Reducing uncertainty and best management practices for minimising greenhouse gas emissions from agriculture

A summary of the research currently being conducted by the Greenhouse in Agriculture program, under the CRC for Greenhouse Accounting.

(Adapted from a paper by Dr Richard Eckard, Program Manager Greenhouse in Agriculture. CRC for Greenhouse Accounting, The University of Melbourne and Victorian Dept Primary Industries. Presented at ABARE National OUTLOOK Conference 2006.)

According to the Australian Greenhouse Office's (AGO) National Greenhouse Gas Inventory, agriculture contributes 17.7% of Australia's net national greenhouse gas emissions (Fig. 1), and is the dominant national source of both methane (67.9%) and nitrous oxide (77.1%) gas in Australia (AGO 2004). Methane and nitrous oxide are potent greenhouse gasses with global warming potentials of 21 and 310 times that of carbon dioxide, respectively. The contribution of methane and nitrous oxide from the agricultural sector is high relative to most developed countries, apart from New Zealand, where their national inventory attributes more than 50% of emissions to the agricultural sector.

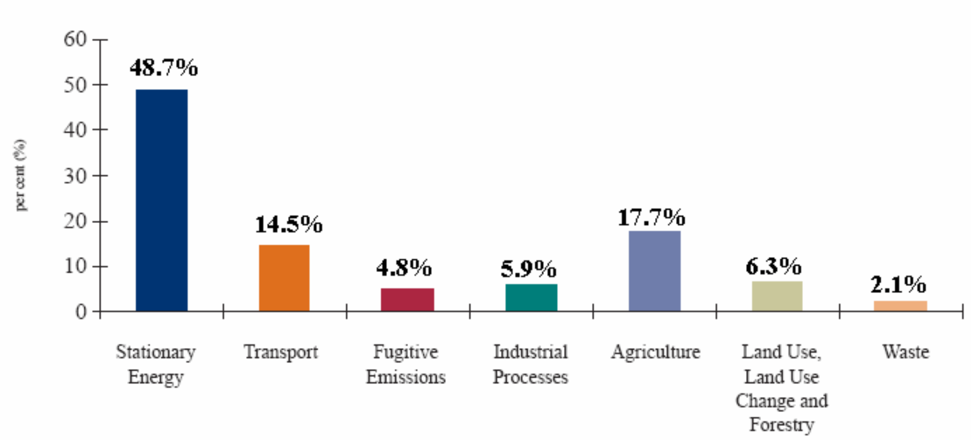

Figure 1. Australian national sectoral greenhouse gas emissions, according to the 2003 National Greenhouse Gas Inventory (AGO 2004).

Enteric methane

Within the agricultural sector, methane is predominantly sourced from enteric fermentation in ruminants. In the rumen a group of microbes called methanogens are responsible for producing methane, utilising surplus hydrogen in the rumen to reduce carbon dioxide to produce methane. The methane produced is then largely belched and breathed out by the animal. However, as methane gas is a high-energy source, this represents a significant loss of energy from the production system that can and should be redirected back into production. The key is therefore to provide another mechanism for reducing hydrogen levels in the rumen, otherwise normal digestion will be adversely affected and the energy savings will not be realised in improved production.

Nitrous oxide

Nitrous oxide is primarily lost from agricultural soils as a result of cultivation, legumes, nitrogen (N) fertilisers and animal excreta. Nitrous oxide is primarily formed through denitrification; a microbially mediated conversion of nitrate into either di-nitrogen (N_2) or nitrous oxide (N_2O). This process is maximised in warm, anaerobic (wet) soil conditions with large amounts of nitrate and available carbon present. To a lesser extent, some nitrous oxide can be produced when soil ammonium is converted to nitrate in a process called nitrification. Any agricultural activity that inefficiently supplies nitrogen to the soil-plant system can lead to large losses of nitrogen through a number of loss processes, including nitrous oxide.

