO_2 emissions, is a major focus of policies and measures to limit emissions of greenhouse gases (GHG). The method used to calculate emissions follows the Intergovernmental Panel on Climate Change (IPCC) guidelines. The GHG inventory is 1990-based with 1990 agreed as the base year for emissions inventories by parties to the UNFCCC.

Further development and enhanced reporting of the energy sector inventory in terms of data sources, emission factors, completeness, uncertainties, transparency and record keeping is required to meet New Zealand's obligations under the UNFCCC and the Kyoto Protocol, once it enters into force. All sectors of New Zealand's GHG inventory must pass international scrutiny in order for New Zealand to be eligible to participate in international emissions trading and to realise the value of its forest sinks.

UNFCCC reviews of NZ Inventory:

Over the past few years, the UNFCCC has undertaken several reviews of New Zealand's overall GHG inventory covering the energy, industrial processes, agriculture, land use changes and waste sectors. An In-Country Review of the submission made by New Zealand in 2001 was carried out in 2002 by a team of UNFCCC delegation of experts. This was followed by a Centralized UNFCCC review & a Desk Review conducted from Bonn in 2002 and in 2003. Recommendations made and clarifications sought in these reviews are taken into account when the New Zealand inventory is submitted in subsequent years.

Energy Sector GPG Review:

The energy sector greenhouse gas emissions inventory prepared for submission to the UNFCCC in April 2002 was reviewed as part of New Zealand's commitment for implementing "Good Practice" (Tom Clarkson, NIWA, 2002). The review was related to a quality assurance/quality control plan to cover inventory methods, emission factors and activity data. It focused on identifying parts of the energy sector GHG inventory which already met the IPCC Good Practice Guidance (GPG) and those which did not.

Energy Emission Factor Review:

One of the key recommendations of the energy sector GPG review was to assess the relevance of all (over 100) emission factors (both CO_2 and non-CO_2) used in the energy sector inventory. The desk-top review of the emission factors was carried out (Hale & Twomey, 2003) first based on a template used for assessing the validity of the New Zealand specific emission factor used. This was followed by a peer review in 2004 of the recommended changes to emission factors by two independent scientists with a number of the changes accepted with few exceptions.

NZ Responses to Energy Inventory Reviews

Implemented Improvements

The QA/QC plan required by the reviews was formulated for adoption by the Ministry of Economic Development (MED) and with the NZCCO having the overall responsibility to ensure its adherence. The energy sector emission factors (CO_2 and non-CO_2) which were recommended for a change, based on the review and subsequent peer review, were incorporated in the preparation of the 2002 inventory as well as in the updates to the 1990-2001inventory. This will be part of the annual Common Reporting Format (CRF) and National Inventory report (NIR) submission by New Zealand to the UNFCCC in 2004.

Planned Improvements

Working to achieve Good Practice in greater part of the inventory, including improvements to documentation in the NIR and data consistency between the sectoral and reference approaches of the CRF submission. Tier 2 approach is to be considered for some of the main key source categories such as the Mobile combustion Road vehicles which will require a work plan over the medium term involving the NZCCO, MED and the Ministry of Transport (MoT).

3 INDUSTRY VIEWPOINTS

3.1 REDUCING RUMINANT METHANE EMISSION – A CONSORTIUM APPROACH

Mark Leslie
Chairman PGGRC,

Background

PGGRC is an investment vehicle that aims to understand, and provide mitigation solutions for, greenhouse gases produced by grazing animals.

NZ livestock farmers need knowledge and tools in order to mitigate agricultural greenhouse gas emissions.

PGGRC's goal is to develop one or more methane and/or nitrous oxide mitigation measure that can be implemented within New Zealand's pastoral agricultural system (i.e. measures that are practical in terms of product safety, animal safety and overall economics and that produce sustainable (medium to long-term) methane/nitrous oxide mitigation results that are recognised by the international regulatory authorities.

Methane and nitrous oxide are two of six major greenhouse gases implicated in global warming and climate change. New Zealand's profile of greenhouse gas production is unique in the world with methane making up 43% of total carbon dioxide equivalents – which is a result of our low population levels, low total fossil fuel use and high grazing animal numbers. Nitrous oxide (N_2O) accounts for about 33% of New Zealand's agricultural greenhouse gas emissions inventory and about 50% of the N_2O emitted is derived from animal excreta in grazed pasture systems, particularly from urine patch areas

PGGRC's research programme aims to provide NZ livestock farmers with the knowledge and tools to mitigate greenhouse gas emissions from the agricultural sector.

One fundamental area of research investigates rumen microbial strategies to lower methane emissions. Already, new information has been obtained on rumen factors that affect methanogen survival and which have potential for use in methane-abatement strategies.

The study on a genomics approach to identify targets for methanogen inhibition has been fast-tracked and has now obtained the first genome sequence information from a rumen methanogen. The process of assembling the genome DNA sequences has started. Preliminary analysis has identified the presence of a wide range of known genes and many unknown genes. Future work will be developed in collaboration with the team outlined above to explore potential target areas for mitigation abatement strategies.

Forage plant components are under investigation to identify those that affect methane formation in the rumen. An in vitro rumen assay has been established as a model to predict the relative potential of different forage species for methane abatement. A number of plant species have already been tested using the assay.

The fourth objective in the programme investigates the extent to which different animals within a population differ in the level of methane emitted. A trial using calves has been used to determine whether animal genotype has a major influence on methane emissions.

The goal of the fifth objective is to measure and/or assess likely methane-abatement procedures in the field. The first trial investigated the effects of the CSIRO "methane vaccine" and a PGGRC modified vaccine on methane emissions from sheep in NZ.

In the coming months the results of the early research into animal factors will be analysed. Exciting prospects for mitigation tools may emerge in the short-medium term although it should be noted that any products will require time to satisfy the regulatory approval process prior to release on the market. The majority of this research, however, is long-term with a mix of low and high risk and basic and applied science.

3.2 COMMERCIAL DRIVERS. IS THERE A MARKET FOR PRODUCTS?

Warwick Green

PGGRC

Wrightson as a stakeholder in PGGRC has aligned interests with other members concerning the strategic commitment to introduce new technologies to NZ agriculture that provide solutions to lowering methane and nitrous oxide gas levels.Wrightson experiences in commercialisation of new technologies and products, is of benefit to the consortium.

The key drivers in ensuring new technologies are market attuned and capable of successful uptake, include demonstrating clear benefit, economic viability, public acceptance, a value proposition and a sustainable point of difference.

Success stories include the AR1 pasture technology which has demonstrated clear deliverables to agriculture.

However, not all new products or technologies are successful. Failure can be due to a number of possibilities that is Wrightson's experience can include:

- Market not determined
- Uptake slower than expected or poor
- No recognition of the need for technology transfer i.e. learning prior to launch
- Wrong value proposition

The key commercialisation message from Wrightson's perspective and experience is:

- Define the market need
- Set clear parameters for future products
- Quantify the product benefits
- Be aware of the need for technology transfer
- Communicate clearly the value proposition and enlist industry support

3.3 THE FARMER'S VIEW ON CLIMATE CHANGE – ADAPTATION AND MITIGATION

Tom Lambie
Federated Farmers of New Zealand

Transcript taken from slides prepared for the Trace Gas Workshop.

Introduction

Climate Change and Kyoto Protocol only one of many pressures farmers face
Competitiveness key to farm sustainability
Productivity gains the research priority for farmers
Not interested in research that isn't economic

Other research priorities

Nitrogen impacts research a more immediate priority than methane research
Research into impact of existing farm management practices helpful

Effects of other policies

Other policies have an effect on farmer acceptance of greenhouse research
On-farm sinks research would have been helpful until United Nations Convention on Biological Diversity and management of biodiversity on private land
Wetlands create dilemma of protecting natural methane emissions but needing to reduce livestock methane emissions

Conclusions

For lasting effective adoption of new technologies and practices, farmer buy-in is essential
Only way to achieve farmer buy-in is to allow the farmer to make mitigation and adaptation decisions appropriate for their own specific farming situation

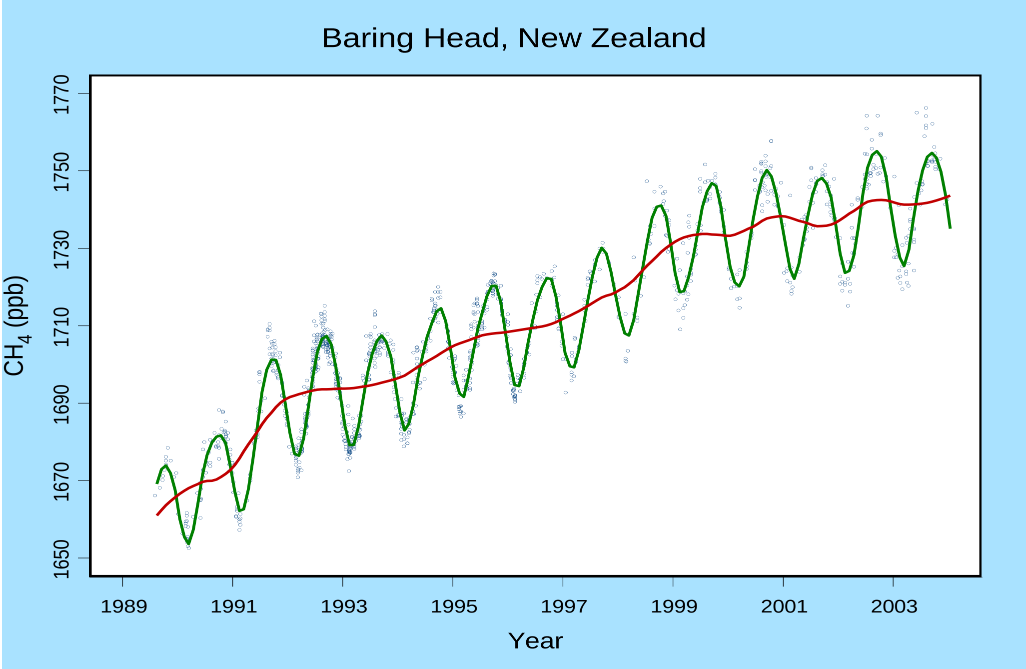
4 OVERVIEWS OF THE SCIENCE

4.1 *WHERE HAS ALL THE METHANE GONE?*

Dave Lowe, Bill Allan, and Katja Riedel
(with apologies to Tom Paxton who wrote the 1960's American folksong "Where have all the flowers gone?")
NIWA, Wellington

Measurements of methane in air trapped in bubbles contained in polar ice cores show that the concentration of the gas has been relatively stable over the last 10,000 years at about 700 parts per billion (ppb). Over the last 200 years, however, the concentration of methane has risen rapidly to its present value of about 1800 ppb. This is of concern because methane plays a significant role in global warming as well as atmospheric chemistry.

We know that methane is emitted by a wide variety of sources including swamps, wetlands, ruminant animals and gas leaking from coal and gas mining and pipelines. These sources release an estimated 500 million tonnes of methane into the atmosphere each year. If this methane stayed in the atmosphere, then, within a few centuries, the concentration of methane would be so high that the atmosphere could ignite during lightning strikes, and would become toxic to human beings. The plot below shows measurements made by NIWA of methane in the background atmosphere at Baring Head, New Zealand. The methane concentration has increased slowly over the last decade, but is only in the ppb range, orders of magnitude less than flammable or toxic levels. So, the question is "Where has all the methane gone?"



To answer this question we need to understand Earth System Science or "Global Biogeochemical Cycling". This field of research applies a systems analysis approach to the planet showing the linkages between the Earth's major reservoirs, namely the oceans, the terrestrial biosphere and the atmosphere. We now know that an activity in one reservoir can have a powerful effect on the other two and that the reservoirs are all very closely linked through processes known as biogeochemical cycles.

A typical biogeochemical cycle for methane involves emission from a terrestrial source into the atmosphere where it is oxidised into products that return to the Earth's surface and oceans. About 30 years ago, it was discovered that the action of ultraviolet light on ozone formed a product that split water molecules. This process produces a very powerful free radical called the hydroxyl or OH radical. Free radicals in the atmosphere are present in tiny amounts (OH is typically 1 trillionth of the amount of atmospheric nitrogen) yet are extraordinarily powerful oxidants. In the case of methane, the OH radical tears it apart by ripping out one of its hydrogen atoms. Once this happens the methane molecule is history, and through a chain of free radical reactions produces CO_2 that enters the Earth's carbon cycle through photosynthesis by green plants.

Levels of OH in the atmosphere are clearly crucial in controlling the concentrations of methane and many other pollutants. Without the tiny amounts of this free radical to act as a kind of atmospheric detergent, life as we know it could not exist on Earth. Critical scientific questions are: 1) what are the long and short term variations of OH in the atmosphere?; and 2) is the ability of the atmosphere to clean itself up through this process being compromised by widespread agricultural and industrial activities?

Current NIWA research into atmospheric chemistry is aimed at answering these questions. Because OH is present in the atmosphere in only vanishingly small quantities, it is very difficult to measure directly. We have therefore used a naturally occurring atmospheric tracer, ^{14}CO, to infer levels of OH over the last 14 years in the New Zealand and Antarctic regions. This work, which has just been submitted to the journal *Nature*, shows that OH levels have been relatively constant over the period, but with two large transient drops in 1991 and 1998. We associate the first of these with the impacts of emissions from the Mt Pinatubo volcanic eruption, and the second with huge wild fires that burned in the Indonesian region, reducing OH levels and hence the ability of the atmosphere to cleanse itself of pollutants. We are also working on estimating the importance of another free radical that destroys methane, namely atomic chlorine in the atmospheric marine boundary layer. This radical occurs in even tinier amounts than OH, and is probably generated indirectly by gases given off by marine phytoplankton. However, atomic chlorine attacks methane much more strongly than OH, and could be significant in cleaning methane from the atmosphere.

It is important to quantify methane emissions into the atmosphere from various sources. However, we clearly need to understand the free radical removal or sink processes for methane because decreases in these could lead to dramatic increases in the concentration of atmosphere methane. Our current research into the atmospheric OH radical and the atomic chlorine radical forms part of a collaborative international effort to understand the role of free radicals in our rapidly changing atmosphere.

4.2 MITIGATING N_2O EMISSIONS FROM AGRICULTURE – AN OVERVIEW OF THE SCIENCE

Cecile de Klein
AgResearch, Invermay

Introduction

Agricultural N_2O emissions contribute about 17% of New Zealand's total GHG emissions, and the development of practical and cost-effective farming practices and technologies to reduce N_2O emissions is one of the priorities in New Zealand's strategy on achieving our 0% target under the Kyoto protocol (O'Hara, et al. 2003). This paper reviews the key sources of nitrous oxide emission in New Zealand and presents an overview of current research on developing N_2O mitigation strategies. In addition, the potential impact of these mitigation option on our total agricultural N_2O emissions is assessed using the New Zealand IPCC methodology for estimating the N_2O emissions (New Zealand Climate Change Office 2003) and the nutrient budgeting model OVERSEER® (Wheeler, et al. 2003) to estimate the amounts of N excreted, leached and volatilised.

Key sources of N_2O emission in New Zealand

The New Zealand N_2O inventory (New Zealand Climate Change Office 2003) indicates that animal excreta deposited during grazing is the single largest source of N_2O in New Zealand, producing over 80% of the direct and indirect N_2O emissions (Figure1a).

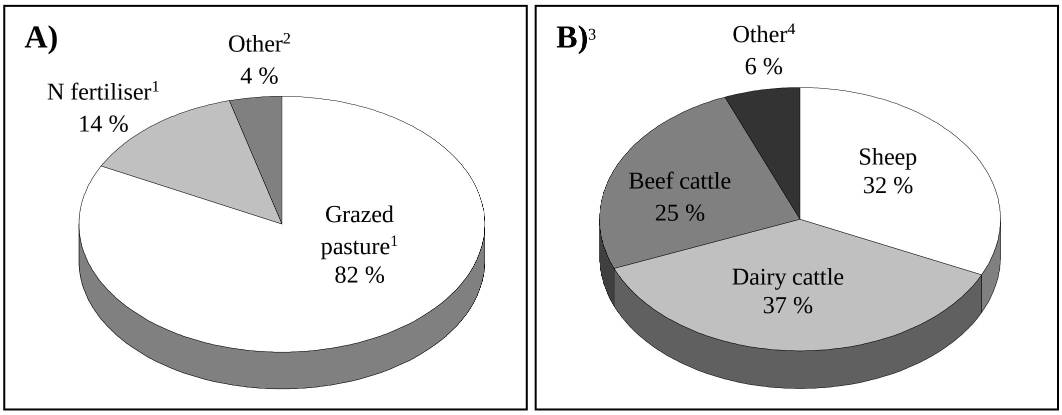


***Figure 1*. The relative contributions of a) different nitrogen sources and b) animal species, to agricultural nitrous oxide in New Zealand in 2001, estimated using the IPCC methodology (New Zealand Climate Change Office 2003). [1]Includes both direct and indirect N_2O emissions. [2] Includes emissions from N-fixing crops, crop residues, and storage of animal manure. [3] Assumes that 65% of the total amount of fertiliser N is applied to dairy pasture. [4]Includes deer, poultry, swine and goats.**

The second largest source of N_2O in New Zealand is N fertiliser at about 14% of agricultural N_2O emissions. National nitrogen fertiliser usage has increased 4-fold since 1990, and its contribution to the agricultural N_2O inventory has increased from 4% in 1990 to 13.5% in 2001 (New Zealand Climate Change Office 2003). The resurgence and intensification of the dairy industry (MAF 2003) is a major reason for the increase in N usage in New Zealand. Although on an area basis the New Zealand dairy industry is relatively small compared to the sheep and beef industry, it still contributes about 37% of total N_2O emissions (Figure. 1b).

Mitigating N_2O emissions

Nitrous oxide mitigation options with the greatest reduction potential for New Zealand can be grouped into those that:
reduce the total amount of excreta N returned to pasture
increase the efficiency of excreta and/or fertiliser N
avoid soil conditions that favour N_2O emissions

Reduce the total amount of excreta N returned to pasture

A reduction in the amount of N excreted by animals, whilst maintaining production levels, can be achieved by increasing the N retention in products or reducing N intake. Although previous research has shown that certain forages (e.g. those containing condensed tannins; Min, et al. 2003) can be used to increase the efficiency of protein digestion, the impact of this on N_2O emissions has never been directly investigated. An example of a practical option for dairy or beef cattle to reduce N intake is to supplement or replace N-boosted pasture with a low-N supplement such as maize silage. Preliminary estimates based on our IPCC methodology suggest that, if applied nationally, this management option has the potential to reduce agricultural N_2O emissions by about 15%. The assumptions used in these estimations are currently being verified in a field study to estimate the effect of maize silage supplement on N_2O emissions at a farm system's level (Luo, et al. 2004).

Increase the efficiency of excreta and/or fertiliser N

One option to reduce N_2O emissions is to increase the utilisation of effluent N combined with an associated reduction in fertiliser N. However, since New Zealand's effluent usage is relatively low, increased effluent utilisation yielded a reduction potential of only 1% of agricultural N_2O emissions (de Klein and Clark 2002).
Recently, various studies have suggested that the use of the nitrification inhibitor dicyandiamide (DCD) could reduce N_2O emissions from animal urine patches by about 75%. (Di and Cameron 2003, Singh, et al. 2004; Smith et al. 2004). If DCD was applied after all grazings throughout the year on all dairy farms, it could potentially reduce national emissions by about 20%.
Finally, a recent field study in Southland showed that the strategic use of a stand-off pad during autumn and winter can reduce N_2O emissions from cattle urine patches by about 50% (de Klein, et al. 2004). Nitrate leaching, and associated indirect N_2O emission, was reduced by about 35%. These measured reductions in direct and indirect N_2O emissions from the pasture were greater than the estimated increase in N_2O emissions following the application of effluent in spring, resulting in a reduction of N_2O emissions from the farm of about 14%. If applied nationally, this option could reduce total agricultural N_2O emissions by about 10%.

Avoid soil conditions that favour N_2O emissions

Nitrous oxide emissions from soils are highest when soil aeration is limited (e.g. under wet or compacted soil conditions) and the availability of soil mineral N is high. Recent studies have shown that avoiding soil compaction (Bhandral, et al. 2003, Thomas, et al. 2004) or increasing soil drainage (de Klein and Paton 2003) can substantially reduce N_2O emissions from soils. Preliminary estimates based on these studies suggest that the reduction potential of these options could be between 5 and 10% of the agricultural N_2O emissions. Results from another study suggested that the amendment of soil with lime to increase the soil pH, or with zeolite to absorb excess soil ammonium, could reduce N_2O emissions and/or decrease the N_2O to N_2 ratio from pasture and wetland soils (Zaman, et al. 2004).

Conclusions

To date, research on N_2O mitigation strategies has largely been ‘fundamental’ or ‘proof of function’. Current estimates suggest that the reduction potential of individual measures range between 1 and 20% of agricultural N_2O emissions. There is scope to combine different options, e.g. including maize silage and using a feed pad, but the reduction potentials of ‘packages’ of options has not been fully assessed. In addition, some N_2O mitigation strategies could affect other environmental losses or farming practices – e.g. a farmer might decide to increase stocking rate following improved drainage. It is therefore crucial that the impacts of N_2O mitigation strategies are evaluated on a farm system, or even larger scale. Finally, even if mitigation options are implemented, New Zealand’s current N_2O inventory methodology will not always be able to account for any reductions in N_2O emissions achieved. Therefore, research on mitigation strategies and the national N_2O inventory should be very closely linked.

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4.3 FIELD AND LABORATORY MEASUREMENTS

Gordon W. Brailsford
NIWA, Wellington

In New Zealand trace gas measurements are made over a wide range of scales ranging from total column to direct source measurements. Different scales are utilised for the process under investigation. A global study would involve a higher precision and longer time period than a source study.

Long term time series studies of trace gases in clean air have been undertaken, these are used to determine global and hemispheric changes in the source sink budgets , transport and chemistry. NIWA has operates a clean air station at Baring Head, in Wellington. At this station CO_2, O_2/N_2 and O_3 are measured continuously on internationally comparable scales. The non-dispersive infrared radiation (NDIR) analyser used at Baring Head for CO_2 must make determinations that are comparable to the WMO calibration scale at a precision of 0.05 ppm.

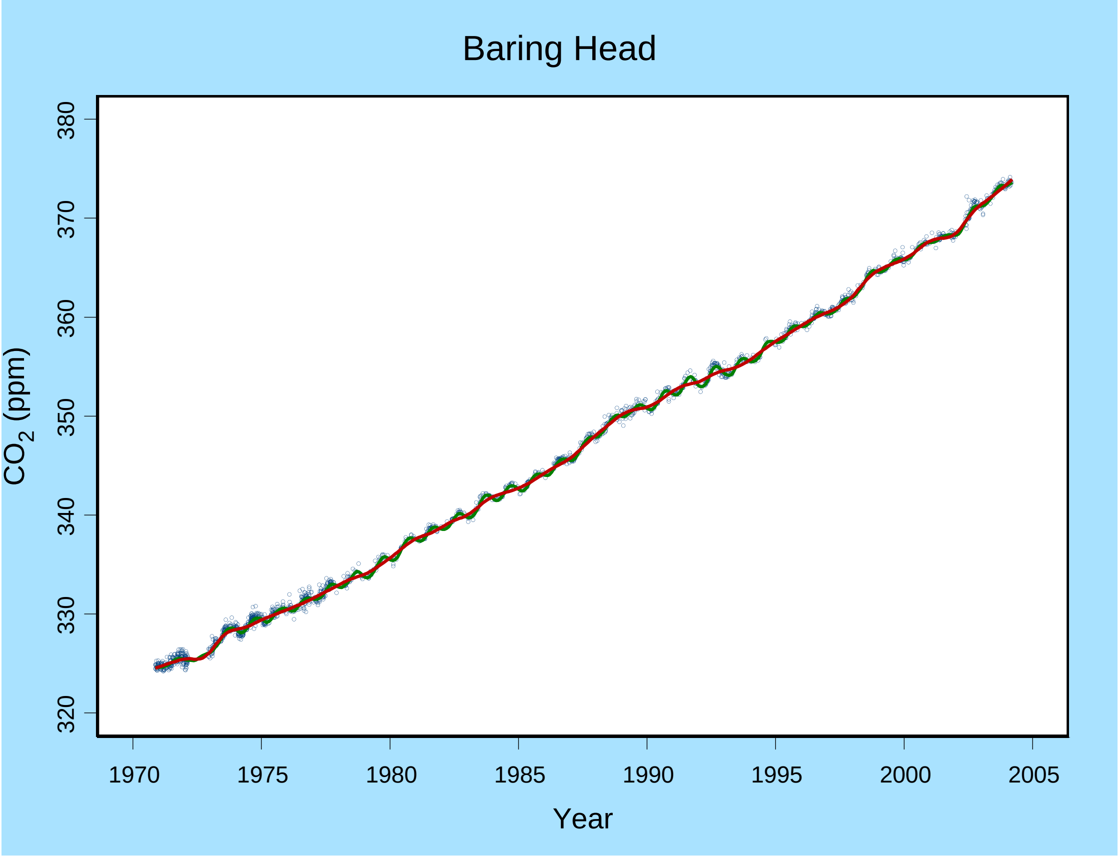


Figure 1: **The Baring Head CO_2 data set from 1972 – 2004 determined using non-dispersive infrared radiation (NDIR) analysis.**

Much of the precision measurements made of trace gases are carried out in controlled laboratories using analytical methods such as gas chromatography. These instruments can have limits of detection that in some cases are as low as parts per trillion in the case of SF_6 measured using an electron capture detector. The advantages that many laboratory based methods offer include the ability to improve precision by making many measurements of the same sample, and the reproducibility that comes from operating in a more stable environment. Some of the more common detectors and gas species that can be measured are listed in Table 1.

Detector	**Gas species**
Flame ionisation (FID)	CH_4, CO_2, NMHC
Electron Capture (ECD)	N_2O, SF_6, CFC
Atomic Absorption (AA)	CO, H_2
Flame photometric (FPD)	DMS, Sulphur species

***Table 1*: Analysis by gas chromatography**

The field investigation of process studies requires methods that are directly applicable to the process of interest and the support of other data that are related to the process. While the collection of methane and sulphur hexafluoride in the ERUCT technique provide a flux this on its own is of little use unless the dry matter intake is also determined. Likewise the collection of enclosure gas samples for nitrous oxide depend on the supporting data from soil moisture and soil type.

***Figure 2*: Micro met techniques used to determine N_2O fluxes in the nocturnal boundary layer are supported by many parameters from soil moisture to solar radiation.**

Recent advances in mass spectrometry mean that isotope techniques can now be used to assist in understanding the pathways involved in individual processes. Both nitrogen and carbon isotopes can be measured to precisions now that make them appropriate for defining the isotopic signature of a source process.

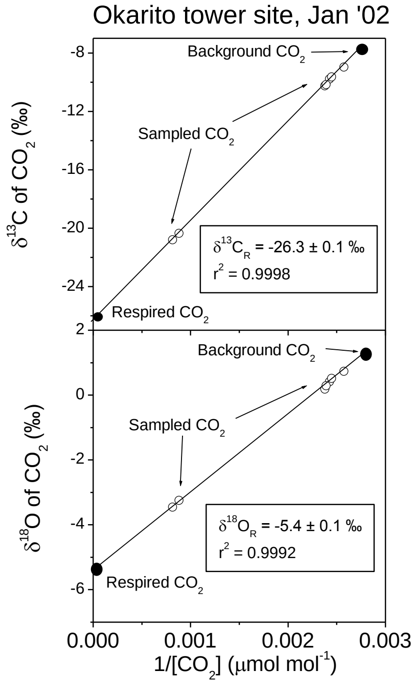
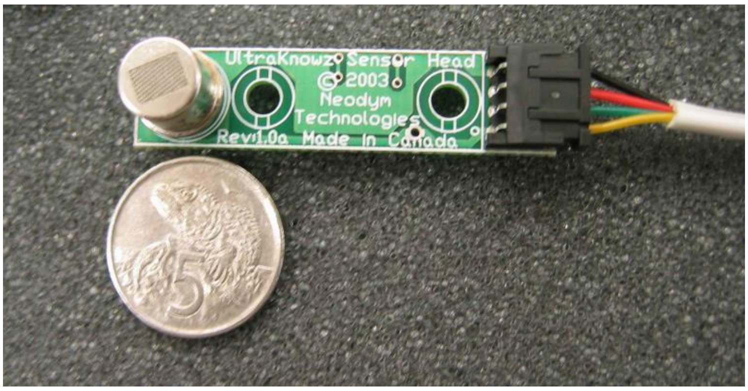


Figure 2 **Using a Keeling plot, 1/concentration vs isotopic ratio the signature of a source can be determined.**

Recent progress in trace gas measurements point in two main directions, the use of optical techniques as in diode laser systems, and in the solid state device area, as in the tin oxide methane sensor under development at NIWA. Both of these measurement systems allow the collection of real time provide more information about the nature of the sources.



5 AGRICULTURAL EMISSIONS - NITROUS OXIDE

5.1 RESTRICTED AUTUMN GRAZING REDUCES NITROUS OXIDE EMISSIONS FROM DAIRY PASTURES IN SOUTHLAND

Cecile de Klein[a], Chris Smith[b], and Ross Monaghan[a]
[a] *AgResearch, Invermay*
[b] *AgResearch, Woodlands*

Introduction

Nitrous oxide emissions from excreta N returned to pasture contribute about 80% of the total N_2O emissions in New Zealand (New Zealand Climate Change Office 2003). These emissions largely occur from cattle urine patches deposited under wet soil conditions (de Klein, et al. 2003, Sherlock, et al. 2003a, Sherlock, et al. 2003b). Therefore, management practices that reduce the amount of excreta N deposited to pasture during wet periods are likely to substantially reduce N_2O emissions. This paper presents the results of a field study on the effect of restricted autumn grazing on nitrous oxide emissions and nitrate leaching from dairy grazed pasture in Southland.

Approach

Field plots were established under two grazing regimes:
Normal grazing practice - rotational grazing from September to May, grazed off-farm during winter (June to Aug).
Restricted autumn grazing – as above, but grazed for only 3 hours per rotation during March, April and May.
Under restricted autumn grazing, the amount of N excreted onto pasture was estimated to be reduced by 22% compared to the normal grazing practice.

The treatment plots were arranged in randomised blocks (n=4) and had a mole-tile drainage system which hydrologically isolated each plot. Nitrous oxide emissions were measured weekly between April and October for two seasons, using a standardised soil cover technique (de Klein, et al. 2003). Total N_2O emissions for each plot were calculated by integrating the weekly measurements over time. The average N_2O emissions from the treatments were calculated from the geometric means of these integrated emissions. Nitrate leaching losses were measured by collecting and analysing the drainage water from each plot. Nitrous oxide emissions from effluent applied in spring was not measured but the expected increase in N_2O emissions due to any extra effluent collected from the feed pad was estimated using the IPCC default methodology.

Results and Discussion

Nitrous oxide emissions showed a typical spiky and variable pattern, but emissions were generally lower under the restricted autumn grazing practice (Fig. 1). Restricted autumn grazing reduced the total N_2O loss from pasture by, on average, 49% (Fig. 2). This reduction was larger than the estimated 22% reduction in excreta N returned to pasture, which suggested that N_2O emissions in autumn/winter make a disproportionately large contribution to the annual N_2O emissions. We estimated that the average annual N_2O emission factor of animal excreta would have be reduced from 1% to 0.65% of N excreted, to achieve a total reduction in direct N_2O emissions from pasture of 49%.

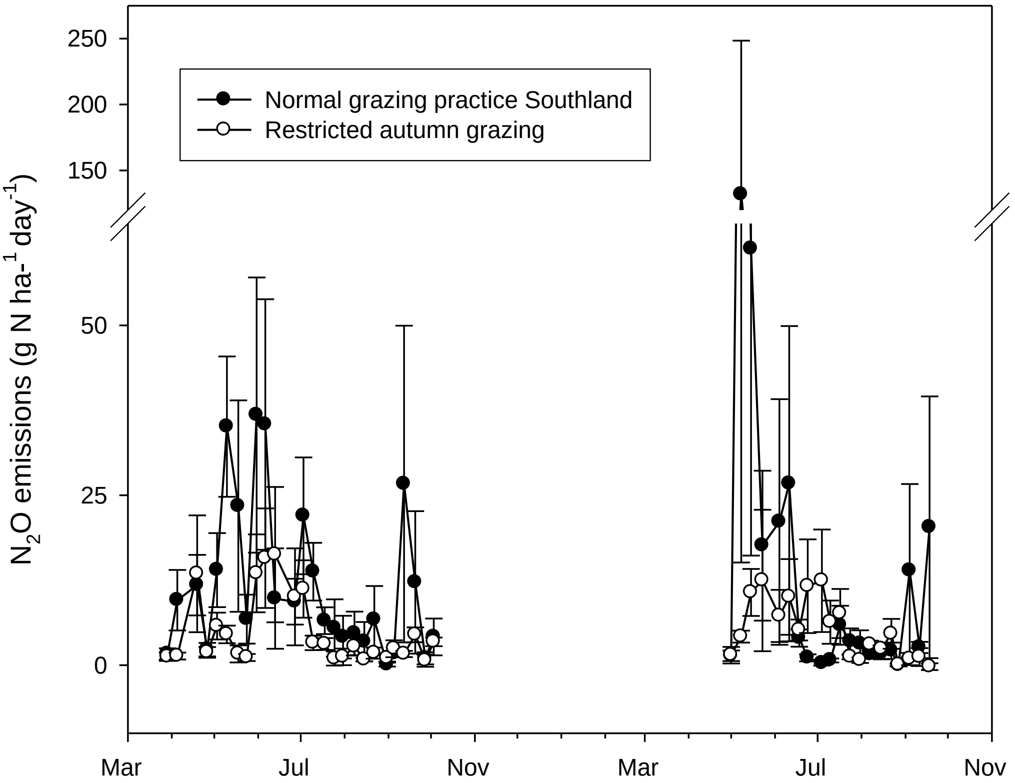


Figure 1: **Nitrous oxide emission from dairy grazed pasture in Southland under two grazing regimes.**

The study further showed that restricted autumn grazing reduced average nitrate leaching losses by about 35% (Fig. 2). As a result, indirect N_2O emissions from leached N would also be reduced by 35%.

The measured reduction in direct and indirect N_2O emissions from the pasture was greater than the estimated increase in N_2O emissions following the application of any effluent collected from the feed pad and applied in spring. It was estimated that restricted autumn grazing in Southland could reduce total farm N_2O emissions by about 14%.

In conclusion, the results of this study showed that the strategic use of a feed pad or stand-off pad in autumn or winter can reduce both direct and indirect N_2O emissions from animal excreta.

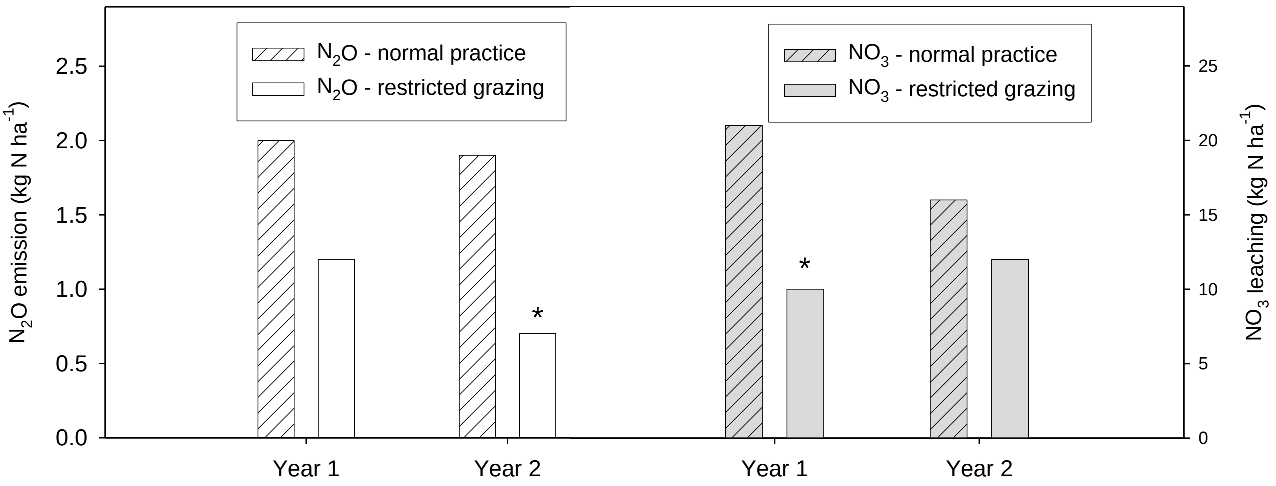


Figure 2: **Cumulative N_2O emission and NO_3 leaching losses during autumn/winter as affected by grazing regime. * $p < 0.05$.**

Acknowledgements

We thank the Foundation for Research, Science & Technology for funding and Beth Henderson for technical support.

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5.2 NITROUS OXIDE EMISSIONS FROM WINTER GRAZED FORAGE CROPS

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Background

In situ grazing of short-term forage crops grown for high quality feed over winter can cause extensive compaction of soils. Such compaction may reduce re-growth of crops and also may lead to large emissions of nitrous oxide (N_2O). A number of management practices may be useful in reducing these negative effects. Such practices include decreasing the intensity of tillage used in the establishment of forage crops and restricting grazing when soils are wet.

This study investigated the effects of simulated cattle grazing at three soil moisture contents on N_2O emissions from winter forage crops established by three tillage practices.

Methods and Materials

A field trial was established on a Wakanui silt loam soil in March 2003. After spraying pasture with herbicide, a winter forage crop of triticale (cv. Doubletake) was sown following either (a) intensive (plough, maxi-till, roll and harrow), (b) minimum (disc, roll and harrow) or (c) no tillage. These main plots were 9 x 9 m in size with three replicates of each. Main plots were each divided into six split plots and then additional treatments were imposed (Table 1). In July the soil moisture content of each plot was adjusted by applying irrigation, then compacted with a mechanical hoof to simulate grazing (Di et al. 2001). Synthetic urine was then applied to appropriate plots at a rate of 800 kg N ha^{-1}. Soil water content (0-7.5 cm) was measured continuously throughout the trial and used to calculate values of water filled pore space (WFPS). N_2O fluxes were measured 27 times during the trial using the closed chamber method, with topsoil (0-7.5 cm) mineral N contents measured seven times.

***Table 1:* Split plot treatments imposed at simulated grazing**

Number	Soil moisture	(%, v/v)	Compaction	Urine application
1	< FC[1]	(27)	Yes	Yes
2	FC	(35)	Yes	Yes
3	> FC	(40)	Yes	Yes
4	FC	(35)	Yes	No
5	FC	(35)	No	Yes
6	FC	(35)	No	No

[1] FC - field capacity

Results

a) Soil bulk density and water filled pore space (WFPS)

Soil bulk density increased following compaction at high moisture contents (FC and >FC), with this effect greatest for the intensive tillage plots and least for the no tillage plots. Compacting the intensive tillage plots at or above FC increased bulk densities from 1.1 to 1.3 g cm^{-3}. This increase in bulk density increased the WFPS of the soil and consequently the likelihood for denitrification to occur. Although WFPS was greatest during July, N_2O emissions during this time were limited by low soil nitrate contents (Fig 1). However, following conversion of the applied synthetic urine to nitrate (i.e. from August onwards), N_2O emission peaks coincided with peaks in WFPS. Peaks in WFPS were associated with rainfall events during the trial.

b) Urine application

Throughout the trial, N_2O emissions were very low (<0.04 mg N m^{-2} h^{-1}) from uncompacted plots where no urine was applied as these plots had low levels of soil mineral N and WFPS for most of the study. N_2O emissions were also low from uncompacted plots where urine was applied. Although these plots had high mineral N contents during most of the study, low values for WFPS values restricted their N_2O emissions.

c) Tillage practice

The greatest N_2O emissions occurred from plots that had been established with intensive tillage, compacted at moisture content >FC during grazing and received urine (Fig 1). The highest N_2O flux rate from such an intensively tilled plot was >5 mg N m^{-2} h^{-1}. High emissions also occurred from the corresponding minimum tillage plots (Fig 2). In contrast, the corresponding plots established with no tillage produced low emissions (Fig 3).

d) Moisture content at grazing

In the intensive tillage plots, soil moisture content at grazing affected WFPS and subsequent N_2O emissions (Figs 1, 4 & 5). The mean (68%) and maximum (90%) values of WFPS during the trial were greater after compaction at moisture content >FC than after compaction at FC (67 and 85% respectively) or after compaction at <FC (56 and 66% respectively). N_2O emissions were much greater following compaction at moisture content >FC than following compaction at either FC or <FC. Minimum tillage plots showed a similar, but smaller effect. No tillage plots were the least sensitive to moisture content at grazing (data not shown).

Conclusions

Soil compaction due to grazing, and the associated increase in WFPS, greatly increased the effect of urine on N_2O emissions.
To minimise N_2O emissions, forage crops should be grazed when soils are below field capacity.
Minimising the amount of soil cultivation used to establish forage crops will help reduce the impact of grazing on compaction and consequent N_2O emissions.

