Grains Research & Development Corporation

Background study into greenhouse gas emissions from the grains industry (DAV478)

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Contents

Forewords

Greenhouse gas emissions are becoming an increasingly important issue for the grains industry. It is imperative that the Australian Grains Industry is well positioned to address concerns from the Australian Government related to the potential ratification of the Kyoto Protocol, and in turn, is able to harness opportunities for increasing on-farm nutritional and energy efficiencies for production and environmental benefit. It is estimated about a 20% of Australia's total net greenhouse gas emissions originate from the agricultural sector, from sources such as methane from livestock, nitrous oxide from fertilisers, soil carbon rundown in pastures and land clearing. However, neither the absolute quantities of emissions, nor the potential for mitigation of greenhouse gases from the various agricultural industries in Australia have been measured.

In June 2002, the Grains Research & Development Corporation (GRDC) funded this one year scoping project "Background Study into Greenhouse Gas Emissions from the Grains Industry (DAV478)". The objectives of this project were:

- *to critically evaluate the existing information on emissions of greenhouse gases (GHGs) from grain production systems;*
- *to provide improved estimates of emission factors for Australian grain enterprises; and*
- *to direct future R&D to secure the potential for production and environmental benefits.*

This project had a National focus and involved farmers, consultants and scientists from each of the three GRDC regions. The following groups of growers were involved: Mingenew-Irwing Group, Liebe Group, Southern Grain Growers in Western Australia; Birchip Cropping Group, Mallee Sustainable Farming Systems Project, Wimmera Farming Systems Group in Victoria; Walgett Sustainable Agriculture Group, Dirnaseer Topcrop, Junee/Euronhgilly Topcrop in New South Wales, and Moonie and Jimbour Grower Groups in Queensland.

All intellectual property generated by these studies remains public domain - providing a strong foundation for continuing research effort.

For further information, comments or to obtain a copy of the Grains Greenhouse Accounting Framework contact:

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Summary

Results from this project highlighted the lack of measurements of GHG emissions from Australian farming systems, and the unsuitability of the existing overseas measurements to be extrapolated to the Australian conditions. There are only two crop years of data from Australia along with one year of pasture measurements and two (separate) years of forest measurements. Most of the measurements of N_2O emissions from agriculture (384 crop years of measurements) reviewed in this report are from northern Europe, Canada and the USA, and in the majority (80%) of the experiments ammonium nitrate was used as a source of N fertiliser.

Achievements of this project include:
- acritical evaluation of available information on emissions of greenhouse gases from the grains industry in Australia and elsewhere and their applicability to Australian conditions;
- a consultation with farmers, and agronomists to characterise typical grain production systems for each GRDC region;
- baseline estimates of emission factors for typical grain production enterprises in each GRDC region;
- a simulation study of the potential for N_2O loss by denitrification from typical grain enterprises in each GRDC region;
- the development of the "Grains Greenhouse Accounting Framework", a tool that allows farmers to estimate emissions from their grain production system and to compare their estimated emissions with those from typical grain enterprises in their region;
- a list of potential mitigation options to reduce greenhouse gas emissions from the grains industry; and
- identification of future research needs and investment opportunities.

Emission factors: After a careful analysis of existing information on emission factors for soil disturbance and for fertiliser application, the values of 0.25 kg N ha^{-1} and 1.0% respectively, are recommended for use in the National Greenhouse Gas Inventory as appropriate estimates for Australian grain production systems. However, it is imperative that the value of these emission factors is corroborated for different soil types, climate regimes and farming system through further research, as no overseas study of which we are aware is relevant to Australia.

Impact of climate variability: Emissions estimated from our simulation study indicated at all locations a considerable year-to-year variation in emissions, and highlighted northern cropping systems as those most likely to emit N_2O during denitrification events. The largest denitrification losses were predicted to occur for the wheat-sorghum rotation on the black earths of the Darling Downs (average 32 kg N ha^{-1} over a 3 year rotation). The biggest losses occurred during fallow with the maximum predicted loss being 37 kg N ha^{-1} during one fallow between a sorghum crop and the next wheat crop. Smaller losses were predicted from the southern and western farming systems. Two factors seem to be contributing. Crops are usually growing at the wettest time of year which is also the coldest time of year, and only small amounts of nitrogen fertiliser are used.

Uncertainty analysis: The impact of a 10% change in the soil disturbance and fertiliser emission factors on the total emissions from each of the case studies produced average changes in the emissions of 4 and 3%, respectively. The biggest impact (6%) was observed by varying the fertiliser emission factor in the Darling

Downs, however in general terms small variations in the soil disturbance emission factor always had bigger effects than small variations in the fertiliser emission factor.