Emissions of nitrous oxide are currently not well quantified, nor have management options been previously developed to reduce them. There is a high level of uncertainty in estimates of nitrous oxide emissions in Australia's National Greenhouse Gas Inventory and the Intergovernmental Panel on Climate Change (IPCC), as these estimates are primarily based on extrapolations of laboratory and enclosure measurements to field scale and predominantly from studies conducted in the northern hemisphere. So far direct field verification has been difficult because of high spatial and temporal variation, and lack of appropriate measurement techniques.

Methane and nitrous oxide emissions not only potentially contribute to our changing climate, but also present an opportunity for efficiency gains in Australian agricultural production systems. The following article summarises the research being conducted by the Greenhouse in Agriculture program to improve our understanding of emission processes and identifies best management practices that offer win-win opportunities for efficiency gains in agricultural systems while reducing greenhouse gas emissions.

The Greenhouse in Agriculture (GIA) Program

In 2003 the GIA collaboration included CSIRO Atmospheric Research, the University of Melbourne, Queensland University of Technology, the University of Western Australia, the University of Wollongong, the Victorian Department of Sustainability and Environment, the Victorian Department of Primary Industries and the Department of Agriculture in Western Australia. Recently scientists from AgResearch and Dexcel in New Zealand, the Garmish Institute in Germany and Agriculture and Agri-Food Canada became collaborators with the GIA team.

Greenhouse gas emissions from agricultural systems present a number of complexities, as the gases are not only difficult to measure and emissions poorly understood, but achieving abatement will require adoption of revised best management practices by a large number of relatively small business enterprises.

To address these complexities the GIA program set up three linked projects (Fig. 2). The F1 "Measurement" (Drivers of non-CO_2 emissions in agro-ecosystems) project delivers reliable emissions data to the F2 "Modelling" (Farming systems to reduce non-CO_2 greenhouse gas emissions) project, which develops and evaluates best management practices (BMPs) and decision-support tools for abatement. The E3 "Marketing" (Partnerships education and communication in agriculture) project engages with the key stakeholders and farmers in the dairy, grains and cotton industries to ensure the overall program understands their needs and that the products developed deliver beneficial outcomes for both the environment and farming systems.

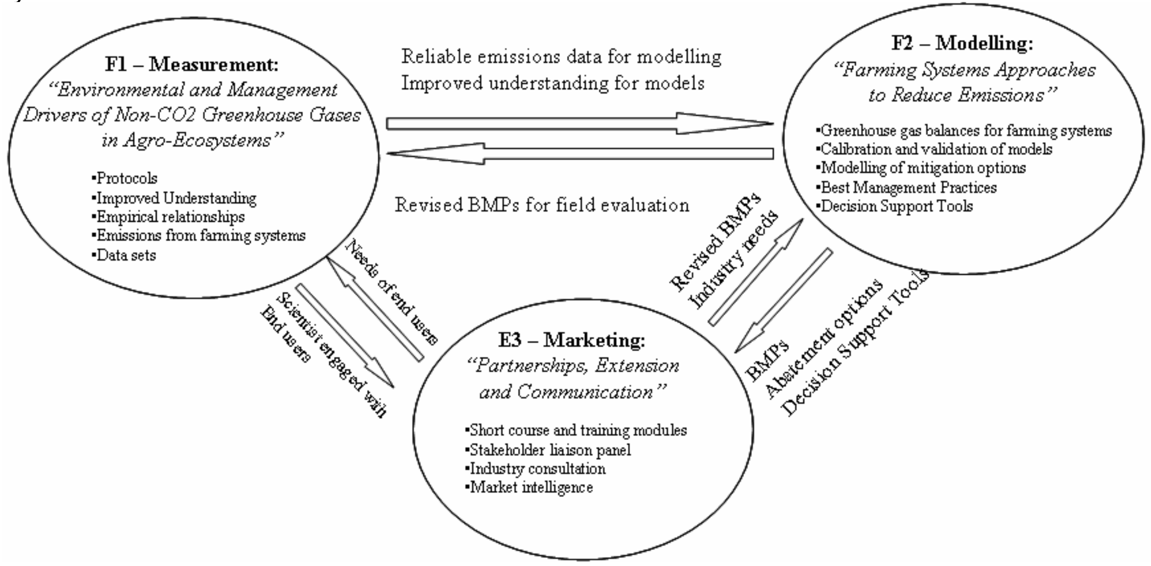

Figure 2. Relationships between projects within the Greenhouse in Agriculture program.