Acknowledgements

This study was funded by the Foundation for Research Science & Technology under contracts C02X0218 and C02X0304. We thank Lincoln University for loaning us their mechanical hoof.

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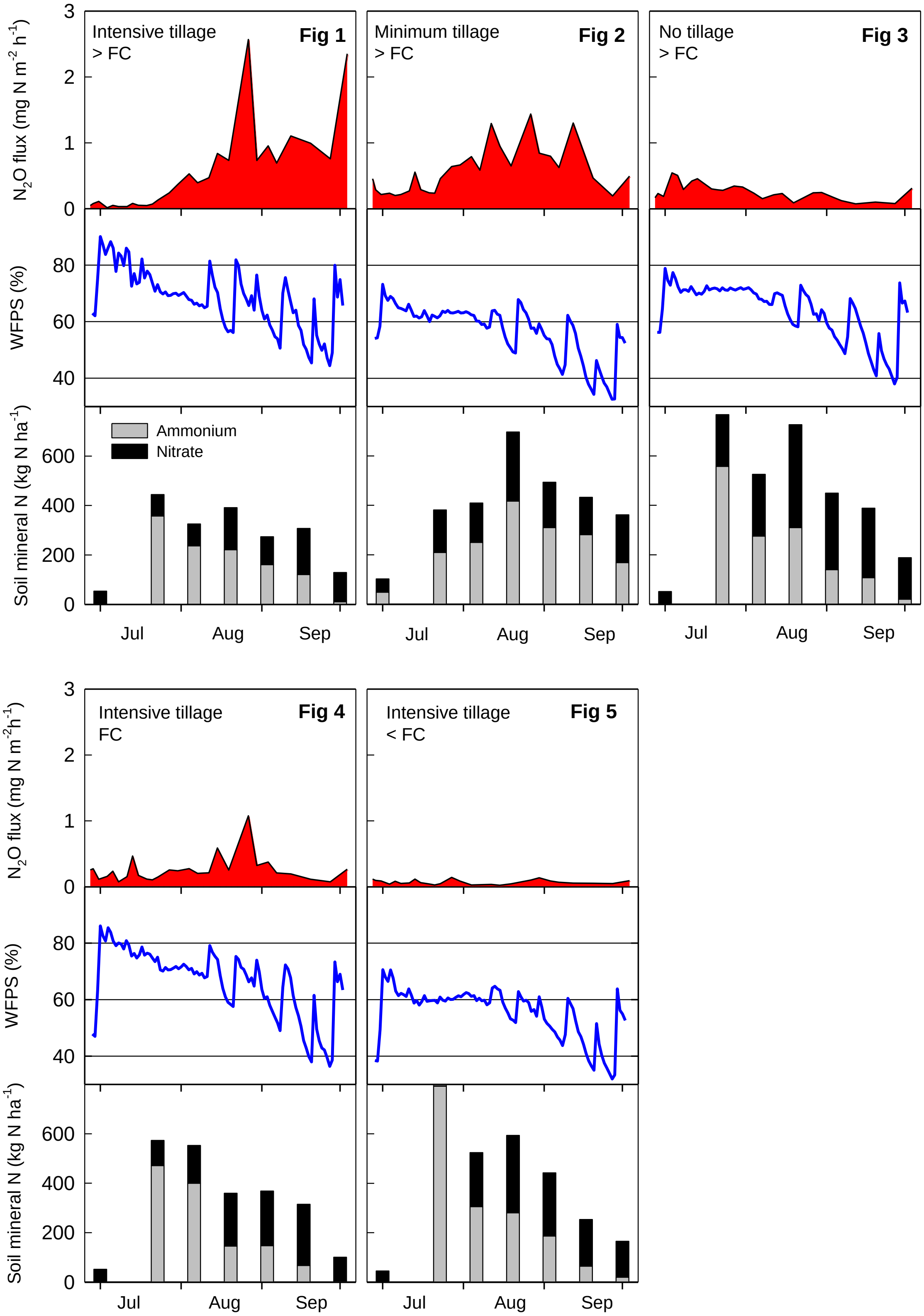

Nitrous oxide fluxes, water filled pore spaces and soil mineral N contents of grazed treatments that received urine applications.

5.3 NITROUS OXIDE EMISSIONS FROM FERTILISED VEGETABLES

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Introduction

Application of high rates of N fertiliser to vegetable crops pose a significant environmental risk from N leaching and runoff to water bodies and emissions of N_2O. In NZ, N fertilizer rates for intensive potato production are typically 300 to 450 kg N/ha. High rates of nitrate leaching have been measured from these crops, but N_2O emissions have not been measured. In addition to high N application rates, potato crops are often irrigated, potentially further enhancing N_2O production. Other management effects such as soil compaction by tractor traffic in row crops, have also been shown to greatly enhance N_2O emissions (Flessa et al, 2002). This field experiment examined the influence of N fertiliser rate, tractor compaction in furrows and water-filled pore space (WFPS) on N_2O emissions from an irrigated potato crop.

Materials and methods

The experiment was established in late spring (Nov 2002) on a well-drained soil (Typic Haplustepts). After cultivation, fertiliser (as calcium ammonium nitrate) was applied to each plot at rates of 0, 225 or 450 kg N/ha. Potatoes were planted at 55 cm spacings in rows 78 cm apart and then all plots were machine ridged such that each plot contained both compacted (by tractors) and uncompacted furrows. In each plot, a PVC cylinder (30 cm i.d.) was pushed into the soil to a depth of 5 cm at each of three sampling positions: the ridge (between tubers), the compacted furrow and the uncompacted furrow. Soil mineral N was measured at each sampling position in each plot on seven occasions during December to February. Headspace gas samples were taken (after covering cylinders for 20 and 40 min) on 24 occasions from November to March. Gas samples were analysed for N_2O concentration by gas chromatography. The experiment was a split-plot, randomised block design with five replicates. Soil temperature (at 5 cm depth) and moisture (at 0-20 cm depth) were recorded hourly using thermocouples and TDR. WFPS was calculated from measured bulk density and water content and an assumed particle density (2.65 g/cm^3). Daily rainfall and spray irrigation (applied five times) were measured throughout the experiment.

Results and discussion

In addition to 65 mm of rainfall, 285 mm of irrigation was applied to the crop. Mineral N contents before fertiliser application were 70 to 90 kg N/ha. Following fertiliser application, most of the fertiliser N was in the ridges and least in the furrows (Fig 1a). The mineral N contents in the potato ridges were approximately 280 and 740 kg N/ha for the 225 and 450 kg N/ha treatments, respectively. Fertiliser and soil mineral N had small, but significant effects on N_2O emissions. More N_2O tended to be emitted from the fertilised plots, however emissions did not differ between the 225 and 450 kg N/ha treatments. Sampling position had a much larger effect on N_2O emissions ($p<0.001$), in the order: compacted furrow > fertilised ridge > uncompacted furrow (Fig 1b). N_2O emissions were strongly related to changes in WFPS (Fig 1c). Highest N_2O emissions occurred when WFPS was high, following rain or irrigation. Even after large irrigation applications (depth = 85 mm), ridge WFPS remained relatively low (<50%). WFPS varied with sampling position in the order: compacted furrow > uncompacted furrow > ridge. The lowest N_2O emissions occurred from the uncompacted furrows that had lower WFPS than the compacted furrows and relatively low mineral N concentrations (Fig 1b).

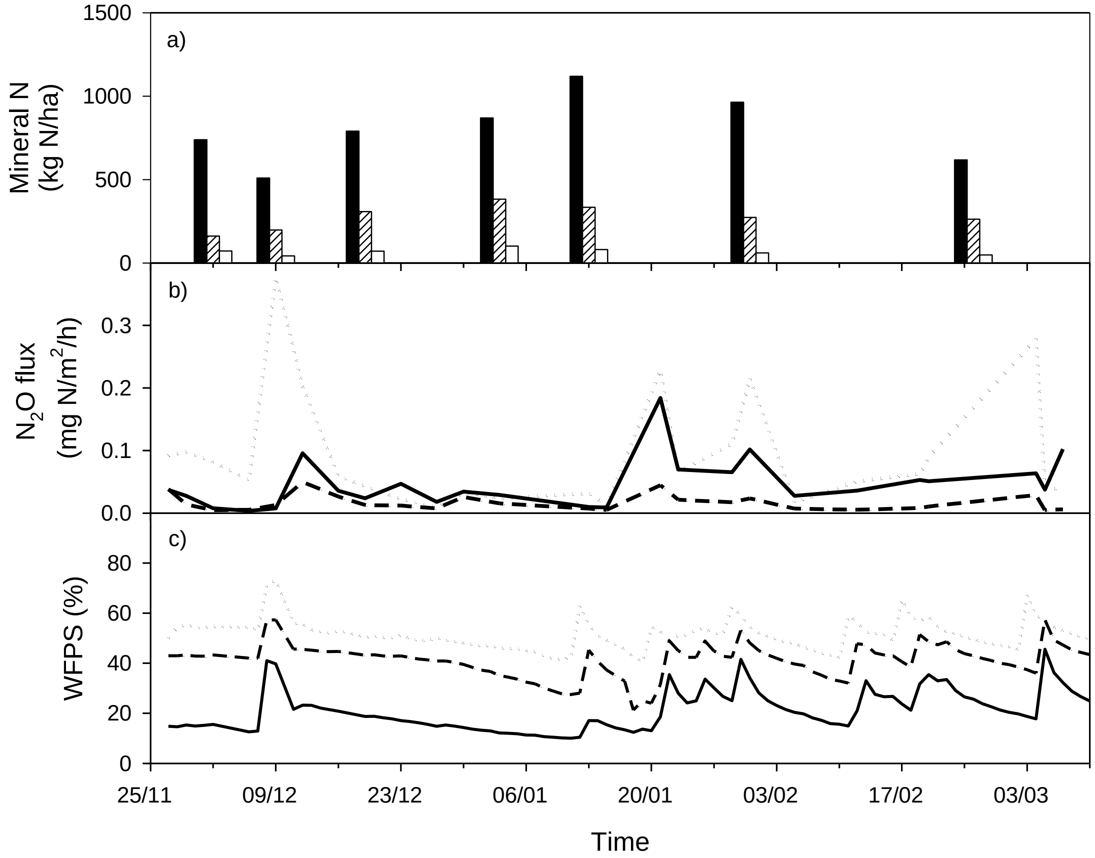

Figure 1. **a) Mineral N concentrations in potato ridges (solid), compacted furrow (hatched) and uncompacted furrow (open); b) N_2O surface flux from potato ridges (solid line), compacted furrow (dotted line) and uncompacted furrow (dashed line); and c) changes in WFPS for ridges (solid line), compacted furrows (dotted line) and uncompacted furrows (dashed line). Data are for the 450 kg N/ ha treatment (n=5).**

Summary and conclusions

The influence of tractor compaction on N_2O emissions was more important than the rate of applied N fertiliser. Both tractor compaction and irrigation affected N_2O emissions by increasing WFPS, leading to enhanced denitrification. However, the effect of irrigation was less important in the well aerated, uncompacted fertilised ridges and furrows. Consequently, management that limits compaction in row crops will help reduce N_2O emissions.

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Acknowledgement

This research was funded by the Foundation for Research, Science & Technology.

5.4 INDIRECT NITROUS OXIDE EMISSIONS FROM LEACHED N

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Introduction

Indirect N_2O emissions from N that is leached or in runoff are considered to make a major contribution (approximately 23% or 5.7 Gg N_2O-N) to the NZ N_2O emission inventory. This value is currently calculated using the IPCC methodology, by applying an emission factor (EF_5) to the amount of N that is leached or in runoff (N_{LEACH}). N_{LEACH} is calculated as a proportion ($Frac_{LEACH}$) of the N inputs from fertiliser and animal excreta. The value of $Frac_{LEACH(NZ)}$ is currently set at 0.15 for NZ inventory reporting. These estimates are uncertain, particularly for the value for EF_5. In addition, it is unclear whether $Frac_{LEACH}$ is appropriate for NZ's agricultural system that is dominated by year-round grazing of clover/grass pastures. This study examined the magnitude and uncertainty of NZ estimates of indirect N_2O emissions. One objective of the study was to determine whether the value of $Frac_{LEACH(NZ)}$ is appropriate, by comparing IPCC estimates using this value with predictions from a field-scale N leaching model for a range of typical farming systems.

Approach and methods

N_{LEACH} estimated using the IPCC calculation were compared with predictions using the OVERSEER® nutrient budget model developed for NZ conditions. Estimates were compared for "typical" dairy, sheep and beef, arable cropping and intensive vegetable farming systems. Comparisons between years were also made for the livestock systems using data for 1990, 2000 and projections for 2010. Recommendations were then made on the appropriateness of (i) using the IPCC calculations and (ii) the value for $Frac_{LEACH(NZ)}$.

Results and discussion

The IPCC estimates for N_{LEACH} for livestock systems (Tables 1 and 2) were much greater than those predicted by OVERSEER®, while IPCC estimates for arable (Table 3) and intensive vegetable systems (data not shown) were lower than the OVERSEER® estimates. NZ has approx 10.4 M ha of pastoral farms, and approx 188,000 ha of arable and 53,000 ha of intensive vegetable cropping. Based on the model predictions we recommend that the value of $Frac_{LEACH(NZ)}$ is reduced from 0.15 to 0.07 for pastoral systems.

The IPCC calculations do not take account of differences in soils or climate, which are important in determining the amount of N that is leached. These calculations are also inappropriate for estimating leaching from NZ arable soils as most of the leached N is derived from net N mineralisation of soil organic matter. In NZ, N leaching from arable soils is largely affected by management and crop rotations, and not fertiliser inputs. Therefore, we recommended that well calibrated, field-scale N leaching models should be used to estimate N_{LEACH} instead of using the IPCC calculations. While we can improve the certainty of N_{LEACH}, EF_5 remains highly uncertain. EF_5 is the highest of the default emission factors for calculating national inventories using the IPCC method (2.5% of N_{LEACH}) and is based on a very small data set. Therefore, it is important that this value is better quantified in the future.

Table 1. **N leaching estimates for NZ dairy farms using IPCC-based calculations and the OVERSEER® nutrient budget model.**

	1990			2000			2010		
	Low	**Av.**	**High**	**Low**	**Av.**	**High**	**Low**	**Av.**	**High**
Cows/ha	2	2.4	3.2	2.5	2.7	3.5	2.4	3	4
N Input (kgN/ha):									
N_{FERT}	0	47	150	0	100	200	40	129	300
N_{EX}	167	266	250	213	360	500	220	418	347
N_{LEACH} (kgN/ha):									
IPCC	25	47	60	32	69	105	39	82	97
OVERSEER	16	26	49	20	40	64	25	48	92

Table 2. **N leaching estimates for NZ sheep and beef farms using IPCC-based calculations and the OVERSEER® nutrient budget model.**

	1990			2000			2010		
	SI High[1]	**Av.**	**NI Int[2]**	**SI High**	**Av.**	**NI Int**	**SI High**	**Av.**	**NI Int**
Stock units/ha:	0.9	6.6	12	1.1	7.3	13.2	1.3	8	14.5
N Input (kgN/ha):									
N_{FERT}	1	2	4	2	7	8	3	12	15
N_{EX}	12	85	176	11	93	192	10	101	212
N_{LEACH} (kgN/ha):									
IPCC	2	13	27	2	15	30	2	17	34
OVERSEER	2	4	14	2	5	16	2	6	18

[1] South Island high country farms, [2] North Island intensive finishing farms

Table 3. **N leaching estimates using IPCC-based calculations and the OVERSEER® nutrient budget model for a "typical" cropping rotation (recently out of clover/grass pasture).**

	Crop in "typical" rotation							
	Ryegrass seed	**Clover seed**	**Winter Wheat**	**Spring Peas**	**Winter wheat[1]**	**Spring barley**	**Spring barley**	**Rotation average**
N input (kgN/ha):								
N_{FERT}	180	0	250	0	250	150	150	140
N_{LEACH} (kgN/ha/year):								
IPCC $Frac_{LEACH(NZ)}$	27	0[2]	37.5	0[2]	37.5	22.5	22.5	21[2]
OVERSEER	34	36	66	61	33	50	53	48

[1] Winter wheat following a cover crop.

[2] The N input for calculating $Frac_{LEACH}$ using IPCC formula does not include crop N fixation .

Acknowledgement

This study was funded by the Ministry of Agriculture and Forestry.

5.5 DETERMINING NITROUS OXIDE EMISSIONS FROM SUB-SURFACE MEASUREMENTS IN GRAZED PASTURE: A FIELD TRIAL OF ALTERNATIVE TECHNOLOGY

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Introduction

In grazed pasture soils, nitrous oxide (N_2O) emissions are stimulated by nitrogen input as animal waste or chemical fertilizer. The soil's nitrogen, water (oxygen) and temperature are unevenly distributed in space and time. This is why N_2O emissions are so variable, making both measurement and prediction extremely challenging. Here we introduce alternative technology for determining N_2O emissions from grazed pastures based on sub-surface measurements that incorporate the soil processes controlling N_2O production and gas diffusion rates. We also report preliminary results from our first field trial.

Materials and Methods

The field trial was located at a Dexcel dairy farm near Hamilton (37°49'S, 175°17'E), and stock was excluded for one year prior to the measurements. The silt loam soils examined are known as Horotiu (free draining) and Te Kowhai (poorly draining). The trial began on 2 April 2003 with the application of 650 kg of nitrogen (N) per hectare as urine collected from the farm's herd. The application simulated a cattle urine deposition event, and the soil became a so-called urine patch. Measurements reported here are for the following 100 days. Rainfall, and water content (expressed as a percentage of soil's total pore space and known as the water-filled pore space or WFPS) and temperature at a depth of 75 mm in both soils were measured continuously with electronic sensors and recorded as half-hourly averages. The soil's mineral N content (NO_3^- -N and NH_4^+ -N, 2M KCl extractable, 0 – 75 mm depth) was measured when gas samples were taken. The soil's N_2O emission rate was measured, three times a week after urine application and gradually reducing to once a week, using air sampled from static chambers (diameter 250 mm x height 130 mm) placed on the soil surface. Sub-surface air was then sampled using probes (12 mm in diameter and 400 mm long) inserted horizontally at a depth of 75 mm. The air samples were analysed to determine the N_2O concentration by a gas chromatograph (Simadzu GC-17A) equipped with ^{63}Ni electron capture detector. The sub-surface N_2O concentrations were used to determine the N_2O emission rate (F_{N2O}) according to Fick's 1st Law:

$$F_{N_2O} = -a \cdot \varepsilon^b \cdot D_{N_2O,air} \cdot \left(\frac{\Delta C}{\Delta Z} \right)$$

where $D_{N2O,air}$ is the diffusion coefficient for N_2O in air (0.0515 m^2 h^{-1}), $\Delta C/\Delta Z$ the vertical N_2O concentration gradient between the surface and –75mm in the soil (µg N_2O-N · m^{-3} soil air · m^{-1}), ε the air-filled pore space (1 – WFPS), a (here, assumed to be 0.9) and b (2.3) the coefficients to account for the soil's pore tortuosity and size distribution.

Result and Discussion

On average, the subsurface technology yielded N_2O emissions that were only 4 % greater and 13 % less than those based on chambers placed on the free- and poorly drained soils, respectively. However, these modest bias errors were not statistically significant. For the 100-day-long trial, the corresponding (direct) N_2O emission factors were 0.4 and 1.3 % that may be compared with the so-called NZ specific value (national average) of 1 %.

During the trial, about 80 % of the N_2O emissions occurred in the first 6 days after urine application (Figure 1). The emissions were often stimulated by heavy rainfall. After urine application, the two soil's emissions were mostly distinguished during two events that happened 4 and 76 days later, but only for the poorly drained soil. These events followed from different, but concurrent biological, chemical and physical processes in the soil that illustrate the complexity of N_2O emissions. The poorly drained soil's WFPS was always much higher than that of the freely drained soil. This corresponded with a higher rate of N_2O accumulation in the poorly drained soil that probably reflected a higher de-nitrification rate and reduced rate of N_2O diffusion from the soil. When WFPS subsequently decreased, nitrification and carbon mineralisation rates increased thereby supplying metabolisable carbon and/or mineral N substrates. The increased substrate availability could then fuel a higher denitrification rate when the WFPS later increased and so on. The effects of these processes on N_2O emissions from the freely drained soil were not evident during these two distinguishing events.

For all measurements from the two soils, correlation analyses did not yield significant relationships between N_2O emissions and the soil's WFPS, temperature or mineral N content. Multivariate analysis also left most of the N_2O emissions variability unexplained.

We recognise some limitations of our application of Fick's Law to determine N_2O emissions from grazed pasture soils. For two differently drained soils, we used the same power function of (1 – WFPS) and so-called representative parameters to account for the pore tortuosity and its size distribution. The sub-surface N_2O concentrations used were assumed to be representative across the 75 mm depth of integration. A net production or consumption of N_2O above our 75 mm deep measurement location was thus not included in the N_2O emissions rate.

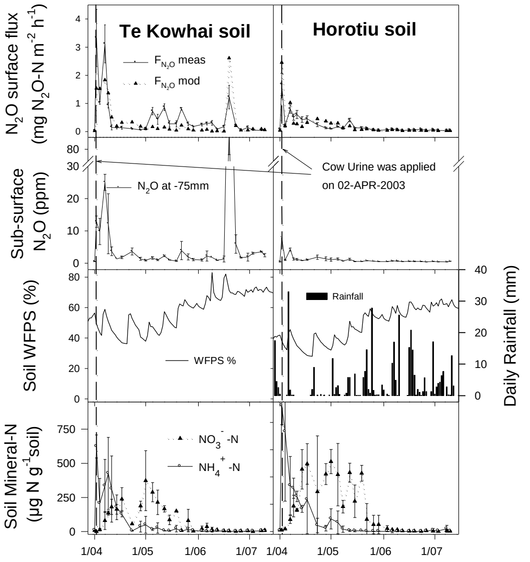

Figure 1: The N_2O surface emission rates, sub-surface concentrations and relevant soil and environmental parameters.

Subsurface gas concentration measurement also has potential for determining methane and carbon dioxide exchange rates between soils and the atmosphere. Fick's Law explained the role of WFPS in regulating gas diffusion and substrate supply to methanotrophic bacteria that consumed methane in a forest soil (Price et al. 2004. Global Change Biology, 10, 16-26). We have recently purchased small carbon dioxide analysers that can be inserted into soil and monitored with a data logger.

Acknowledgments

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5.6 SIMULATION OF NITROUS OXIDE EMISSIONS FROM NEW ZEALAND GRAZED PASTURES USING ‘NZ-DNDC’ MODEL

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Introduction

Under UNFCCC, New Zealand is required to produce an annual inventory of N_2O emission from all anthropogenic sources to assess the magnitude and change in total emissions since 1990. New Zealand ratified the Kyoto Protocol in December 2002 and this agreement has its own set of requirements, including the continuation of annual greenhouse gas reporting. New Zealand currently relies on the IPCC default methodology (New Zealand Climate Change Project 2003), and on animal population statistics for each region to estimate its N_2O emission inventory. Direct and indirect emissions from animal excreta (dung and urine) are estimated using N excreted by each animal type. IPCC default methodology is only a first approximation, because of i) uncertainty in emission factors, ii) uncertainty in indirect emissions, iii) limited data on the type and amount of N excreted by grazing animals, and iv) the spatial and temporal variability of N_2O emission. The methodology therefore appears to be too simplistic and generalised, ignoring all site-specific controls. It is also not sufficiently flexible to allow the assessment of mitigation options. Current emission rates from excretal input and from different soils in New Zealand have an uncertainty of ±65% (Sherlock et al. 2001), which must be reduced if changes since 1990 are to be reported internationally.

Accordingly, a more robust, process-based approach is required that is internationally acceptable and quantifies N_2O emissions at the field level more accurately than the IPCC methodology. Such an approach is needed to develop regional- and national-scale inventories with known levels of uncertainties. DNDC (DeNitrification DeComposition; Li et al. 1992) is a process-based model with reasonable data requirements that has been used to produce regional estimates for the US (Li et al. 1996), China (Li et al. 2001), Germany (Butterbach-Bahl 2001), Canada (Smith et al. 2002), and the UK (Brown et al. 2002). Although the model is suitable for simulation at appropriate temporal and spatial scales there were particular limitations in applying this model directly to New Zealand pastoral soils and climatic conditions. The DNDC model has therefore to be modified to represent New Zealand grazed pastoral systems.

Objectives

Our objectives were: i) to present seasonal variations in N_2O emissions from two dairy pastures with contrasting soils and from a sheep pasture; ii) to assess the ability of a modified DNDC model “NZ-DNDC” to simulate these emissions; and iii) to compare the N_2O emissions from dairy- and sheep-grazed pastures using an empirical methodology recommended by the IPCC, currently used in preparing New Zealand’s annual N_2O emission inventory from grazed pastures.

Materials and methods

Intensive chamber measurements of soil N_2O emissions were taken throughout the year to account for spatial and temporal variability from two highly productive grass/legume ungrazed and grazed dairy pastures, to assess the influence of soil moisture, temperature, and availability of N (NH_4^+ and NO_3^-) on N_2O emissions, and to calibrate a process-based model to simulate these emissions. The soils at these New Zealand pasture sites differed in texture and drainage characteristics. Full descriptions of the chambers, collection and analyses of gas samples, calculation of N_2O flux, and soil sampling and analyses are presented elsewhere (Saggar et al. 2002, 2004).

Modelling

DNDC was modified to better represent New Zealand's grazed pasture systems. Modifications were made to version 6.7 of the model, which was the most recent version at the time the research was begun [a newer version has since been released that may address some of the deficiencies found in version 6.7]. Details of the modifications are given in Saggar et al. (2004). The modified model, hereafter named "NZ-DNDC", was then used to simulate N_2O emissions from the ungrazed and dairy and sheep grazed pastures.

Results and discussion

***Seasonality Of N_2O Fluxes*:** In both soils, N_2O emissions for the grazed areas in winter were higher than those in spring (Figs 1a, b). The emissions were lower by about one-third in autumn. The spring season was characterised by significant rainfall events, rapidly fluctuating soil water content, mild temperatures, and increased plant growth that resulted in medium levels of N_2O emissions. The lowest emissions were obtained during the periods when soil water content was below field capacity. Large fluxes were generally observed after each grazing and rainfall event, and were followed by a decline.

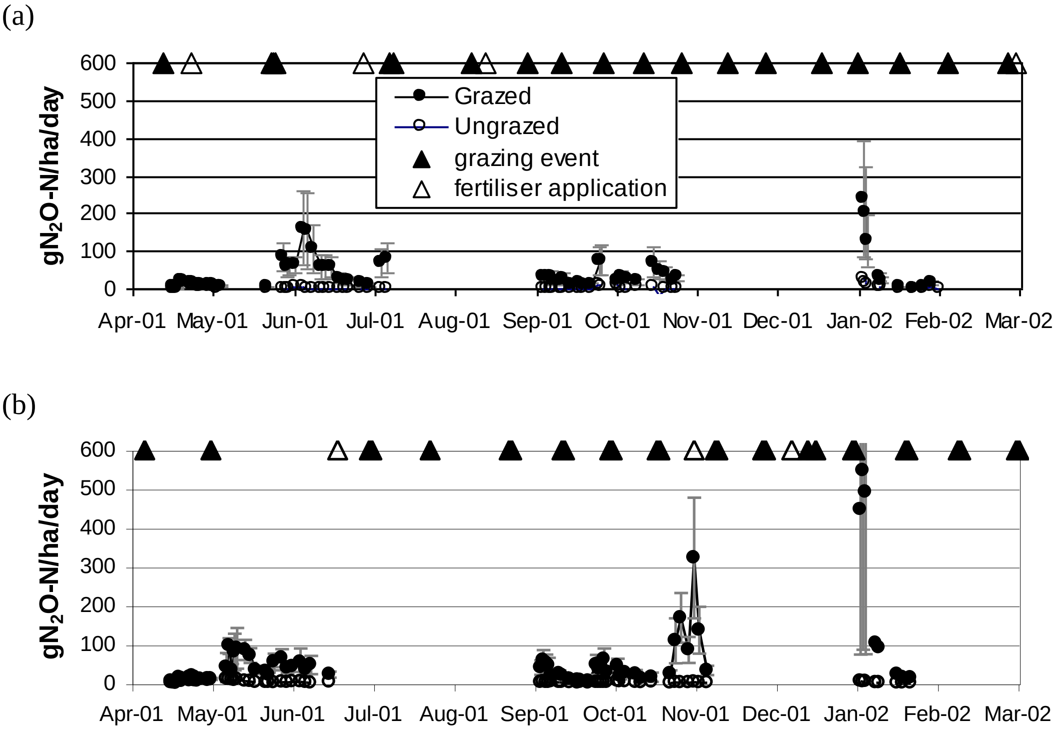
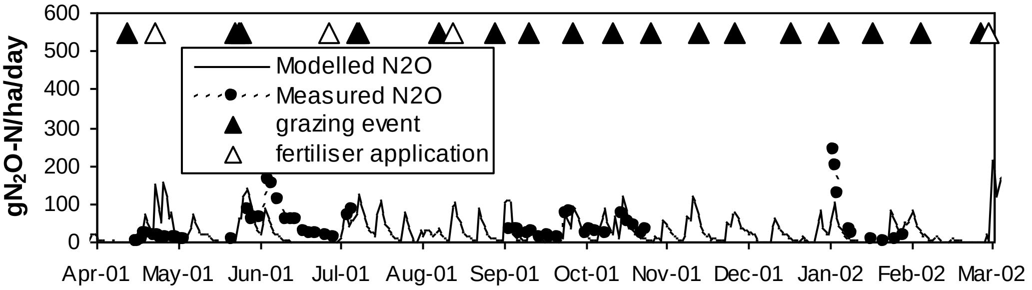


Figure 1. **Measured means and ranges of nitrous oxide emissions from grazed and ungrazed pastures from (a) Karapoti fine sandy loam and (b) Tokomaru silt loam soils.**

Comparisons Of Modelled With Measured Emissions: NZ-DNDC simulated well the average daily N_2O fluxes from the control and grazed plots (Figs 2a, b). However, it slightly overestimated spring (October) emissions, underestimated the very high emissions observed at both grazed sites in summer (January), due to high temperature and moisture after a rainfall event, but simulated well the following low emissions that dropped quickly as the soils dried out.

(a)



(b)

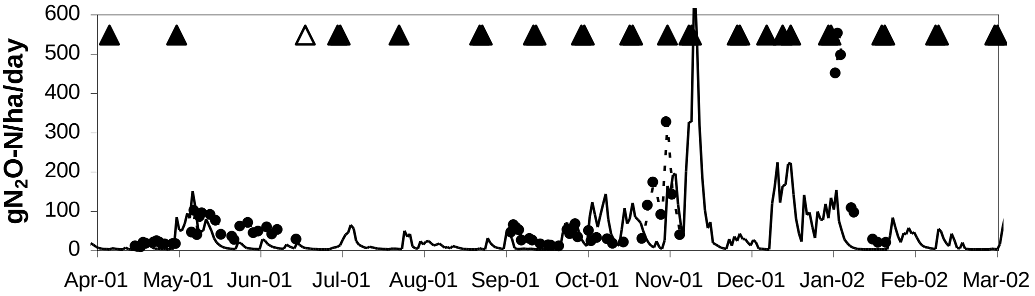


***Figure 2.* Comparison of modelled and measured nitrous oxide emissions from (a) Karapoti fine sandy loam and (b) Tokomaru silt loam soils.**

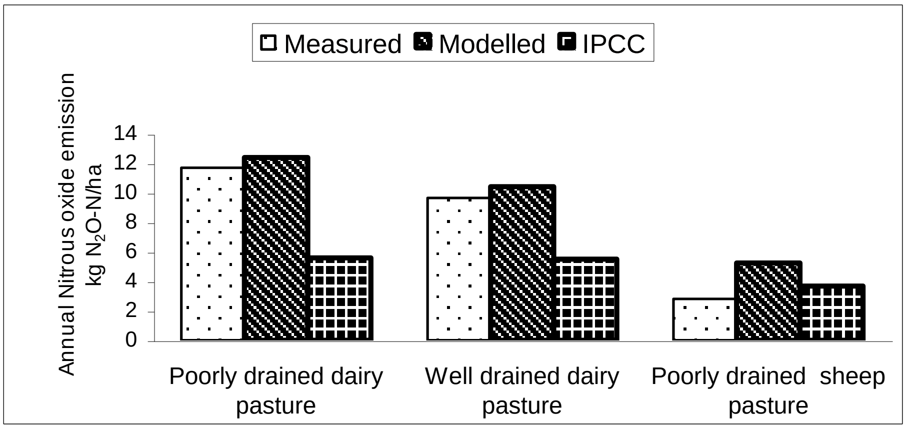


***Figure 3.* Annual-measured, NZ-DNDC-predicted and IPCC-calculated nitrous oxide emissions from two dairy-grazed and a sheep-grazed site.**

Figure 3 compares the measured annual emissions from two dairy farms and a sheep farm with emissions estimated using IPCC approach and NZ-DNDC model. Both the dairy farms had similar grazing management, pasture production and rainfall but differed in soil texture. Sheep were set stocked, which resulted in daily excretal inputs. The measured emissions were about 20% higher in the poorly drained Tokomaru silt loam soil than in well-drained Karapoti fine sandy loam soil. The NZ-DNDC model was also able to pick up the differences in emissions resulting from differences in soil texture. But the IPCC default methodology cannot account for such influences. We observed very significant differences in emission between sheep-grazed and dairy pasture. Our measured values for the sheep-grazed pasture were slightly lower than that predicted by the model. No measurements were made during a high rainfall December period that may have been underestimated. Also it was not possible to shift chambers daily to capture daily excretal inputs. We have now modofied our chambers to allow sheep to graze over the chambers, which captures daily excretal inputs.

Our measurements and model estimates show Emission Factors (EFs) are different for dairy and sheep-grazed systems and suggest one EF for all as used in the current inventory using the IPCC approach will not give accurate emission estimates. The overall comparisons of predicted and measured annual emissions indicate NZ-DNDC should be applicable to the simulation of N_2O emissions from a range of grazed pastures.

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5.7 DNDC AND ITS APPLICATIONS

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Background

The denitrification-decomposition (DNDC) model was originally developed for US EPA to quantify impacts of agricultural management on national nitrous oxide (N_2O) emissions. Through the modeling effort, it was found that (1) N_2O fluxes were highly variable in space and time and were driven by a group of environmental factors such as soil temperature, moisture, pH, Eh, and substrate concentration gradients, (2) these environmental factors collectively affected N_2O emissions through altering a series of biogeochemical processes including decomposition, nitrification, denitrification and other relevant reactions, and (3) spatial and temporal variations of the environmental factors were controlled by five major primary drivers including climate, topography, soil, vegetation and anthropogenic activity. To bring such a complex system into a computable framework, biogeochemical concepts were employed to construct the model framework. Basic laws of physics, chemistry and biology were adopted to build up the functions regulating the plant, water and soil processes. Equipped with the fundamental processes, DNDC is applicable across climatic zones, soil types, and management regimes. It took about 5 years (1989–1994) to have the model framework constructed and another 10 years (1995–2004) for calibrations and validations. During the past 15 years US EPA, NSF, NASA, USDA and NOAA have continuously provided support for this effort to expand the modeling capacity to trace gases, carbon (C) sequestration, and crop yield. Since 1995, more and more international researchers have been involved in the modeling efforts through testing, modifying and using DNDC. Their contributions have significantly advanced the development and applications of DNDC.

Model structure

DNDC consists of two components that reflect the two-level driving forces controlling the biogeochemical processes related to water, C and N dynamics. The first component, consisting of the soil climate, crop growth and decomposition sub-models, predicts soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles (ammonium, nitrate, dissolved organic carbon) based on ecological drivers (e.g., climate, soil, vegetation and anthropogenic activity). The second component, consisting of the nitrification, denitrification and fermentation sub-models, predicts NO, N_2O, CH_4 and ammonia (NH_3) fluxes based on the soil environmental variables. Classic laws of physics, chemistry and biology, and empirical equations generated from laboratory observations, were used in the model to parameterize each specific reaction. The entire model forms a bridge between basic ecological drivers and water, C and N cycles (Li, 2000; Li et al., 1992, 1994, 1996, 2004). Geographic Information System (GIS) databases with spatially and temporally differentiated information on climate, soil, vegetation and management practices have been used to upscale the model predictions to local, regional and national scales. The input parameters required for DNDC runs are daily meteorological data (e.g., air temperature, precipitation and radiation), atmospheric nitrogen (N) deposition, soil properties (e.g., texture, bulk density, organic matter content, and pH), and management practices (e.g., crop type and rotation, tillage, fertilization, manure amendment, irrigation, weeding, and grazing). The output parameters include daily crop photosynthesis, respiration, C allocation, litter production, root exudation, water demand and uptake, and N demand and uptake; daily soil C and N pools, rates of decomposition, nitrification, denitrification, ammonia volatilization, methane production and oxidation, N leaching, and emissions of CO_2, N_2O, NO, NH_3 and CH_4 for both upland and wetland agricultural ecosystems.

Model validations

DNDC has been validated against numerous datasets observed worldwide. The tested items included crop yield, soil temperature and moisture, ecosystem C sequestration, N leaching, and emissions of CO_2, N_2O, NO, NH_3 and CH_4 (Cai et al., 2003; Brown et al., 2002; Zhang et al., 2002; Li, 2000; Smith et al., 1999; Xiu et al., 1999; Frolking et al., 1998; Plant et al., 1998; Smith et al., 1997; Wang et al., 1997; Li et al., 1994, 1992; Xu-Ri et al., 2003). For example, by tracking crop biomass production and decomposition rates, DNDC captured long-term soil organic carbon (SOC) dynamics in cropland or grassland in the US, Canada, Germany, the UK, Australia, China, and Brazil. DNDC has been tested in more countries on N_2O and CH_4 emissions. With its prediction capacity of the whole suite of greenhouse gases (i.e. CO_2, N_2O and CH_4), DNDC is ideal for mitigation-offset analyses that examine both C sequestration and N_2O and CH_4 emissions for agro-ecosystems.

Uncertainty analyses

In regional modeling studies, a region is usually divided into grid cells, and within each cell all the attributes are assumed uniform. This approach has been widely used to build various Geographic Information System (GIS) databases to support modeling calculations at regional scale. In fact, soil properties or other input parameters within a cell still vary. The spatial heterogeneity in the input parameters is a major source of uncertainties for GHG estimation when applying process-based models such as DNDC to regional scale. To bring the uncertainty under control, an approach called Most Sensitive Factor (MSF) method was developed for DNDC (Li et al. 1996, 2001, 2002). Based on this method, soil databases are compiled with the range values that are commonly observed for each grid cell. DNDC runs twice for each cell with the maximum and minimum values of the most sensitive factors (e.g., SOC for N_2O, soil texture for CH_4) to produce two fluxes. The two fluxes will form a range assumed to be wide enough to cover the “real” flux with a high probability. To verify the MSF approach, a Monte Carlo routine has been built in DNDC to quantify the uncertainties by randomly combining values of the input parameters (e.g., soil texture, SOC content, pH, bulk density, etc.). The default sample size is 5000. Based on the results from the 5000 simulations, frequencies of the modeled fluxes can be calculated. The comparison between the results from MSF and Monte Carlo indicated that 60–90% of the GHG fluxes produced from the Monte Carlo approach were located within the ranges produced from the MSF method (Li et al., 2004). The Monte Carlo method provides frequency distribution information but requires longer computing time (about 3 hours for 5000 simulations). The MSF method provides reasonable ranges without frequency information but requires much less computing time (10 seconds for two simulations). Due to its feasibility and effectiveness, we adopted the MSF method for regional simulations.

Model applications

For more than a decade, DNDC has been mainly used for GHG inventory and mitigation. Several large-scale projects are ongoing to quantify GHG emissions with alternative management scenarios in North America, Europe and Asia. The major approach used in these projects is to construct DNDC-required GIS databases to hold the spatially and temporally differentiated information of climate, soil, vegetation, and management, and then use the databases to drive DNDC across the target regions. Preliminary results have been reported for the studies in the US, Canada, the UK, Germany, and China. Some results revealed very interesting phenomena at large scales. For example, applying DNDC for all of the rice paddies in China with different water management scenarios (i.e. continuous flooding vs mid-season drainage) has indicated that methane emissions from the Chinese rice agriculture reduced by 5 Tg/yr during the last 2 decades when water-management practice shifted from continuous flooding to mid-season drainage nationwide between 1980 and 2000. The magnitude of reduction in methane emissions in China was consistent with the observed decrease in the increasing rates of atmospheric methane concentration during the same time period (Li et al. 2002). In addition, comparison of C and N cycles in US and Chinese agro-ecosystems at the national scale, found that (1) the cropland was losing C in China but gaining C in the US, and (2) agricultural N loss was dominated by leaching in the US and by ammonia volatilization in China. Modeled results indicated the difference in C and N cycling between the two countries was due to management approaches, which are subject to climate/soil conditions (Li et al. 2001, 2003). The modeled regional results have provided a sound basis for policy making for GHG mitigation or environmental protection.