Trends in the use of N fertilisers: Assuming linear increases in N use by the grains industry, the biggest changes in estimated emissions can be expected from the Wimmera and high rainfall zone grain enterprises in western Victoria, and the smallest changes from grain enterprises in central Western Australia, and south Australian and Victorian Mallee.

Mitigation options: Changes in the farming system could increase soil carbon sequestration by 0-5 tCO_2-eq ha^{-1} $year^{-1}$. Potential reductions in the emissions of nitrous oxide from the Australian grain industry from: better use of fertilisers have been estimated to be 0.5-2.8 tCO_2-eq ha^{-1} $year^{-1}$ after matching N applications to reduce gas production to emission goals; 0.9-3.3 tCO_2-eq ha^{-1} $year^{-1}$ by using controlled release fertilisers and nitrification inhibitors; 0.3-0.9 tCO_2-eq ha^{-1} $year^{-1}$ after matching fertilise type and amount to seasonal conditions.

Needs for future research and investment: There is an urgent need for improving and developing tools for decision-making concerning greenhouse gas (GHG) emissions from the Grains Industry for farmers, the Industry and Government. This should be delivered through a coordinated systems approach that incorporates both the physical and economic aspects of farm management along with greenhouse gas emissions. Planned field investigations will provide rates of production of GHGs from a limited number of crops, treatments (including mitigation options), and soil conditions, on a daily time scale and up to one or two years. Quantification of the impact of seasonal conditions (inter-annual and climate variability), the extrapolation to different farming systems, regions and temporal and spatial scales will be undertaken with the use of modelling tools. Existing modelling tools that are able to produce estimates of GHGs have been developed in the USA and Europe for different climate and production environments than the Australian. These models should be tested and against local data, to deliver a modelling tool producing reliable estimates of GHG emissions from our farming systems and at the same time reproducing the Australian production environment. We believe this is the only way forward to help guide future research, policy formation and the development of realistic and sustainable management practices and farming systems for Australia.

Acknowledgments

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Mingenew-Irwing Group, Liebe Group, Southern Grain Growers; Birchip Cropping Group, Mallee Sustainable Farming Systems Project, Wimmera Farming Systems Group, Walgett Sustainable Agriculture Group, Dirnaseer Topcrop, Junee/Euronhgilly Topcrop, Moonie and Jimbour Grower Groups. Harm van Rees, Liam Leneghan, Darryl Pearl, Felicity Pritchard, Alan Bedggood, Bernard Noonan, Audrey Bird, Roger Butler, Jeremy Lemon, Greg Rummery, Phil Egan, David Alexander, and Richard Eckard.

Greenhouse gas emissions

Project background

Australia faces significant environmental problems, shortage of clean and accessible freshwater, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in the chemistry of the atmosphere and the possibility of important changes in climate. These changes are result of human activity, they are recent, profound and many are accelerating. It is imperative that the Australian Grains Industry becomes better positioned to address concerns from the Australian Government relating to meeting greenhouse gas emission targets, and in turn is able to harness opportunities for increasing on-farm nutritional and energy efficiencies for production and environmental benefit.

Greenhouse gas emissions are an increasingly important issue for the grains industry as demonstrated, for instance, by the outcomes of the Grains Industry SCARM Greenhouse Workshop (Perth 8 Aug 2001). It is estimated about 20% of Australia's total net greenhouse gas emissions originate from the agricultural sector from sources such as methane from livestock, nitrous oxide from fertilisers, soil carbon rundown in pastures and land clearing. Unfortunately, neither the absolute quantities of emissions, nor the potential for mitigation of greenhouse gases from the various agricultural industries in Australia have been measured.

What are greenhouse gas emissions?

The enhanced greenhouse gas effect refers to a rise of the equilibrium temperature at the Earth's surface resulting from anthropogenic emissions of greenhouse gases into the atmosphere. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the major gases responsible for this enhanced greenhouse gas effect, with agriculture being the largest contributor to the last two. These gases are nearly transparent to the visible and near infrared wavelengths in sunlight. However, they absorb and re-emit downward a large fraction of the longer infrared radiation emitted by Earth creating the effect of trapping heat. Consequently, in the presence of these gases, long-wavelength radiant energy received at the Earth’s surface is nearly double that received directly from the sun. Although the magnitude and timing of climate changes are uncertain, it is known that atmospheric concentrations of radiatively active gases are increasing. Each different greenhouse gas has a different capacity to cause greenhouse warming. This capacity is known as the “global warming potential” (GWP) of the radiation absorber and by the lifetime of the gas in the atmosphere. The GWP of carbon dioxide is by definition 1, and the values for methane is 21 and for nitrous oxide is 296.

Soils and their agricultural use have an important role in the global budgets of these gases. The main processes underlying exchange of greenhouse gases between soils and the atmosphere are biological or physical in nature.