GIA measurement sites

A spatially explicit inventory of emissions, developed by the CSIRO Division of Marine and Atmospheric Research, was used together with state and industry-based inventories to determine the industries and regions where emissions of methane and nitrous oxide from agriculture were most intensive. An example of this map for nitrous oxide is provided in Fig 3. Using this analysis, the GIA program focused research on methane emissions from intensive livestock (dairy and beef cattle) and nitrous oxide emissions from dairy pasture, grain (irrigated maize and dryland winter wheat) and cotton production systems.

A number of research measurement sites were established across the country, with enteric methane being measured from dairy cattle at Ellinbank (site 1, Fig. 3) and from beef cattle at Hamilton (site 2, Fig. 3). Nitrous oxide emissions where measured from dryland winter wheat production at Rutherglen (site 3, Fig. 3) and Cunderdin (site 7, Fig. 3), and from irrigated maize at Griffith (site 5, Fig 3), irrigated dairy pastures at Kyabram (site 4, Fig 3) and irrigated cotton at Narrabri (site 6, Fig 3).

Methane

In the first instance the challenge was to establish appropriate methods for measuring enteric methane losses from cattle, with three key methods developed for three different purposes:
a) The field-based SF_6 tracer method, for measuring methane from individual cows in the field, which uses evacuated collars around the cows necks continuously sampling methane from the cows nose, together with a slow release capsule of a tracer gas placed in the rumen;
b) The Open Path Laser and FTIR methods, for measuring total methane loss from groups of animals, where a sample of methane and a tracer gas are measured as they cross a long open path beam downwind of a herd of cows, and
c) The Open Circuit Respiration Chamber method, for absolute measurement of methane from an individual cow, where cows are placed in a sealed respiration chamber, with incoming and exhaust air measured for methane, carbon dioxide and oxygen.

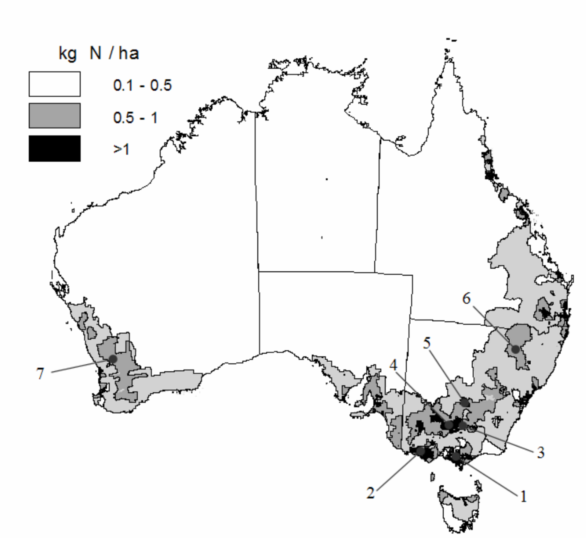

Figure 3. The national distribution of nitrous oxide emissions from cultivation, fertilizer addition, animal waste and agricultural waste burning estimated using the National Greenhouse Gas Inventory methodology. Numbers represent the GIA measurement sites located at Ellinbank (1), Hamilton (2), Rutherglen (3), Kyabram (4), Griffith (5), Narrabri (6) and Cunderdin (7) (after Galbally *et al.* 2005).