New Zealand situation

DNDC has been modified to represent New Zealand grazed pasture systems ("NZ-DNDC"), and used to simulate N_2O emissions. The NZ-DNDC model simulated effectively most of the N_2O emission pulses and trends from both the ungrazed and grazed dairy pastures, and fairly reproduced the real variability in underlying processes regulating N_2O emissions (Saggar et al. 2002, 2003, 2004). The NZ-DNDC estimates of total yearly emission of N_2O from the grazed and ungrazed sites were within the uncertainty range of the measured emissions. The model accounted for the climatic variations in rainfall, and was also able to pick up differences in emissions resulting from differences in soil texture. Results suggest the model's applicability to simulating N_2O emissions from a range of New Zealand grazed pastures. However, when the model was used for the MAF-funded urine trials and upscaling project we observed the water balance and evapotransiparation components did not represent NZ specific conditions well. The soil moisture component of the model is currently under review. Our current research also focuses on using NZ-DNDC to monitor the efficacy of mitigating urine-induced N_2O emissions from grazed pasture systems, using nitrification inhibitors. Our ultimate goal is to be able to estimate emissions accurately on a regional and national scale based on available climatic data, soil types, and numbers and types of grazing animals and their excretal N inputs, and develop a farm-scale N_2O emission model for use by farmers to encourage their enhanced N use efficiency.

Acknowledgements

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5.8 N_2O AND N_2 EMISSIONS FROM PASTURE AND WETLAND SOILS RECEIVING NITRATE-N AS INFLUENCED BY SOIL AMENDMENTS

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Abstract

A laboratory incubation was conducted at 25°C to quantify N_2O and N_2 emissions from pasture and wetland soils with or without added soil amendments (lime or zeolite) and NO_3^- –N at 200 kg N ha^{-1} rate in 10 L plastic containers. Paired sub-soil samples from each container were taken out at different days and transferred to 1 L gas jars to measure N_2O and N_2 emission by acetylene (C_2H_2) technique. Nitrate addition to wetland and pasture soils resulted in a significant increase in N_2O emissions from those soils, which was higher from the former than the later. Lime or zeolite did not have any effect on N_2O emission from any soils. Lime application enhanced N_2 emissions from both pasture and wetland soils by 62%. More N_2 was emitted from wetland soils treated with NO_3^- than from pasture soils probably due the higher WFPS and greater availability of organic C in the former. Liming pasture and wetland soils can shift the balance between harmful N_2O and non-greenhouse N_2 and may be considered as one of the potential mitigation tool.

Introduction

In New Zealand, pastoral soils emit significant amounts of N_2O as they receive N inputs from excreta of grazing animals, N fertilizer and dairy waste applications and clover fixation. Similarly riparian wetlands, (a buffer zone of undrained land directly adjacent to the stream or river channel) receive N inputs from upland agricultural catchments via surface runoff and seepage flows; have been advocated to process nitrate (NO_3^-), and other contaminants through microbial processes (Cooper et al. 1997). N_2O emissions from pasture soils have been studied extensively (de Klein et al, 2001). However, limited information is available on N_2O emissions from riparian wetlands, which are considered as one of the best management practices to process NO_3^- from farmland. It is therefore important to develop strategies for mitigating N_2O emission from both pasture and wetland soils. The objectives of our study were to quantify the N_2O and N_2 emissions from pasture and wetland soils receiving NO_3^--N as influenced by soil amendments (lime or zeolite).

Materials and methods

Soil samples (0-10 cm soil depth) were collected from pasture and adjacent riparian wetland zone in October 2003. Soil samples were picked free from visible plant roots and litters and used in the incubation. The water filled pore spaces (WFPS) of pasture and wetland soils were 0.63% and 1.72% respectively. Four sub soil samples from pasture and wetland soils were analyzed for their initial chemical properties. Pasture soil had a pH of 5.6, total N 0.44% and total C 4.50%. Wetland soil had a pH of 5.3, total N 0.5% and total C 6%. For uniform application, potassium nitrate (KNO_3) was first dissolved in water and then applied to pasture or wetland soils at 200 kg N ha^{-1} rate. Lime and zeolite were added to raise soil pH to 7 and sorb N respectively on the basis of our previous studies (Zaman etal., 2003; Nguyen and Tanner, 1998). Control treatments (no N) with or without lime and zeolite were also included for both pasture and wetland soils. Each soil mixture was transferred to 10 L plastic container and incubated at 25ºC. The incubation lasted for 28 days. To measure N_2O and N_2 emissions from the amended soil mixture, 2 sets of sub soil samples (100 g oven dry basis) were taken out from each treatment and transferred to 1 L incubation jar. The incubation jars were covered with a lid containing rubber septum for gas collection. One set of soil sample was treated with 5% v/v C_2H_2 and the other with no C_2H_2. The 2 sets of soil samples were then incubated at 25ºC for 24 hours. After 24 hours, 12 mL gas samples were taken out from the headspace of each jar with 60 mL syringe and put into 12 mL exetainer and analyzed for N_2O concentration using gas chromatographs (Shimadzu, Japan). The N_2 concentration was calculated from the difference of N_2O coming out of C_2H_2-treated soils and non-C_2H_2 treated soils.

Results and discussion

Total N_2O and N_2 emissions from pasture and wetland soils during incubation The total amounts of N_2O and N_2 that emitted from NO_3^- treated soils of pasture and wetland during 28 days incubation were significantly higher than those of the no N treatments (Fig.1). In pasture soils, total N_2O emissions were 13 kg N ha^{-1} from NO_3^- treated soils compared to 4.6 kg N ha^{-1} from no N treated soils. Total N_2O emissions from wetland soils were 48 kg N ha^{-1} and 0.10 kg N ha^{-1} from NO_3^- and no N treated soils respectively. Such increases were due to the greater availability of the added NO_3^- that generates N_2O through denitrification and dissimilatory NO_3^- reduction to NH_4^+ (DNRA) (Tiedje 1988; Matheson et al. 2003). The applications of zeolite or lime did not have any significant effect on N_2O emissions from both soils. In our previous study, zeolite application significantly reduced N_2O emission from pasture soils treated with NH_4^+-N (Zaman et al 2003). The lack of response in this study could be due to exclusion of NO_3^- by added zeolite. Lime application generally stimulates nitrification and thus reported to increase N_2O emissions (Zaman et al, 2003), however, no such trend was observed in our study probably due to abundant availability of added NO_3^-.

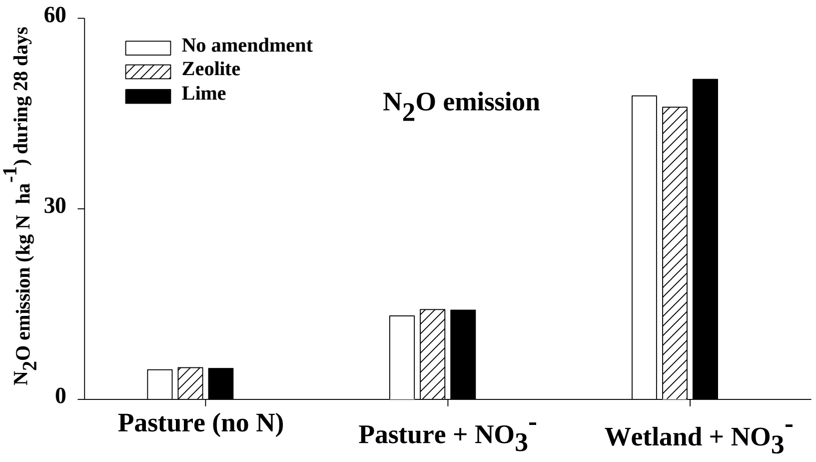

Figure 1. **N_2O emissions from pasture and wetland soils with or without NO_3^-, lime & zeolite**

Di-nitrogen (N_2) emissions were also significantly affected by the added NO_3^- and lime to pasture and wetland soils (Fig 2). More N_2 was emitted from wetland soils treated with NO_3^- than from pasture soils probably due the higher WFPS and greater availability of organic C in the former. Lime application significantly enhanced N_2 emissions in pasture and wetland soils by 62%. Such increases were probably due to the increase in soil pH in these treatments, which favors the reduction of N_2O to N_2 by stimulating the activity of N_2O reductase and other reductase enzymes (Flessa et al., 1998). Zeolite did not have any effect on N_2 emission in any treatment because it did not have any increasing effect on soil pH. These results are consistent with our previous study (Zaman etal., 2003). Our study suggests that wetland soil could offer best option to be used to intercept N lost from adjacent farmlands through surface runoff or leaching before entering water bodies. Similarly liming pasture and wetland soils can shift the balance between harmful N_2O and non-greenhouse N_2 and may be considered as one of the potential mitigation tool for N_2O emission.

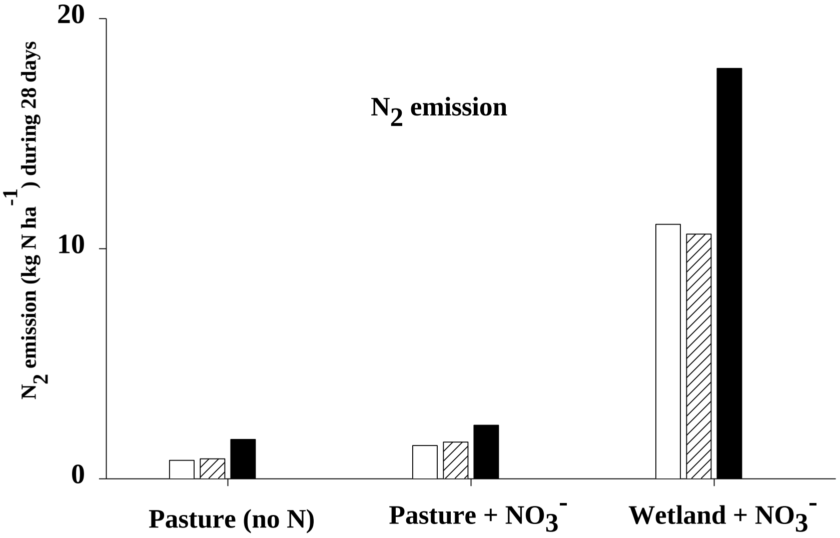

Figure 2. **N_2 emissions from pasture and wetland soils with or without NO_3^-, lime & zeolite**

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5.9 EFFECT OF UREASE AND NITRIFICATION INHIBITORS IN REDUCING GASEOUS N LOSSES FROM PASTURE SOILS

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Introduction

In grazed pastures, nitrogen (N) input is derived from biological N fixation by clover, fertilizer application and deposition of animal excreta, especially urine. New Zealand's 4.98 million dairy cows, 4.54 million beef cattle and 41.36 million sheep annually excrete approximately 108 million m^3 of urine on grazed pastures contributing about 1.16 million tons of N to pasture soils. Fertiliser N application adds another 0.25 million tons of N to New Zealand's agriculture. Nitrogen is lost through leaching and gaseous emissions as ammonia (NH_3) volatilization and nitric oxide (NO), nitrous oxide (N_2O), and dinitrogen (N_2) emissions during ammonification, urea hydrolysis, nitrification and denitrification. Various separate approaches are being attempted for the abatement of NH_3 volatilization and N_2O emissions. One such approach is the use of urease and nitrification inhibitors. Strategies to reduce emission of one gas may effect the emission of the other. Therefore, abatement strategies require quantitative information about the effect of these inhibitors simultaneously on ammonia (NH_3) volatilization and nitrous oxide (N_2O) emissions. This study examines the effect of urease and nitrification inhibitors on N losses through ammonia volatilisation and denitrification from urine and fertiliser N-inputs in intact pasture soil cores.

Approach

Intact soil cores (100 mm diameter, 100 mm depth) were collected from a sheep-grazed permanent legume based pasture at Massey University Frewens Research Block, Turitea campus. The soil at this site was a Manawatu fine sandy loam, classified as weathered fluvial recent soil. These cores were first saturated overnight with deionised water and then kept on pressure plates at -10 kPa pressure for 2 days to bring them to field capacity. Cores were weighed and then maintained at field capacity moisture content through out the experiment. Two experiments were conducted to assess the impact of urease inhibitor (Agrotain) and nitrification inhibitor (DCD)

Experiment 1

Treatments were: T1- Control with inhibitor; T2 – Control without inhibitor; T3 – Urine with inhibitor; T4 – Urine without inhibitor; T5 – Urea with inhibitor (SustaiN); T6 – Urea without inhibitor. Nitrogen in the form of urine and urea was added at the rate of 600kg N/ ha .The amount of urease inhibitor (Agrotain) added to urine treatment was similar to that present in SustaiN (@1 litre/ton urea). During the 10-week experimental period gas samples were collected using the developed technique and analysed for NH_3 and N_2O emissions.

Experiment 2

Treatments were: T1 – Urea with inhibitor; T2 – Urea without inhibitor; T3 – SustaiN with inhibitor; T4 – SustaiN without inhibitor. Nitrogen in the form of urea and SustaiN was applied @100kg/ha. Nitrification inhibitor (DCD) was added @ 25kg/ha.

Results and Discussion

Effect of Urease Inhibitor

Ammonia emissions

Very high NH_3 emissions were observed within 3-4 days of urea application and these emissions quickly declined to the background levels in 2 weeks. In case of SustaiN (urea with urease inhibitor-Agrotain), there was slow increase in NH_3 emissions, which also declined to background levels within 2 weeks. NH_3 volatilization loss was significantly lower with SustaiN than urea alone (Fig. 1). Initially (5-7 days after the application of urea and SustaiN treatments to the soil cores) the amount of NH_3 volatilized was markedly higher for unamended urea than for SustaiN. This may be due to the fact that in the absence of urease inhibitor most of the urea added to soil was converted to NH_4^+ ions, whereas in the presence of urease inhibitor substantial amounts of urea could remain in soil for approximately one week after urea application (Watson *et al*, 1994). However, towards the end of the experiment, the rate of NH_3 loss was similar in both the treatments, indicating that the effect of the inhibitor (Agrotain) was short-lived and also that the rate of NH_3 emissions from untreated urea was decreasing. Overall there was 27 % and 11% decline in NH_3 emissions from Sustain and urine with Agrotain as compared to that in urea and urine respectively.

Application of urine resulted in immediate loss of NH_3 within 24 hours of application (Fig 1). As the urea ($CO(NH_2)_2$) in urine undergoes hydrolysis in the presence of urease enzyme within the first 24 hours of urine addition to soils (Eq. 1) so this high loss of ammonia was expected.

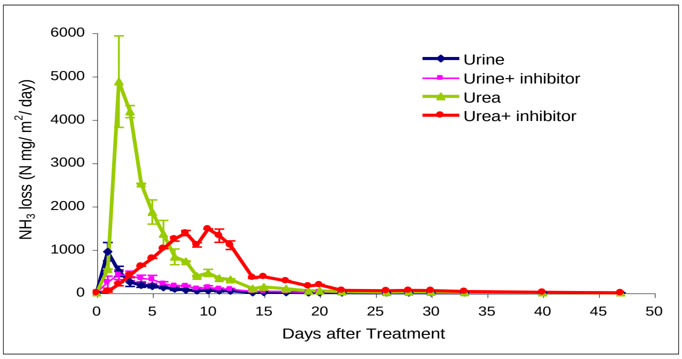

Figure 1. **Ammonia volatilization losses with and without urease inhibitor from urine and urea applications**

In this process, large amounts of ammonium (NH_4^+) ions accumulate in the soil. This process also releases alkali ions (OH^-) and hence the pH in soil increases. The NH_4^+ ions dissociate into NH_3 in the presence of OH^- (Eq 2), resulting in the release of NH_3 gas.

$$CO(NH_2)_2 \rightarrow 2NH_4^+ + 2OH^- + CO_2 \qquad (1)$$

$$NH_4^+ + OH^- \rightarrow NH_3 + H_2O \qquad (2)$$

However addition of urease inhibitor with urine resulted in decrease in NH_3 volatilization. It is interesting to note that surface application of urea resulted in higher NH_3 volatilization than the urine application. This may be due to the downward movement of urine and absorption of NH_4^+ ions in the soil while in case of surface applied urea these ions were not effectively absorbed.

Nitrous oxide emission

The amount of N_2O emitted from urea was less than that from SustaiN. However, more N_2O was emitted from urine without inhibitor than with inhibitor (Fig 2).

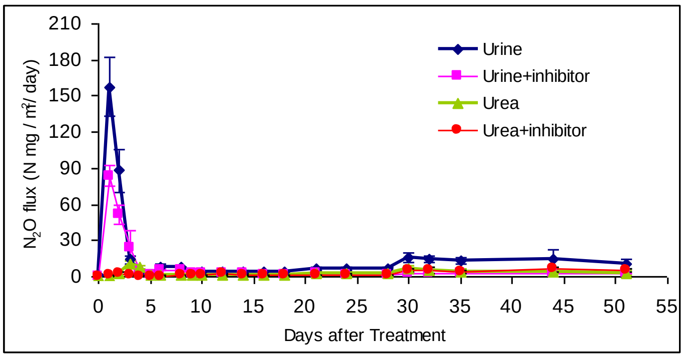

***Figure 2*: Nitrous oxide losses with and without urease inhibitor (Agrotain) from urine and urea applications**

Effect of Nitrification Inhibitor

Ammonia emissions

NH_3 losses peaked two days after the N fertilizer application in both urea+DCD and urea treatments. However, no significant difference in NH_3 emissions was observed between treatments with and without DCD addition. When DCD was added to Sustain, a small decrease of 6% was seen in NH_3 emissions as compared SustaiN without DCD (Fig 3).

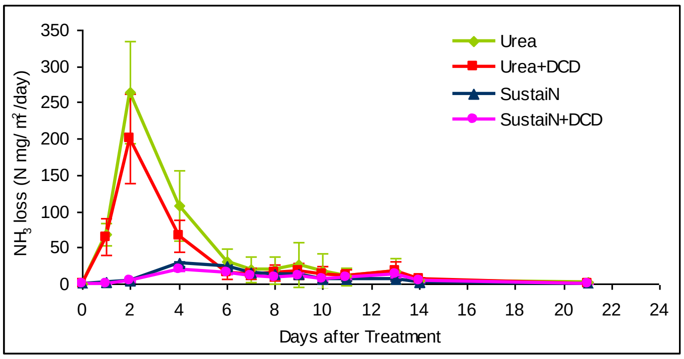

***Figure 3.* Ammonia volatilization losses with and without DCD and DCD+Agrotain**

Nitrous oxide emissions

N_2O emissions in urea reached a peak of 2.94 mg N_2O-N/ m^2/day before gradually declining to background levels. In contrast, where DCD was added to urea, N_2O flux was reduced to below 0.40 mg N_2O-N/ m^2/day. It was seen that with DCD, the N_2O flux was reduced by 78%. Thus the use of DCD with urea is an effective way of reducing emissions. This confirms the earlier observations of McTaggart et al. (1997), Dobbie et al. (2003) and Di and Cameron (2003). In case of SustaiN N_2O emission peak was observed after two weeks of application however, no such peak was observed with DCD addition. Addition of DCD to SustaiN resulted in 68% reduction in N_2O emissions (Fig 4).

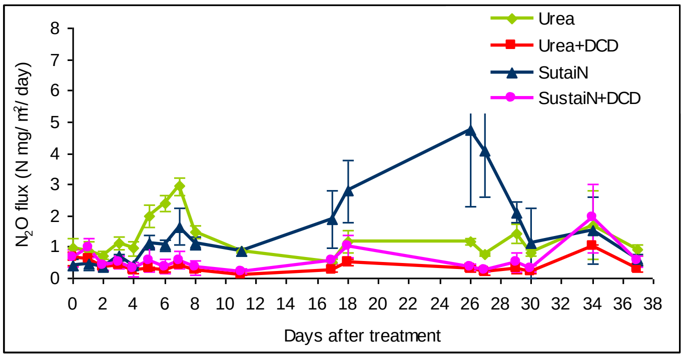

***Figure 4*. Nitrous oxide losses with and without DCD and DCD+Agrotain**

Conclusions

Urease inhibitor delays the onset and reduces the rate of NH_3 volatilization**.** In this study, urease inhibitor reduced NH_3 losses by 27% and 11% for surface applied urea and urine, respectively. Nitrification inhibitor reduced N_2O emissions but did not change NH_3 emissions from urea. A combination of urease and nitrification inhibitor reduced N_2O emissions and also resulted in a small decrease in NH_3 emissions.

Acknowledgements

Landcare Research for equipment and analytical facilities; Carolyn Hedley, Bob Toes and Ian Furkert for laboratory assistance; Ted Pinkney for setting up the equipment**.**

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5.10 NITROUS OXIDE EMISSIONS FROM EFFLUENT APPLICATION

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Introduction

In New Zealand the dairy cattle number has increased from 3.44 million 1990 to 5.16 million in 2003. The beef cattle and pig number have shown a slight decrease in the given time period. However, the increase in the dairy cattle number has increased the quantity of effluent produced each year. It is estimated that on an average 70 million m^3 of dairy effluent and 75 million m^3 of meat effluent is produced annually, that supply about 31125 tonnes of N respectively. With the introduction of the Resource Management Act (1991) discharge of effluents to surface waters is now a controlled activity and many regional council encourage land irrigation of effluents. Moreover, due to high nutrient content, land application of effluents is considered a move towards sustainable farming. But this policy has been made without due regard to its impact on the air quality. It has been reported that effluent irrigation leads to increased emission of greenhouse gases, such as nitrous oxide (N_2O) and methane (CH_4). Besides, effluents generated from different farming systems may lead to different levels of emissions primarily due to their varied composition. Hence, quantification of the gaseous emission of N due to land application of effluent is important.
Massey University and Landcare Research have initiated a number of studies examining on the effects of various factors, such as the nature of the effluent, hydraulic loading, time of application, soil type and compaction, on N_2O emissions from effluent irrigation. Here we outline the various components of this research to quantify the impact of effluent application from various sources on N_2O emission.

Approach

Various field experiments conducted during the course of study were:

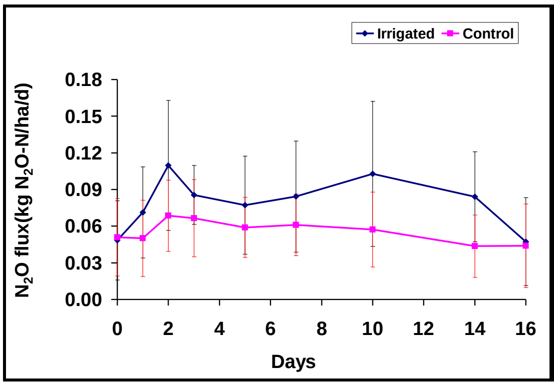
Effluent irrigation: In this experiment N_2O emissions and related soil and environmental parameters were monitored for two weeks following the dairy treated effluent applications in September 2003 and January 2004. Experiment was conducted at pasture at Dairy 4 of Massey University.

Types of effluent: In a separate study, N_2O fluxes from dairy treated, dairy untreated, piggery and meat effluents were compared. Effluent were applied to 2m x 1m replicated pasture plots, lined with 7.5cm deep polythene to restrict the surface flow, at Frewens block of Massey university. Water and control treatments were also included. N_2O emissions were monitored regularly over a period of 13 weeks in summer (February, 2003).

Compaction effects: This experiment comprised of two main treatments (compacted and uncompacted) to which four N sources (cattle urine, potassium nitrate, ammonium sulphate and urea at the rate of 600kg N/ha) and a control (water only) were applied, each replicated four times. Compaction was obtained through driving close parallel tracks by the wheels of the vehicle. Various soil properties related to soil compaction (bulk density, water filled pore space (WFPS), oxygen diffusion rate (ODR)) were measured. The N_2O fluxes were measured for 3 months (between 10th September and 4th December, 2002) using closed chamber technique.

Results and discussion

Effluent irrigation: N_2O emissions increased immediately after the application of the effluent, and subsequently dropped after about two weeks. The total N_2O emitted from effluent application after first and second irrigation was 1.95% and 5.25% respectively of the total N added through effluent (Fig 1a and 1b). Emissions were observed to be higher during second effluent irrigation (Fig 1b) because of the high soil moisture content during the measurement period. Moreover effluent was applied immediately after grazing event leading to more nitrogen input in the soil.



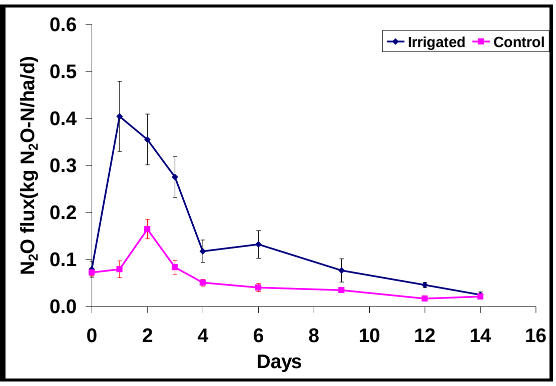


Fig 1a **Fig 1b**

There was no residual effect of the effluent irrigation observed on N_2O emissions (Fig 2). The emissions from the control and effluent irrigated plots were similar when it was measured two months after the effluent irrigation.

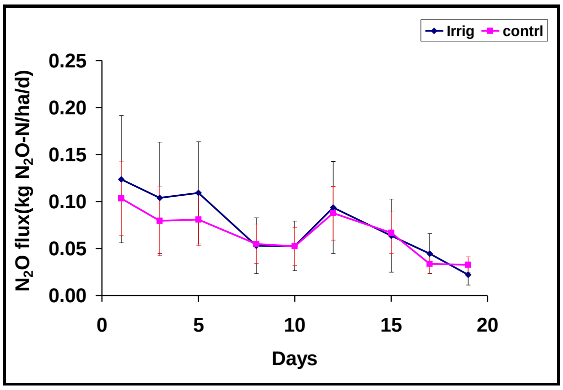


Fig 2

Types of effluent: Our results showed significantly higher emissions from all effluent irrigation treatments than the control and water treatments (Fig 3). Among the effluents, emission from the piggery effluent (0.392 kg N_2O/ha) was higher than the rest of the treatments resulting in 1.43% of the total added N being emitted during the experimental period of 13 weeks. Emissions from dairy untreated (0.42%) and meat effluent (0.67%) were statistically similar. Emissions from dairy treated effluent were the least. This indicates that supply of C and N through effluent irrigation contributed to increased N_2O emission.

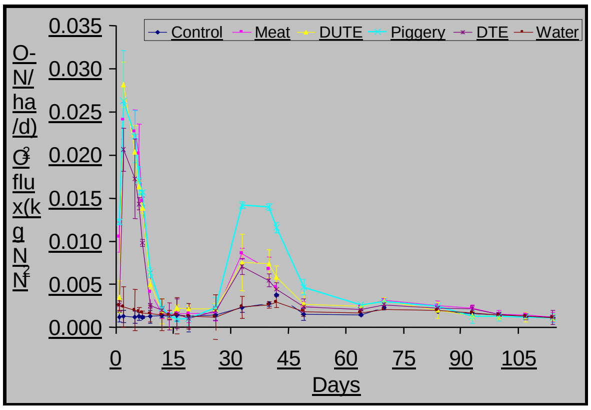


Fig 3

Compaction: Compaction caused a seven fold increase in N_2O emission (Fig 4). Nitrate source was the most effective of all the treatments in causing potential emission. Under compacted soil 9.87% of the total N applied in form of nitrate was emitted whereas under uncompacted soil this loss was only 0.54%. N_2O loss was found to decrease progressively from the time of application of N treatments. Total N_2O emission for different N sources, during the three month experimental period, ranged from 2.62 to 61.74 kg N_2O/ha for compacted soil and 1.12 to 4.37 kg N_2O/ha for uncompacted soil.

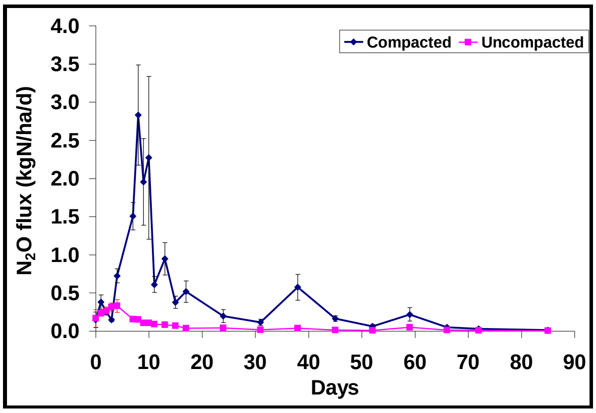


Fig 4

Conclusion

Effluent irrigation increases N_2O emissions for a short duration. No long term residual effect of effluent irrigation on emissions was observed.

Emissions vary with the type of effluent which in turn depends on the amount of available N and C in the effluent.

Animal treading, which leads to compaction can cause considerable increase in emissions.

Acknowledgements

Our thanks to Landcare Research for analytical facilities; Carolyn Hedley, Bob Toes, Ian Furkert and Ross Wallace for their assistance in the collection and analyses of gas and soil samples.

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5.11 AN ATMOSPHERIC GAS-FLUX RATIO METHOD FOR QUANTIFYING NITROUS OXIDE EMISSION FROM NEW ZEALAND DAIRY FARMS

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NIWA, Wellington

Emissions of anthropogenic N_20 in New Zealand account for 17.5% of total anthropogenic greenhouse gas emission on a CO_2 basis. To meet obligations under the Kyoto Protocol strategies must be developed to reduce the agricultural emissions, which requires that they be better quantified and their determinants better understood. Quality-controlled emission measurements are the key to both inventory compilation and to verification of claimed emission abatement.

The gas emission flux density in the rural environment is small and variable; 80 $\mu gN_2O\ m^{-2}\ h^{-1}$ is a typical flux density for N_2O compared with about 20 times the mass of 1 $mgCH_4\ m^{-2}\ h^{-1}$ from a paddock of ruminating sheep (Harvey et al., 2002) and 20,000 times the mass of 1 $gCO_2\ m^{-2}\ h^{-1}$ from soil respiration. The small mass flux density of N_2O presents a measurement challenge. The aims of this work were to deploy a micrometeorological technique on the farm, capable of quantifying the small area averaged fluxes ($<50\ \mu gN\ m^{-2}\ h^{-1}$). As far as possible, the technique was automated to allow continuous measurement and quantify variability caused by various environmental drivers. With the anticipated measurement difficulties of the flux-gradient technique for N_2O, we consider here an alternative approach of nocturnal boundary-layer concentration build-up. These micrometeorological measurements are compared to concurrent soil cover (small static chamber) estimates of the flux.

The emission flux *F* from the surface into a well-mixed box of mixing height *z* can be calculated from the growth in concentration *C* of that gas with time:

$$F = \int_0^z (dC/dt)dz \qquad \textbf{(1.)}$$

In the nocturnal boundary-layer (NBL), an increase in atmospheric stability limits vertical eddy diffusion and the magnitude of *z*, and can lead to a relatively large build-up rate *dC/dt* in the concentration of gases in light wind conditions. However, the light-wind conditions also mean poor mixing and generate problems of large spatial inhomogeneity and uncertainty in *z*. If the source distribution, vertical eddy diffusivity and relative rates of horizontal advection of N_2O and a tracer are similar then the ratio of their fluxes can be determined from Equation 1 with the elimination of *z* so that:

$$\frac{F_{N_2O}}{F_{tracer}} = \frac{d[N_2O]/dt}{d[tracer]/dt} \qquad \textbf{(2.)}$$

Equation 2 describes a technique we will refer to as the gas flux ratio (GFR) method, which has the advantage of not requiring an explicit boundary-layer height input. If the surface emission flux of the tracer gas is known and its rate of change in concentration at a given height is measured then flux of N_2O can be inferred from measuring its rate of change in concentration at the same height.

With simplification and rearrangement Equation 2 becomes:

$$F_{N_2O} = F_{CO_2} \frac{dN_2O}{dCO_2} . \qquad \textbf{(3.)}$$

The surface flux of F_{CO_2} was measured at a number of sites within about a 100 m radius of the gas ratio measurement point using a soil respirometer. The regression coefficient of gas ratio dN_2O/dCO_2 was determined from many (5 minute) measurements at a single height during the hours of darkness (*i.e.* in the absence of the photosynthetic drawdown of CO_2).

Field measurements

Measurements were done on ryegrass (*Lolium perenne* L.)-clover (*Trifolium repens* L.) pasture on 2 dairy farms, both in important dairying areas; Waikato in the North Island, and Lincoln on the Canterbury Plains in the South Island.

Tracer gas emission flux density

The nocturnal surface emission of CO_2 from soil and plant respiration was measured at about 20 sample points around the paddock using a portable chamber, covering an area of 0.008 m^2, and an infrared gas analyser (IRGA) system (coupled SRC-1 chamber and EGM-3 IRGA; PP Systems, Ltd, Hitchin, Hertfordshire, England). At intervals of 2 to 4 hours on measurement nights, a sequence of CO_2 emission flux measurements were made at each of the IRGA sample sites.

Nocturnal boundary layer gas sampling

Ambient mixing ratios of N_2O and CO_2 were determined at 5 minute intervals by gas chromatography.

Air samples were taken from a (6mm diameter) polyethylene line with a fixed height intake (10 m (Waikato) or 2 m (Lincoln)) continually purged at 2.5 L min^{-1}.

N_2O was detected by electron capture detector (ECD). CO_2 was separated chromatographically from the air components and then catalytically reduced to methane on a nickel catalyst (Agilent Technologies) at 400°C in H_2 and detected by a Flame Ionization Detector (FID). The precision of the measurements in the laboratory is 0.1 ppb and 0.05 ppm for N_2O and CO_2 respectively, but was reduced to 0.2 ppb (>0.06%) and 0.1 ppm (>0.03%) under field conditions.

Soil cover fluxes

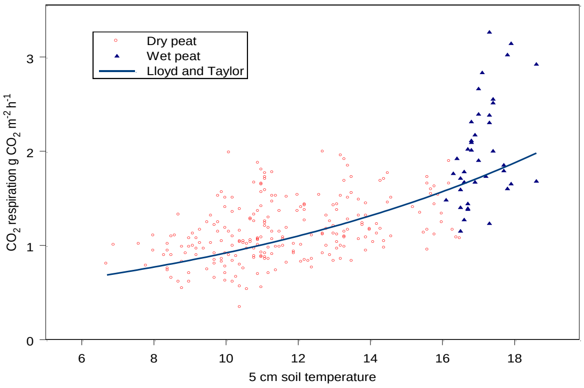
A number of small soil covers (chambers) were deployed concurrently around the paddock for estimation of soil emission flux by headspace gas sampling for comparison with the GFR method.

Headspace gas sampling was done at 0, 20 and 40 mins after the chamber was sealed with repeated flushing (4 times) with 50 mL of air through a 6 mL glass sample vial by syringe. At the final flush, air in the vial was over pressured by 5 mL. The maintenance of overpressure was used as an indication of sample integrity at the time of analysis.

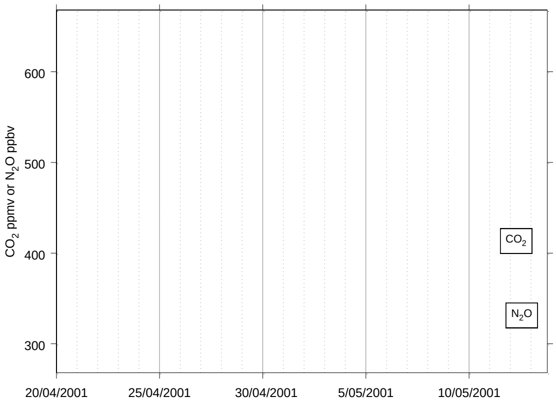
Results

Surface CO_2 tracer flux from chamber and IRGA.

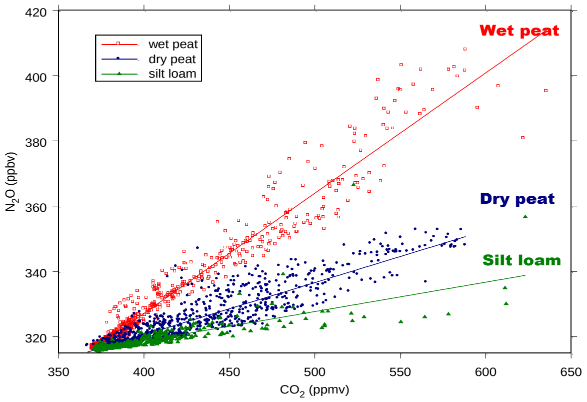
Significantly larger respiration fluxes were measured on wet peat compared with dry peat and significantly lower values found on the silt loam compared to peat. Soil temperature appears to have accounted for much of the difference between the dry and wet peat respiration rates.



the time course of gas concentration measured at 10 metres height over 4 weeks at the Waikato (peat) site shows a clear diurnal variation but greater day-to-day variability. Minimum concentration typically occurs around 15:00 (local time). In contrast with the small daytime variability, there is very large variability in nocturnal concentration.



The degree of correlation between CO_2 and N_2O for the night-time only data is excellent and interestingly for the entire data-set, the gradient for wet peat is a factor of two larger than dry peat which is a factor of two larger than silt loam. There is a rapid response to rain, in the regression coefficient of the gases on both the peat and silt loam sites in the day following the initial rainfall. There is a greater nocturnal build-up rate $d[N_2O]/dt$ compared with $d[CO_2]/dt$ after rain.



N_2O emission flux

N_2O fluxes calculated by the GFR technique show that emissions from the peat site were generally larger (range: 55 to 837, median 103 µgN m^{-2} h^{-1}) than the silt loam site (range: 35 to 148, median 59 µgN m^{-2} h^{-1}). At the peat site, there was a dramatic increase in N_2O emission flux following rain and high levels were maintained for the final (one week) period of in-situ measurement.

Conclusions

These are some of the first N_2O emission flux estimates made using the micrometeorological gas-flux ratio technique applied to New Zealand dairying pasture. The GFR technique has been found to work well at the range of flux densities encountered, in particular at the lower end of the flux range (<50 µg m^{-2} h^{-1}) where gas chromatographic (or indeed FTIR) measurement does not have adequate precision to detect atmospheric gradients required for the flux-gradient technique. The GFR technique also has the advantage over flux-gradient methods of not having the uniform flat terrain fetch requirements. However, as implemented with CO_2 as the tracer, it is restricted to night and therefore care needs to be taken in scaling nocturnal measurements to daily averages. Indications from this work are that the ratio of 24 hour flux to nocturnal only flux is around 1.1 to 1.15 and should be determined case-by-case.

6 AGRICULTURAL EMISSIONS – METHANE

6.1 STOCKING RATE EFFECTS ON METHANE AND CARBON DIOXIDE PRODUCTION BY CATTLE

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1. Introduction

Managed grasslands play an important role in the biosphere-atmosphere exchange of greenhouse gases (GHG). The main processes underlying this exchange are of a biological and physical nature and may be influenced by the wide range of grassland management and environmental conditions. Stocking rate (SR), the number of animals per unit of land area, is a simplification of the relationship between herbage demand and supply and remains as the simplest management tool in pastoral farming. However, little is known about the influence of SR on GHG of ruminant origins (Howden et al., 1994).

The gases exhaled by the ruminant come from respiration and eructation and the rate of these events are about 20 and 0.7 per min (Ulyatt et al., 1999). Eructed gases are primarily carbon dioxide (CO_2) and methane (CH_4). In contrast to CH_4, which is entirely originated from fermentative digestion, most of the CO_2 emission comes from animal respiration and only a small proportion originates from fermentation (about 20% in penned and forage-fed ruminants) (Vermorel, 1995). The sulphur hexafluoride (SF_6) tracer technique (Johnson et al., 1994) has become the measurement method of choice in CH_4 production studies with grazing animals. Interestingly, studies using tracheostomized cattle (Colvin et al., 1957; Dougherty and Cook, 1962; Hoernicke et al., 1965) have shown that the major part (70−99%) of eructed gas is inhaled into the lungs and does not escape directly to the atmosphere. Thus, if eructed and respired gases were well mixed before expiration, the SF_6 technique would also account for CO_2 production.

The objectives of this study were: (1) to compare the CH_4 emissions from cattle under low and high SR; and (2) to explore the potential of the SF_6 technique for CO_2 measurement.

2. Materials and methods

The study was conducted during the 2002 grazing season on a 6.7 ha semi-natural grassland (Massif Central, France; 1250 m of altitude). The area was subdivided into two paddocks, which were allocated to low (1.2 heifers ha^{-1}, LSR) and high (2.1 heifers ha^{-1}, HSR) SR treatments, respectively. Each paddock was continuously grazed with seven 20-months-old Holstein-Friesian heifers (442 ± 28.5 kg). The study comprised four experimental periods: early June, mid July, late August and late September, each comprising a 6-d acclimatisation period (d 1 to 6), followed by an 8-d (d 7 to 14) sample collection period. The 'put and take' approach was used to regulate the herbage mass (HM) on the HSR system.

HM (kg DM ha^{-1}) was determined at the start (d 7) and end (d 14) of the sample collection period by cutting (within quadrats) the herbage to ground level. Samples of the grazed herbage (diet) were also collected on days 7 and 14 by closely following the grazing animals and imitating their biting behaviour.