Carbon dioxide is the most important greenhouse gas, and its atmospheric increase is mostly the result of fossil fuel combustion. In contrast the major sources of methane and nitrous oxide emissions and a secondary contributor to CO_2 emissions are agricultural activities. Carbon dioxide is released during respiration by various organisms and consumed during its assimilation by plants. Methane is produced in methanogenic breakdown of organic compounds and consumed in methane oxidation in microbial processes. Denitrification and nitrification by micro-organisms can produce N_2O. Nitrous oxide may be further reduced or consumed during denitrification. The presence of organic material drives respiration, methanogenesis and denitrification. Changes in soil organic matter content and drainage, are important drivers that affect emissions of CO_2, CH_4 and N_2O, and contribute to the enhanced greenhouse effect.

In order to contribute to the mitigation of climate change, the agricultural sector seeks better understanding about the sources and rates of emission of these greenhouse gases. The simulation tool created as a part of this project, the Grains Greenhouse Accounting Framework, will help farmers to better understand the impact of their farming practices on the emissions of the different greenhouse gases. The Grains Greenhouse Accounting Framework was developed based on previous work by Rob Nussey and Anne Bennett.

Methane

Methane is the most abundant hydrocarbon in the Earth's atmosphere where it has a lifetime of about 10 years. The atmospheric concentration of methane has more than doubled from 800 ppb to 1720 ppb since the industrial revolution and during the last decade this increase has slowed to a halt. Methane is formed under anaerobic conditions by microbial decomposition of organic matter. This occurs in wetlands and with flood irrigated cropping, for example rice. For rice, emissions of methane average 200-500 mg m^{-2} during an average growing season of 130 days. Methanotrophic bacteria in the aerobic soil can consume methane. Methane is also formed in the fore-stomach of ruminants, pseudoruminants, and insects. Total annual emissions of methane in Australia have been estimated to be about 1.2Tg. This project focuses on greenhouse gas emissions produced by the rainfed grains industry, therefore methane emissions from rice farming is not considered.

Nitrous oxide

Nitrous oxide is an important greenhouse gas with a life of about 150 years in the atmosphere. Its present concentration is 310 ppb, which is about 8% higher than the pre-industrial concentration of 285 ppb. Nitrous oxide is quite inert in the troposphere. It is decomposed in the stratosphere producing reactive nitrogen oxides that participate in stratospheric ozone destruction. The main sources of N_2O are: natural soils, agricultural soils, biomass burning, fossil fuel combustion and industrial processes. Unfortunately the sources and sinks of this gas have not been well quantified. Nevertheless, soil processes of nitrification and denitrification are generally accepted to be the main sources of N_2O.

Nitrification is the biological oxidation of soil ammonium to soil nitrite and nitrate, producing N_2O as a by-product. Denitrification is the stepwise biological reduction of soil nitrate to gaseous nitrogen compounds, with N_2O and N_2 being the main products. Both nitrification and denitrification are affected by the oxidation state of the soil, which is influenced by a number of soil factors. Increasing soil water content to levels above the drained upper limit usually triggers denitrification while nitrification is usually triggered below the drained upper limit. Other factors such as soil temperature, mineral N concentration, amount of substrate for microbial activity and soil pH are also important influences for nitrification and denitrification.

Soil and crop management practices also have an effect on N_2O production. For example soil temperature is affected by ground cover and therefore the management of crop residues becomes important. Similarly, mineral N concentration is affected by applications of N fertilisers and crop rotation. Previous crop or fallow periods affect the level and quality of microbial substrate essential for these microbial processes.

Nitrous oxide emissions from agricultural systems are often measured by enclosing the atmosphere above the soil and measuring N_2O concentration increases within the headspace over time. The main disadvantages of this methodology are the effect of the enclosure on soil gas emissions, and the high spatial variability of the emissions in the field. These issues create inaccuracies and uncertainties in the measurements of the emissions. Also, N_2O emissions from arable lands have been estimated by assuming that fertiliser induced emissions and background (natural) emissions are additive, which is a gross oversimplification of these processes. Nevertheless, according to this assumption, the background flux may range from 0.01 to 2.9 kg N ha^{-1} per year, and the global average fertiliser induced emission has been estimated to be around 0.7 kg N ha^{-1} per year. Due to the complexity of the system under study, and the limited availability of reliable experimental data, systems analysis and the use of models to simulate physical and biological soil processes that affect emissions are useful tools to quantify nitrous oxide emission estimates. Crop simulation models can be used to integrate our present understanding of the above processes with the complex interacting effects of the soil resource, its environment and enterprise management to determine the magnitude of the emissions. Similarly, the mitigation potential of different management options can be evaluated using simulation models.