Having established these methods the research focused on quantifying the impact of diet on methane emissions, with diets ranging from grass-only, to grass supplemented with grain and total mixed rations. Results from this phase indicate that individual animals may be consistently high or low methane producers (ranging from 330 to 750 g methane/cow/day), and this is commonly linked to their production efficiency. This data highlights the opportunity to breed for more efficient animals that produce less methane and more milk (Fig 4). It also highlighted that diet quality will affect methane loss, with high emissions from dry summer pasture (February) and lower emissions from lush cooler season pasture (September; Fig 4).

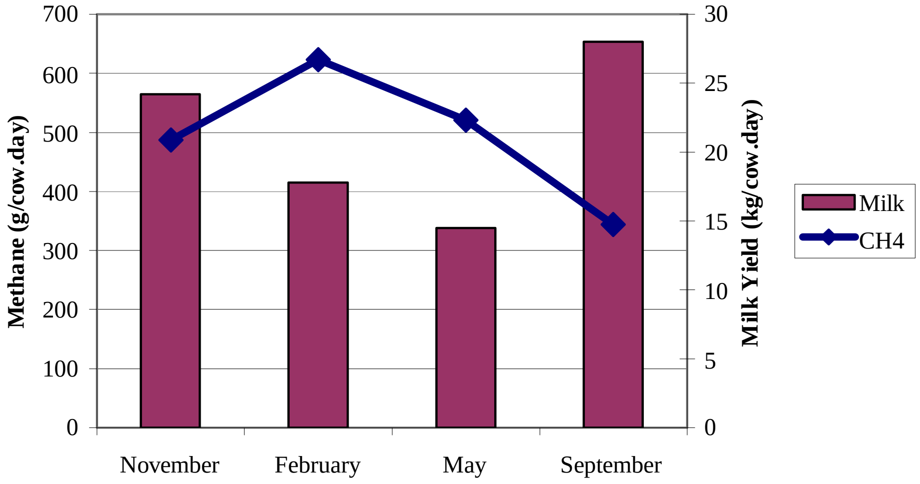

Figure 4. Daily methane emissions from dairy cows measured during the dry summer (Feb), after the autumn break (May) and during the early (Sept) and late spring (Nov) (data from M. Auldist, DPI Ellinbank, Victoria).

The final stage of this research now focuses on the use of cost-effective dietary supplements that both reduce methane loss and improve productivity. Examples of products tested include rumensin, as a rumen modifier, and condensed tannin, which can both improve the efficiency of nitrogen use in the animal and reduce methane. The first criterion in the research is to evaluate the impact of dietary supplements on animal performance, comparing the improved production against the cost of feeding. If this evaluation results in a neutral or positive financial return, the option is only then tested for its methane abatement potential, as this presents a possible win-win opportunity and a driver for adoption.

Best Management Practices for Enteric Methane

From the work conducted to date and the reviews of published literature, an abatement of over 20% of methane produced per animal is achievable, but most of these options are yet to be fully evaluated and commercialised in Australia. However, there are a number of management practices that will continue to improve livestock production efficiency, while also reducing methane losses. The two key determinants of methane loss are animal numbers and their diet.

Animal numbers

An obvious management practice would be to run fewer animals, but to manage each animal to be more productive. By improving genetic and nutritional management, production can be maintained from a smaller herd. Associated with producing more per head on pasture-based systems is an increase in the emission/head, but this is more than compensated for by less animals. A practical example of this is the current research on managing extended lactations in dairy cows. With the shift towards North American genetics in the Australian dairy herd, farmers are finding it increasingly difficult to get their cows in calf within a 12 month cycle. This research has shown that these cows could be milked on an 18-month to 2-year inter-calving interval with only a 1 to 10% loss in annualised milksolids, respectively (Auldist *et al.* 2006). In this management system there are less replacement heifers required and a reduced period with dry cows. This means that the farm needs fewer cows in total, has less unproductive cows at any one time and thus less methane in total and less methane per litre of milk produced.