Organic matter intake (OMI, kg d^{-1}) of individual cows was calculated using their mean fecal OM output (kg d^{-1}) and OM digestibility (OMD, %) estimations. Ytterbium oxide (Yb_2O_3)

was used to estimate fecal OM output. OMD was estimated from fecal N contents (FN, g kg^{-1} OM) using the equation of Chenost (1985), specific for the kind of herbage used in the present study.

Daily CH_4 and CO_2 productions were determined during seven consecutive days (days 7–13) by the SF_6 technique as described by Pinares-Patiño et al. (2003a). A gas chromatograph fitted with an electron capture detector was used to determine the concentration of SF_6, whereas a flame ionization detector was used to determine the concentrations of CH_4 and CO_2. The daily CH_4 and CO_2 productions were calculated from the known permeation rate of SF_6 and the concentrations of SF_6, CH_4 and CO_2 in the breath samples: CH_4 or CO_2 (g d^{-1}) = SF_6 permeation (g d^{-1}) × [CH_4 or CO_2]/[SF_6].

OM, crude protein (CP) and neutral detergent fibre (NDF) contents in herbage and faecal samples and Yb concentrations in faecal samples were determined according to the procedures described by Pinares-Patiño et al. (2003a)

Effects of SR (treatment) upon mean LW, feed intake, apparent feed digestibility and daily CH_4 and CO_2 emissions were analyzed by ANOVA using a split-plot model.

3. Results and discussion

Grazing conditions, animal LW and herbage intake

At all the experimental periods the LSR system had higher HM than the HSR system (5205 vs. 3154, 7793 vs. 3945, 6179 vs. 3296 and 4488 vs. 3146 kg DM ha^{-1} in June, July, August and September, respectively). The large increase in HM between June and July in the LSR system was associated with a large increase in senescent material (from 18 to 51%, DM basis). The CP and NDF contents (%, DM basis) of the herbage on offer in the HSR system were higher (13.8 vs. 9.4) and lower (65.0 vs. 70.0), respectively than in the LSR system. In despite of selective grazing, diets of heifers in the LSR system contained higher proportions of senescent material than in the HSR system. This material represented 2.8, 13.2, 11.6 and 11.7% of the DM eaten by heifers in the LSR system in June, July, August and September, respectively; whereas the corresponding values for the HSR system were 4.9, 8.2, 7.4 and 8.0%. On average, the CP and NDF contents (%, DM basis) of diets in the HSR system were higher (26.0 vs. 23.4) and lower (56.4 vs. 58.7), respectively than that in the LSR system.

Liveweight (LW) of heifers increased significantly ($P < 0.001$) throughout the season. With progress in season, heifers in the HSR system tended to have larger LW than their counterparts in the LSR system (453 vs. 457 kg, $P = 0.61$; 498 vs. 480 kg, $P = 0.03$; 518 vs. 507 kg, $P = 0.18$; 552 vs. 537 kg, $P = 0.07$, in June, July, August and September, respectively).

There was no difference between grazing treatments on mean daily OMI, but heifers in the HSR treatment had higher CPI than their counterparts in the LSR (2.53 vs. 2.13 kg d^{-1}, $P = 0.03$). In June, heifers in the LSR system had higher OMI (9.6 vs. 7.7 kg d^{-1}, $P < 0.05$) than in the HSR system. However, the converse was observed in July (11.2 vs. 8.5 kg d^{-1}, $P < 0.01$) and this pattern of difference tended to be maintained in August and September. In June, OMD (%) by heifers in the LSR system was higher than that by their HSR counterparts (76.1 vs. 73.7, $P < 0.05$). However, OMD at the subsequent periods (July, August and September) were higher ($P < 0.001$) in the HSR than in the LSR system (75.8 vs. 64.9, 73.6 vs. 63.9 and 73.0 vs. 66.2). During the later three periods, the differences between systems in NDF digestibility (NDFD) were much larger than those observed for OMD.

Feed intake by heifers in the HSR system followed the pattern of HM accumulation, whereas that by heifers in the LSR system decreased as old standing herbage accumulated and then recovered as this material lied down and new vegetative herbage became available towards the end of the study. The fact that diets of heifers in the LSR system contained higher proportion of dead material and were of slightly lower quality than that in the HSR system suggests that both rate of intake (Flores et al., 1993) and selectivity (Morley et al., 1978) in the former system were depressed by the standing dead material.

CH_4 Production

Treatments (SR) did not differ ($P > 0.05$) in daily CH_4 production (mean 232 g d^{-1}) or CH_4 production per unit of OMI (mean 26.4 g kg^{-1}). However, at all the experimental periods, but June, the heifers in the LSR grazing treatment produced significantly higher ($P < 0.01$) amounts of CH_4 per unit of digested NDF (DNDFI) (g kg^{-1}) than their counterparts in the HSR (69.3 vs. 51.0, 81.0 vs. 55.7 and 73.1 vs. 59.5 in July, August and September, respectively). The latter was probably due to the differences between systems in NDFI and NDFD (both higher in the HSR system) as influenced by differing grazing conditions. Nevertheless, within SR systems, CH_4 production per unit of DNDFI remained unchanged throughout the study and thus confirming the relationship between DNDFI (kg d^{-1}) and CH_4 production (g d^{-1}) (Pinares-Patiño et al., 2003a,b). In this study, the overall relationship between these two variables was significant ($r = 0.40$, $P = 0.003$), but more evident in the HSR than in the LSR system.

CO_2 Production

Heifers in the HSR system produced larger ($P = 0.05$) amounts of CO_2 than their counterparts in the LSR, both on absolute (10496 vs. 9363 g d^{-1}) and per kg of LW (20.7 vs. 18.9 g) basis. Neither CO_2 production per unit of OMI (mean 1128 g kg^{-1}) nor the CO_2/CH_4 production ratio (mean 15.5, vol/vol) differed between systems. CO_2 production (g d^{-1}) increased ($P < 0.05$) by 34% from June (8844) to September (11886). The latter corresponded to 11.8% ($P < 0.05$) and 7.5% ($P > 0.05$) increases in CO_2 production per kg LW and kg OMI, respectively.

Kirchgessner et al. (1991) reported total CO_2 productions by confined lactating dairy cows in the range from 9.7 to 12.8 kg d^{-1}. These authors found that total CO_2 production (kg d^{-1}) was a function of feed dry matter intake (DMI, kg d^{-1}) and metabolic liveweight ($LW^{0.75}$, kg) ($CO_2 = -1.4 + 0.42\ DMI + 0.045\ LW^{0.75}$; $R^2 = 0.842$). CO_2 productions by heifers in the present study were within the above range, but 31.6 (LSR system) and 38.4% (HSR system) higher than those predicted by using the proposed equation. CO_2 production is a measure of heat production (Johnson, 2000) and grazing animals have extra energy cost for activity (walking and grazing). The Standing Committee on Agriculture (1990) suggested that increases in maintenance energy requirements for grazing cows are in the range from 10–20% in intensively produced pastures to 50% for animals grazing low-producing hilly pastures. Therefore, it can be suggested that activity was one the reasons for the discrepancy between the measured and the predicted CO_2 production values found in this study. Nevertheless, in line with the findings by Boadi et al. (2002), it can be suggested that the SF_6 technique overestimates CO_2 production.

The fact that heifers in the HSR system produced 12% higher CO_2 (g d^{-1}) than those in the LSR system probably was due to differences in grazing behaviour. Grazing pressure in the HSR system maintained a short vegetative sward of lower herbage availability than in the LSR system. Under these conditions it is expected that animals compensate for reductions in bite weight by increasing grazing time and/or biting rate and both these activities increase the maintenance energy requirements. For example, a study conducted by di Marco et al. (1996)

using the ^{14}C-entry rate technique (CERT) revealed higher biting rates (59 vs. 28 bites min^{-1}) and consequently higher CO_2 production rates (1029 vs. 754 ml kg^{-1} $LW^{0.75}$) by cattle grazing under low herbage availability than their counterparts grazing at high herbage availability. In the present study, the weather tended to be colder and drier towards the end of the study and it is likely that thermoregulatory energy demand (Derno et al., 1994) contributed to the increased CO_2 production (g kg^{-1} LW) observed during this period. In addition, the unsettled behaviour of heifers (oestrus) towards the end of the study may have contributed to the latter. SR and period effects upon CO_2 production observed in the present study are not only in general agreement with the pattern of change in heat production described by Young and Corbett (1972) and other authors (Derno et al., 1994; di Marco et al., 1996), but interestingly CO_2 production (g d^{-1}) by heifers on both systems was found be linearly related to LW (kg) [LSR: CO_2 = 17.1(±6.8)LW + 884(±3380), $P = 0.018$, $R^2 = 0.20$, n = 28; HSR: CO_2 = 33.9(±4.6)LW – 6648(±2348), $P < 0.001$, $R^2 = 0.67$, n = 28]. The latter relationship differed ($P = 0.04$) between systems and suggests that influences of factors other than LW on CO_2 production were greater in the LSR than in the HSR system. Overall, CO_2 production (g d^{-1}) and LW (kg) correlated very well (r = 0.68, $P<0.001$).

Certainly, there is a need to validate the accuracy of the SF_6 technique for CO_2 measurement under grazing conditions. Such a validation should be against techniques such as the CERT or mobile indirect calorimeter, rather than the standardised calorimeter technique. If accurate, this technique could be highly useful in heat production and energy balance studies with grazing ruminants. This could also allow the possibility of using CO_2/CH_4 concentration ratio in breath samples for purposes of screening animals with differing CH_4 production rates, given that CO_2 productions under particular circumstances are predicted.

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6.2 TOP-DOWN DETERMINATION OF AGRICULTURAL METHANE FLUXES

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Abstract

In recognition of the importance of agricultural methane emissions in New Zealand we have developed "top-down" techniques to assess average methane fluxes over spatial scales from a few hectares to regional landscapes. These techniques infer the fluxes that are responsible for measured concentration gradients, especially horizontal gradients in vertical profiles. This paper summarises the key measurements of atmospheric composition and of meteorological parameters that underlie those techniques, and the flux estimation methodology, illustrated by a case study.

Context

Agricultural greenhouse gas emissions account for ~50% of NZ's CO_2-equivalent emissions, a prominence unmatched by the emissions profile of any other Annex I party to the United Nations Framework Convention on Climate Change (UNFCCC). More particularly, methane emitted by livestock via "enteric fermentation" by itself accounts for one third of our CO_2-equivalent emissions. Figure 1 illustrates the contributions to enteric methane by various livestock classes.

Thus, a policy response to anticipated obligations under the Kyoto Protocol must address possible strategies to mitigate enteric methane emission.

Principle

Air becomes more concentrated in methane, especially near the surface, as it is blown across a region containing methane sources such as grazing livestock. Vertical profiles of methane concentration are measured both upwind and downwind, and the contrast between them reflects the strength of those sources. Models of wind flow and dispersion are used to determine those source strengths as an average methane flux [Gimson et al., 2002; Gimson and Uliasz, 2003].

Measurements

Concentration profiles downwind of the source area are determined by collecting air samples in bags from points on a fixed 6m mast and through tubing raised by helikite or kytoon (figures 2–4). An upwind concentration profile to ~6m is determined using a similarly equipped mast. A radiosonde suspended beneath the helikite or kytoon transmits a near-continuous meteorological record that includes pressure, potential temperature, humidity, wind speed and direction. Profiles up to at least 100m can be determined this way. For higher altitudes that are needed for regional scale fluxes, light aircraft are used for sampling [Lassey et al., 2000; Wratt et al., 2001].

A typical sampling configuration is shown in figure 5 (Battersea, Wairarapa, 18 June 2003). An anemometer atop each mast enables the wind direction at mast height to be verified. Further confirmation of direction and breadth of the dispersing methane plume is obtained as a downwind transverse transect by sample collections near ground level (collection "bins", 1.5m above the ground, are shown in figure 5).

Methane mixing ratios are measured by gas chromatography under controlled laboratory conditions to achieve the best precision attainable, about 0.1%. This minimises the uncertainty on inferred fluxes, noting that upwind-downwind concentration contrasts may differ by only a few percent.

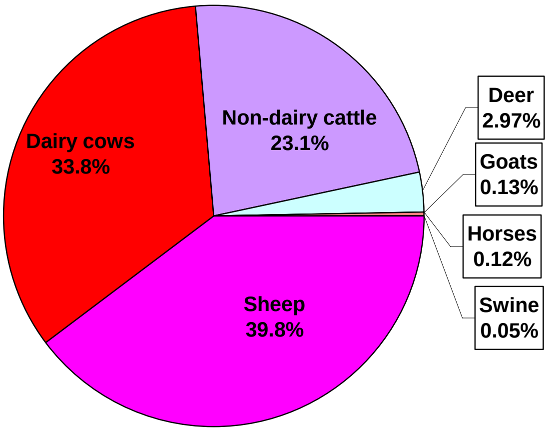

Figure 1. **Enteric methane emission by animal (2001)**

Figure 2. **Sampling from a helikite**

Figure 3. **Helikite being raised with suspended radiosonde and sampling tubes at various heights**

Figure 4. **Fixed 6-m mast with anemometer and sample collection tubes at various heights**

Data Analysis and Modelling

We use dispersion models to interpret the spatial gradients in methane in terms of the causal fluxes. Observations of wind and temperature from surface weather stations and radiosoundings from the helikite are used to derive boundary-layer information, including a full profile of wind and turbulence components up to the helikite height, that are fed into the dispersion model.

Inverse-modelling techniques are used to determine the origins of the sampled air (figure 5), and infer the emission fluxes that best account for the observed profiles. A preliminary analysis for the case study illustrated in figures 5–6 leads to an emission rate of 71 kg/d averaged over the afternoon of 18 June 2003. This amounts to 440 g/d per dairy cow from the 160-strong herd.

A more sophisticated analysis, calculating confidence intervals and accounting for emission estimates derived using other methodologies, is in progress. The aim is to combine the available information and reduce uncertainties overall.

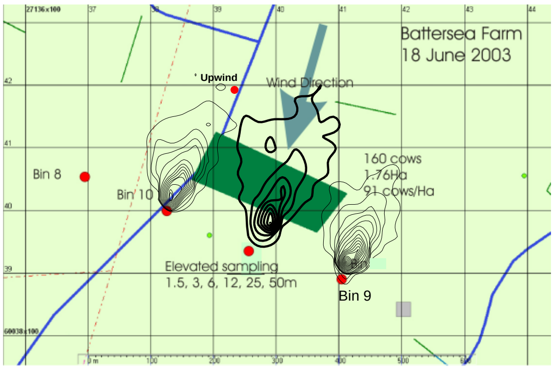

Figure 5. **Air sampling near a paddock of dairy cows. Contours show the surface regions whose emissions influence the samples at Bins 9 & 10 and the helikitesample at 25 m, as simulated by the dispersion model**

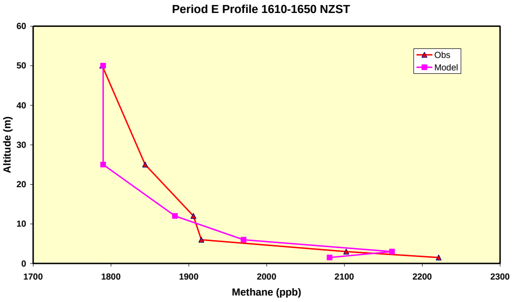

Figure 6. **Comparison of observed and modeled downwind profiles at Battersea, 18 June 2003. The modeled profile is optimized at a methane. emission rate of 3 kg/hour from the paddock**

Acknowledgments:

Research is supported by FRST contract C01X0204. Models were developed with Marek Uliasz (Colorado State University). Martin Manning and David Wratt contributed initial concepts and ideas.

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6.3 METHANE EMISSIONS FROM FARMED RED DEER

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Introduction

Methane (CH_4) is one of the end products of the microbial fermentation of ingested feed in the rumen of farmed ruminant livestock. It represents a potential loss of 2-12% of gross energy consumed, and is a potent greenhouse gas. The New Zealand deer industry is a small, but significant component of the livestock sector, currently consisting of approximately 2 million farmed deer. The objective of this study was to firstly measure methane emissions from grazing farmed red deer (*Cervus elaphus*) for the first time using the sulfur hexafluoride tracer technique in red deer, and secondly to compare methane emissions of deer grazing permanent ryegrass-based pasture *(Lolium perenne* cv Nui) with deer grazing the forage herbs chicory (*Cichorium intybus* cv Grasslands Puna) or plantain (*Plantago lanceolata* cv Ceres Tonic).

Methods

Grazing experiment- Methane production per day and per kg of dry matter intake (DMI) was measured using the sulfur hexafluoride tracer technique[2] coupled the with n-alkane technique for feed intake estimation[1] in 25 adult red deer grazing ryegrass-based pasture, chicory (Plate 1) or plantain in March and May of 2003 at the Massey University Deer Research Unit.

Indoor experiment- Methane production[2] per day was measured from 12 adult hinds housed individually in metabolism cages while DMI was concurrently measured directly in August 2003 at the Massey University Deer Metabolism Facility.

Plate 1. Deer grazing chicory while wearing methane collecting equipment.

Results and Discussion

Methane production per unit DMI of deer grazing ryegrass-based pasture obtained in this study (37.8 g / kg DMI Figure 1) was approximately 75-80% greater than values used in the New Zealand National Greenhouse Gas Inventory[3] for dairy cows and sheep, and estimated for deer grazing ryegrass-based pastures. Deer grazing chicory and plantain in March exhibited lower methane emissions per kg DMI compared with ryegrass-based pasture ($P < 0.02$) (Figure 1). However, in May, methane emissions per kg of DMI from plantain were similar to pasture, which were both higher than from chicory ($P < 0.001$). The variability and accuracy of estimated DMI at pasture obtained using the alkane technique were questionable (DMI shown in Figure 2), particularly with regards to the high estimated intake of deer grazing chicory in May. A lack of published information regarding methane production by red deer provided few possible explanations for the apparently high methane emissions. This prompted the initiation of an indoor study where DMI could be accurately measured concurrently with methane production using some of the same animals from the grazing study.

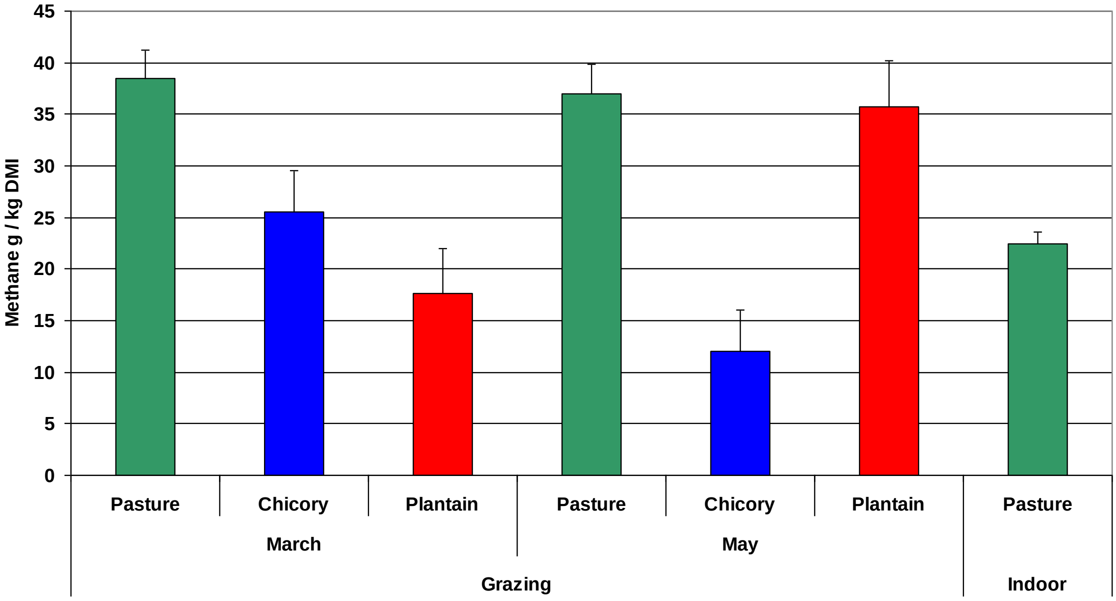

***Figure 1*. Methane emissions per kg of DMI of deer grazing ryegrass-based pasture, chicory or plantain, and deer housed indoors and fed fresh cut ryegrass-based pasture.**

Mean methane production per kg DMI of 12 mature hinds housed indoors in metabolism cages and fed fresh ryegrass-based pasture in August 2003 was 22.5 g CH_4/kg DMI (Figure 1). This figure is similar to published results obtained from sheep and cattle on similar diets and was 42% lower than the grazing study in autumn. This latter result emphasises the importance of obtaining accurate individual DMI measurements with which to express methane emissions per unit feed intake.

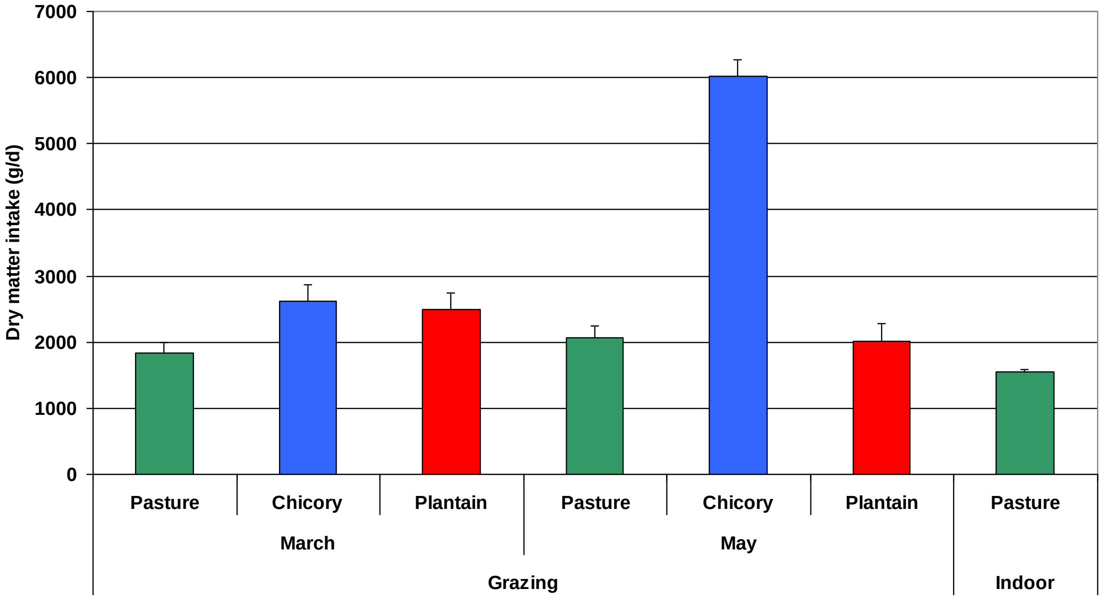

Figure 2. **Dry matter intake of grazing ryegrass-based pasture, chicory or plantain estimated using the double n-alkane technique, and of deer housed indoors fed fresh cut ryegrass-based pasture where DMI was measured directly.**

Conclusions

Findings of this study suggest that the measurement of methane from grazing and/or forage-fed animals should be conducted under conditions where DMI can be measured accurately, otherwise comparisons of methane production per unit feed intake across treatments, experiments or species may be invalid. The indoor study indicated that methane production of forage-fed red deer may be similar to published values for sheep and cattle. However, this should be confirmed by direct comparisons where all species are fed the same diet, methane measurements are conducted using identical methods, and feed intake can be accurately determined over the same time period.

Acknowledgments

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6.4 MEASURING METHANE EMISSIONS AT THE HERD SCALE

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Introduction

Micrometeorological methods can provide integrated methane (CH_4) emission data from animals under commercial farm management, including free grazing (Laubach & Kelliher, 2004). On-farm, campaign data represent the whole herd. This is valuable because the largest source of uncertainty is animal-to-animal variability of emissions (Ulyatt et al., 2002). Here, we compare three micrometeorological methods to determine CH_4 emissions from a grazing herd of dairy cows. The focus is to evaluate and minimise the uncertainty.

Experimental

Three campaigns of 2 – 3 weeks duration were conducted on the Lincoln University Dairy Farm, 20 km SW of Christchurch, in January, March, and October 2002. The herd consisted of ca. 500 cows, Friesian and Friesian-Jersey crosses. Rotational grazing was practiced, on 5 to 9 ha paddocks. Wind and CH_4 concentrations were measured on a mast either within the paddock grazed or in the adjoining one, so that most of the herd was upwind. Table 1 lists the instrument types and the variables measured with them. All data were saved as half-hour averages. Data with unsuitable wind direction (too few cows upwind) were excluded. The setup is schematically shown in Figure 1.

***Table 1.* Instrumentation and measurements**

Instrument	Measurement
Flame ionisation detector (in gas chromatograph), air sampled via automatic valve-switching system	CH_4 concentration profile (5 heights) Background CH_4 concentration
Cup anemometers	Windspeed profile (5 heights)
Ultrasonic anemometer	Turbulence & stability parameters of airflow

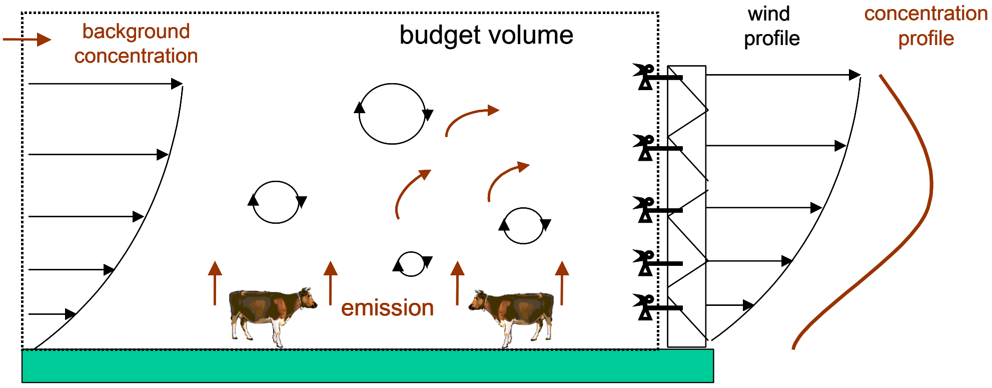

***Figure 1*: Schematic of methane emission, airflow, instrument mast and measured variables**

Methods to calculate emission rate

The three methods used to calculate emission rates are: the flux-gradient method (FG), mass-budget method (MB) and a backward-trajectory model (BTM). The first two were used to measure CH_4 emissions from ruminants, FG for freely grazing sheep by Judd et al. (1999) and MB for penned and supplementally-fed sheep and heifers by Leuning et al. (1999) and Harper et al. (1999), respectively. The BTM (Flesch et al. 2004) is a Lagrangian dispersion model of airflow in the surface layer. From upwind and downwind concentration, wind and turbulence data, the model simulates the flight paths of a large number of gas parcels backwards to their emission points ("touchdowns"). The distribution of these touchdowns allows calculation of the emission rate.

For each method, Table 2 shows which input variables are required, how the emission rate is calculated, what the main sources of measurement error are, and how the errors combine to determine the uncertainty of individual half-hour data. This uncertainty is specific to our measurement setup. We find that with FG it is difficult to achieve an uncertainty below 25 %. With MB, an uncertainty as small as 10 % is possible, and unlike FG, it does not require an assumption on homogeneous flow. The uncertainty of BTM is, in our realisation, between FG and MB, but there is potential for improvement.

***Table 2.* Method characteristics and errors that determine the uncertainty of half-hourly data**

Method	**Flux-Gradient**	**Mass-Budget**	**Backward-Trajectory Model**
Inputs	CH_4 concentration at two heights turbulence & stability parameters	CH_4 concentration profile & background value windspeed profile	CH_4 concentration at one or more heights & background value windspeed at one height & surface roughness (from wind profile) turbulence & stability parameters
How is the emission rate obtained?	Product of conc. gradient, turbulent diffusivity, and a source area factor	Integral (over height) of windspeed times concentration elevation (above background)	Function of "touchdown" probability in the backward trajectories of emitted CH_4 molecules
Main error sources	Differential conc. measurement, source area factor	Extrapolation of profiles to top of emissions plume, background concentration	Surface roughness (by flow disturbances), concentration measurement
Resulting uncertainty	27 – 45 %	11 – 30 %	25 – 31 %

Results of field campaigns

The three micrometeorological methods were compared to a gas (SF_6) tracer method (Lassey et al., 1997). For the latter, 20 cows were each fed a so-called permeation tube emitting SF_6 at a constant rate, then from these cows breath samples (integrated over 24 hours) were collected for 5 days of each campaign and analysed for the ratio of CH_4 concentration to SF_6 concentration. Table 3 shows the campaign averages of CH_4 emission rate, obtained with the four different methods, and their uncertainties (expressed as 95 % confidence intervals). In general, there is agreement of the methods within the uncertainty limits. The October campaign had unusually low pasture production affected by low temperature. Some of the uncertainty in the micrometeorological methods may be due to uneven cow distribution (relative to the prevailing wind direction), cow movement, and diurnal eruction variability.

Table 3. **Campaign averages of CH_4 emission rate (g CH_4 d^{-1} cow^{-1}) by four methods. The 95 % confidence intervals (in brackets) quantify statistical uncertainty of the averages.**

Campaign	**No. of half-hours**	**Flux-Gradient Method**	**Mass-Budget Method**	**Backward-Trajectory Model**	**SF_6 Tracer Method**
January	98	382 (47)	365 (34)	428 (38)	375 (27)
March	40	315 (46)	366 (56)	404 (67)	373 (22)
October	105	320 (27)	284 (22)	300 (20)	345 (32)
All	243	344 (24)	330 (19)	369 (22)	364 (28)

Conclusions and outlook

On average, the four methods yielded similar CH_4 emission rates. The micrometeorological methods were thus corroborated by the scaled-up SF_6 tracer method. For all methods, statistical uncertainty of campaign averages at the herd scale was of order 5 to 10 %.

The mass-budget and backward-trajectory methods included fewer assumptions and less measurement uncertainty than the flux-gradient method. A substantially taller (than 5 m) mast may reduce uncertainty of the mass-budget method, but this is operationally challenging with rotational grazing. The backward-trajectory method is sensitive to flow disturbances but has potential for reduced uncertainty, in particular where downwind concentation can be measured along a path. Our next campaign in April 2004 will include optical measurement of CH_4 concentration along four laser paths deployed around a grazing herd.

Acknowledgements

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6.5 LOWERING RUMINANT METHANE: DEER, DIET AND PROTOZOA

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Methane emitted from grazing ruminants is a major contributor to New Zealand's greenhouse gas emissions. One group of microbes, the methanogenic archaea (methanogens) are directly responsible for methane formation in the rumen. Another group, the ciliate protozoa, are involved indirectly in a significant amount of methane formation in the rumen because of the symbiotic association between methanogens and some ciliate species. An understanding of pasture factors affecting ruminal ciliate populations in NZ ruminants could lead to grazing options for controlling ruminant methane emissions. The aim of this study was to determine whether NZ forages have the potential to influence ruminal ciliate populations. We describe here preliminary data from a comparison of ruminal ciliates in farmed red deer fed either perennial ryegrass (*Lolium perenne* cv Nui), a traditional forage or narrow-leaved plantain (*Plantago lanceolata* cv Ceres Tonic), a less typical forage.

Five rumen-fistulated red deer were allowed to adapt to specific forages by grazing on appropriate pasture and then were maintained indoors in metabolism crates with *ad libitum* access to fresh feed and water. In the first sampling period, two animals (Twiggy and Squeak) received plantain whereas the other three (Abo, Grumpy and Pete) received ryegrass. Rumen samples were collected on five consecutive days into screw-top containers, flushed with O_2-free CO_2 and taken to the lab for assessment. The diets were reversed and after re-adaptation by grazing pasture, animals were returned indoors for further maintenance and sampling.

After collection, rumen samples were examined by epifluorescence microscopy (420 nm) to identify ciliate protozoa hosting methanogens. Each sample was fixed with formaldehyde solution and after further dilution ciliates were examined and counted using a Fuchs Rosenthal counting chamber. During examination and enumeration, at least 500 individual ciliates in each sample were inspected and classified to species or genera using morphological criteria.

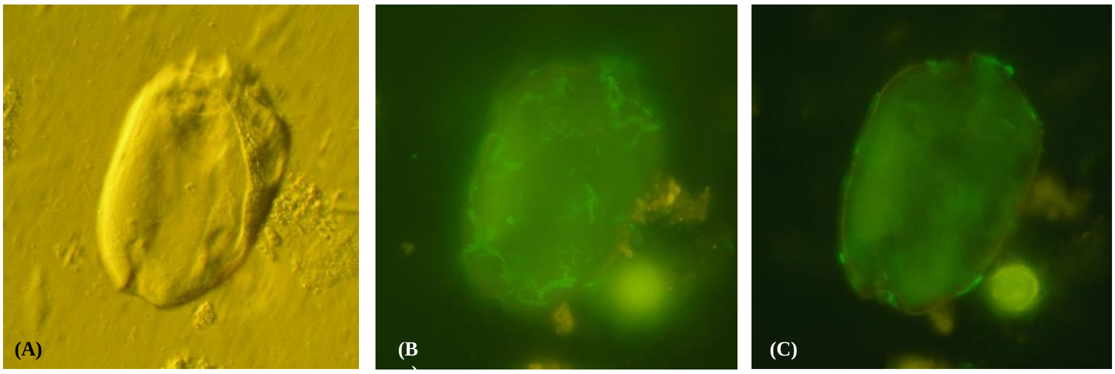

Figure 1. **Methanogens associated with the ciliate *Elytroplastron bubali*.**
Phase contrast micrograph (A) showing chains of cells on the lower surface of the ciliate. Micrographs (B & C) showing cells autofluorescing and confirming their identity as methanogens. Bar = 50 µm.

Examination of cells under epifluorescence revealed that endo- and ecto-symbiotic methanogens could be observed in association with ciliates. Both vestibuliferid and entodiniomorphid ciliates contained endosymbionts. Several, including *Elytroplastron bubali* (Fig. 1), consistently hosted methanogen ecto-symbionts.

In general, all five deer contained similar types of ciliates including *Dasytricha, Isotricha, Entodinium, Diplodinium, Epidinium, Eudoplodinium, Elytroplastron* and *Metadinium*. For each animal, the total population density of rumen ciliates was found to be higher in deer fed plantain than in the same deer fed ryegrass (Table 1). Dietary effects were found for some types of ciliate including *Isotricha* and *Diplodinium* species (except *D. flabellum*) as shown in Table 1. There was little or no effect of diet on the population densities of *Dasytricha, Entodinium, Epidinium and Eudiplodinium*.

***Table 1*. Effect of diet on rumen ciliate populations in grazing red deer. Numbers of ciliates given to 2 significant figures.**

Animal	Diet	Total ciliates/ml	*Isotricha* spp./ml	*Diplodinium* spp./ml
Abo	Ryegrass	520 000	0	30 000
	Plantain	540 000	5000	260
Grumpy	Ryegrass	380 000	1400	5000
	Plantain	640 000	16 000	0
Twiggy	Ryegrass	420 000	260	26 000
	Plantain	700 000	2700	450
Pete	Ryegrass	140 000	0	3300
	Plantain	440 000	4800	0
Squeak	Ryegrass	280 000	0	830
	Plantain	320 000	5800	0

Summary

When grazing red deer were switched between ryegrass and plantain there was a significant and consistent effect on the overall population density of ciliates in their rumens. Some genera of ciliates were unaffected by the diet changes whereas others either increased or decreased markedly. This work is still in progress, but the preliminary data suggest that the use of appropriate pastures could provide a means for selectively and stably manipulating rumen ciliate populations and thus may offer a means for lowering ruminant methane emissions.

Acknowledgement

This work was funded by the Pastoral Greenhouse Gas Research Consortium.

6.6 THE EFFECT OF LEVEL OF FEEDING AND FORAGE QUALITY ON METHANE EMISSIONS BY WETHER LAMBS

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Introduction

The current methodology for preparation and reporting of annual inventories of greenhouse gas (GHG) emissions is known as “Tier 2”. This method uses a constant value for the amount of methane emitted per kg of feed intake, values that have been derived from experiments conducted in New Zealand with sheep and cattle consuming a variety of fresh forages. (Clark *et. al.,* 2003). Our knowledge of the process of methane formation in the rumen suggests that methane emissions are unlikely to be accurately described by the use of these constants. Literature review reports effects of both feed quality and level of intake on the amount of g CH_4/kg DMI (i.e., Blaxter and Clapperton, 1965 and Moss *et al*., 1995).

Materials and Methods

Sixteen wether lambs 15 month old with an average weight of 54.6 kg were randomly allocated to four different levels of feed allowance in two different periods. In period 1 all animals were fed ryegrass harvested during its reproductive period of growth. In period 2 all animals received ryegrass harvested at a vegetative stage of growth. The herbage allowance in period 1 was 0.75, 1.0, 1.25 and 2.0 times maintenance, and in period 2 was 1.0, 1.25, 1.5 and 2.0 times maintenance. CH_4 output was measured for five consecutive 24-h periods using the SF_6 tracer gas technique. The nutritional composition of the forages, was predicted using Near Infrared Reflectance Spectrophotometry (NIRS). Grass cut at the vegetative stage had higher protein, lower fibre, higher OMD and higher ME than grass harvested at the reproductive stage.

***Table 1.* Nutritional composition of ryegrass in reproductive and vegetative stages.**

Pasture	**DM (%)**	**Gross Energy (GE %)**	**CP (%)**	**Ash (%)**	**ADF (%)**	**NDF (%)**	**CHO (%)**	**OMD (%)**	**ME (%)**
Reproductive	24.16	16.9	10.8	7.0	29.3	51.5	11.1	66.6	9.9
Vegetative	16.4	17.2	24.6	11.5	24.7	46.9	9.1	76.6	10.7

Statistical analysis

Dry matter intake and apparent digestibility are outcomes of the amount and quality of feed offered, but at the same time they are considered treatments impose to the animals in order to investigate their effect on CH4 output per unit of intake. The treatments and the results are presented by periods (n=2) and levels of intake (n=4), in order to make it more clear, but the statistical analysis (REML) was done on individual values of intake (n=32), apparent digestibility (n=32) and CH4 output (n=32)
Level of intake, level of feed offered and diet quality (digestibility %) and their interactions were analysed for their effect on the amount of CH_4 produced per unit of intake, using the Residual Maximum Likelihood (REML) procedure of Genstat 6. Dry matter intake, level of feed offered and diet quality were treated as main effects and sheep as a random effect

Results and Discussion

The range of values shown in Table 2 of g CH_4 / kg DMI (From 20.1 to 26.6 g CH_4 / kg DMI) and % of GE intake lost as CH4 (from 6.7 to 8.69 %) reported in this study are slightly higher than values previously reported in New Zealand (Clark *et.al.*, 2003 where g CH4 / kg DMI equal 20.9 and GE percent lost as CH_4 equal 5.1), On the other hand this data is comparable to results reported by authors out of New Zealand; Boadi and Wittenberg, (2002) report values between 4.6 and 9.4 %, of GE intake lost as CH_4.. Figure 1 shows a strong positive relation between DMI and daily methane production (g/d). A simple linear regression between these two parameters show an R^2 of 82.6%. The outcome of the REML analysis was : g CH4 / kg DMI = 23.3 - 0.03681 * DMI + 4.377 * Level of feed offered – 0.04510*Dig %. Where P= 0.408 and 0.461 for DMI an apparent digestibility respectively, indicating no significant effect of these two parameters on methane per unit of intake was found. These results suggest that, for New Zealand inventory purposes, using a constant value for the amount of CH_4 emitted per unit of DMI is a valid alternative to using more complex algorithms that try to take into account the influence of herbage quality and level of feeding

Figure 1. Effect of level of intake on daily CH4 (g/d) output and CH4 emission per unit of intake (g/kg)

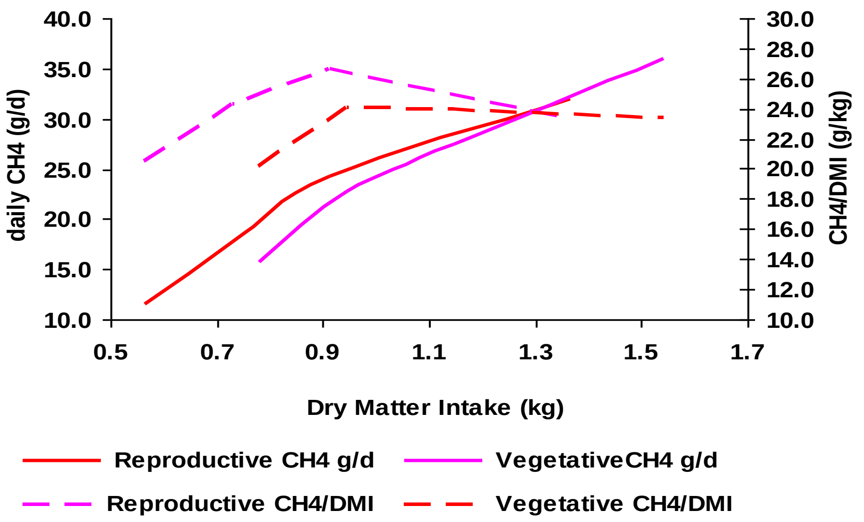

Table 2. **Mean dry matter intake, apparent digestibility and methane emissions for sheep fed forages of differing maturity at 4 levels of herbage allowance. Data in parenthesis are the standard deviation.**

Period	**Feeding Level**	**DMI (g/d)**	**Digestibility (%)**	**CH_4 (g/d)**	**CH_4 g/kg DMI**	**% GE lost as CH_4**
1. Reproductive	0.75	566 (25)	61.5 (3.66)	11.5 (0.88)	20.5 (2.06)	6.3 (0.62)
	1.0	729 (38)	62.5 (4.70)	17.7 (4.19)	24.2 (5.77)	7.6 (1.85)
	1.25	914 (35)	61.1 (1.37)	24.3 (2.81)	26.6 (3.46)	8.3 (1.15)
	2.0	1365 (72)	65.1 (3.13)	31.9 (5.71)	23.3 (2.89)	7.4 (0.84)
2 Vegetative	1.0	781 (35)	74.5 (1.03)	15.6 (0.37)	20.1 (1.28)	6.4 (0.42)
	1.25	945 (56)	76.9 (2.13)	22.7 (3.34)	24.1 (3.56)	7.5 (1.23)
	1.5	1145 (36)	74.1 (1.53)	27.4 (5.98)	24.0 (5.59)	7.5 (1.70)
	2.0	1541 (141)	75.9 (2.66)	35.9 (1.86)	23.5 (2.03)	7.6 (0.84)

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6.7 METHANE EMISSIONS FROM GROWING BEEF CATTLE GRAZING HILL COUNTRY PASTURE

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Introduction

Methane emissions from the beef sector make up almost 25% of the total emissions from the New Zealand agricultural sector (NIR 2003). To date all methane emission data in the national inventory relate to dairy cattle and sheep with specific beef cattle emissions rates presumed to be the same as for dairy cattle. The main aim of this experiment was to quantify methane emission data for beef cattle grazing typical New Zealand hill country pastures. Obtaining these data expands the emission database of the national inventory.