Diet quality

Methane producing rumen microbes thrive on highly fibrous feeds (eg. mature pasture, tropical grass and hays). These low digestibility diets ferment to a near-neutral pH producing large amounts of hydrogen gas, which the methane-microbes require. In contrast, cereal grain concentrates ferment to produce little hydrogen gas and a highly acidic rumen, both of which are restrictive to methane producing rumen microbes. Ensuring a high quality pasture (i.e. high quality ryegrass rather than Setaria or Paspalum) will cause cows to eat more, produce more, but produce less methane per unit of output. Thus providing animals with the best combination of pasture quality and concentrate feeding will effectively reduce methane emissions from the herd. The above best management practices are entirely consistent with continual efficiency improvements in livestock production.

While it is too early to endorse specific feed additives or rumen modifiers until further research has proven their efficacy, there are a number of promising and potentially cost-effective options currently being researched. Future options may include animal breeding, dietary supplements, rumen modifiers and biological control.

Nitrous Oxide

As nitrous oxide emissions from soils are highly variable in both space and time, the challenge initially was to establish appropriate methods for measuring these losses; two main methods were employed. At the Kyabram site, a micrometeorological technique involving the flux-gradient method was used to determine nitrous oxide emissions over an entire irrigation bay. This method is particularly useful where the spatial deposition of dung and urine make nitrous oxide emission even more variable across the paddock. Automatic chambers were also used to determine fluxes from specific treatments at all the sites (Meyer *et al.* 2001). Where the chambers either sampled air into sample bags for later analysis (Rutherglen and Griffith), or directly coupled to either a gas chromatograph (Cunderdin and Narrabri) or Fourier Transform Infrared (FTIR) spectrometer in the field (Kyabram).The treatments imposed at each site are listed in Table 1 and a more detailed description of each site and treatments is provided by Galbally *et al.* (2005).

Table 1. Preliminary estimates of nitrous oxide emission factors (EF) from four agricultural systems in Australia. Annual application rates of fertilizer nitrogen in kg N/ha are listed with the treatments (Galbally *et al.* 2005).

Site	**Crop**	**Treatment**	**EF (%)**
Griffith, NSW	Irrigated maize	Stubble burning 300N	2.8
		Stubble retention 300N	1.6
Kyabram, VIC	Irrigated dairy pasture	Urine 1000N	0.4 – 0.5
		Urea 150N	0.4 – 0.5
Rutherglen, VIC	Rain-fed winter wheat	Conventional cultivation 83N	0.05 – 0.1
		Direct drilling 83N	0.05 – 0.1
Cunderdin, WA	Rain-fed winter wheat	0 and 100N	n/a
Narrabri, NSW	Irrigated cotton (C)	(Rotation sequence)	
	in rotation with vetch (V)	CC 100N	0.03
	and wheat (W)	CC 200N	0.24
		WVC 100N	0.39
		WVC 200N	0.51
		WVC 300N	2.47
		WC 100N	0.09
		WC 200N	0.26

Nitrous oxide emission factors

Emission factors are used in national inventories to estimate the nitrous oxide being emitted from a region or agricultural industry. The default fertiliser emission factor currently used by the IPCC and in Australia is 1.25% of nitrogen fertiliser applied and 0.4% of urinary nitrogen excreted by animals is deemed to be lost as nitrous oxide. The preliminary emission factors observed from these experiments (Table 1) range between 0.03 to 2.8% of nitrogen applied (urine or fertiliser).

The data in Table 1 suggest that nitrous oxide emissions from nitrogen fertiliser studies in Australia appear much lower than the average emission factors (1.25%) from northern hemisphere studies. These low emission factors reflect a combination of the climate and soils specific to Australian agriculture, but also suggest that the application of best management practices for nitrogen fertiliser may result in lower nitrous oxide emissions. Conversely, the data in Table 1 suggests that where nitrogen fertiliser is applied at higher rates, potentially exceeding immediate plant requirements, it is increasingly susceptible to loss to the environment. This work is now likely to result in emission factors for Australian agriculture being revised downwards, thereby reducing the relative contribution of N fertilisers, and agriculture in general, to the national greenhouse gas emissions inventory.

Best Management Practices for Nitrous Oxide

While actual nitrous oxide emissions are relatively small, the abatement potential can be significant through improved fertiliser, soil and animal management. In a recent modelling study, Eckard *et al.* (2006) reported a potential 80% reduction in emissions of nitrous oxide, with only a 4% loss in pasture growth from dairy farming systems, when managed with strategic nitrogen fertiliser inputs, relative to nitrogen applied after every grazing rotation. Likewise, Beer *et al.* (2005) reported on data from the Griffith site (see Fig 3) that greenhouse gas emissions are 44% higher with stubble burning of maize residues than where stubble was incorporated into the soil. Clearly this is a best management practices that reduces nitrous oxide emissions, reduces carbon dioxide loss and, although slow, improves soil carbon over time. Both these studies present best management practices that benefit overall farm efficiency and the environment.

From our research to date, the following best management practices are likely to both improve overall nitrogen efficiency and reduce nitrous oxide losses. The best management practices presented below are entirely consistent with current industry best practice for overall nitrogen efficiency and thus present a win-win opportunity.

Fertiliser Management

- **Source, rate and timing (split) of Nitrogen (N) applications**
  - Nitrate nitrogen sources (ie, ammonium nitrate, potassium nitrate, calcium ammonium nitrate) may result in greater denitrification and leaching than ammonia-based sources of nitrogen (ie, urea, DAP, ammonium sulphate) if applied under cold, wet and waterlogged (soils close to field capacity or above) conditions. However, ammonia-based sources could lose high amounts of ammonia gas if top-dressed under warmer and windy conditions, especially on alkaline soils. Urea is currently the cheapest straight source of nitrogen, while DAP is the cheapest mixed source of nitrogen.
  - Match crop or pasture demand - Only apply nitrogen when crop or pasture is actively growing and can utilise the nitrogen. Nitrogen is always more efficiently utilised when applied strictly according to growth potential ie, only apply the highest recommended rates when no other limiting factors are restricting yield potential.
  - Avoid excessive nitrogen fertiliser rates. For pastures, do not apply above 50 to 60 kg nitrogen/ha in any single application and do not apply nitrogen closer than 21 (30 kg nitrogen/ha in spring) to 28 (50 kg nitrogen/ha) days apart, as this will increase nitrogen losses dramatically.
  - Warm and waterlogged soils - Avoid high nitrogen rates on waterlogged soils, particularly if soil temperatures are above 10 °C, as this will increase denitrification losses. Denitrification is highest under anaerobic soil conditions, particularly when these conditions are coupled with warmer soil temperatures.

- **Coated/chemically treated fertilisers -** There are a number of coatings that can be applied to nitrogen fertilisers that will greatly reduce nitrous oxide losses directly from fertiliser. However, these coatings have no effect on losses of nitrogen derived from legumes and urine. At this stage these products are too expensive to justify their commercial use in broad acre agriculture and require further research to evaluate performance under Australian conditions.
  - **Nitrification inhibitors** - this coating inhibits the conversion of ammonia to nitrate in the soil, thus reducing the chance of both nitrate leaching and denitrification loss. An example of such a compound is dicyandiamide (DCD), proven effective in many studies.
  - **Controlled -release** - A range of polymer-coated / impregnated fertiliser products are available, releasing their nitrogen according to the predicted crop growth pattern. This controlled release significantly improves fertiliser efficiency. However, if the onset of conditions favourable to denitrification coincides with nitrogen release form the coated fertilisers, denitrification may still result albeit at a lower rate than would have occurred using conventional forms of fertiliser nitrogen.