Methods

Methane measurements were taken in February, July, September and November 2003.

All trials were carried out at AgResearch Ballantrae Farm using 12 Hereford x Fresian steers.

The steers were aged approximately 6 months at the time of the first measurement.

Methane was determined using the SF_6 tracer dilution technique (Lassey 2001) with samples collected over 24hr periods for 5 consecutive days at each period of analysis.

Intakes were estimated using two methods, an alkane double marker technique and an Australian Feeding Standard algorithm which took into consideration liveweight (LW), liveweight gain (LWG), and chemical characteristics of pasture.

Results

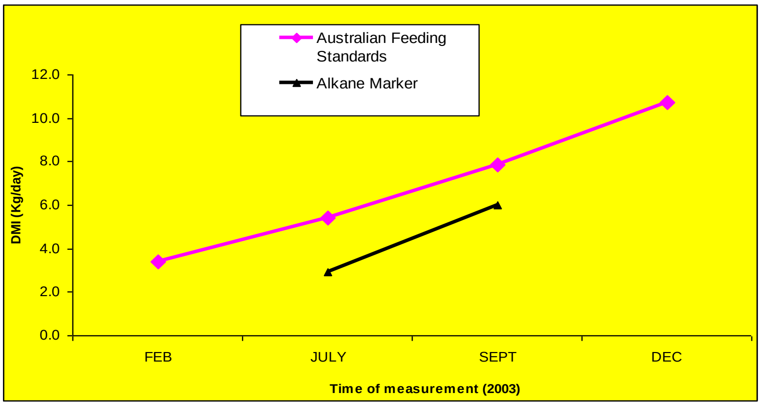
The chemical composition of the pasture on offer varied considerably over the four periods (Table 1). The severe drought conditions in the Manawatu in February 2003 resulted in very poor quality pasture being available for grazing.

Table 1 **Chemical composition (%) of the diet offered during the methane measurement periods.**

	ADF	ASH	CP	DM	LIP	ME	NDF	OMD	SSS
Feb	28.5	9.3	16.3	37.8	3.8	9.1	47.5	64.3	7.9
July	24.8	10.1	23.5	19.3	4.4	10	48.6	72	9
Sept	24.9	11.1	22.1	17.2	3.9	9.6	43.1	69.4	8.1
Nov	22.3	9.7	24.2	17.4	4.6	11.4	42.9	81.3	10.6

Alkane markers gave lower DMI than those estimated using the Australian Feeding Standards (Figure 1). LWG which has a major influence when using the Australian Feeding Standards equations showed large fluctuations when measured over short periods of time.

Methane emissions increased slowly over the February to September period despite the cattle increasing in weight from 157 to 238kg. By November average liveweight had increased to 320kg and methane emissions more than doubled from their February value.



Fi gure 1 **DMI for the four methane measurement periods**

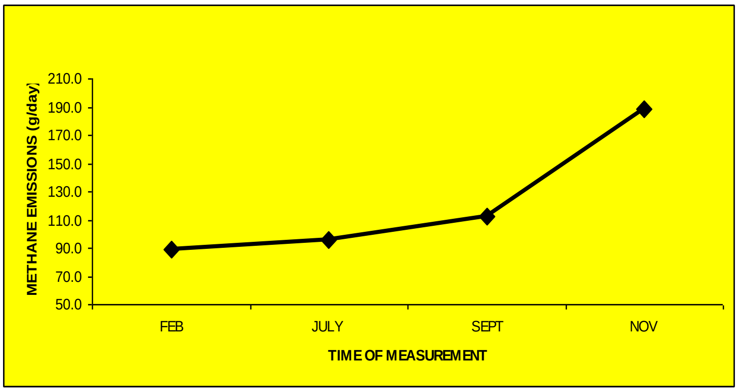


Figure 2 **Average methane emissions measured using the SF_6 tracer technique over four measurement periods in 2003.**

The intake of soluble sugars & starch was the best predictor of methane emissions, followed by the intake of lipids. DMI was as good a predictor as the intake of fibre or crude protein. However, all of the regression equations are of limited generality due to the problem of estimating accurate DMI values.

Table 2 **Relationships between methane emissions (g CH_4/day) and intake of dietary components (kg/day)**

DIET COMPONENT	PREDICTION ALGORITHM	ADJUSTED R^2
Starch and Soluble Sugars	$y = 121.4x + 4.9$	0.92
Lipid	$y = 286.6x + 37.9$	0.87
Dry Matter Intake	$y = 13.4x + 30.0$	0.77
Crude Protein	$y = 49.3x + 5.67$	0.77
NDF	$y = 33.5x + 9.22$	0.76
ADF	$y = 64.3x + 4.51$	0.68

Mean methane emissions predicted by the current national inventory method agree well with the measured mean methane emissions from the four periods, although there are considerable differences when individual measurement periods are compared. Predicted emissions were calculated using a constant LWG of 0.667kg/d from Feb through to November which cannot capture the short term fluctuations in LWG that occur in practice in free grazing animals.

Table 3 **Methane emissions from this trial compared with predicted methane emissions using the New Zealand national inventory**

MEASUREMENT DATE	FEB	JULY	SEPT	NOV	MEAN
Mean Animal Liveweight (kg)	157	203	238	320	
Measured methane emission (g/day)	89	96	113	189	122
Predicted emissions (g/day)	106	110	112	143	118

Conclusions

Average methane emissions in this study using beef cattle were lower per unit of intake than found in studies using dairy cattle. Methane output was 17.8g/kg DMI compared to the mean value of 21.6g/kg DMI from experiments with dairy cattle. However the animals used in this study were younger than those used in the dairy cattle experiments. Experiments with sheep have consistently found emissions from animals aged <1 year old to be lower than for those aged >1 (Clark 2003).

Difficulties both in measuring intake (alkane technique) or estimating intake (Australian Feeding Standards) make it difficult to obtain simple predictive relationships between the intake of feed components and methane emissions.

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6.8 CAN TRACERS OTHER THAN SF_6 BE USED TO MEASURE ENTERIC METHANE EMISSIONS FROM INDIVIDUAL ANIMALS ?

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Measurement of enteric methane production by grazing ruminants was not possible prior to development of appropriate SF_6 releasing permeation tubes and their use in the rumen to provide a constant release of SF_6 (Johnson et al., 1994). The low background of SF_6 coupled with its low detection limits and similar solubility to methane made SF_6 a desirable marker. The high global warming potential of SF_6 itself however, limits its application. We have sought alternative markers for measuring enteric methane emissions, and approaches being considered are summarised in (Table 1),

***Table 1.* Tracer gases being considered as alternatives to SF_6 for intra-ruminal delivery by permeation tubes.**

Class	Tracer	Advantages	Disadvantages	Past use
Isotopes	$^{14}CH_4$, CH^3_4 radioisotopes	Very low detection limits (scintillation counting)	Radioactive so not useful in food chain	Infusion studies[1]
	$^{13}CH_4$ Stable isotope	Little C transfer to other molecules. OK for food chain	Very expensive	Natural flux across paddock[2]
	CH^2_4 Stable isotope	Cheap, safe, OK for food chain	Hydrogen transfer to other molecules	In-vitro use[3]
Noble gases	Argon	Low detection limit and moderate cost	High background concentration	Not known
	Xenon	Low background	High cost	Not known
	Krypton	Low background	Very high cost	Respiration study[4]
Other gases	Ethane	Availability	High detection limit	Infusion study[5]
	Propane	Availability	High detection limit	Not known

Refs:[1]: Murray et al. (1978). *Brit. J. Nutr*.39:337. [2]:Harvey et al. (2002). *Atmos. Env*. 36:4463 [3]: Czerkawski (1975).Tracer studies on non-protein nitrogen for ruminants II. IAEAVienna pp55-63. [4]: Shimazu et al. (1996). *J. Appl. Physiol*. 81:2250. [5]:Moate et al.(1997) *J. Agric. Sci* 129:459.

A requirement for applying these less readily detected or high background gases as markers of enteric methane production, is an ability to deliver the marker gas at a rate considerably higher than the 1-3 mg/d achieved by current permeation tubes. To facilitate this delivery, a high-flow permeation tube has been developed (Hegarty et al., 2003) which will be used to deliver up to 300mg of marker gas/d from a permeation tube over a 3-4 week period. Emission estimates using selected markers will be compared with direct measures of total methane exhaled from cattle over a 24 h period.

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6.9 LOWERING RUMINANT METHANE: DIET AND DEER METHANOGEN POPULATIONS

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The majority of New Zealand’s methane is produced by methanogens, living in the rumens of grazing livestock. Both direct isolation methods (Jarvis et al., 2000; Miller et al., 1986) and the use of 16S rDNA probes (Lin et al., 1997) have shown that methanogens belonging to the genera *Methanobrevibacter*, *Methanobacterium*, *Methanomicrobium* and *Methanosarcina* can be present in the rumen. Diet, especially the fibre content of the diet, has a major effect upon ruminant methane emissions (Kirchgessner et al., 1995) but the effect of differing diets upon methanogens in grazing animals is not known. The aim of this study was to determine methanogen populations in red deer grazing NZ perennial ryegrass (*Lolium perenne* cv Nui)-based pasture and to determine whether these populations were affected by changing diet from ryegrass to narrow-leaved plantain (*Plantago lanceolata* cv Ceres Tonic).

Digesta samples were obtained from red deer fitted with rumen cannulae. Immediately after collection, samples were diluted in selective growth medium and methanogen populations were enumerated as outlined previously (Miller et al., 1986). Most probable number (MPN) calculations were carried out using the method described by Clarke and Owens (1983). In the initial sampling, 3 deer were fed ryegrass and 2 were fed plantain. Then the diets were reversed and after three weeks re-adaptation, further ruminal samples were collected.

Single colonies of methanogens were picked from agar roll tubes inoculated from serial dilutions and further purified (Jarvis et al, 2000). DNA was extracted and 16S rRNA genes were amplified by PCR using archaeal primers. The PCR products were sequenced to identify isolates.

In all five animals, changing the diet from ryegrass to plantain led to a decrease in culturable methanogens as shown in Table 1.

***Table 1*. Effect of diet on ruminal methanogen population densities in forage-fed deer.**

Deer	**Rye grass (cells/ml)**	**Plantain (cells/ml)**
Abo	3.51×10^{9}	5.87×10^{8}
Grumpy	6.70×10^{9}	9.49×10^{8}
Pete	1.10×10^{10}	3.34×10^{9}
Twiggy	1.79×10^{10}	5.13×10^{8}
Squeak	4.27×10^{9}	2.40×10^{8}
Mean	$\mathbf{8.68 \times 10^{9}}$	$\mathbf{1.12 \times 10^{9}}$

16S rDNA sequence analysis of the predominant methanogens in animals on both diets revealed that the isolates were very similar to each other and were phylogenetically related to strains of *Methanobrevibacter ruminantium* (Figure 1).

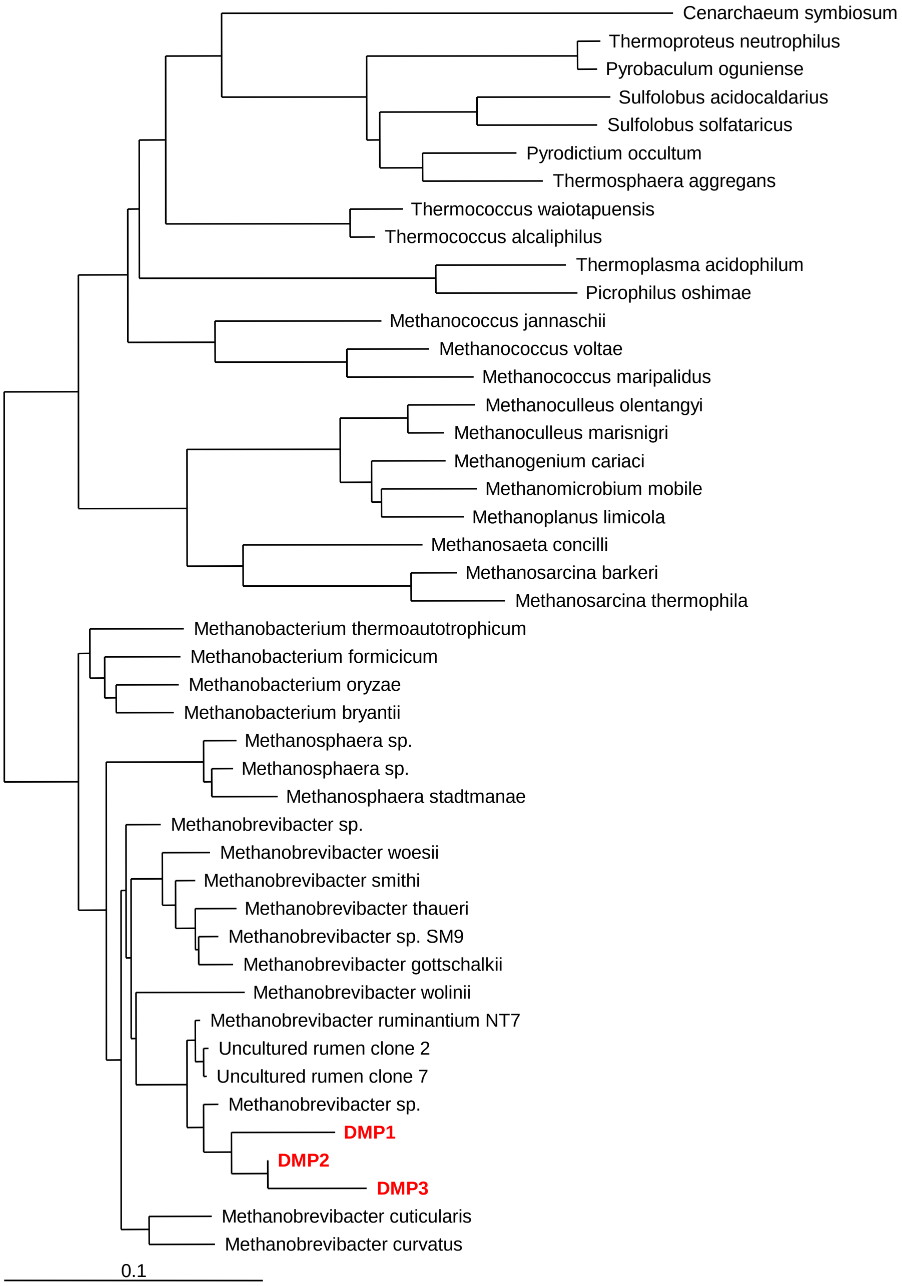

***Figure 1*. Phylogenetic relationship between methanogen isolates and other methanogens. DNA sequences from isolates were aligned with reference sequences in the RDP database. Cluster analysis was performed using PHYLIP.**

When the diet was changed from ryegrass to plantain, population densities of culturable methanogens decreased. Currently, work is in progress to identify the factors involved. The predominant methanogens in deer on both diets were found to be strains of *Methanobrevibacter ruminantium*. Molecular ecology methods are being used to gain further information. It appears that methanogen populations in grazing deer are similar in terms of diversity and population density to those in cattle and sheep and can be influenced by diet.

Acknowledgement

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6.10 LOWERING RUMINANT METHANE: PHAGE THERAPY

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Phage are viruses which attack and destroy bacteria. Their existence was first reported in 1917 by Felix d'Herelle who isolated viral particles which produced small cleared areas (plaques) on bacterial lawns and which were capable of destroying bacterial cultures. Between the 1920s and 1940s, clinical trials showed that phage in some instances were successful in controlling pathogenic bacterial infections. With the discovery and commercialisation of penicillin in the 1940s, the West turned to antibiotics to control pathogens. Eastern Europe however, continued to study and use phage to control a variety of different diseases. With increasing concern over antibiotic resistance, there is now renewed interest in phage therapy as a natural alternative to antibiotics. Although, the rumen is known to contain a wide range of differing phage, little is known about the presence or activity of phage active against the methane-producing microbes (methanogens). These are a possible target for phage therapy as a means of lowering ruminant methane.

Phage are obligate parasites that require a bacterial host for replication and survival. There are two potential pathways in the phage lifecycle (Figure 1). In the lytic phase, phage infect and kill their host, leading to a dramatic reduction in the target population. In the lysogenic (prophage) phase, phage integrate into the host's chromosome, and can lie dormant for many generations, until an induction event causes them to enter the lytic pathway. This then leads to cell lysis and death.

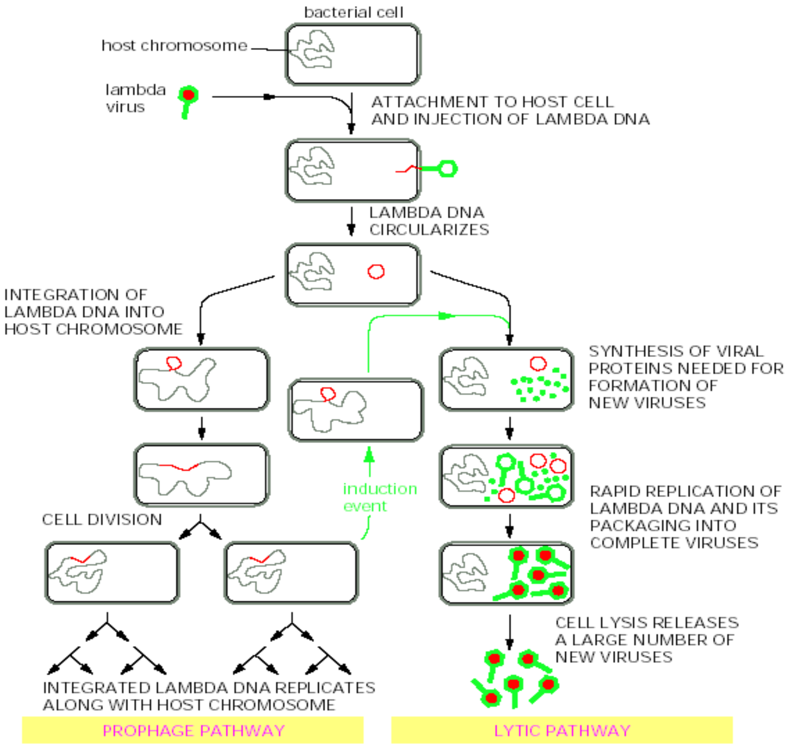

***Figure 1.* Lifecycle of lambda phage. The figure shows the two possible pathways of phage development in bacteria.**

There are several advantages in using phage as a means of targeting and controlling different populations. Phage are a "natural" alternative to antibiotics and chemicals and are very specific for the host organism they target. They do not cause allergies, affect the natural commensal microflora, or affect the immune system. However, there are also some disadvantages. Phage can shuttle genetic sequences between different bacterial species and strains and in some clinical instances, phage have been known to trigger pathogenic events.

In the clinical, agricultural and environmental sectors there are several potential applications for phage therapy. In clinical applications, phage can be used as an alternative to antibiotics, especially targeting antibiotic resistant populations. In agriculture, lytic phage have already been isolated which target the pathogen *Escherichia coli* O157 (Raya et al., 2003). Research into lytic phage which target vancomycin resistant *Enterococci* is ongoing. In the environment, phage may be used to lower ruminant methane by targeting the methanogen population.

In the rumen, phage with a wide range of different morphologies (Figure 2) occur in population densities of $>10^9$ viral particles/ml (Klieve and Bauchop, 1988; Klieve and Swain, 1993). Although knowledge of ruminal phage has progressed recently, knowledge is still limited. Our research is concerned with developing the potential of phage therapy as a means of lowering ruminant methane (Klieve and Hegarty, 1999).

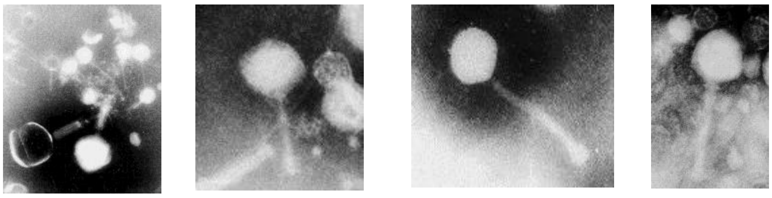

***Figure 2*. Morphological diversity of ruminal phage. T
e supernatant from ruminal samples from a grazing sheep was filtered to remove bacteria, and phage particles were sedimented by high speed centrifugation. Aliquots were stained with potassium phosphotungstic acid and visualised by transmission electron microscopy.**

To conclude**,** the rumen microbial ecosystem contains a wide range of phage - most of which have not been investigated. Phage also offer an opportunity for controlling targeted populations in the rumen. The isolation of phage which specifically attack methanogens could lead to methods for lowering ruminant methane emissions.

Acknowledgement

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6.11 METHANE EMISSION ESTIMATES FROM ANIMAL DUNG AND WASTE-MANAGEMENT SYSTEMS IN NEW ZEALAND

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Introduction

The use of Good Practice enables reporting of emissions and uncertainties in a consistent manner, and provides valuable input to national inventory research and development activities (IPCC 2000). The IPCC guidelines include two tiers of methodology to estimate methane emissions from animal excreta and manure-management systems. The IPCC recognises the Tier 1 default methodology is too general for accurate estimation, and therefore encourages the development of a Tier 2 approach in which inventory methodologies are developed that capture the unique circumstances of the country.

In New Zealand, the methodology used to estimate enteric methane emissions has been upgraded from the Tier 1 to Tier 2 approach, consistent with IPCC (2000) guidelines for methane inventory from agriculture (Clark et al. 2003). This has resulted in a general downward revision in the absolute emissions and a change from a pattern of falling emissions since 1990 to one of rising emissions (National Inventory Report New Zealand 2003). However, the methodology used to estimate methane emission from animal excreta and manure management has not been updated and still relies on what is essentially a Tier 1 approach. In order to provide more accurate estimate of methane emissions from New Zealand animal wastes there is a need to develop an improved methodology that accounts for variations in animal species, animal management and waste management procedures. This poster reports the results of a study that compared different methods that could be used to estimate methane emissions from animal wastes and recommended which methods should be adopted by New Zealand for each animal species to the development of a greenhouse gas inventory that is good-practice compliant.

Objectives

review the national and international literature on methane emissions from animal faeces and provide improved estimates of these emissions. These new values will account for variations in animal species, animal management and waste management procedures;

use this information to examine the alternative methods available for estimating methane emissions from faeces (including an assessment of the IPCC good practice methods as one of the alternatives);

recommend a method for use by New Zealand that contributes to the development of a greenhouse gas inventory that is compliant with good-practice.

Approaches used to estimate methane emissions

Current New Zealand estimates, which are based on, a fixed amount of faecal material produced per head and New Zealand derived estimate of the maximum methane emission per unit of faecal material.

IPCC Tier 2 based on NZ estimates of the actual amount of faecal material produced annually and the IPCC default methane emission factors.

NZ best estimates based on NZ estimates of the actual amount of faecal material produced annually and NZ specific methane emission factors (where available).

Results

Emissions from dung: In the last 2 years, in situ methane emissions from cattle and sheep dung excreta have been measured under the New Zealand grazed pastures conditions. The results of these studies and another PhD study at Lincoln University on methane emissions from field-applied pig slurry are summarised in Table 1. Although these studies have been conducted using different techniques there is generally good agreement between them when methane emissions are expressed as CH4 emission per unit of substrate (Table 1). Also, the emission rates measured for cattle dung in New Zealand studies are similar to those obtained under cool temperate field conditions in UK, Germany, and Denmark (Jarvis et al. 1995; Flessa et al. 1996; Holter 1997; Yamulki et al. 1999). However, the specific rate of methane emitted from dung deposited on pastures is likely to be influenced by such factors as diet type and environmental conditions.

Table 1. **Summary of New Zealand studies of methane emissions from animal dung.**

Animal Type	Procedure	Methane emitted ($kg\ CH_4\ kg\ dung\text{-}C^{-1}$) $x\ 10^{-3}$	Reference
Sheep	In vitro study:		Joblin and Waghorn 1994
	Outdoors (10–20°C)	0.167	
	Lab (37°C)	2.836	
Sheep	*In situ* on pasture	0.854–3.236	Carran et al. 2003
Dairy cattle	*In situ* on pasture:	2.567	Saggar et al. 2003
Dairy cattle	Reconstituted dung pats on pasture	2.268	Sherlock et al. 2003
Pig	Slurry applied to soil	1.071	Sherlock et al. 2002

Current inventory from animal waste management: Table 2 produces 3 alternative totals. The New Zealand best estimate uses data from the individual animal species, calculated using New Zealand-generated field data. The values based on IPCC Tier 2 method or those based on the best New Zealand data available, are higher than the New Zealand current inventory (Table 2).

Two different processes have caused these differences. First measured emissions from animal excreta deposited on pasture are lower than those currently reported and this has revised downward the amount of methane produced from faecal material deposited on pastures. Second, both the New Zealand best estimate and the IPCC Tier 2 method partition dairy cattle excreta between field and effluent ponds and emissions per unit of faecal material from dairy ponds are six times higher than field emissions. Emissions from dairy cattle manure stored in anaerobic lagoons make up to 50% of total emissions from animal waste. However, we must emphasise that there is a lack of data on emissions from effluent ponds. We have only a single New Zealand measurement of methane emissions from this source on which to base our estimates. In addition, estimates of the proportion of dairy cattle manure handled in anaerobic lagoons vary markedly, and this proportion has a big influence on estimated emissions. These two areas are priority areas for further work.

There are not enough data to allow alternative methodologies to be developed for the non-ruminant species – pigs, poultry and horses.

Table 2. **Total annual estimated methane emissions (Gg) from livestock manures in New Zealand 1990–2001 estimated.**

Year	New Zealand current Inventory	IPCC Tier 2	New Zealand best estimate
1990	27.3	45.1	34.9
1991	26.9	45.3	35.3
1992	26.6	45.7	35.9
1993	26.7	46.8	37.1
1994	27.1	48.3	38.5
1995	27.5	49.8	39.9
1996	27.5	51.0	40.8
1997	27.1	51.4	41.2
1998	26.8	52.0	41.5
1999	26.6	53.2	42.7
2000	26.3	54.9	44.1
2001	26.2	55.9	45.1

Recommendations

New Zealand has developed detailed datasets on animal categorisation and feed intake that allow an accurate estimation of faecal output. Data are now available from New Zealand studies on specific rates of methane production from faeces deposited on pastures. Combining these data produces an inventory method that complies with IPCC good practice guidelines. This method should be adopted in future inventory estimates for methane emissions from New Zealand livestock waste.

New Zealand continues to use IPCC default values for methane emissions from manure deposited by non-ruminants. The use of IPCC default values for non-ruminant species is entirely consistent with IPCC "good practice" since estimated emissions from these animals are small and they are therefore defined as non-key source categories.

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6.12 METHANE EMISSIONS FROM CATTLE DUNG AND METHANE CONSUMPTION IN NEW ZEALAND GRAZED PASTURES

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Background

New Zealand's annual agricultural methane emission estimates of 1128 Gg (New Zealand climate Change Project 2003) place New Zealand among the top methane-producing nations per capita

In New Zealand grazed pastures freshly voided dung is a potential source of methane production (methanogenesis) as well as entrained enteric methane in the voided dung (Saggar et al. 2003a)

The major sinks for methane are biological oxidation at or near the sites of production, uptake by soils (methanotrophy) and photochemical oxidation

Soil uptake of methane is globally significant (equivalent to annual increase in atmospheric methane concentration) (IPCC 1996), and susceptible to changes associated with land use and land management (Steudler et al. 1989; Mosier et al. 1991; Priemé et al. 1997)

The sink strength of New Zealand soils (based on limited soil uptake data) could amount to ~147 Gg CH_4 y^{-1}, with the major contribution from indigenous forest soils (Price et al. 2004)

Changes in the sink strength of pastoral soils due to increased intensification of agriculture, particularly dairying, need to be quantified to assess intensification influence on the national methane budget.

Objectives

Investigate methane emissions (methanogenesis) from dung pats

Quantify the potential of pastoral soils to oxidise methane (methanotrophy)

Determine the contribution of net emissions to New Zealand's methane budget to satisfy proposed IPCC Good Practice Guidance (IPCC 2000).

Approach

Methane measurements were periodically made from randomly selected *in situ* freshly voided dung pats during the early spring season at two pastures sites (Karapoti fine sandy loam and Tokomaru silt loam) using closed chambers.

At the end of each grazing period the pasture area covered by dung was about 1%.

Soil methane fluxes were measured intensively (~12-18 chambers ha^{-1}) throughout the year in the unimproved, ungrazed and intensive dairy- and improved sheep-grazed pastures to assess the spatial and temporal variability in methane fluxes, and to estimate soil methane sinks.

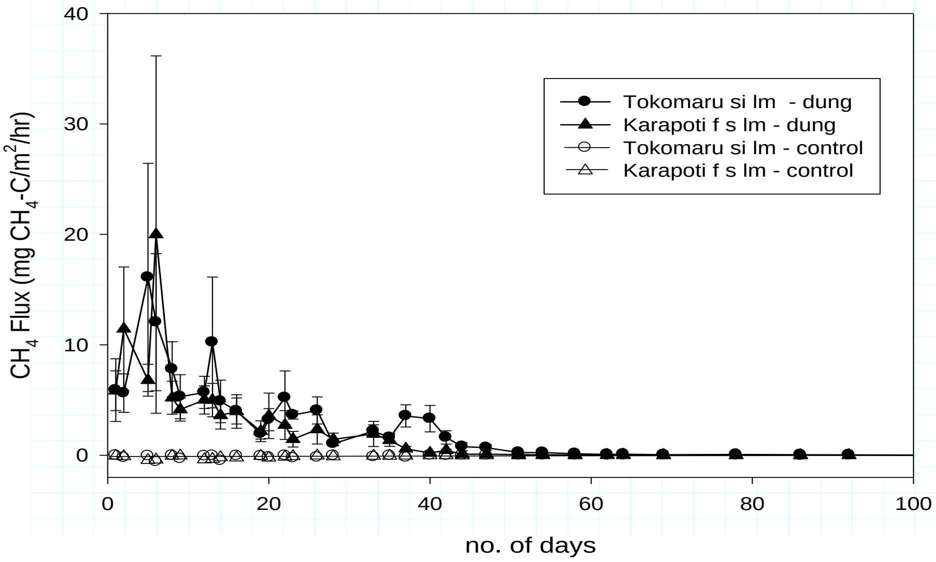
Table 1 **Cattle dung characteristics**

Area covered (m^2)	Thickness (mm)	Volume (cm^3)	Moisture (%)	Dry weight (g)	C (%)	N (%)
0.05	40-56	1750-2480	480-860	100-325	36.5-42.1	2.43-2.77

Results

Methane emissions from dung

Fresh dung pats are a strong source of methane, with maximum methane-C release rates of up to 20 mg m^{-2} h^{-1} in the first week after defecation at two dairy farms, providing evidence for the generation of methane by fermentation of the dung after voiding. Emission rates slowly declined as the dung pats dried out and decomposed.



Overall methane emission from cattle dung was 0.0256 kg CH_4 kg^{-1} dung C (Saggar et al. 2003a) and from sheep dung is 0.0185 kg CH_4 kg^{-1} dung C (Carran et al. 2003).

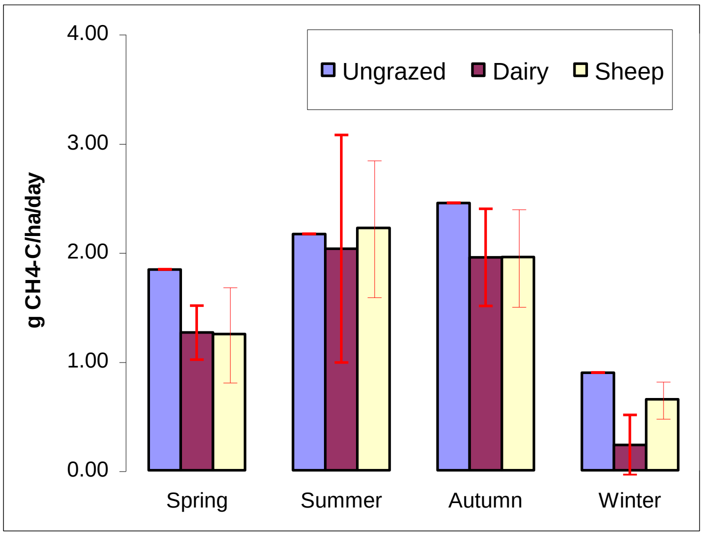
The current New Zealand best estimate from livestock waste methane emissions is 45.1 Gg (Saggar et al. 2003b).

Table 2. **Soil methane consumption**

Land Use	Annual consumption (kg CH_4 ha^{-1} yr^{-1})	Reference
Pine	4.20	Tate et al. (unpublished)
Native Beech	10.50	Price et al. (2004)
Arable cropping	0.95	Khan (1999); van der Weerden (1999)
Dairy pasture	0.50- 0.64	Saggar et al. (unpublished)
Sheep pasture	0.30-0.55	Saggar et al. (unpublished); Carran et al. (unpublished)
Ungrazed pasture	0.66	Saggar et al. (unpublished)
Unimproved pasture	0.56	Carran et al. (unpublished)

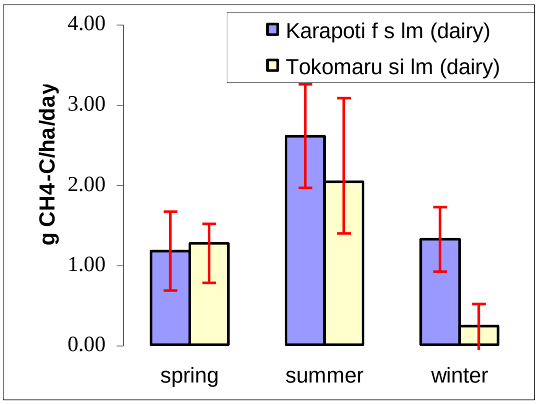
Methane consumption is highest for the New Zealand Beech forest soils (10.50 kg CH_4 ha^{-1} yr^{-1}), intermediate in pine forest soils (4.20 kg CH_4 ha^{-1} yr^{-1}), and lowest in all pasture and cropped soils (<1 kg CH_4 ha^{-1} yr^{-1}).

In pastoral soils, methane consumption in dry summer and autumn is about two to three times the consumption in wet winter, indicating a strong seasonal pattern of soil methane sink capacity.



All soils saturated after heavy rainfall events emitted methane immediately.

Well-drained, fine sandy loam soil has higher overall methane consumption than has poorly drained silt loam soil.



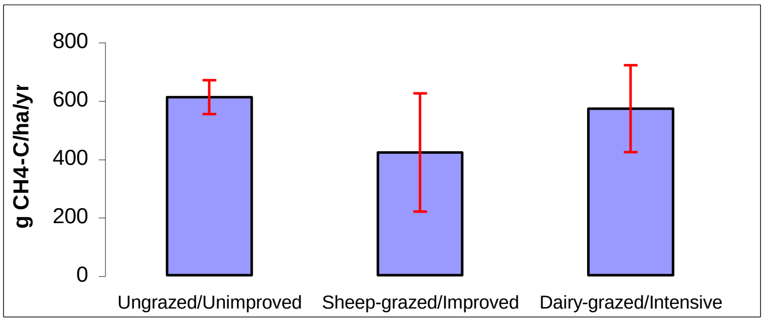
Ungrazed and unimproved pasture soils had similar methane consumption to improved and intensive dairy- and sheep-grazed pasture soils, suggesting increased intensification of agriculture from sheep to dairying has little impact on soil methane sink capacity.

Conclusions

The annual contribution of methane from livestock waste (45.1 Gg) to New Zealand’s methane budget is small.

Pasture soils oxidise methane and the oxidation rates vary with season (highest in summer and lowest in winter).

Soils emit methane immediately after heavy rainfall events.
The estimated amount of methane oxidised by New Zealand agricultural and forest soils is approximately three times of that emitted from the animal wastes.
Intensification of pastoral agriculture may cause little change in soil methane sink capacity.



Acknowledgements

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6.13 FIELD TESTING AN AUSTRALIAN DEVELOPED ANTI-METHANOGEN VACCINE IN GROWING EWE LAMBS

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Introduction

CSIRO have been developing a novel approach to methane mitigation which involves vaccinating ruminants so that they produce antibodies against their own rumen methanogen populations. Because of its ease of use and potential universal applicability this approach is highly attractive. The CSIRO research programme has reached the stage where prototype vaccines are available for field testing. This poster presents the results of a PGGRC funded project that tested two formulations of the vaccine in New Zealand sheep.

Experimental details

Duration of trial

20 June 2003 – 31 August 2003

Vaccination treatments

- Adjuvant only
- Vaccine A
- Vaccine B1

- 1Vaccine B is Vaccine A + additional methanogenic material isolated from New Zealand sheep.

- Two stage vaccination procedure
- Primary vaccination June 20th 2003
- Booster vaccination July 31st 2003

Animals

- 15 ewe lambs (aged approx 9 months) per treatment
- Fed chaffed ad-lib lucerne hay
- Animals allocated to treatments based on pre-trial methane emissions
- Confined in metabolism crates during methane measurement periods

Measurements

- Herbage intake
- Liveweight gain
- Total methane production using the SF_6 tracer technique 4 weeks post vaccination

Results

Feed Intake (g/day)

	Control	Vaccine A	Vaccine B	SED	*P*
Pre vaccination	1180	1202	1216	71.6	NS
Post primary	1137	1151	1184	55.3	NS
Post booster	1310	1307	1265	31.3	NS

Animal liveweights (kg)

	Control	**Vaccine A**	**Vaccine B**	**SED**	***P***
Pre vaccination	33.7	33.9	33.5	0.82	NS
Post primary	33.8	33.0	34.2	0.45	<0.05
Post booster	36.8	37.3	36.3	0.47	NS

Methane emissions (g/day)

	Control	**Vaccine A**	**Vaccine B**	**SED**	***P***
Pre vaccination	22.4	21.5	24.4	2.01	NS
Post primary	21.7	21.2	23.1	1.61	NS
Post booster	21.2	21.9	22.4	1.19	NS

Discussion

Herbage dry matter intake, liveweight gain and total methane output did not differ significantly between the control and vaccine treated groups in either of the post vaccination measurement periods.

The lack of response was disappointing given that recent work in Australia has indicated that the vaccine can successfully reduce methane emissions.

Additional tests are being undertaken to try to elucidate why there was no methane abatement in this study.

6.14 EFECT OF SARSAPONIN ON RUMINAL METHANE, FERMENTATION AND MICROBES IN VITRO AND IN CATTLE

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Methane produced during anaerobic fermentation in the rumen represents 2-12% gross energy loss to the host animal and contributes to emission of green house gases into the environment (Moss, 1993). Microbial-intervention strategies target specific microbial processes involved in methane formation in the rumen and a range of potential intervention sites have been identified (Joblin, 1996). These include interventions to decrease hydrogen, the development of alternative hydrogen sinks (Joblin, 1999), the administration of anti-methanogens or the removal of protozoa (Itabashi et al.,1984).

Sarsaponin is a group of steroidal glycosides extracted from the *Yucca schidigera* plant. Addition of sarsaponin to diets improved the growth of steers (Goodall and Matsushima, 1979), reduced ammonia and increased propionate concentrations in vitro (Lila et al., 2003) and in vivo (Hristov et al., 1999). In subsequent studies, Goetsch and Owens (1985) reported that sarsaponin had also beneficial effects on ruminal fermentation with low concentrate diets, improved ruminal organic matter digestion and did not affect animal performance. Saponins have also antimicrobial properties, particularly in suppressing ciliate protozoa (Wallace et al., 1994), peptidase producing bacteria (Wallace et al., 1994; Wang et al., 2000) and cellulolytic bacteria (Wang et al., 2000). Furthermore, methanogenic bacteria were metabolically co-related with ciliate protozoa, and ciliate protozoa actively produce hydrogen, which is utilized by methanogenic bacteria (Ushida et al., 1997).

We investigated the effects of sarsaponin on ruminal methane, fermentation and microbes in vitro and in cattle. In the in vitro study, diluted ruminal fluid (30 mL) was incubated anaerobically at 38˚C for 6 or 24 h with or without sarsaponin using soluble potato starch, corn starch or hay plus concentrate (1.5:1) as substrates. Sarsaponin was added at various concentrations (0, 1.2, 1.8, 2.4 and 3.2 g/L). Excluding the lower level of sarsaponin, pH of the medium was slightly decreased. Ammonia-N concentration and numbers of protozoa were decreased ($P < 0.05$) in a dose dependent manner. Total VFA and total gas production were increased ($P < 0.05$). Molar proportion of acetate was decreased and propionate was increased with a corresponding decrease ($P < 0.05$) in acetate:propionate ratio. Hydrogen production was decreased ($P < 0.05$). As the concentration of sarsaponin increased from 1.2 to 3.2 g/L, fermentation of soluble potato starch, corn starch or hay plus concentrate decreased ($P < 0.05$) methane production from 20% to 60% (6 h) and 17% to 50% (24 h); 21% to 58% (6 h) and 18% to 52% (24 h); and 23% to 53% (6 h) and 15% to 44% (24 h), respectively. Excluding the lower dose level (1.2 g/L) of sarsaponin, the in vitro disappearance of dry matter of hay plus concentrate was decreased ($P < 0.05$) after 24 h. The effect of sarsaponin on methane production, ruminal fermentation and microbes was further investigated in vivo using three Holstein steers in a 3 × 3 Latin Square design. The sarsaponin supplement (0, 10.5, or 21 g) was mixed in the concentrate portion of a (1.5:1) Sudangrass hay plus concentrate mixture that was fed twice daily to the steers. Ruminal samples were collected 0, 2, and 5 h after morning feeding. Ruminal pH was numerically decreased in sarsaponin supplemeted steers. Numbers of protozoa were decreased ($P < 0.05$) by treatment. Relative to control, ruminal ammonia was reduced ($P < 0.05$) with sarsaponin supplementation. Molar proportion of acetate was decreased ($P < 0.05$) and propionate was increased ($P < 0.01$) by treatment. Methane was decreased ($P < 0.05$) with sarsaponin supplementation. Numbers of cellulolytic bacteria were decreased significantly ($P < 0.05$), while numbers of total bacteria were numerically decreased with sarsaponin supplementation.

These results indicate that supplementation with sarsaponin can be used to decrease methane production in steers.

Acknowledgments

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6.15 METHANOGEN GENOMICS TO DISCOVER TARGETS FOR METHANE MITIGATION

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Methanogenic archaea are responsible for methane production in the rumen. *Methanobrevibacter ruminantium*, a prominent methanogen in New Zealand ruminants, is the subject of a Pastoral Greenhouse Gas Research Consortium-funded genome sequencing project which is being carried out by AgResearch's Rumen Microbial Genomics team. The project is the first genome sequencing of a rumen methanogen and it aims to build a better understanding of the biology of *Methanobrevibacter* to discover targets for inhibition of methane formation.

Methods and Materials

Before beginning a microbial genome sequencing project an estimation of genome size is useful to determine the scale of sequencing required. Therefore *M. ruminantium* strain M1^T (DSM1093) was grown on BY+ medium and genomic DNA extracted using a modified freezing method[1]. Cell homogenates were imbedded in agarose plugs and subsequent manipulations were carried out in the plugs to reduce the physical shearing of genomic DNA. Restriction endonuclease digestions were performed with *Mlu* I, *Apa* I and *Sma* I and the resulting DNA fragments were separated using pulsed-field gel electrophoresis. The DNA of the *M. ruminantium* genome was sequenced using a random shotgun cloning approach[2] (Agencourt Biosciences Corp.Massachusetts, USA). Libraries of *M. ruminantium* DNA were constructed in *Escherichia coli* by random physical disruption of genomic DNA and separation of fragments by gel electrophoresis. Large fragments in the 40 Kb range were retrieved from the gel and used to generate a large insert fosmid library. DNA fragments in the 2 to 4 Kb range were recovered and used to generate a small insert plasmid library. Clones resulting from both large and small insert libraries were grown, their fosmid or plasmid DNA recovered and sequenced using high throughput sequencing technology. Sufficient clones were sequenced to give a theoretical 8× coverage of the *M. ruminantium* genome. DNA sequences were aligned to find sequence overlaps and assembled into contiguous (contig) sequences using Paracel Genome Assembler (Paracel Inc, CA, USA). Contigs were analysed using the open reading frame (ORF) finder GLIMMER (Gene Locator Interpolated Markov Model ER[3]) and each ORF was analysed by BLAST (Basic Local Alignment Search Tool[4]) against non-redundant nucleotide and protein databases. The contigs were joined by artificial linking sequences to generate a "pseudomolecule" and submitted to The Institute for Genomic Research (TIGR, Rockville, MD, USA) for autoannotation.

Results and discussion

Pulsed-field gel electrophoresis was used to separate restriction fragments of *M. ruminantium* genomic DNA (Figure1). Fragment sizes of the digests indicated a genome size of approximately 2.5-2.9 Mb. The results from Paracel assembly, GLIMMER and BLAST analyses and TIGR autoannotation are presented in Table 1. The sequence assembled into 756 contigs which were associated with 105 scaffolds (linked contigs). The combined contig length indicates an approximate genome size of 3.04 Mb. The size and G+C content of the *M. ruminantium* DNA sequence appear consistent with genomes of other methanogens. The *M. ruminantium* genome is intermediate in size between *Methanobacterium thermoautotrophicum* (1.75 Mb[5]) and *Methanosarcina acetivorans* (5.75 Mb[6]). The 33.62% G+C content of *M. ruminantium* is similar to other rumen methanogens such as *Methanobrevibacter smithii* (30.6%[7]). GLIMMER analysis detected slightly more ORFs than TIGR autoannotation, while TIGR assigned more functions to ORFs. The 51% of unassigned TIGR ORFs were either conserved hypothetical proteins, proteins/enzymes of unknown specificity or hypothetical proteins which have not yet been classified. The TIGR autoannotation placed ORFs with assigned functions into role categories and together with subsequent manual annotation, there are at least 42 *M. ruminantium* genes involved in methanogenesis (Table 2). Many of these genes show homology with genes from other, non-rumen, methanogens. Comparison of gene order in *M. ruminantium* with its closest genome-sequenced relative, *Methanobacterium thermoautotrophicum*[5], has shown that methanogenesis gene organisation is conserved.

The results from sequence analysis indicate that many of the *M. ruminantium* genes involved in methanogenesis, and their organisation within the genome, are conserved among, and unique to, the methanogens. We are continuing to characterise these methanogenesis genes and the functions that they encode. Despite the conservation of methanogenesis gene sequences, over half of the ORFs in the *M. ruminantium* genome are unknown. This indicates that *M. ruminantium* is genetically very different to other sequenced methanogens. Determining the function of these new genes will improve our understanding of the biology of this organism and help define its role in methane formation in the rumen.

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***Table 1*. Sequence assembly and analysis**

Genome size (bp)	3043768
Contigs	756
Scaffolds (linked contigs)	105 (329)
GC content	33.62%
rRNA operons	Number uncertain
tRNAs	67
Genes identified by GLIMMER	2769
BLAST matches	1176 (42%)
Unknown	1593 (58%)
ORFs identified by TIGR	2608
ORFs with assigned function	1280 (49%)
Transposases	8

***Table 2.* Methanobrevibacter ruminantium genes involved in methanogenesis**

ORF	Common name	Gene symbol	EC
ORF00030	methyl coenzyme M reductase system component A2	mcrA2	2.8.4.1
ORF00076	methenyltetrahydromethanopterin cyclohydrolase	mchA	3.5.4.27
ORF00441	methyl coenzyme M reductase system component A2, putative		
ORF00722	coenzyme F420-dependent N5, N10-methylene tetrahydromethanopterin dehydrogenase		
ORF00787	formylmethanofuran dehydrogenase, subunit C homolog (tungsten)	fwdC	
ORF00846	formylmethanofuran-tetrahydromethanopterin formyltransferase		
ORF00891	methyl coenzyme M reductase I, beta subunit	mcrB	2.8.4.1
ORF00892	methyl coenzyme M reductase I, operon protein d	mcrD	2.8.4.1
ORF00893	methyl coenzyme M reductase I, operon protein c	mcrC	2.8.4.1
ORF00894	methyl coenzyme M reductase I, gamma subunit	mcrG	2.8.4.1
ORF00895	methyl coenzyme M reductase I, alpha subunit	mcrA	2.8.4.1
ORF00896	tetrahydromethanopterin S-methyltransferase, subunit E	mtrE	2.1.1.86
ORF00897	tetrahydromethanopterin S-methyltransferase, subunit D	mtrD	2.1.1.86
ORF00898	tetrahydromethanopterin S-methyltransferase, subunit C	mtrC	2.1.1.86
ORF00900	tetrahydromethanopterin S-methyltransferase, subunit B	mtrB	2.1.1.86
ORF00901	tetrahydromethanopterin S-methyltransferase, subunit A	mtrA	2.1.1.86
ORF00902	tetrahydromethanopterin S-methyltransferase, subunit F	mtrF	2.1.1.86

ORF00903	tetrahydromethanopterin S-methyltransferase, subunit G	mtrG	2.1.1.86
ORF00904	tetrahydromethanopterin S-methyl transferase subunit H	mtrH	2.1.1.86
ORF00920	methyl coenzyme M reductase system, component A2	atwA	2.8.4.1
ORF01383	H2-dependent N5, N10-methylene tetrahydromethanopterin dehydrogenase	hmd	
ORF01647	coenzyme F420-dependent N5, N10-methylene tetrahydromethanopterin reductase	mer	
ORF02208	formylmethanofuran dehydrogenase, subunit G (tungsten)	fwdG	
ORF02209	formylmethanofuran dehydrogenase, subunit D (tungsten)	fwdD	1.2.99.5
ORF02210	formylmethanofuran dehydrogenase, subunit B (tungsten)	fwdB	1.2.99.5
ORF02211	formylmethanofuran dehydrogenase, subunit A (tungsten)	fwdA	1.2.99.5
ORF02212	formylmethanofuran dehydrogenase, subunit A (tungsten)(part of ORF02211)	fwdA	1.2.99.5
ORF02213	formylmethanofuran dehydrogenase, subunit C (tungsten)	fwdC	1.2.99.5
ORF02274	formylmethanofuran-tetrahydromethanopterin formyltransferase-like protein		
ORF02482	tetrahydromethanopterin S-methyltransferase, subunit A	mtrA	2.1.1.86
ORF02532	formylmethanofuran dehydrogenase, subunit F (tungsten)	fwdF	

7 GREENHOUSE GAS EMISSION INVENTORIES

7.1 NIWA INVENTORY OF NEW ZEALAND GREENHOUSE GAS EMISSIONS – 2001

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http://www.niwa.co.nz/ncces/ghge/

What is the inventory?

The inventory is a web-mounted database of greenhouse gases, which comprises the six greenhouse gases recommended by the Intergovernmental Panel on Climate Change (IPCC, 2001). The gases are: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFC's), perfluorocarbons (PFC's), and sulphur hexafluoride (SF_6).

How is the inventory organised?

The inventory is divided into five activity sectors.
The spatial framework for the inventory is based upon Territorial Local Authority boundaries. The latest census (2001) is used as the base year for the inventory.

Agricultural emissions
Livestock Enteric Fermentation
Agricultural Solis
Manure Management
Off-road vehicles

Area emissions
Domestic and commercial fuel
Off-road vehicles
Open burning
Landfills
Lawn mowing
Refrigeration
Waste Water

Industrial emissions
"Top 12" industry - process emissions
"Top 12" industry - combustion emissions
"Other" industry - process + combustion emissions

Natural emissions
Vegetation/water
Geothermal/volcanic

Transport emissions
Motor vehicles
Rail
Aviation and Marine

Why the need for the inventory?

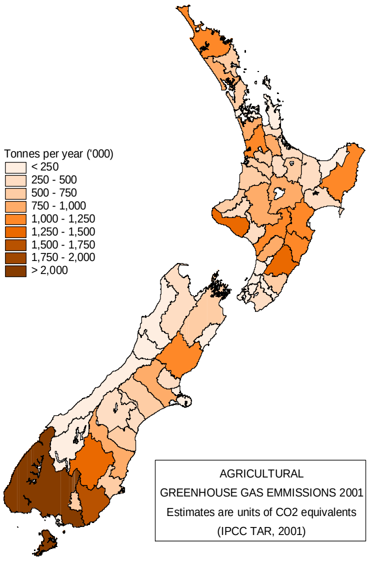
The inventory is designed to help government departments, territorial authorities, industry, and other stakeholder groups to formulate effective policies for mitigating greenhouse gases and other air quality issues. It is hoped the inventory will assist management efforts to ensure we have a healthy and safe living environment for people.

How are the estimates calculated?

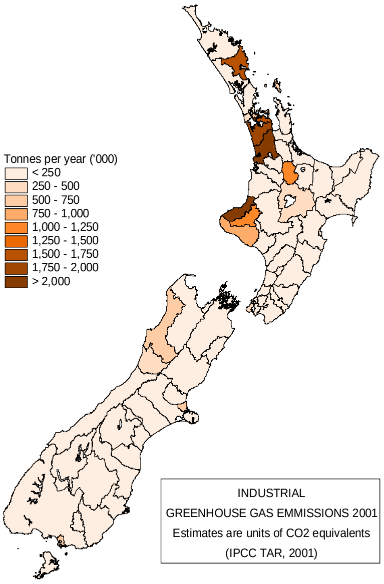
Emissions have been calculated using ‘top down’ and ‘bottom up’ approaches. The top-down approach typically uses national totals and aggregates these across the TLA’s based on population or area. In comparison, the bottom-up approach uses often detailed and localised emissions for each TLA, which are summed to give a national total. This method is usually more reliable but is very time-consuming. The choice of approach is dependant on access to activity information and appropriate emission factors (both local and overseas).

Where can you access the inventory?

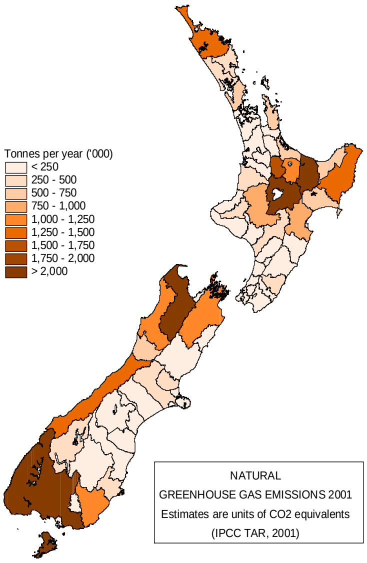
The inventory can be accessed via NIWA’s web-link to the National Centre for Climate and Energy Solutions. The site provides free access to downloadable tables and maps (see examples below) of all greenhouse gas estimates, including the assumptions and formulae used to calculate these emissions.



AGRICULTURAL
GREENHOUSE GAS EMMISSIONS 2001
Estimates are units of CO2 equivalents
(IPCC TAR, 2001)



INDUSTRIAL
GREENHOUSE GAS EMMISSIONS 2001
Estimates are units of CO2 equivalents
(IPCC TAR, 2001)



NATURAL
GREENHOUSE GAS EMISSIONS 2001
Estimates are units of CO2 equivalents
(IPCC TAR, 2001)

This tool is a refinement of the 1995 Air Emissions Framework developed P. Wright and G. Kuschel. NIWA scientists D.N.T. King, T. Clarkson, K. Lassey, S. Petrie, B. Sorrell and A. Scoggins contributed to the 2001 project. The project is part of the FRST funded research programme: Urban Air Quality Processes.

7.2 DATABASE OF EMISSION FACTORS AND OTHER PARAMETERS

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WMO

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

NATIONAL GREENHOUSE GAS INVENTORIES PROGRAMME

UNEP

http://www.ipcc-nggip.iges.or.jp/EFDB

What is it?

The Emission Factor Database (EFDB) is an easily accessible public database of emission factors (EFs) and other parameters such as are used by parties to the UN Framework Convention on Climate Change for annual compilation of their national greenhouse gas emission inventories. The "other parameters" include all those parameters in equations cited in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* and in the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Examples of "other parameters" in the agriculture sector might be $\mathbf{Y_m}$, the "methane conversion factor" used for emissions by enteric fermentation, and $\mathbf{Frac_{LEACH}}$, the fraction of total nitrogen applied to agricultural soils that is leached to groundwater.

The EFDB will become a major resource for the next revision of the IPCC Guidelines for National Greenhouse Gas Inventories, due for completion in 2006. In particular, that revision will be able to cite the EFDB as a source of default parameters rather than tabulate them in situ.

Access to the EFDB, whether to search for data or to submit new data, is via the website (URL above) which also reports descriptive information about the EFDB.

Rationale

The intent is that the EFDB will help improve the quality of national greenhouse gas emission inventories in a cost-effective way by providing an accessible database of the necessary parameters supported by documented scientific information ("properties") that describes the conditions under which the data were determined. Sharing data and information this way will help avoid unnecessary duplication of research efforts. Countries without the appropriate research structure will be able to search for the best possible EFs that suit their circumstances.

As of March 2004, the EFDB contains in excess of 8000 EFs and parameters. Many of these are the "IPCC default" values familiar to users of the *Revised 1996 IPCC Guidelines* or the *IPCC Good Practice Guidance* manual (*op cit*).

Using the EFDB

The EFDB supports the community of greenhouse gas inventory specialists by serving as:

A library of well-documented emission factors and other parameters;

A communication platform for disseminating and commenting on new EFs.

However, the responsibility of using this information appropriately always remains with the user.

The following features of the EFDB ensure easy access to the most up-to-date EFs and other inventory-related data:

Web and CD_ROM versions are available;

Powerful database search functions;

Export capability to Excel;

Documentation on parameter applicability;

Inclusion of references to technical background information wherever possible;

Inclusion of direct cross-references to *IPCC Guidelines* manuals and to IPCC worksheet number in the "Common Reporting Format".

Providing data to the EFDB

Data provision may be done on-line or off-line; by pre-registered providers. Following initial checks by the Technical Support Unit (TSU) of IPCC National Greenhouse Gas Inventories Programme (NGGIP) which may involve data revisions by the provider, each datum is evaluated by the EFDB EB against criteria which include:

Robustness: within the accepted uncertainty the value is unlikely to change is there was a repetition of the determination;

Applicability: the proposal matches a well=defined source category that can be used in compiling a national inventory;

Transparent documentation: the conditions of its derivation and information regarding uncertainty are well described, allowing the user to evaluate its applicability; the documentation should preferably include a peer-reviewed report (which may include a national inventory) or publication.

As of March 2004, the EFDB EB comprises 27 experts from 21 countries. The EB reports to the TSU which is based at the Institute for Environmental Strategies (IGES) in Tsukuba, Japan, and to whom enquiries should be directed (email ipcc-efdb@iges.or.jp).

Custodians of appropriate new inventory-related data should consider submitting that data to the EFDB. The data provider need not be the data originator, but the latter should preferably be 'in the loop'. Benefits of data inclusion to the data provider and/or originator include:

Promotes your work, your publications, and your institute or organization;

Improves data coverage of the database;

Improves utility of the database as a tool for inventory compilers and researchers;

Improves the comparability of data;

Enhances collaboration among interested experts and can be added to the originator's CV!

7.3 ALTERNATIVES TO THE GLOBAL WARMING POTENTIAL CONCEPT FOR COMBINING THE EFFECTS OF EMISSIONS OF DIFFERENT GREENHOUSE GASES ON CLIMATE

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NIWA, Lauder

Introduction

The global warming potential (GWP) is a greenhouse gas (GHG) metric used to weight the emissions of non-CO_2 GHGs to CO_2 equivalent emissions. It expresses the contribution of a gas to radiative forcing (energy flux across the tropopause), relative to that of CO_2, over some *time horizon* (the period over which the comparison is made). However, the GWP is not the only metric that can be used to make such comparisons, and there have been many criticisms of GWP, e.g.

- The GWP does not actually represent the impact of gas emissions on temperature. A strong GHG with a short lifetime could have the same GWP as a weaker GHG with a longer lifetime, but 1 kg emissions could produce quite different temperature changes.

- The GWP does not reflect the damages caused by emissions.

- The choice of the time horizon for GWPs is critical but arbitrary.

In this paper we investigate two alternatives to the GWP, the global temperature change potential for pulse emissions (GTP_p) and the global temperature change potential for sustained emissions (GTP_s) (*Shine et al.*, 2003).

The simple climate model

The simple climate model used in this analysis tracks the 'cause and effect chain' from emissions, to changes in concentrations, to changes in radiative forcing, to changes in global mean surface temperature, to change in damages (in this case sea-level rise is used as a proxy for climate change damages). A carbon cycle model, incorporating exchange of CO_2 between the terrestrial biosphere and atmosphere, and between the atmosphere and ocean, is used to calculate the change in atmospheric CO_2 loading in response to prescribed CO_2 emissions. Differential equations describe CH_4 and N_2O concentration responses to emissions and sinks, assuming

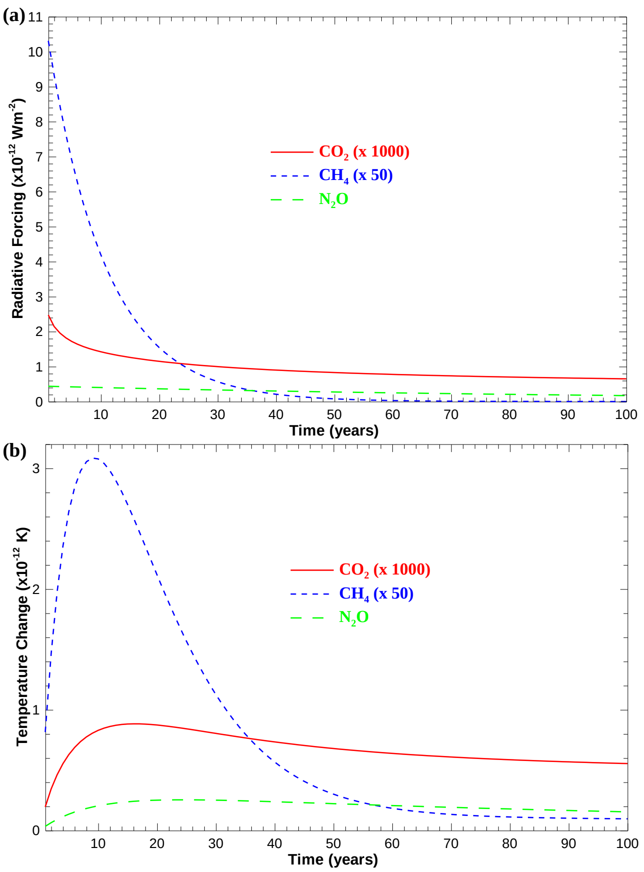

Figure 1: **(a) The radiative forcing (in 10^{-12} Wm^{-2}) due to a 1 kg pulse emission of CO_2, CH_4, and N_2O. (b) The temperature response to the radiative forcing shown in (a). Note that the CO_2 signals in both panels have been multiplied by 1000 and those for CH_4 by 50.**

lifetimes of 10 and 114 years respectively. Changes in radiative forcing resulting from changes in concentrations are calculated using expressions from the IPCC third assessment report (TAR) (*IPCC*, 2001). Changes in global mean surface temperature resulting from changes in radiative forcing are calculated using a parameterisation from a coupled ocean-atmosphere climate model.

		20	**100**	**500**
Methane (CH_4)	This study	62	23	7
	IPCC TAR	62	23	7
Nitrous Oxide (N_2O)	This study	265	307	170
	IPCC TAR	275	296	156

***Table 1*: GWPs for CH_4 and N_2O for time horizons of 20. 100 and 500 years.**

The global warming potential

To calculate GWPs for CH_4 and N_2O, 1 kg pulse emissions of these gases were provided as input to two separate runs of the simple climate model and the changes in radiative forcing were compared to those for a 1 kg pulse emission of CO_2. The resultant changes in radiative forcing and global mean surface temperature, for the first 100 years after the pulse emissions, are shown in Figure 1. The radiative forcing resulting from increased atmospheric concentrations of the gases is immediate and as the concentrations decay, so too does the radiative forcing resulting from the pulse emission. Different lifetimes for the gases result is different rates of decay of radiative forcing with time. The GWP is then calculated buy integrating under the radiative forcing curves and ratioing the CH_4 and N_2O integrals with the CO_2 integral. The resultant GWPs are listed in Table 1 together with the values from the IPCC TAR. Note that the 100 year time horizon GWP for CH_4 (GWP100) of 23 is different to that assigned to the Kyoto Protocol. The Kyoto Protocol uses the GWP100 from the IPCC second assessment report, of 21. This value changed between the second and third assessment reports as a result of revision of CO_2 radiative properties.

The CH_4 GWPs calculated here agree well with those listed in the IPCC TAR but differ slightly for N_2O, perhaps because of different specification of the N_2O lifetime (changing the N_2O lifetime from 114 to 105 years results in far better agreement with the IPCC TAR values).

The global temperature change potential

Because integrated radiative forcing is similar to instantaneous temperature change, we consider here two alternatives to GWP based on the Global Temperature Change Potential (GTP):

***GTP_p*:** The ratio of the temperature change induced by a pulse emission of 1 kg of the gas to that of CO_2 at some specified time after the emission.

***GTP_s*:** The ratio of the temperature change induced by sustained emissions of 1 kg of the gas each year over a specified time period to that of CO_2 at the end of the specified time period.

	GWP			**GTP_p**			**GTP_s**		
	20	100	500	20	100	500	20	100	500
CH_4	62	23	7	49	3.5	1.6	68	25	8
N_2O	265	307	170	292	299	56	253	307	183

***Table 2*: Comparison of GWP, GTP_p and GTP_s for time horizons of 20, 100 and 500 years.**

The temperature responses plotted in Figure 1b were used to calculate GTP_p while similar curves for sustained emissions were used to calculate GTP_s. A key difference between GWP and GTP is that the

GTP is the ratio of the temperature changes at a particular time, t, rather than the ratio of integrated changes over the period leading up to t. A pulse emission of 1 kg of a gas will give an identical temperature change in year t as $GTP_p(t)$ kg CO_2. The GWP does not show this equivalence.

Calculated GTP for CH_4 and N_2O are listed in Table 2. Note that although 100 times more gas was emitted in the model runs for the calculation of GTP_s than in the runs for GTP_p, the GTP_s is not $100\times GTP_p$. This is because emissions closer to the end of the time horizon have less time to drive changes in global mean surface temperature. Note also that the GTP_s values are not very different from the GWP for both CH_4 and N_2O. The advantages of GTP over GWP are:

- The suitability of a GHG emissions equivalence metric increases as one moves down the cause and effect chain (see above). Ideally these metrics should be directly associated with the quantity we are trying to mitigate – primarily damages resulting from climate change. However, metrics further down the chain can be less precisely calculated than those further up the chain. The GTP is one step further down the chain than the GWP.
-
- The GTP represents an actual climate impact, rather than the more abstract concept of integrated radiative forcing due to a pulse emission.
-
- GWPs assume that trade off ratios between different GHGs remain constant over time and are independent of the ultimate goal. Neither of these assumptions make economic sense.

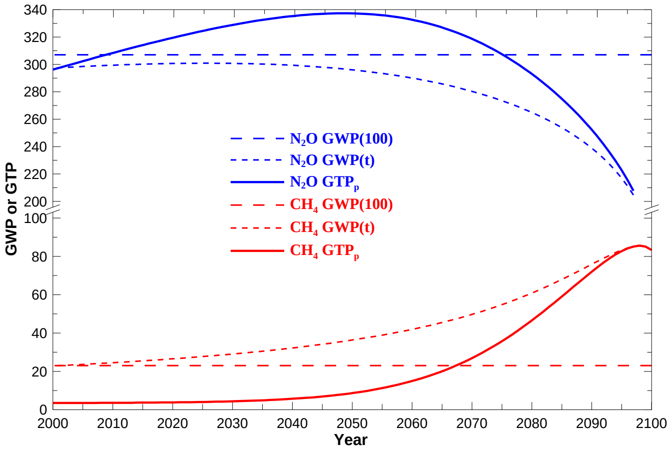

***Figure 2:* GTP_p plotted as a function of time assuming the need to restrict global mean surface temperature change at 2100. The values show the relative importance of emissions of a gas as that time is approached. The GWP at the 100 year time horizon and the GWP for a time horizon given by the difference between 2100 and the time of emission is also shown.**

Policy relevance

One concept that is certain to feature in future climate change policy negotiations is that of a stabilization scenario. This is an emissions scenario designed to lead to stabilization of a climatically relevant parameter by a specified date e.g. stabilization of CO_2 concentrations at 550 ppm from 2100 onwards. Stabilization scenarios are more relevant to the UNFCCC expectation that polices and measures should be designed to 'prevent dangerous anthropogenic interference with the climate system'.

An example of how GWP and GTP could be used as policy tools for targeting stabilization of global mean surface temperature is shown in Figure 2. The GTP_p plot reflects the fact that a 1 kg pulse emission of CH_4 in 2000 produces only 3.5 times the temperature change in 2100 compared to a 1 kg emission of CO_2, essentially because the lifetime of CH_4 is only 10 years. However, because CH4 is a very effective absorber of outgoing terrestrial radiation (see Figure 1) as one approaches the target date of the stabilization scenario, the GTP_p increases very rapidly, reaching a maximum value of 86.

This application of GTP_p is an example of ‘backward discounting; i.e. it lessens the importance of times far into the future that are considered less important for the present than the near future. For a temperature stabilization scenario, the emissions of short-lived gases at a much earlier time are effectively physically discounted by the climate system. The GWP(100) puts equal weight on radiative forcings whenever they occur.

The GTP_s may be a more policy-relevant metric as it represents the relative climate impact of sustained emission changes. GTP_s and GWP produce very similar values suggesting that time varying GWP, as illustrated Figure 2, could be used as a tool in the development of stabilization scenarios.

Discussion

The formulation for GTP can be extended further down the cause and effect chain by considering proxies for climate change damages such as sea-level rise. Together with an analysis of the economic consequences of climate change, a metric could be developed that reflects the relative contribution of a gas to economic damage. An optimal metric would take into account economic as well as physical considerations. This requires closer collaboration between natural and social scientists.

The results presented here assumed a fixed lifetime for methane. However, methane lifetimes are sensitive to a number of global change processes including changes in stratospheric ozone, changes in the oxidizing capacity of the atmosphere, changes in atmospheric water vapour etc. A more detailed understanding of these processes must be developed to ensure that the models used to calculate time varying metrics such as those presented here are accurate.

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7.4 DISPOSAL OF CARBON DIOXIDE IN THE NEW ZEALAND OCEAN.

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Introduction

Several methods have been mooted for the offshore disposal of carbon dioxide (CO_2) in liquid or solid forms. They include:
direct injection of liquid CO_2 via a seabed pipeline at ~1000 m water depth;
direct injection of liquid CO_2 to ~1000 m depth from a moving vessel;
liquid CO_2 injection to >3000 m via a seabed pipeline or floating platform;
deep injection (~4000 m) of liquid CO_2 to form abyssal pools;
disposal as free-falling, solid CO_2 blocks.
In this note, we briefly examine these methods and their potential applicability to the New Zealand ocean.

Environmental Setting

Offshore New Zealand is large and dynamic. Extending from latitudes $24^0$30' S to $55^0$30' S, the region encompasses the world's fourth largest Exclusive Economic Zone (EEZ) with an area of 4,053,049 km^2. Much of the region is underlain by continental crust that is presently being deformed by the boundary between the colliding Pacific and Australian crustal plates. The resultant tectonic and volcanic activity has created a diverse submarine topography which interacts with an equally active physical oceanographic regime. Global current systems and water masses are all strongly affected by the submarine microcontinent. Finally, there is the meteorology. Strong and persistent westerly winds of the *Roaring Forties* and *Furious Fifties* ensure a vigorous wave climate and wind-influenced ocean circulation that is also sensitive to El Niño-Southern Oscillations and other climatic cycles, as well as the present phase of climatic warming.

New Zealand Production of CO_2

New Zealand is not a major producer of CO_2. Emissions for 1999 were 30,525 million tonnes of CO_2, excluding emissions associated with land-use change and forestry (Ministry for the Environment, 2001). Over 90% came from the utilisation of fossil fuels, with the remainder originating from industrial processing. The main contributors were small, widespread sources such as fossil fuel-powered vehicles, that collectively make up 47% of the total emissions (Transport Sector 38%; Other Sectors 9%). As such, collection of CO_2 for disposal is presently impractical, and emission mitigation will eventually rely on alternative energy systems, for example, hydrogen- or electrical-powered vehicles. Any collection and liquefaction/solidification of CO_2 emissions for disposal would need to focus on prominent point sources, which in New Zealand are presently associated with thermal power generation, petroleum refining, methanol production and industrial processing (production of iron, steel, aluminium and cement). The widespread location and relatively small size of most of these sources must be measured against the high cost of offshore CO_2 disposal which requires gas separation, transport to a port for liquefaction/solidification, offshore transport and finally, disposal.

Ocean Disposal of Carbon Dioxide

Direct injection of liquid CO_2 via a seabed pipeline at ~1000 m depth.

This option relies on the construction of a pipeline across the continental shelf to the slope where liquid CO_2 is introduced via a diffuser. A rising plume is created with the aim of dissolving CO_2 to assist its dispersal by ocean currents.

Advantages

Less expensive than deep-water disposal due to shorter submarine pipelines.

Technologies are either established or are feasible (Ormerod et al., 2002).

Model studies suggest dissolution of gas within 100 m of a diffuser thus minimising environmental impacts.

Disadvantages.

May affect marine life by lowering the pH and increasing the pCO_2 of seawater within the zone of influence at the discharge point (Ormerod et al., 2002).

Reduced dissolution caused by the formation of crystalline CO_2 chlathrates (Warzinski and Holder, 1998; Hunter, 1999), which may also affect diffuser efficiency.

Models show that sequestration at shallow sites is less than that for deep (>3000 m) sites (e.g., Wickett et al., in press). Sequestration could be exacerbated in the shallow Southern Ocean where there is a high uptake but low storage of CO_2.

The energetic New Zealand continental shelf, together with benthic fishing activities, pose risks to submarine installations.

Direct injection of liquid CO_2 to ~1000 m water depth from a moving vessel.

Proposed by Ozaki et al. (1995), this method relies on a vessel trailing a pipeline from which a rising droplet plume is generated at ~1000 m depth.

Advantages.

Dispersion can be controlled by vessel speed to allow maximum dissolution/dispersal of CO_2 thereby reducing any environmental impact.

Avoids the high cost and risk of pipelines although savings are offset by costs of owning/operating liquid CO_2 carrying ships.

Dispersal is not restricted to one site thus reducing any environmental effects.

Disadvantages.

Short sequestration time compared to deep injection methods (e.g., Caldeira et al., 2001), especially in a dynamic ocean settings such as New Zealand.

Chlathrate armouring of droplet plume (see above).

Weather dependent.

Liquid CO_2 injection to >3000 m via seabed or platform-based pipeline

Most model-based studies favour disposal at water depths $\geq$3000 m because of the increased sequestration time (Caldeira et al., 2001). At ~3000 m the density of liquid CO_2 exceeds that of seawater forming a descending plume that is available for dispersal by local currents. Transport to the dispersal site could be by a seabed pipeline or by ship to a floating platform supporting a vertical injection pipe. Off New Zealand, $\geq$3000 m-deep water comes to within 25 km of shore at Fiordland and 60 km near East Cape.

Advantages

Longer sequestration periods compared to shallow injection with models indicating up 82% retention after 500 years depending on location.

Floating platforms would provide the freedom to change disposal sites.

Environmental risks associated with large scale CO_2 spillages would be less for platforms due to their distance from population areas.

Compared to pipelines, platforms have less exposure to geological hazards.

Disadvantages

Injection via a seabed pipeline, although feasible has high capital costs and exposure to environmental hazards. Similarly, liquid CO_2 carriers and floating platforms have high capital costs.

A floating platform would face New Zealand's vigorous wave climate.

Chlathrate armouring of droplet plume.

Deep Injection of to Form Abyssal Pools.

Sequestration in "stable" pools of liquid CO_2 at depths >4000 m (Ohsumi, 1995) has similar advantages and disadvantages to the previous option of injection and dispersal at >3000 m, with the additional disadvantages:

In geologically active settings there is uncertainty about pool stability.

Environmentally stable areas of the ocean floor are distant from New Zealand.

Pools may affect benthic organisms through altered water chemistry.

Disposal of Solid CO_2

Disposal of solid CO_2 in encased blocks designed to penetrate the seabed has been proposed by Guevel et al. (1996) and others.

Advantages

Possible increased length of sequestration due to burial below the seabed, although the post-burial behaviour of the blocks is uncertain.

Disadvantages

A tectonically stable substrate would favour optimum storage, but as noted previously, stable substrates require lengthy transport from New Zealand.

Lengthy transport is also envisaged if carbonate-rich substrates are needed to chemically buffer the effects of any escaping CO_2-rich waters.

The manufacture of solid CO_2 penetrating blocks is a prolonged process compared to liquid CO_2 production.

Depending upon the block design, CO_2 is lost during free-fall deployment.

Discussion

Methods for the disposal of CO_2 are largely conceptual with support coming mainly from laboratory and modelling studies. While these studies do not negate the proposed methods, they fail to assuage uncertainties concerning real-life applications. Observations of liquid/solid CO_2 in the ocean are few (e.g., Brewer et al., 1999), but that information suggests liquid CO_2 reacts with seawater and benthic ecosystems in a way more complex than previously envisaged. For instance, experiments with liquid CO_2 disposal in Monterey Canyon revealed no short-term response of organisms to lowered pH, but noted respiratory distress of mobile animals with increased pCO_2 (Tamburri et al., 2000).

Knowledge of ocean processes is essential for successful disposal and storage. Sequestration relies on the upward diffusion/ upwelling of deep waters, i.e. slower diffusion rates, longer storage time. Yet there is little precise data on diffusion/upwelling rates in key areas of the ocean such as the central Pacific.

Thorough site investigations are essential. While there is a sound but broad knowledge of the deep-ocean circulation around New Zealand, information on its spatial and temporal variability is known only for a few sites. Also there is a paucity of data on abyssal benthic organisms, and even less on their ecology and response to increased CO_2.

Given the present state of knowledge about the methods and environmental responses to disposal, the following comments relating to New Zealand are tentative.

- Of the methods reviewed, deep injection to $\geq$ 3000 m from a floating platform is preferred in terms of maximising sequestration time. Subsequent lateral advection through the deep SW Pacific Ocean will be on a decadal scale, but the return of CO_2-charged waters to the surface will take centuries (a more precise time has to be determined). The method has other advantages relating to the cost and safety of delivery to the disposal site.
- Selection of disposal sites will need to consider distance of transport, sea conditions, seafloor character, ocean circulation, environmental impacts and sequestration times. Possible sites are the South Fiji Basin and east of the Kermadec Trench by virtue of their relative proximity to prominent CO_2 sources, the less vigorous sea conditions, the presence of weak dispersing currents, and occurrence within the EEZ. Transport distances, however, are large (>300 km).
- Regarding responses of marine ecosystems, the formation of a semi-permanent liquid/chlathrate CO_2 pool probably will have the most negative effects through asphyxiation of benthic communities and any other responses to changes in water chemistry. Also, the stability of a pool is uncertain in the active geological regime of New Zealand. Burial of solid CO_2 blocks below the seafloor offers the possibility of reduced environmental impact, but this must be viewed against uncertainties of block behaviour in sediments. The more favoured mode of disposal is via droplet plumes within a deep current of sufficient strength to disperse and dissolve the plume at a rate that minimizes any negative impacts.
- The economics of shore-based collection, liquefaction/solidification, storage and transport have yet to be realized. Present estimations from the international literature (e.g., Ormerod et al., 2002) indicate that costs are high, but are likely to reduce with improving technology. Some examples of recent estimates: submarine pipeline (~ NZ$2.7 million/km); liquid CO_2 carrier (~ NZ$83 million/vessel), CO_2 removal from flue gases (NZ$50-83/t CO_2), pipeline operation costs (NZ$20/t CO_2) and ship transport (NZ$3/t CO_2).

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7.5 EFFECTIVE ABATEMENT OF GREENHOUSE GASES AT INSTITUTE LEVEL FROM A COMPLETE INVENTORY OF SOURCES AND SINKS

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Background

Greenhouse gas (GHG) emissions have increased for centuries due to industrial, agricultural, and household activities. Carbon dioxide is the most important long-lived greenhouse gas. Although the effects of increased CO_2 levels on the functioning of ecosystems and energy systems are uncertain, many scientists agree that a doubling of atmospheric CO_2 concentrations could have a variety of serious environmental consequences (Adams et al., 1999).