Crop and Pasture Management

- **Reduce fallow -** During the fallow period the soil continues to break down organic soil nitrogen into nitrate (mineralisation followed by nitrification) but there is no crop to utilise this nitrate; as a result this nitrate is susceptible to nitrate leaching and denitrification loss following heavy rainfall.
- **Cover crops -** Where possible use non-leguminous cover crops to use residual nitrate nitrogen in soil such as in cotton cropping.
- **Water use efficiency -** Use efficient soil and pasture management practices, including nutrition, to make the best use of water; unused water if left in excess creates conditions for future runoff from rainfall, waterlogging for denitrification or leaching of nitrates.
- **Other nutrients -** If there are other nutrients limiting the growth potential of the crop or pasture, nitrogen fertiliser use will be less efficient leading to greater loss potential.
- **Subsoil limitations** - Such as transient salinity, sodicity, acidity, restrict the ability of crops to effectively utilise soil nitrogen. Nitrogen inputs (from either fertiliser or legumes) should be adjusted (reduced) to reflect the true yield capacity of crops where subsoil limitations are present.
- **Animal stocking rate** - The higher the stocking rate the higher the volume of nitrogen deposited in dung and urine per unit area. Dung and especially urine are very inefficiently recycled in the soil plant system, with up to 60% of the nitrogen in a urine patch being lost to the environment. Higher stocking rate systems demand a higher nitrogen input regime (either fertiliser or imported feed) and thus result in a higher nitrogen content excreted in urine. A urine patch from dairy cow commonly contains between 800 and 1400 kg N/ha effective application rate with the patch. A higher stocking rate also leads to greater pugging (hoof compaction) of the soil; pugged soils tend to be more anaerobic due to hoof compaction leading to higher nitrous oxide losses.
- **Plant breeding -** A longer term strategy is breeding plants that are less nitrophylous ie, a ryegrass plant that does not require as much nitrogen fertiliser, or plants with a deeper rooting system to extract nitrate from a greater volume of soil.

Soil management

- **Tillage -** Soil disturbance such as a tillage operation breaks up soil organic matter, stimulating greater mineralisation of organic nitrogen. This leads nitrate becoming available in the soil at a greater rate following tillage and thus a greater loss potential. It also reduces soil structure, leading to poorer plant growth and greater potential for temporary water logging.
- **Irrigation and drainage -** Irrigation aims to maintain the soil above wilting point and below field capacity. Poorly drained soils are anaerobic thus promoting denitrification of soil nitrate. If soil nitrate is in excess of crop growth, nitrous oxide loss can be high in both cases.
- **Soil compaction -** The more compact a soil, the more anaerobic it becomes, leading to higher nitrous oxide loss through denitrification. Soil is commonly compacted through wheel traffic in cropping systems and through treading from animal hooves, especially under wet conditions, in grazing systems.

Conclusions

Significant reductions in both methane and nitrous oxide can be achieved within the agricultural industries through the implementation of current best management practices that are entirely consistent with improving the efficiency of agricultural production. These best management practices represent a clear win-win opportunity for Australian agriculture.

There are also a number of options still being developed to further improve overall dietary efficiency in animal production systems and nitrogen cycling efficiency in grazing and cropping systems. These options will all need to be economically assessed prior to being communicated to the agricultural community to ensure a positive driver for adoption.

The adoption of greenhouse specific management practice is not likely to be a high priority for the farming community, and there are currently no policy drivers or market incentives for adoption of these practices. Researchers and policy makers would therefore be unwise to publish greenhouse-specific best management practice manuals, but should rather aim to seamlessly integrate greenhouse best practice into existing industry adoption pathways and mechanisms. This also ensures that these greenhouse best management practices are consistent with other industry best management practices, thus improving the adoption and the opportunity for a win-win outcome; this is the approach taken by the Greenhouse in Agriculture program team.

Acknowledgments

The research program described in this article is supported by the following; Department of Education, Science and Training through the CRC for Greenhouse Accounting, the Australian Greenhouse Office, The Grains Research and Development Corporation, the Cotton Research and Development Corporation, Victorian Greenhouse Strategy and MAFF New Zealand, with staff and support from The University of Melbourne, Queensland University of Technology, University of Western Australia, University of Wollongong, CSIRO Marine and Atmospheric Research, Victorian Dept of Primary Industries, Dept of Agriculture Western Australia, AgResearch and Dexcel New Zealand and Agriculture and Agri-Food, Canada.

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