To meet the requirements of the Framework Convention for Climate Change, New Zealand has adopted the approach that 80% of the necessary reductions in CO_2 emissions will be met by a net increase in uptake and storage of carbon by forest ecosystems. This could be achieved during the next two decades by widespread planting of exotic coniferous species, but only if the carbon pool in the 7.8 million ha of indigenous forests is not subject to fluctuation. Since the carbon stored in indigenous forests is large in comparison with that in plantation forests, small changes in storage are likely to have a large effect on the national carbon balance (Tate et al. 1993).

New Zealand ratified the Kyoto Protocol in December 2002 and the Government is encouraging industries and businesses, individuals, and communities to reduce greenhouse gas (GHG) emissions. (see http://www.climatechange.govt.nz/sp). Some businesses and organisations are already taking action to prepare for and adapt to climate change. Before the first commitment period for the Kyoto protocol starts in 2008, efforts from a number of research institutes/organisations and Universities will be required to help different sectors prepare their own emission budgets for compliance.

Little attempt has yet been made at an institute level to determine the aggregated net emissions of the major GHGs - carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4)

Project Goals

Develop a spread-sheet based computer model for calculating GHG budget at Massey University Turitea campus.

Suggest measures for protection and enhancement of GHG sinks

Develop and recommend strategies to limit and/or reduce GHG emissions

Enable other institutions/organisations to estimate the scope and scale of their GHG emissions and sinks from the use of this model, and so devise practice appropriate for achieving a GHG neutral enterprise.

Methodology

Potential sources of emission and sinks at the Turitea campus will be identified and a model will be developed to calculate all emissions and sinks.

The campus is being divided into different management units based on activities and functions of each unit.

Separate account of GHG sources/sinks will be maintained for every management unit to assess its contribution to an overall emission.

Per capita emission for all units will then be calculated.

Practical and effective abatement strategies to reduce emissions will be identified.

The results will be critically analysed and compared with other available models.

Verification will include the use of data from national and international studies.

Outcome of the project

A complete greenhouse gas budget of the Massey University Turitea campus since 1990.

Projected future emissions from different sources within the campus for use by the University administration.

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7.6 EFFECTS OF DAIRY FARMING INTENSIFICATION AND MITIGATION PRACTICES ON ENVIRONMENTAL EMISSIONS

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Introduction

Milk production on dairy farms in New Zealand has been steadily increasing since the 1970s. This has occurred through a number of factors including increased feed supply through greater use of nitrogen (N) fertiliser and increased use of supplementary forage feeds. Potentially, the integration of low-protein forage (e.g. maize), to reduce dietary-N concentration, or winter management practices (e.g. use of stand-off pads), to reduce excreta to soil, can mitigate environmental N emissions and increase efficiency. However, effects of these mitigation practices on resource use efficiency and environmental emissions, such as greenhouse gas emissions and N leaching, have not been tested. These effects are currently being investigated by AgResearch, using simulation modelling and field testing. In this paper, findings from simulation modelling using a Life Cycle Assessment (LCA) approach are presented for resource use efficiency and environmental emissions associated with intensification of dairying involving increased N fertiliser use and forage cropping. A comparison of an average New Zealand dairy farm and an example EU dairy farm is also presented. A farmlet study of the effects of the intensification and mitigation practices on environmental emissions (including N_2O emission) is also described.

Farm Systems, Data and Modelling

An LCA study was used for whole-system analysis. Three whole-farm systems were evaluated, representing the average farm system (base dairy farm carrying 2.8 cows/ha and land used for dairy replacements and forage) and two intensification options (base farm plus extra 200 kg fertiliser-N/ha or extra 2 t DM/ha of maize/oat silage) to achieve a 20% increase in milk production.

Data were obtained for “average” and “intensive” dairy farms using farmer interviews and dairy industry statistics. Maize cropping data were supplied by Gavin Grain Ltd. Nutrient losses were estimated using the OVERSEER® nutrient budget model (Wheeler et al. 2003). Greenhouse gas emissions were calculated using NZ-IPCC methodology.

Dairy Farm Intensification: Modelling Estimates

The two intensification options involved increased use of N fertiliser or forage. In terms of land use efficiency, N fertiliser was the most efficient at increasing productivity per unit of land area, particularly when the land use of the whole-system was accounted for (Table 1). However, N leaching per m^3 of milk increased by about 70% for the +200N system, and there was a similar increase when estimated on a whole-system basis. In contrast, the forage treatment decreased N leaching per m^3 of milk by 10% on the dairy farm, but this efficiency gain was reduced when total land use was considered.

Greenhouse gas emissions per m^3 of milk were similar for the base farm and +forage system, but increased by about 15% for the +200N system due to increased N_2O emissions. However, results for the forage system depend on how the maize cropping is treated. If a dedicated area is used for long-term maize cropping, emissions would be higher due to the long-term emission of CO_2 from land cultivation and cropping by an equivalent of approximately 220 kg CO_2-equivalent/ha/yr on a whole-system basis (using summary of published data). If it was a part of pasture renewal strategies on farm, there would be little net long-term change in soil C and this could be ignored. This evaluation highlighted that the choice of intensification method influences the potential for gain in dairy farm system efficiency.

Table 1: **Effect of intensification from 10 (average) to 12 m^3 milk/ha, using N fertiliser (+200 kg N/ha/yr) or forage (+2 t DM/ha/yr as maize + oats silage), on environmental emissions, estimated by modelling. Data for the dairy farm only and the whole-system (dairy farm + grazing + forage land) are compared.**

	Dairy Farm			**Whole-system**		
	Av.	**+200N**	**+Forage**	**Av.**	**+200N**	**+Forage**
Milk (m^3/ha/yr)	10.0	12.0	12.0	8.3	10.0	9.4
N leached (kg/ha/yr)	36	74	38	32	64	35
GHG (kg CO_2-equiv/ha/yr)	8590	11970	10780	7790	10590	9940[1]
Efficiency indices:						
kg N leached/m^3 milk	3.6	6.2	3.2	3.9	6.4	3.7
kg CO_2-equiv/m^3 milk	859	998	898	939	1059	1058

[1] Not accounting for CO_2 emission from soil (see text).

New Zealand Average Farm vs Swedish Farm

GHG emissions per m3 of milk for the average NZ dairy farm were similar to those for the Swedish dairy farm of Cederberg (1998) (Fig. 1). While the energy-related CO2 emissions were greater for the Swedish farm, this was countered by lower methane emissions per unit of milk from high-producing Swedish cows. Total farm energy use per m3 of milk on the Swedish farm was over 5-fold higher than that of the NZ farm on a whole-system basis. This was mainly due to high fuel use in the Swedish farm system for crop production, feeding and heating the farm dairy. The NZ farm system with all-year-round grazing of long-term permanent legume-based pastures is a low energy requiring system, but this advantage may diminish with intensification. Further research is required to determine whether the energy advantage of the NZ farm system is sufficient to compensate for “food-miles” or the energy cost associated with shipping dairy produce from NZ to Europe.

Field Research

A Dexcel Resource Efficient Dairying farmlet systems trial (RED trial) has commenced to evaluate new intensive dairy farm systems and includes treatments with integration of N fertiliser, maize silage and winter management strategies (Clark 2003). A key goal of this trial is to define farm systems for increasing milk production while minimising N losses to the environment. This trial provides an ideal opportunity to evaluate the effects of intensification on nutrient use and flow, soil physics, soil C changes, N losses to groundwater and N_2O emissions.

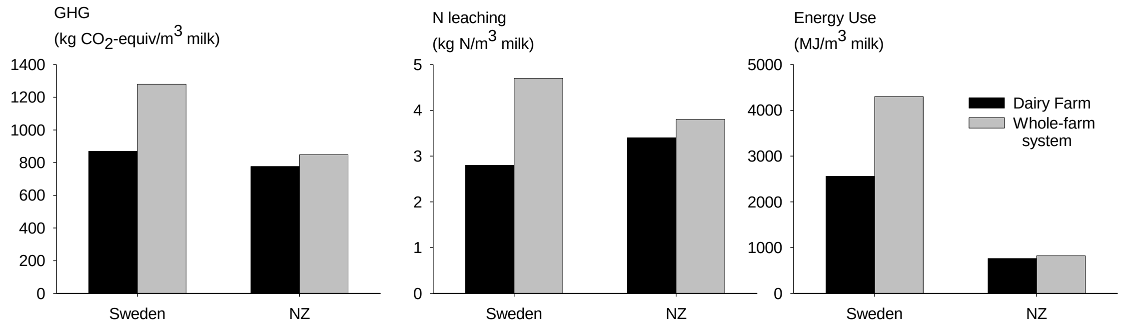

Figure 1: **Comparison of an average NZ dairy farm and an example Swedish dairy farm (Cederberg 1998) for GHG emissions, N leaching and energy use (fuel+electricity) based on the dairy farm unit or the whole farm system which includes land for grazing and production of forages and concentrates.**

N_2O emissions are currently being measured (using cover chambers) from farmlets in the RED trial associated with three management practices. These management practices are:

N fertiliser application,
strategic use of a stand-off pad between mid-autumn and early-spring but with 6-hour grazing (to reduce nitrate leaching and soil physical damage),
maize/annual ryegrass cropping for silage (and the associated N fertiliser use).

Management practices II and III offer the potential to increase productivity while reducing N_2O emissions. Understanding the extent and seasonal variation of N_2O emissions from N fertiliser is important for defining best management practices for N fertiliser use. We are also measuring N_2O emissions from all components of the farm systems (including that from the dairy farm, cropping land and stand-off pad). Total emissions of N_2O from different “whole” systems will be calculated. The calculated data will be used to validate nutrient cycling models and to contribute full greenhouse gas budgets for the farmlets. The ultimate aim is to develop cost-effective management practices and technologies to reduce greenhouse gas emissions while increasing productivity.

Conclusions

Model simulation using an LCA approach indicates that fertiliser N increases production and economic efficiency but decreases environmental efficiency through predicted increases in N leaching and greenhouse gas emissions. In contrast, using forage increases the use of land and production efficiency, with a decrease in N leaching and no increase in greenhouse gas emissions (per litre of milk). Field research is currently being conducted to measure the effects of dairy farming intensification and mitigation practices on environmental emissions.

Acknowledgements

FRST, PGGRC and FertResearch for funding. James Gavin for maize industry data. Dave Clark (Dexcel) for research links to the RED trial.

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8 CLEAN AIR MEASUREMENTS

8.1 METHANE AND NITROUS OXIDE MEASUREMENTS IN CLEAN AIR

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NIWA, Wellington

Agricultural methane (CH_4) and nitrous oxide (N_2O) emissions comprise about 50% of New Zealand’s greenhouse gas emissions. This makes New Zealand unique amongst developed countries.

Over a 100-year time horizon, CH_4 has a Global Warming Potential (GWP) of 23, making it 23 times more effective as a greenhouse gas than CO_2. N_2O has a GWP of 296.

Methane

The main sources of CH_4 in New Zealand are emissions from ruminant animals, primary production processing waste, and rotting waste at landfills. Other sources are fossil fuel burning, biomass burning, wetlands, rice paddies, and termites.

The main sink of CH_4 is destruction by the hydroxyl radical (OH) in the atmosphere.

NIWA has measured CH_4 at Baring Head (42°S, 175°E) and Arrival Heights (78°S, 167°E) since 1989. CH_4 values are slightly higher at Baring Head than at Arrival Heights.

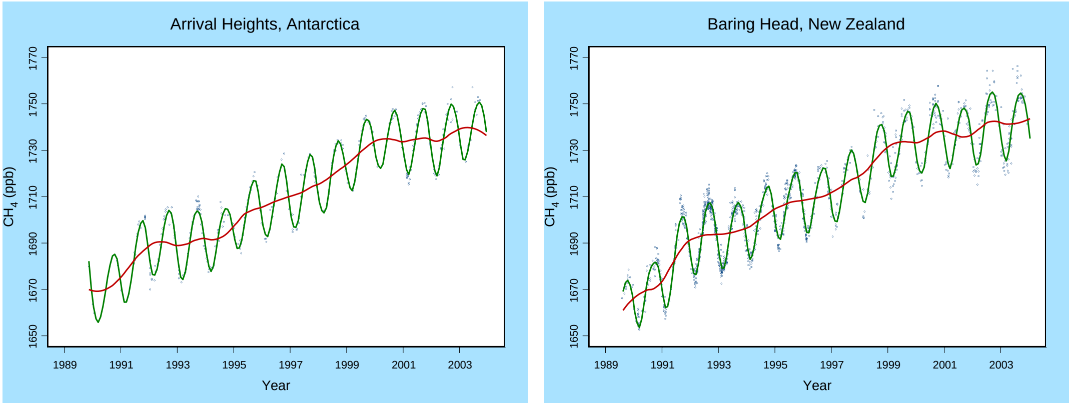

Figure 1. **Methane in clean air at Baring Head and Arrival Heights. The green line is a smooth curve through the data, based on a time varying trend and seasonal cycle. The red curve is a time varying trend in which the seasonal cycle has been removed. Both sites have a strong seasonal cycle, with a maximum in September and a minimum in March. The rate of increase of CH4 varies over time. Large growth rates (10-20 ppb/yr) occurred at Baring Head in 1991, 1992, and 1998. The growth rate has slowed since 1999.**

^{13}C in Atmospheric Methane

Measurements of the isotope ratio $^{13}C/^{12}C$ (reported as $\delta^{13}C$ values) in CH_4 have been made at Baring Head since 1989 and at Arrival Heights since 1991.

Different CH_4 source types produce CH_4 with different isotope ratios, so the $\delta^{13}C$ values help to constrain the methane budget.

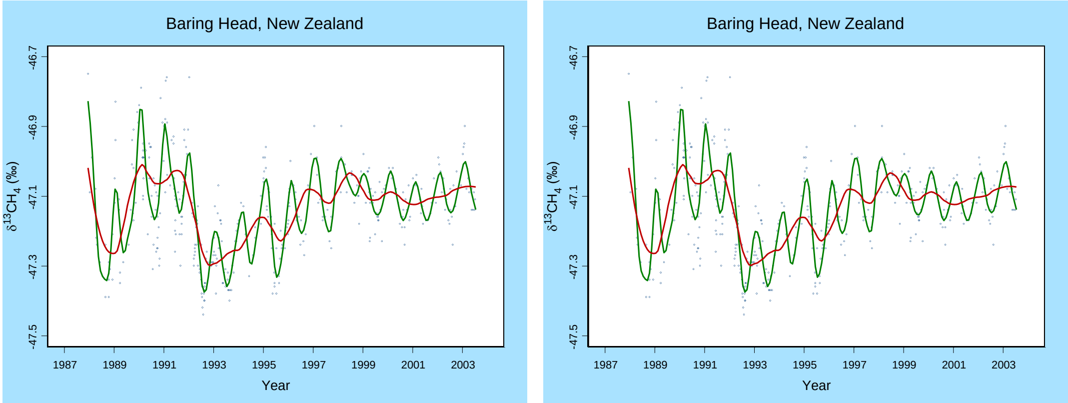

***Figure 2*. $\delta^{13}C$ in clean air at Baring Head. The green line is a smooth curve through the data, based on a time varying trend and seasonal cycle. The red curve is a time varying trend in which the seasonal cycle has been removed.**

At Baring Head there is a seasonal cycle in the $\delta^{13}C$ values, about 6 months out of phase with the CH_4 mixing ratio seasonal cycle.

There was a sharp drop in $\delta^{13}C$ values at Baring Head in early 1992 followed by a steady recovery.

Nitrous Oxide

There are many sources of N_2O: use of nitrogen-based fertilisers, fossil fuel combustion, use of groundwater for irrigation, crop production, production in soils and oceans, biomass burning, nylon manufacture.

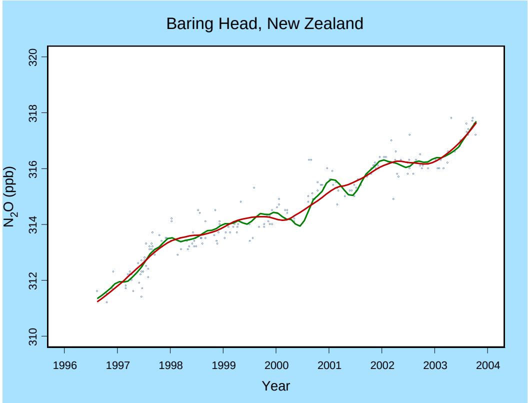

***Figure 3*. N_2O in clean air at Baring Head. The green line is a smooth curve through the data, based on a time varying trend and seasonal cycle. The red curve is a time varying trend in which the seasonal cycle has been removed.**

The main sink of N_2O is destruction in the stratosphere. N_2O is chemically inert in the troposphere.

N_2O has been measured at Baring Head and Arrival Heights since1996.

Baring Head has a weak seasonal cycle, with a maximum in December/January, and a minimum in May/June.

The growth rate at Baring Head varies between 0.5 and 1.5 ppb/yr.

Acknowledgements:

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8.2 THE USE OF HIGH-RESOLUTION FOURIER TRANSFORM MEASUREMENTS IN TRACE GAS RESEARCH

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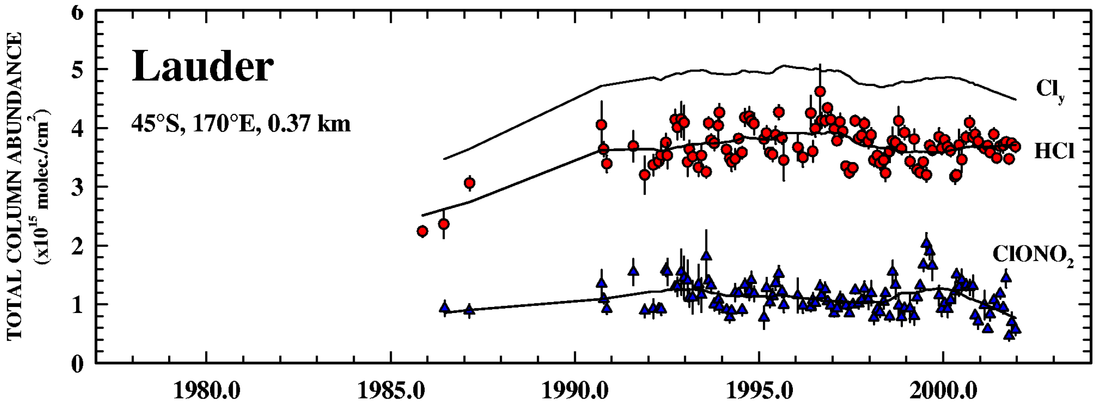
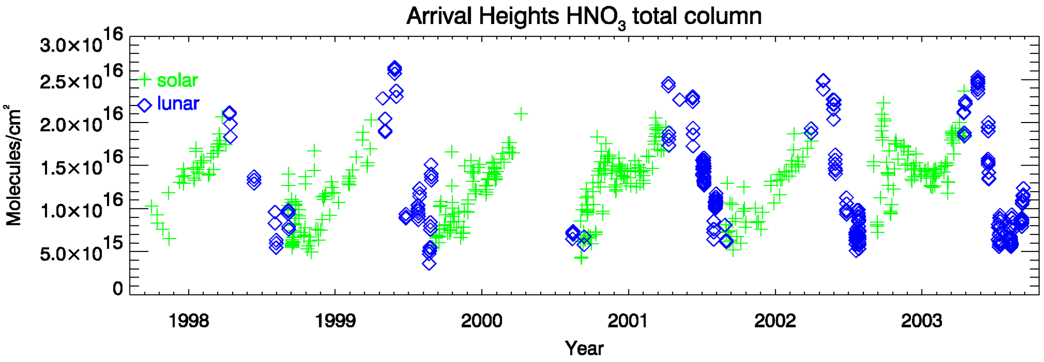
Introduction

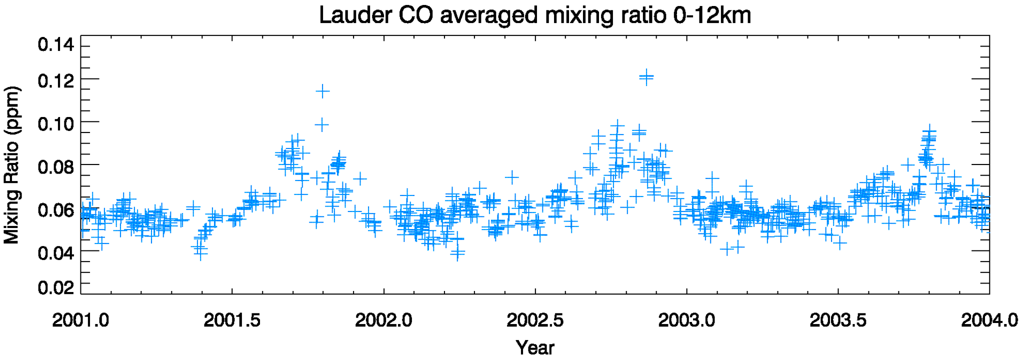
High-resolution Fourier transform spectrometers have been used for many years in remote sensing of atmospheric traces gases. The measurement technique is to use a ground-based instrument to record spectra of direct sunlight, which contain the absorption signatures of the atmospheric gases of interest. In particular this technique has been used for stratospheric gases, where the high resolution is required to resolve absorption lines. Typical wavelengths of operation are from 2.5 to 14 microns, the “mid-infrared”. Retrievals are inversions of a forward model that simulates the spectrum as a function of the atmospheric state, usually using optimal estimation techniques.



Examples of results

The spectra record absorptions of many trace gases that are present in the stratosphere and troposphere. Three examples of results are shown here. The first shows the record, from the Lauder FTS site, of two chlorine trace gases that represent the bulk of the chlorine in the stratosphere, and the fact that this chlorine is just starting to level off and possibly decline as a result of Montreal protocol measures. The second shows the record of nitric acid (HNO_3) from Arrival Heights, Antarctica, showing the strong seasonal changes due to the formation of polar stratospheric clouds which contain HNO_3 during the winter, a key step in Antarctic ozone depletion. The third example is the record of carbon monoxide (CO) from Lauder in Central Otago for the last three years, plotted as an averaged tropospheric mixing ratio, showing the enhancement in CO during the springtime from biomass burning.





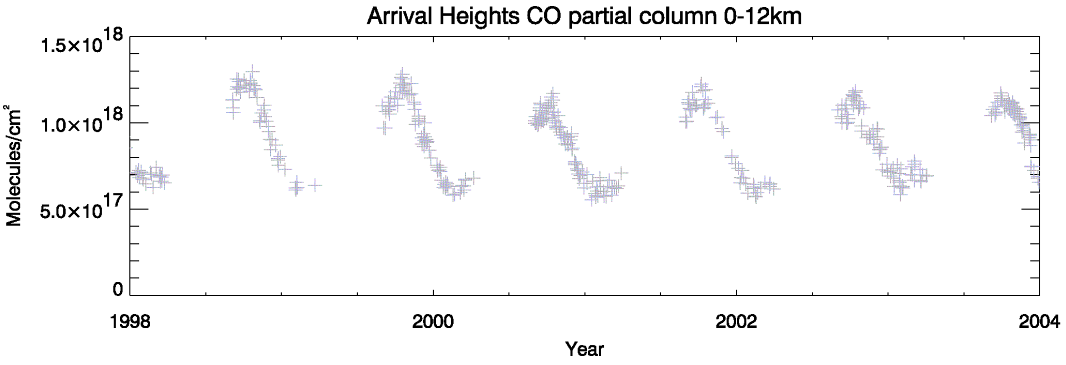
Height information in the measurements

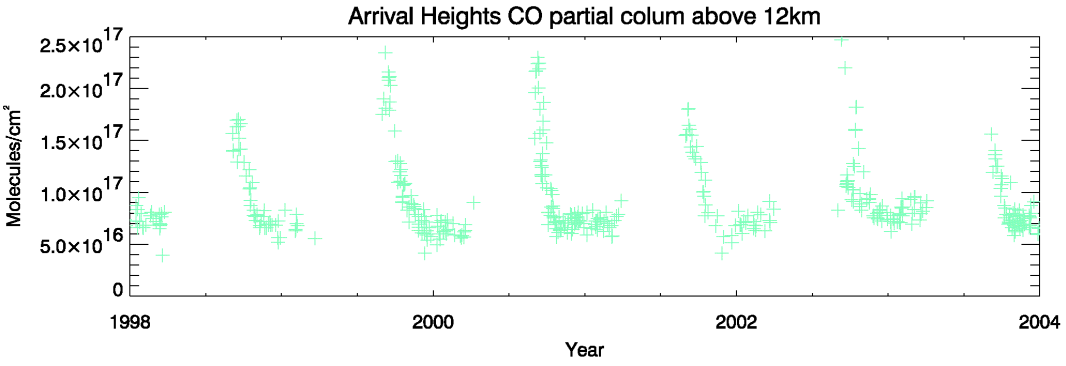
In many instances information on the height distribution of the gas measured can be determined from observed lineshapes. For example, the following figureshows that stratospheric CO above Arrival Heights in Antarctica follows a different seasonal cycle from tropospheric CO. The tropospheric partial column follows a smooth seasonal cycle driven by tropospheric transport from mid-latitudes, while the smaller partial column stratosphere shows enhancement in spring due to cooling and descent during the polar night (CO mixing ratios increase with height in the stratosphere and mesosphere).

New work on greenhouse gases

Ground-based FTS has an important new role in the validation and characterisation of proposed new satellite sensors for greenhouse gases, eg CO_2, CH_4. For this it is best to move to shorter wavelengths, near-infrared and visible, requiring some instrument modifications.

- the measurements need high precision to be useful –
- the target for CO_2 is 0.1% in total column. As well as making measurements to the required quality, retrievals to this precision may need improvement in the spectral model. to reduce some of the measurement error, the O_2 column is measured as well as the gas of interest and used to derive a column weighted mixing ratio.
- ground-based FTS measurements will be used as a transfer or comparison standard to relate satellite measurements to point in-situ measurements. The satellite measurements are generally making a similar spectral measurement to the ground-based FTS but have spatial averaging and different height sensitivity. Ground-based FTS measurements will characterise these effects.





Testing of this measurement capability has begun at Lauder by modifying one of the existing instruments there, in partnership with the Californian Institute of Technology, where similar measurements are underway.

Acknowledgements

This work is supported by the Foundation for Research, Science & Technology, Antarctica New Zealand and several international collaborators. Figures have been adapted from
Rinsland, C.P.;et al (2003). Long-term trends of inorganic chlorine from ground-based infrared solar spectra: Past increases and evidence for stabilization. Journal of Geophysical Research 108(D8): 10.129/2002JD003001.
Wood, S.W.; et al (in-press, 2004). Ground based nitric acid measurements at Arrival Heights, Antarctica, using solar and lunar FTIR observations. Journal of Geophysical Research.

8.3 THE MEASUREMENT OF HYDROGEN AND METHANE GAS USING A SEMICONDUCTOR CHIP SENSOR

Akio Takenaka, Kiyoshi Tajima, Makoto Mitsumori, Hiroshi Kajikawa, Takashi Osada, and Mitsunori Kurihara
National Institute of Livestock and Grassland Science, Tsukuba, Ibaraki, Japan.

A novel gas analyzing system using a semiconductor chip sensor designed for the analysis of human expired gases has been used to analyze environmental gas samples. This sensor can detect hydrogen, methane, and carbon monoxide gas within 5 minutes and with a sensitivity of 0.1 ppm for each gas.

In order to analyze environmental gases near cattle barns and manure composting areas, gas samples were collected into 50 ml disposable syringes and then transferred to evacuated 30 ml vials. The glass vials were used for transport and storage. Standard gas samples kept in the vials at room temperature were stable for at least for 2 weeks. Expired gases from cattle were collected into an evacuated container via a sampling tube placed near the nose. Ammonia concentration was measured at the site of sampling using an ammonia detector. Nitrous oxide concentration was determined by gas chromatography (GC), and hydrogen and methane concentrations were measured using the semiconductor chip sensor gas analyzer (SCGA) (Model mBA-3000, TAIYO Instruments Inc. Osaka, Japan).

Eighty to 90 gas samples for analysis were collected from around cattle barns and composting areas in Hokkaido. Analyses showed that methane concentrations varied from 2.0 to 181 ppm, whereas hydrogen concentrations varied between 0 and 5 ppm. There was no correlation between methane and hydrogen concentrations or methane and nitrous oxide concentrations, but there was a weak correlation between methane and ammonium concentrations (Fig.1). Sometimes methane concentrations as high as 200 ppm were recorded, especially in cattle barns. The monitoring of methane concentration could be used to monitor conditions such as air ventilation in barns containing animals, or could be used to monitor composting.

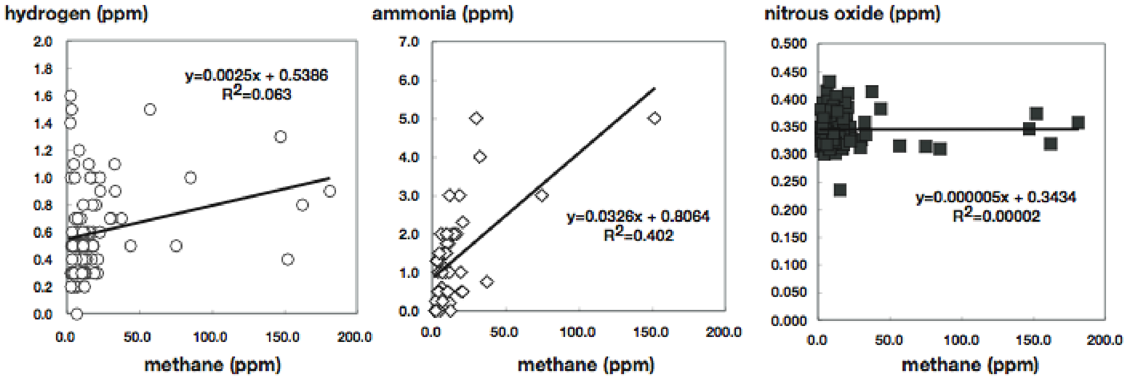


Fig. 1 Correlation between methane concentration and hydrogen, ammonia, or nitrous oxide concentration in the environmental gas.

Gas analysis of expiration of cattle.

A further 70 gas samples were collected from cattle maintained indoors or in a metabolism chamber. The measured methane concentrations were found to vary from 1.1 to 315 ppm. Methane concentrations detected by SCGA were similar to those detected by GC, and there was high correlation between values measured by two methods (Fig.2). The mean of the values detected by SCGA was higher than that detected by GC. There was no correlation between methane and hydrogen concentration in the expiration of cattle (Fig.3). This indicates either that hydrogen is not accumulating in the rumen or that there are difficulties in collecting the hydrogen. The results show that the semiconductor chip gas analyzer could be used to measure methane and hydrogen gases in animal production areas, and also may form the basis of a future system for monitoring these environmental gases.

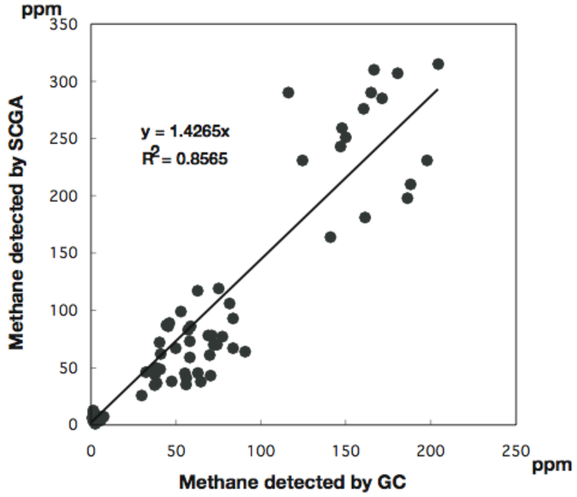


Fig. 2 Correlation between the concentration of methane gas deteced by GC and SCGA. (GC: Gas Chromatography, SCGA: Semiconductor chip sensor gas analyzer)

8.4 MONITORING NEW ZEALAND METHANE EMISSIONS

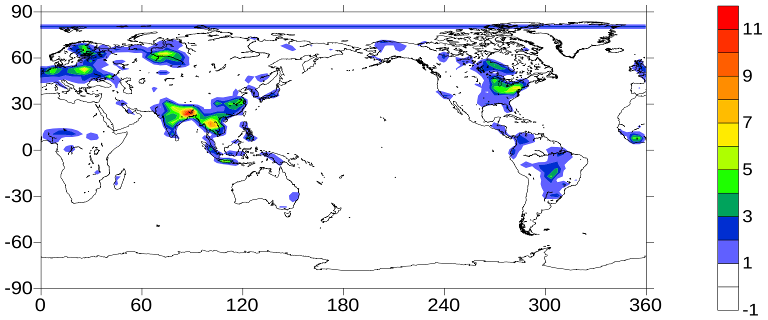
Ben Liley, Hamish Struthers, and Brian Connor
NIWA, Lauder

With its ratification of the Kyoto Protocol, New Zealand needs to measure and monitor emissions over a range of scales. If significant reduction in emissions can be achieved, and proven, the country can earn ‘carbon credits’. This applies especially to methane and nitrous oxide, for which New Zealand's emissions are very large, per capita, by comparison with the rest of the world.

How can we measure New Zealand’s methane emissions to verify the inventories and detect any unexpected sources or sinks? Experience with ozone and other important trace gases suggests one line of attack:

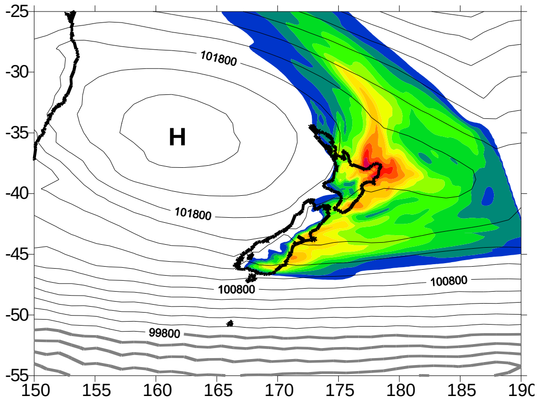
- Satellite observations give national coverage and automated measurement of many trace gases, including methane.
- General circulation models describe the transport of atmospheric species with well-characterised reliability.
  Embedding a local model within the global model allows local sources to be treated with precision.
- Retrieval theory can relate measurements to atmospheric concentrations and profiles.

It can be extended to relate them to sources and sinks.



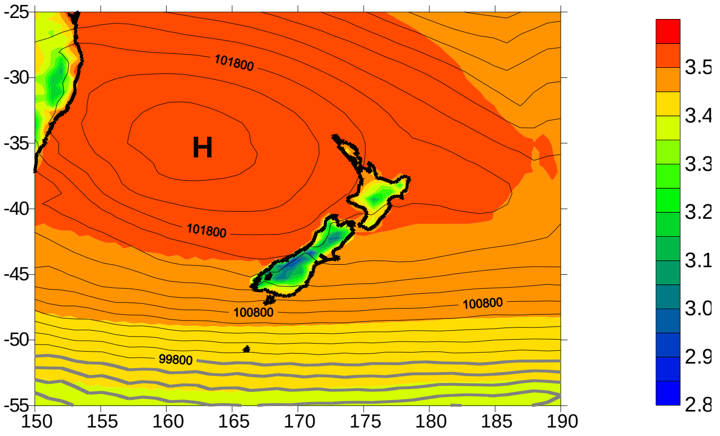
EDGAR global CH_4 emissions (mg km^{-2} s^{-1})

Using the Emissions Database for Global Atmospheric Research (EDGAR) in conjunction with the UKMO Unified Model, boundary conditions for the ‘limited area model’ NZLAM are established. Ruminant stock numbers, human population density, and wetland areas for each Territorial Local Authority (TLA) provide an a priori estimate of NZ methane emissions totalling 1.2 Tg yr^{-1}. Advecting these sources for four weeks within NZLAM yields a pattern of transport and accumulation in the column.



**Daily average CH_4 column for 11 March 2000, for NZ emissions only.
Contour intervals are 2.5 x 10^{15} cm^{-2}.**

This looks promising, until the background from global emissions of ~600 Tg yr-1 is added. What little pattern remains over land is misleading – it is simply the changing depth of the column allowing for underlying topography. Dividing out this factor (not shown) yields the same lack of detail over land as seen over the surrounding ocean.

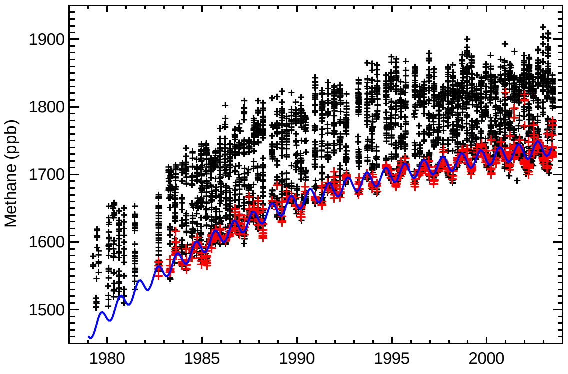


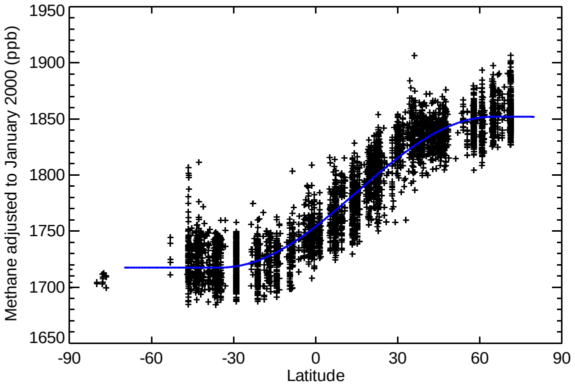
As above with global emissions added. Units are now 10^{19} cm^{-2}.

Satellite instruments now in development or in prospect have, at best, the relative precision of contours in the plot (~1%). At this precision and in ideal conditions, they are unlikely to detect even that New Zealand emits methane. Retrieval of national source strengths from satellite data alone is not possible without 1-2 orders of magnitude improvement in measurement precision.

The same model results show that if it is possible to measure just in the boundary layer, the patterns of emissions may be readily discernible.

We test this by examination of a data series from over twenty years of sampling New Zealand air for methane and other hydrocarbons. The measurements come from a latitudinal study by the University of California at Irvine, which has sampled air across the Pacific from Alaska to Antarctica quarterly since 1979. Of the 4378 samples to June 2003, 571 are from New Zealand and cover all latitudes from Cape Reinga to Stewart Island.

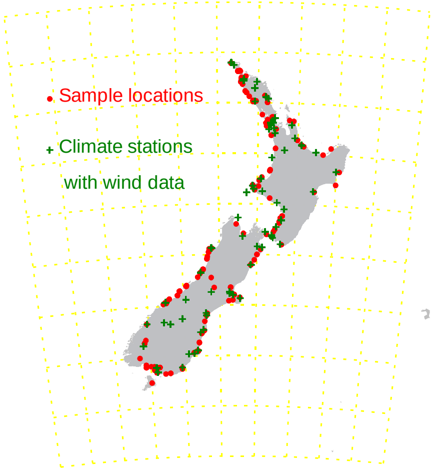


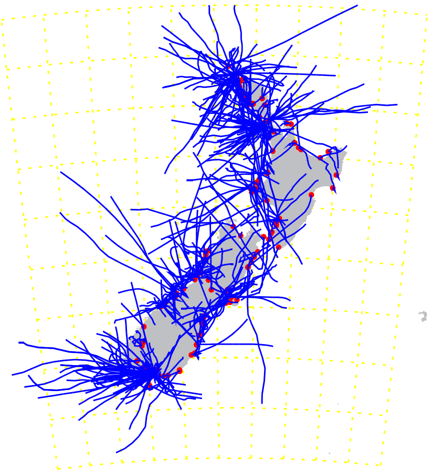


UCI CH_4 data; New Zealand samples in red

Latitudinal variation of CH_4 at Earth's surface

A regression fit of seasonal, latitudinal and secular variation highlights samples that seem anomalously high, though it can be noted that the highest concentrations measured in New Zealand are still below typical values for northern latitudes.

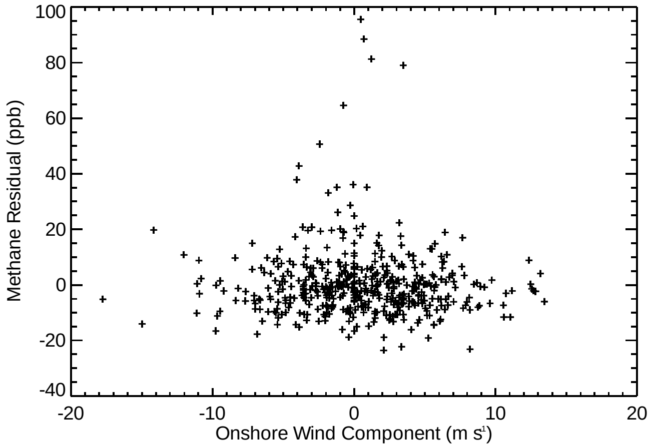




From the New Zealand climate network, those stations with hourly surface wind data within 50 km and 12 hours prior to sampling are identified. The wind records are used to obtain approximate 12-hour back trajectories for each sample.

As the trajectories are generally consistent in direction over the 12 hours, we can treat the wind direction at sampling time as a reasonable index of wind origin. In particular, the wind component perpendicular to the nearest coastline is a measure of local (land-based) or remote origin.

Methane enhancement relative to the regression fit is plotted against on-shore wind component in the figure below. Marked enhancement is visible in 12-15 samples collected in very light winds, when concentrations can build up in the boundary layer.



Ruminant emissions are a plausible source for some samples, but in these conditions industrial, transport, or residential emissions of natural gas cannot be ruled out.

The problem can be compared with proposed satellite-based measurement, which can achieve excellent coverage but will not be able to distinguish the surface enhancement within the whole atmospheric column. *In situ* sampling can readily achieve the required precision, but substantial methane enhancement occurs in conditions where their representativeness is unclear.

For any future monitoring of New Zealand methane emissions, new techniques and technology are required.

We thank Don Blake of UC Irvine for use of these data.

8.5 A NEW TECHNIQUE FOR AGRICULTURAL CH_4 EMISSION MEASUREMENTS

D. Ferretti, R. Martin, G. Brailsford, J. McGregor, and K. Lassey
NIWA, Wellington

We are developing a new technique to determine methane (CH_4) emissions from agricultural livestock.

The overall aim is to improve information on New Zealand emissions of agricultural greenhouse gases so that we can better quantify and manage greenhouse gas inventories. More specifically, the improved methodology will allow accurate estimates of methane emission rates by grazing ruminant livestock. Thus it will be a practical means to demonstrate that strategies to mitigate emissions do actually achieve their goals (or not). This will give us an assured basis for claiming emission reductions in the national greenhouse gas emission inventory and for claiming any consequent carbon credits.

Our technique involves the use of a very small solid state Metal-Oxide Semiconductor. Key requirements are:
–Rapid & low cost field deployment.
–Non-intrusive to animals.
–Useful resolution, precision & accuracy.
–Validated tracer to determine emission rate.
Environmental parameters affect the CH_4 concentration measurement (*e.g.* Relative Humidity, Temperature, Pressure, Flow rate, and deoxidizing gases such as hydrogen and hydrocarbons). Therefore careful gas handling procedures and are necessary and calibration is required to correct apparent CH_4 concentration for influencing parameters across the range expected in the field.

In addition to the environmental parameters, electronic signal processing affects the measurement (*i.e.* digital to analogue conversion). To maximize both the resolution and the CH_4 measurement range, the resolution is very small for low concentrations and then gets progressively more granular at higher concentrations. In practice the finest reporting resolution is 1 ppm.
We have measured real-time CH_4 variations in the field (Figure 1) and are investigating the use of natural tracers *e.g*. Temperature, Relative Humidity and Oxygen because the sulphur hexafluoride (SF_6) tracer usually used does not meet all of the requirements (especially low cost).

By using a natural tracer we aim to determine livestock breath sampling efficiency and CH_4 emission rate. Once we have validated the technique against the SF_6 tracer technique it can be used to provide a better understanding of New Zealand's CH_4 agricultural emissions.

Acknowledgements:

Research funded by the Foundation for Research, Science & Technology. Collaborative support and funding from AgResearch and Dexcel is also acknowledged.

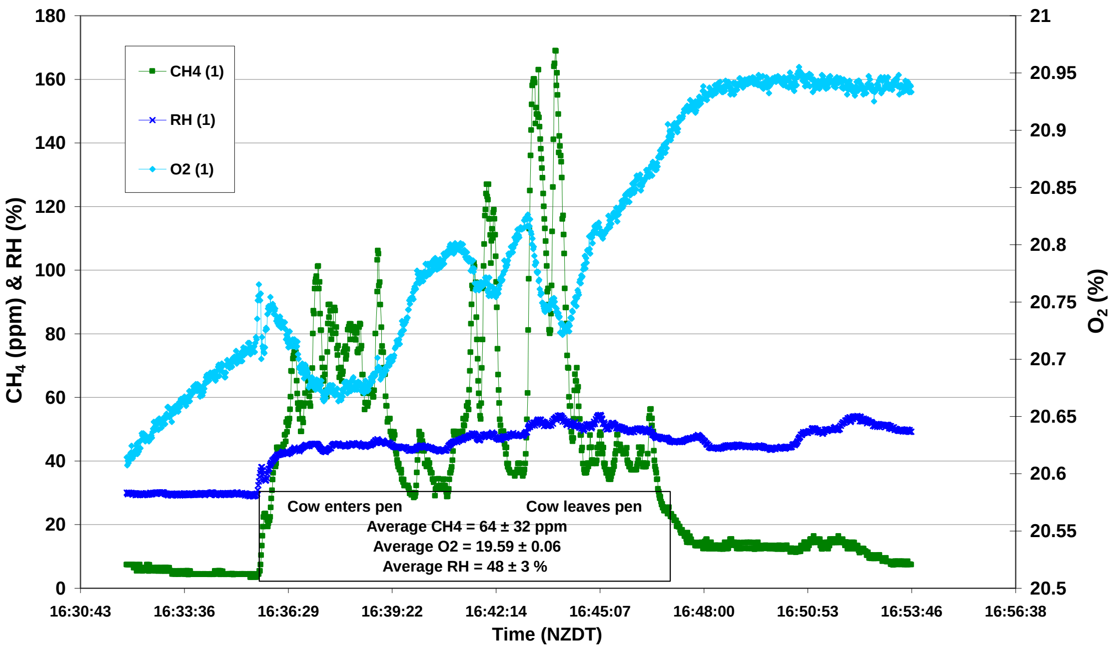


Figure 1. **RH, CH_4 and O_2 concentration variations from breath collection during milking. Relatively large and rapid emission variations are observed. The collection efficiency varies with time as does the milking shed CH_4, RH & O_2 background because ~150 cows move through and wind velocity changes.**

9 THE HUMAN DIMENSION

9.1 COMMUNICATING CLIMATE CHANGE TO STAKEHOLDERS

Terry G Parminter
AgResearch, Ruakura

Background to the Study

Landowners' beliefs about greenhouse gases and climate change provide the key determinants of any communication strategy on those issues. They form the basis of peoples' feelings of responsibility and provide the motivation for them to make any behavioural changes. Landowners want good reasons to be given to them about why they should change their management for other than commercial results. These reasons should be related to the known goals and values of landowners.

In a research project of peoples' beliefs about greenhouse gases and climate change, a postal survey was held for rural landowners in March 2003. The information that was obtained from the survey can be used by government agencies to assist them in understanding the attitudes and motivations behind landowners' responses to policy initiatives on these topics. A total of 3,000 landowners were sent the questionnaire and 23% responded. Although the final sample may be less than representative, the number of respondents was sufficient to provide statistically significant results.

Importance of Greenhouse Gases the Climate Change Issue

More than two thirds of respondents to the survey identified human activities and the production of greenhouse gases as the main cause of climate change problems in the world. They were almost evenly split over whether the issue was significant enough to require their attention or not. Even if they considered the issue of climate change to be important, the majority of landowners believed that changes to farming practices in New Zealand would cause little or no reduction in climate change at an international scale. Some landowners (38%) considered that climate change was more of a political (rather than a technical) issue, related to the Government's desire for international trading agreements rather than environmental outcomes.

The survey findings show a low level of certainty over the importance of the issue, and an expectation that changes by landowners will have little effect. There is also confusion over whether the issue is the environmental responsibility of landowners or the political responsibility of Central Government. This confusion about the need for management practices to reduce climate change is important. It is no use Government agencies promoting climate change *solutions* to landowners until landowners have been able to understand the *problem* that needs to be solved and the level and limits of their *responsibilities* towards resolving it.

Communication about Climate Change

The need for clarity about climate change issues indicates the importance of early public communication and readily accessible information. The information should describe the effects of climate change upon New Zealand. If New Zealand's climate change policy is being determined by the Kyoto Agreement, then a simple, clear rationale for this needs to be included. Alternatively, if New Zealand's climate change policy is being determined by the responsibility of individual landowners towards consumers in export markets or local communities, then the benefits of landowners acting on this responsibility should also be included. Landowners wanted scientists to be more objective in their research and to separate themselves from any political agendas. Providing technical information about possible management practice changes for landowners should be presented only in the second stage of a communication strategy after sufficient numbers of landowners recognise that ‘a problem exists’ and understand the level of their responsibility to address it through practice change. Any action by Government agencies to ‘push’ practice changes before the need for them has been established can be expected to meet landowner resistance.

The general media (newspapers, magazines, radio, and TV) were landowners’ main sources of information on climate change, but landowners often thought that the media provided unbalanced material. Landowners wanted more information on climate change, particularly more useful information. Generally, the usefulness of information was more limiting to landowners than any lack of ability to access it when required.

Based on the survey results, landowners can be segmented into different groups depending upon how they are likely to respond to Government interventions about this topic. The results of segmentation indicate that just under 50% of landowners were likely to respond to further communication about climate change issues that encouraged them to take greater responsibility for the consequences of their actions. Further social research and consultation will be required before the needs of these groups can be clearly specified and addressed in any communication strategy.

Acknowledgment

This work was supported by the New Zealand Foundation for Research, Science & Technology under contract C10X0223.

Further Reading

Parminter TG and Wilson JA, 2004. Landowners’ Beliefs about Greenhouse Gases and Climate Change as an Agricultural Issue of Importance. AgResearch Report.

9.2 MĀORI AND CLIMATE CHANGE: CARBON SEQUESTRATION OPPORTUNITIES ON MĀORI LAND

Garth Harmsworth
Landcare Research, Palmerston North

Introduction

Interim results are given from ongoing work in the FRST programme "Reducing Greenhouse Gas Emissions from the Terrestrial Biosphere (C09X0212)". A Maori research focus is helping to develop strategies to increase Māori participation at all levels and to provide Māori perspectives and Māori land data in GHG research. The work is being carried out as part of a larger human-dimensions objective "Mitigation processes and strategies" to achieve:

- information sharing, and understanding of national and international climate issues and policy
- exchange information and highlighting of opportunities for indigenous vegetation restoration/reversion projects for carbon mitigation, and to reduce forest clearance
- participatory research

Background

Between 1 and 2 million hectares of New Zealand is considered marginal land that could potentially sequester 2-4 million tonnes of carbon per year [MtC/yr], approximately equal to 25% of New Zealand's annual emissions. Large tracts of Maori land have been described as 'undeveloped' – figures commonly quoted as 600 000 hectares. We know little about the physical characteristics of this Maori land and where it is, or about the drivers of land-use change on such land. Our research therefore seeks to find out:

- Some of the key Maori issues and research questions regarding climate change, and whether Maori are interested in participating
- How much Maori land is available (at 1990 and present) that could be eligible for carbon sequestration, such as through afforestation/reforestation
- How Māori are likely to respond to policies
- How governance structures affect Maori land use
- How to design policies that adequately address Maori concerns
- What opportunities there are for Māori

Methods

Methods have been developed to quantify 'Kyoto eligible' Maori land and to increase Māori dialogue and participation in climate and Kyoto research through case studies and collaborative learning with Maori landowners, researchers, policy makers, and other groups. A large number of GIS analyses were carried out using various spatial data, including the Maori Land Information Base (MLIB) 1998 & 2002, the Land Cover Database (LCDB) of New Zealand, the Vegetative Cover Map (VCM) of New Zealand, and the New Zealand Land Resource Inventory (NZLRI). The MLIB basically contains information on all Māori freehold land, which is largely multiple-owned land in New Zealand. A number of hui and participatory learning workshops have concurrently been undertaken to find out Maori issues, perspectives, understanding of climate change, land ownership and use, and governance. This work has involved both Māori landowners and a number of staff from Government and non-Government agencies.

Because there are large areas of manuka/kanuka scrub and marginal land on the Gisborne-East Coast, a regional learning case study is being carried out in this area. Central to helping with this work have been the Office of the Māori Trustee in Gisborne, Te Puni Kokiri Gisborne, and Ngati Porou researchers and landowners. Research to date has identified opportunities for Maori landowners to sequester carbon, by:

- understanding the nature and characteristics of Maori land
- determining the governance structures on Maori land
- determining and understanding barriers/problems/challenges
- identifying and quantifying Maori land blocks under different land uses

Such information enables researchers to understand Maori aspirations for land development and contributes to conceptual and empirical analysis of policy design.

Findings to date

Maori freehold land makes up only 3.07% of the total New Zealand land area, or 6.85% of the North Island. Maori land information (MLIB) was combined with vegetative cover data (LCDB), the VCM, and the NZLRI, to show that between 300 000 and 400 000 ha of Māori land is marginal. However, most of this land (~80%) is covered in native forest, mature scrub, or production forest, and is regarded as an appropriate and sustainable land-use. About 255 000 to 345 000 ha or 31–42% of the total Māori land area is covered in mature indigenous scrub and native forest. Pastoral or grazing land represents only 28% of Māori land, compared with 52% nationally. An area of between 40 000 and 50 000 ha of marginal Māori land is in pasture (as at 1990) and it is this land that may provide an opportunity for reforestation or regeneration to scrub under landuse/climate change schemes. Much of this Maori marginal land in pasture is located in the Gisborne East Coast and in Northland.

Some of the major Māori land issues surrounding land-use change mean that any climate/land-use change policy will have to take into account:

- Māori control, retention and use of their land in perpetuity
- costs associated with new schemes
- existing governance structures and decision-making
- cost of rates on developed land
- payment schedules with any contract or agreement
- other posssible income sources and opportunities for diversification
- customary access, use, and rights
- future land-use development

Governance issues for Māori land that have to be taken into account and understood include:

- multiple ownership
- management structures
- different levels of decision-making ability
- difficulties in raising capital and associated costs

Conclusions

Research results to date have provided new quantitative information on Māori land including areas, physical characteristics, vegetative cover, area and geographic location of marginal land, and areas eligible for indigenous reversion under “Kyoto forest” definitions. This information shows that a range of factors needs to be understood to realise opportunities on Maori land. These include: governance and existing management structures; barriers to land development; control and ownership issues; development aspirations; requirements for capital; associated costs; customary use; and questions on how land-use development on Maori land is viewed by local and central Government.

There are many opportunities to use Maori land for carbon sequestration and to promote sustainable land use and management. Policies along with Māori aspirations and values can be used to encourage afforestation and reforestation, and discourage forest clearance, as a short-term tool to mitigate greenhouse gas emissions. These opportunitues need to work alongside other schemes such as the East Forestry Project and Nga Whenua Rahui (DOC) and require understanding, effective, and targeted policy.

Future research

This research continues through collaborative learning and participatory research with Māori landowners and policy agencies to determine Māori aspirations for land development. It is providing improved data on the physical characteristics of Māori land and contributing to climate policy and other research. Information gathered to date also contributes to climate change – land-use models being developed by Motu Economic and Public Policy Research Trust to help understand drivers for land-use change and to predict future land-use scenarios. More information on the Reducing Greenhouse Gas Emissions from the Terrestrial Biosphere (C09X0212) can be found at: http://www.landcareresearch.co.nz/research/greenhouse/

References:

Harmsworth, 2003: Maori perspectives on Kyoto policy: Interim results. Landcare Research report: LC0203/084. 30 p.

Harmsworth, 2003: Maori and climate change: Carbon sequestration opportunities on Maori land. Poster 1: A poster presented at the Motu workshop, December 2003, Nelson, New Zealand.

Harmsworth, 2003: Maori land: a regional learning case study on the Gisborne-East Coast. Poster 2: A poster presented at the Motu workshop, December 2003, Nelson, New Zealand.

9.3 LOOKING SEAWARDS – COASTAL HAZARDS ASSOCIATED WITH CLIMATE CHANGE

Terry Hume and Rob Bell
NIWA, Hamilton

Developed areas around the New Zealand coast are usually nestled in or near low-lying coastal margins, such as beaches, estuaries and harbours, and will therefore become increasingly vulnerable to the effects of global warming. Coastal development and global warming are on an eventual collision course, which will result in further ‘coastal squeeze’ between the land and the sea.

Global warming, climate change and sea-level rise have seen the sea level rise 0.3 m since the mid 1800s and sea temperature by 0.4 to 0.5°C since 1870. This rise is expected to continue and accelerate. The relative sea-level rise in New Zealand is most likely to be 0.14 to 0.18 m by 2050 and 0.31 to 0.49 m by 2100. The oceans are a vast heat ‘reservoir’, so it may take centuries for the oceans to cool and for sea-level rise to level out, even after curtailing greenhouse gas emissions. Regional New Zealand climate projections for the 2080s by NIWA are for a rise in mean air temperature of 1.6 to 2.2°C (winter) and somewhat less in summer will increase sea temperatures in estuaries and coastal waters, affecting aquatic ecosystems. Extreme storms are unlikely to be more frequent, but may be more intense, especially with regard to rainfall and wind strength. A more westerly wind stream over New Zealand (more El Niño-like). The sediment supply to the coast to be affected in a number of ways by climate change, such as changes in river flows (and sediment load) after heavy rainfall, winds, wave climate and currents. These projections are based on the assumption of continued increase in greenhouse gas emissions and use current global climate model results. Uncertainties are associated with both projected greenhouse gas emissions and model calculations.

The expected impacts on coastal margins are for:

- Sea-level rise relative to the landmass is the main concern locally, rather than global sea-level rise *per se*. Local effects, such as subsidence and tectonic movements, can cause a departure, up or down, on the global average.
- Parts of the coastline have historically been eroding or retreating, and climate change will exacerbate these trends.
- Sea-level rise will eventually lead to permanent inundation of very low-lying margins, episodic sea flooding of higher margins, increased coastal erosion, salinisation of adjacent freshwater, drainage problems in adjacent low-lying areas, and further coastal squeeze where shorelines are held and constrained by structures such as seawalls and stopbanks.
- Climate change will affect not just sea-level rise, but most physical drivers that shape coastal margins and ecosystems, such as winds, waves, storms, sediment supply and sea temperature.
- Predicting shoreline response as a result of climate change is complex, and simpler conceptual models based solely on sea-level rise are of limited use. Beach response will also depend on factors such as sediment supply, wave climate, storm frequency and alongshore changes in sediment movement.
- Increase in storm rainfall intensities will lead to lowland river flooding and impacts on water quality from increased sediment loads to estuaries, although sediment availability will also depend on catchment land-use and construction practices.
- The sea level around New Zealand is presently rising at a steady rate. This is projected to accelerate, which will exacerbate coastal erosion, flooding and (for some areas) permanent tidal inundation.

- Impacts on coastal margins will differ between regions and even between localities within regions, depending on shoreline parameters (such as slope, erodibility, sediment type), sediment supply, and potential offshore changes in wave climate and sediment movement.

An assessment of vulnerability and adaptation options has shown:

- The diversity of New Zealand coastal types requires local or regional investigations and solutions.
- In largely undeveloped areas, pre-planned retreat by way of setback hazard zones is the only cost-effective long-term option.
- For communities or infrastructure that are vulnerable, managed retreat and adaptation are the only reasonable long-term options, given that sea level is projected to continue rising for several centuries.
- Continued or new protection options for high-density population beaches, such as beach re-nourishment or holding structures, may be the only palatable solution in the medium term (several decades) because of the large investment in real estate. However, situations that may require new protection measures are complex, particularly if those measures are likely to have significant adverse environmental effects.
- A robust planning and policy framework is already in place to manage and mitigate natural coastal hazards, under the umbrella of the RMA. However, the framework needs some fine tuning to ensure that integrated management across coastal margins and long-term (over 100-year) planning occur, possibly through a revised New Zealand Coastal Policy Statement and Building Act 1991. It must also continue to be flexible at regional and local scales.
- Topography and cadastral databases for coastal margins need to be upgraded before the scale of the sea-level rise impacts and feasible response options can be assessed on local, regional, and national scales.

*The challenge is not to find the best policy today for the next 100 years, but to select a prudent strategy and to adjust it over time in the light of new information. - **IPCC, 1996***

Note - Much of the content of this presentation was extracted from: Bell, R.G.; Hume, T.M.; Hicks, D.M. 2001. Planning for climate change effects on coastal margins. Ministry for the Environment Report ME410 prepared for the NZ Climate Change Programme. September 2001. 73 pp.

9.4 DRIVERS AND MITIGATION OF GLOBAL CHANGE - ECONOMIC SCENARIOS

Adolf Stroombergen
Infometrics, Wellington

The aim of this part of the research programme is to understand how social and economic developments affect emissions of greenhouse gases (notably CO_2) and thus contribute to climate change. The focus for the analysis is the period to 2012, the end of the first commitment period under the Kyoto Protocol.

It is hoped that the research will deliver an improved understanding of the degree of uncertainty that attaches to CO_2 emission projections, as well as demonstrate that how the country develops economically can be as important a determinant of CO_2 emissions as any policy aimed directly at reducing emissions.

Seven scenarios are analysed:

- "Business as Usual" scenario
- Charge on atmospheric CO2 emissions
- Lower growth and greater energy efficiency
- Increase in population with no change in employment
- Increase in population with a corresponding change in employment
- More forestry output processed in NZ before being exported
- A sufficiently large gas discovery for methanol production to continue.

The scenarios present a wide range for projected CO_2 emissions in 2012, ranging from 37,096 Gg to 46,169 Gg. Neither of these figures are extreme in the sense that plausible combinations of the individual scenarios could lead to lower or higher projected emissions. For example high energy efficiency plus a carbon tax would produce emissions lower than 37,096 Gg, while higher immigration coupled with the continued production of methanol would produce more than 46,169 Gg of emissions. Compared to 1990 emissions of 25,267 Gg, it is clear that by 2012, emissions could be 30% higher or 90% higher.

With a such a wide range for projected CO_2 emissions (albeit that total GHG emissions are unlikely to rise by this much given static or even falling methane emissions), it is clear that the wrong type of policies aimed at reducing CO_2 could have high cost in terms of national economic welfare. Similarly, policies which are not aimed specifically at emissions, such as immigration policy, could nonetheless have a significant effect on emissions. In particular, government needs to be wary about promoting or protecting highly energy intensive industries that contribute relatively little to economic welfare, but considerably exacerbate the already difficult task of reducing the country's GHG emissions.

10 2004 WORKSHOP CONCLUSIONS

10.1 FRIDAY AFTERNOON DISCUSSIONS
from notes taken by Tom Clarkson at the open discussion

Panel: Kevin Tate, Landcare
Warwick Green, PGGRC
Marc Ulyatt
Howard Larsen, NZCCO

Warwick Green.
Noted broad nature of scientific interests – much increased in last 2 or 3 years – perhaps due to formation of PGGRC.
Better prospects for longevity of funding
Pleasing to see number of younger scientists participating
Must go forward – avoid overlaps – avoids replicating trials etc
Clear message from Federated Farmers. They have considerations to take into account to get hem on board.

Marc Ulyatt.
Are we sure that funding coming in is what we think

Harry Clark
PGgRc much more a coordinationg group – can they direct more $$$ towards ghg research.

Warwick Green
Communicating and lobby group for “good science”. Possibility of leveraging $$$ from offshore.

Roger Hegarty
Know enough now re mitigation of N_2O for pggrc to get into getting the message to farmers

Warwick Green
Agree.

Dave Lowe
Echoes the comments on encouraging young scientists.

Murray Poulter
question to Marc Ulyatt about whether the O’Hara report is being followed.

Marc Ulyatt
believes recommendations are being closely followed by PGGRC.

Marc Ulyatt
sharpens the mind to remember that of all methods, science has to be able to stand up to formal cross-examination if necessary – if public or sector groups don't get what they want.

Murray Poulter
try to get more representation next time from user sectors – eg like Tom Lambie from Federated Farmers

Marc Ulyatt
why has no sector taken "ownership" of the problems.

Howard Larsen
important to get to being able to say, what can we do about it?

Howard Larsen, Kevin Tate
debacle of f-tax made NZ look rather ridiculous to international media – should be avoided.

Gerald Rys
noted that Minister yesterday reckoned f-tax increased the knowledge of the problem for the general community

Gerald Rys
liked structure – posters – timing etc of workshop worked well.

Kevin Tate, Marc Ulyatt
liked meetings of this type – formats and scientific interaction are maturing.

Helen Plume
good meeting structure – reminded us that there is a policy development – publicity campaign – process going on there. Lucky that we are still small enough to get everyone in one room for a couple of days.

Andy Reisinger
important to always integrate end-user groups in deciding where science is heading.

Greg Bodeker
eager for feedback from policymakers - necessary for science planning.

11 TRACE GAS WORKSHOP PRESS RELEASE

17 March 2004

greenhouse gases and climate change

That is just one of many issues scientists, industry, and government representatives will discuss at a workshop on greenhouse gases in Wellington on Thursday and Friday this week.

The workshop has been organised by NIWA, the National Institute of Water & Atmospheric Research, in conjunction with PGgRc, the Pastoral Greenhouse Gas Research Consortium, and will be opened by Pete Hodgson, Minister of Research, Science & Technology. Keynote speakers include Tom Lambie, the President of Federated Farmers of New Zealand, Warwick Green from Wrightsons, and David Wratt, New Zealand's representative on the Intergovernmental Panel on Climate Change from NIWA

"This workshop provides an ideal opportunity to bring stakeholders together for an exchange of views with scientific experts researching methane, nitrous oxide, and carbon dioxide mitigation in New Zealand", said Mark Leslie, Chairman of the NZ research consortium studying agricultural greenhouse gas emissions (PGgRc).

"One of the goals is to ensure that scientists gain a better understanding of the concerns and needs of New Zealand's pastoral sector, and that farmers, farmer representatives, and those involved in the wider agriculture industry hear more about the research being done in this area", Mr Leslie said. "We will be discussing some of the promising scientific leads in terms of productivity improvements and how greenhouse gas mitigation tools can be applied on New Zealand's pastoral livestock farms", he added.

"NIWA has been running workshops like this every three years", said Chief Executive Dr Rick Pridmore. "We want to enhance communication between industry, scientists, and regulators."

"New Zealand needs an accurate assessment of the amount of greenhouse gases released from all sources, and needs to know what happens to them when they get into the atmosphere. That means we need go right down to farm scale and do things like measure air currents and methane around paddocks, so we can produce detailed models of dispersion', Dr Pridmore said.

"While the focus of the workshop is primarily national, it provides an important opportunity for us to monitor international developments", said Mr Leslie, "and we are delighted to be able to host at the workshop a high-level delegation from Japan, including leading scientists, Professor Hisao Itabashi and Dr Mitsunori Kurihara".

“This visit has been supported by the Ministry of Research, Science & Technology, the Royal Society of NZ, and the Ministries of Agriculture, Forests and Fisheries, and Foreign Affairs of Japan. During the group’s visit we will be discussing opportunities for New Zealand and Japan to work collaboratively, through the PGGRC” Mr Leslie explained.

Notes
PGGRC is partly funded by the Foundation of Research, Science & Technology and has the following participants: Fonterra Limited, Meat NZ, AgResearch Ltd, Dairy InSight, Wrightson Ltd, DEEResearch Ltd and the Fertiliser Manufacturers’ Research Association.

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12 THE WORKSHOP PROGRAMME

12.1 THE PROGRAMME

Thursday, 18 March 2004, morning

0830–1000	**Registration**, setting up posters, morning tea
1000	**Welcome and Overview Session**, Introductions and outline of programme and Workshop themes Chair: Rick Pridmore, CEO NIWA
	Opening: Hon Pete Hodgson, Minister of Research, Science and Technology
1020	**Review:** "The relevance of NZ trace gas research – an introduction and an international perspective" David Wratt, NIWA, Southwest Pacific member of the Bureau of the IPCC
1040	**Review:** "The state of play" Helen Plume, Ministry for the Environment, NZ Climate Change Office
1100–1150	**Short presentations** which address some major topics in the science of trace gases
	The agricultural inventory research programme. Gerald Rys, MAF.
	Where has all the methane gone? Dave Lowe, NIWA.
	The New Zealand Greenhouse Gas Inventory 2001. Len Brown. NZCCO.
	GDP and CO_2 – Equilibrium modelling for climate change scenarios. Adolf Stroombergen, Infometrics.
1150–1215	**Very short introductions** to Posters
	DNDC model applications in estimating trace gas emissions — Changsheng Li — U. New Hampshire Inventory of New Zealand Greenhouse Gases — Darren King — NIWA Nitrous oxide emissions from fertilised vegetables — Glyn Francis — Crop & Food Research Top-down determination of agricultural methane fluxes — Keith Lassey — NIWA Satellite Measurements of Greenhouse Gases — Brian J. Connor — NIWA
1215–1330	**Lunch & Poster session**

Thursday, 18 March 2004, afternoon

1330–1410	**Research Theme 1:** “Pastoral Greenhouse Gas Processes” Chair and facilitator: Marc Ulyatt, scientist, Tauranga.		
1332	**Review:** “The strategic approach from the viewpoint of the pastoral agricultural sector” Warwick Green, PGGRC		
1345-1415	**Review of the Science:** Keith Joblin, AgResearch/PGGRC Cecile de Klein, AgResearch		
1415–1505	**Short presentations** from science users.		
	*Commercial Drivers – is there a market for products?” Warwick Green, Wrightsons, PGGRC.		
	“The Farmer – the farmer’s view on climate change – adaptation and mitigation” Tom Lambie, President, Federated Farmers		
	Communicating climate change to stakeholders. Terry Parminter, AgResearch.		
1505	Discussion		
1515–1545	**Afternoon tea & Poster Session**		
1545	**Very short introductions** to Posters		
	Methanogen genomics to discover targets for methane mitigation	Graeme Attwood	Ag Research
	Grazing intensity effects on GHG production by cattle	Cesar Pinares-Patiño	AgResearch Grasslands
	Measuring net carbon uptake by a stand of kanuka	Frank Kelliher	Landcare Research
	Field testing of an antimethanogen vaccine	Harry Clark	Ag Research
	Effect of urease on reducing gaseous losses	Jagrati Singh	Massey University
	The Effects of intensification of dairy farming in NZ	Jiafa Luo	AgResearch
	Potential nitrous oxide and dinitrogen emissions	Long Nguyen	NIWA
1615–1705	**Research Theme 2:** *“Trace gas emission inventories”* *Chair and facilitator, Kevin Tate, LandcareResearch*		
	Reviewers: Frank Kelliher, LandcareResearch Harry Clark, AgResearch. Methane inventories. Ram SriRamaratnam, Ministry of Economic Development, Energy Sector Inventories		
1705	**Very short introductions** to Posters		
	Lowering ruminant methane: diet and deer protozoa	Matthew Nicholson	PGGRC
	Lowering ruminant methane: phage therapy	Nicola Walker	PGRRC
	Lowering ruminant methane: effect of diet on methanogens	Paul Evans	PGGRC
	Factors controlling N_2O emissions from effluent application	Rita Bhandral	Massey University
	Distinguishing of N_2O emitted from soils	Roland Bol	Inst. of Grassland and Environ. Research, UK
	Simulations of N_2O emissions from pastures using DNDC.	Surinder Saggar	Landcare Research
	Nitrous oxide emission after urine application	Zheng Li	Landcare Research
1735	Appropriate **refreshments** will be available in the conference room and we hope that discussions will continue at suitable informal venues into the evening		

Friday, 19 March 2004, morning

0830–0900	**Poster session**		
0900	**Research Theme 3:** "Trace gas measurements" Reviewers: Gordon Brailsford, NIWA, Field and laboratory measurements Greg Bodeker and Ben Liley, NIWA, Remote sensing.		
0930–1030	**Very short introductions** to Posters		
	Agricultural methane emission rate measurements	Dominic Ferretti	NIWA
	Alternatives to the Global Warming Potential concept	Greg Bodeker	NIWA
	Evaluation of ocean sequestration in New Zealand Region	Lionel Carter	NIWA
	Computer demo of NIWA's UV atlas	Richard McKenzie	NIWA
	Fourier transform measurements in trace gas research	Stephen Wood	NIWA
	Non SF6 tracer use to measure methane emissions?	Roger Hegarty	NSW Agriculture Beef Industry Centre, Armidale
	Methane production from farmed red deer	Natasha Swainson	AgResearch/ Massey University
	Nitrous oxide emissions from winter grazed forage crops	Steve Thomas	Crop & Food Research
	Indirect nitrous oxide emissions from leached N	Steve Thomas	Crop & Food Research
	Methane emission estimates from animal waste	Surinder Saggar	Landcare Research
1030–1100	**Morning tea & Poster session**		
1100	**Research Theme 4: "**Where Science and Social-Science Meet: Human Dimensions Climate Change Research". Chair: Howard Larsen, NZ Climate Change Office.		
1100–1120	Integrating Economics & Science for Effective Climate Change Policy: Motu's Land-use, Climate Change and Kyoto Programme. Presenter: Jo Hendy, Motu Economic and Public Policy Research		
	Maori and Climate Change: Carbon Sequestration Opportunities on Maori Land Emma Brunton (Motu) on behalf of Garth Harmsworth (Landcare Research)		
1130	Linking greenhouse gas emissions with an agricultural trade model Anita Wreford (Agribusiness and Economics research unit, Lincoln University)		
1145	Looking seawards – coastal hazards associated with climate change. Terry Hume, NIWA		
1200	A communications and public awareness campaign – four million careful owners. Lisa Marie Richan, NZCCO		
1210-1230	**Very short introductions** to Posters		
	Methane emissions from cattle dung	Surinder Saggar	Landcare Research
	Methane and nitrous oxide in clean air	Sylvia Nichol	NIWA
1230–1330	**Lunch & Poster session**		

Friday, 19 March 2004, afternoon

	Very short introductions to Posters		
1330-1420	Methane emissions from beef cattle on hill country pastures	Adrienne Cavanagh	AgResearch
	Effects of sarsaponin on ruminal methane production	Hisao Itabashi	Tokyo University of Agriculture and Technology, Japan
	The measurement of hydrogen and methane gas	Akio Takenaka	National Institute of Livestock and Grassland Science, Japan
	Measuring methane emissions at the herd scale	Johannes Laubach	Landcare Research
	The IPCC Emission Factor Database	Keith Lassey	NIWA
	Nitrous oxide emission from dairy pastures in NZ	Tony Bromley, Ross Martin	NIWA
	Effect of abatement of greenhouse gases at institute level	Zulfiquar Haider Butt	Massey University
1420–1500	**Conclusions of Workshop.** “Have we achieved the Workshop goals?” Facilitated discussion.		
1500	**Close:** Tom Clarkson, Workshop Convener		
	Afternoon tea and Poster Retrieval		

Posters not Listed Above

Restricted autumn grazing to reduce N_2O emissions	Cecile de Klein	AgResearch
Refining the uncertainty in N_2O emissions from NZ	Frank Kelliher	Landcare Research
Pastoral Greenhouse Gas Research Consortium	Julie Iommi	PGGRC
The effect of feeding on methane emissions by lambs.	German Molano	AgResearch
The New Zealand Greenhouse Gas Emission Inventory	Len Brown	NZCCO
A communications and public awareness campaign – four million careful owners	Lisa Marie Rican	NZCCO
Can the physiology of animals influence methane emissions?	Marie Krause, Harry Clark	PGGRC
Effect of soil drainage on N_2O emissions from soils	Cecile de Klein	AgResearch
Monitoring NZ methane emissions	Ben Liley	NIWA
Maori and Climate Change: Carbon sequestration opportunities on Maori land	Emma Brunton, Garth Harmsworth	Motu
Maori Land: A regional learning case study on the Gisborne- East Coast region	Emma Brunton, Garth Harmsworth	Motu

12.2 LIST OF POSTERS by first author

WORKSHOP ON THE SCIENCE OF ATMOSPHERIC TRACE GASES

convened by NIWA at the Brentwood Hotel, Kilbirnie, Wellington

Methanogen genomics to discover targets for methane mitigation	Graeme Attwood	AgResearch
Factors controlling N_2O emissions from effluent application	Rita Bhandral	Dept. of Soil Science, Massey University
Alternatives to the Global Warming Potential concept for combining the effect of emissions of different greenhouse gases on climate	Greg Bodeker	NIWA
Distinguishing of N_2O emitted from soils from nitrification and denitrification processes using dual (□^{15}N and □^{18}O) isotope and isotopomer (□$^{15}N_\alpha$ and □$^{15}N_\beta$) values	Roland Bol	Institute of Grassland and Environmental Research, UK.
Nitrous oxide emission from dairy pastures in NZ	Tony Bromley	NIWA
Climate Change: New Zealand Greenhouse Gas Emissions	Len Brown	Ministry for the Environment
The New Zealand Greenhouse Gas Emission Inventory	Len Brown	NZCCO
Maori Land: A regional learning case study on the Gisborne- East Coast region	Emma Brunton	Motu
Effect of abatement of greenhouse gases at institute level from a complete inventory of sources and sinks	Zulfiquar Butt	Massey University
Evaluation of ocean sequestration in New Zealand Region	Lionel Carter	NIWA
Methane emissions from beef cattle grazing hill country pastures	Adrienne Cavanagh	AgResearch
Field testing an Australian developed anti-methanogen vaccine in New Zealand Sheep	Harry Clark	Ag Research
Satellite Measurements of Greenhouse Gases: a NZ-centric Overview of Plans and Assessment of Prospects	Brian Connor	NIWA
Restricted autumn grazing to reduce nitrous oxide emissions from dairy pastures in Southland	Cecile de Klein	AgResearch
Effect of soil drainage on nitrous oxide emissions from pastoral soils	Cecile de Klein	AgResearch
Lowering ruminant methane: effect of diet on deer methanogens	Paul Evans	AgResearch Grasslands/PGGRC
A new technique for agricultural CH_4 emission measurements	Dominic Ferretti	NIWA
Nitrous oxide emissions from fertilised vegetables	Glyn Francis	Crop & Food Research
Maori and Climate Change: Carbon sequestration opportunities on Maori land	Garth Harmsworth	Landcare Research

Can tracers other than SF_6 be used to measure enteric methane emissions from individual animals?	Roger Hegarty	NSW Agriculture Beef Industry Centre, Armidale
Pastoral Greenhouse Gas Research Consortium	Julie Iommi	PGGRC
Effects of sarsaponin on ruminal methane, fermentation and microbes in vitro and in cattle	Hisao Itabashi	Tokyo University of Tech, Japan
Refining the uncertainty in nitrous oxide emissions from New Zealand	Frank Kelliher	Landcare Research
Measuring net carbon uptake by a stand of kanuka near Rakaia Island Dairy farm	Frank Kelliher	Landcare Research
Inventory of New Zealand Greenhouse Gases	Darren King	NIWA
Can the physiology of individual animals influence the quantity of methane they emit?	Marie Krause	AgResearch
Top-down determination of agricultural methane fluxes	Keith Lassey	NIWA
The IPCC Emission Factor Database	Keith Lassey	NIWA
Measuring methane emissions at the herd scale	Johannes Laubach	Landcare Research
DNDC model applications in estimating trace gas emissions	Changsheng Li	University of New Hampshire
Nitrous oxide emission and underground profile after urine application in two Waikato pasture soils	Zheng Li	Landcare Research
Monitoring NZ methane emissions	Ben Liley	NIWA
The Effects of intensification of dairy farming in NZ on resource use efficiency and Greenhouse Gas emissions.	Jiafa Luo	AgResearch
Computer demo of NIWA's UV atlas	Richard McKenzie	NIWA
The effect of level of feeding and forage quality on methane emissions by wether lambs.	German Molano	AgResearch
Potential nitrous oxide and dinitrogen emissions from pastoral and wetland soils	Long Nguyen	NIWA
Methane and nitrous oxide measurements in clean air	Sylvia Nichol	NIWA
Lowering ruminant methane: diet and deer protozoa populations	Matthew Nicholson	AgResearch Grasslands/PGGRC
Grazing intensity effects on methane and carbon dioxide production by cattle	Cesar Pinares-Patiño	AgResearch Grasslands
A communications and public awareness campaign – four million careful owners	Lisa Marie Rican	NZCCO
Simulations of nitrous oxide emissions from New Zealand grazed pastures using NZ-DNDC.	Surinder Saggar	Landcare Research
Methane emission estimates from animal dung and waste management systems in New Zealand	Surinder Saggar	Landcare Research
Methane emissions from cattle dung and methane consumption in New Zealand grazed pastures	Surinder Saggar	Landcare Research
Effect of urease and nitrification inhibitors on reducing gaseous losses of N from pasture soil	Jagrati Singh	Massey University

Methane production from farmed red deer	Natasha Swainson	AgResearch/ Massey University
The measurement of hydrogen and methane gas using a semiconductor chip sensor	Akio Takenaka	National Institute of Livestock and Grassland Science, Tsukuba, Japan
Nitrous oxide emissions from winter grazed forage crops	Steve Thomas	Crop & Food Research
Indirect nitrous oxide emissions from leached N	Steve Thomas	Crop & Food Research
Lowering ruminant methane: phage therapy	Nicola Walker	AgResearch Grasslands/ PGRRC
The use of high resolution Fourier transform spectroscopy for trace gas measurements	Stephen Wood	NIWA

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WORKSHOP ON THE SCIENCE OF ATMOSPHERIC TRACE GASES
18-19 MARCH 2004

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