The rate of N_2O emissions in Australia increased by 21% from 1990 to 1999 (Australian Greenhouse Office, 2001). Thus, the rate of increase for N_2O in Australia is already more than 2.5 times that of allowable increases of 8% for all emissions under the Kyoto Protocol. This is a cause for concern and therefore requires concerted efforts by industries to reduce N_2O emissions from the Australian agriculture.

Achievements

Feedback from growers and consultants

Consultation with agronomists and groups of growers provided feed back on the basic assumptions included in our estimation of greenhouse gas emissions and the basis to define typical grain enterprises in each of the regions (Table 1 to Table 4).

In this exercise the following groups of growers have been contacted:

- Western Australia: the Mingenew-Irwing Group, Facey Group, and Liebe Group
- Victoria: the Birchip Cropping Group, Mallee Sustainable Farming Systems Inc., and Wimmera Farming Systems Group
- New South Wales: Walgett Sustainable Agriculture Group, Dirnaseer Topcrop, Junee/Euronhgilly Topcrop
- Queensland: Moonie and Jimbour Grower Groups.

In addition we consulted numerous private and TopCrop agronomists and scientists from the three GRDC regions.

Table 1. GRDC Regions, locations soils and cropping systems involved in this study

Region	Location	Soil	Cropping system
Western	Buntine	Yellow sandy loam	Wheat after lupin
	Wickepin	Loamy sand	Wheat after lupin
	Grass Patch	Duplex soil	Wheat after wheat
South	Mallee – Southern	Mallee clay loam	Wheat after wheat
	Mallee – Northern	Sandy loam	Wheat after wheat
	Wimmera	Grey cracking clay	Wheat after pulse
Northern	Darling Downs	Black earth (Waco)	Wheat / sorghum rotation
	Western Down	Brigalow/belah (Warra)	Opportunity cropping (wheat, sorghum, chickpea)
	Northern NSW	Coolibah grey clay	(a) Sorghum – Wheat (b) Chickpeas - Wheat

Research into emission factors

A literature review was conducted to assess the availability of data world-wide and its relevance to Australian conditions, and to derive corrected emission coefficients for soil disturbance and use of fertilisers.

This analysis refers primarily to the methodology used for the Australian National Greenhouse Gas Inventory (Workbook 5.1). The methodology uses five emission factors:

1. Soil disturbance;
2. Inorganic fertiliser;
3. Animal waste – urine deposition;
4. Animal waste – faecal deposition;
5. Animal waste – manure deposition;

Only 1 and 2 are relevant for the grains industry and these are discussed below.

Table 2. Basic assumptions for the GRDC Southern Region, utilised in this project for the estimation of greenhouse gas emissions from the grains industry.

GRDC Southern Region				
Location	**Soil details**	**Sowing**	**Fertiliser**	**Fallow Management**
Wimmera Wheat after pulse (lentils)	Grey cracking clay (self-mulching) Rooting depth 1.2 m PAWC 179 mm Available water 47 mm NO_3-N 35 kg/ha Residues 2.4 t/ha C:N in residues 25 Roots 1.1t/ha C:N in roots 25	Window: 1 May – 20 July, with 45 mm available water in 0-0.4 m soil	Pre-drilled: 25 kg N/ha as urea in mid-April	Residues burnt (30-40% cereals), 1-2 cultivation before sowing
Southern Mallee (Birchip) Wheat (or barley) after wheat	Mallee clay loam Rooting depth 0.9 m PAWC 142 mm Available water 42 mm NO_3-N 17 kg/ha Residues 3.3 t/ha C:N in residues 80 Roots 1.1 t/ha C:N in roots 40	Window: 7 May – 15 July, with 40 mm available water in 0-0.35 m soil	Pre-drilled: 20 kg N/ha as MAP/DAP in mid-April. Sowing: 20 kg N/ha as urea.	Residues burnt (10-20% cereals), 2 cultivations before sowing
Northern Mallee (Werrimull) Wheat after wheat	Sandy loam Rooting depth 1.2 m PAWC 110 mm Available water 36 mm NO_3-N 12 kg/ha Residues 2.5 t/ha C:N in residues 80 Roots 1 t/ha C:N in roots 40	Window: 7 May – 30 June, and rain accumulated in the previous 4 days > 15 mm	10 kg N/ha as MAP/DAP at sowing.	Residues burnt (10-30% cereals), 2-6 cultivations before sowing

- Soil Disturbance

  Soil disturbance is defined in Workbook 5.1 as the difference between N_2O-N emission between the cropped soil in the absence of inorganic fertiliser addition, and undisturbed soil from a pristine ecosystem, which farming replaced. This factor accounts for the indirect effects of nitrogen deposition from NO_x and NH_3 volatilisation, nitrogen fixation, and nitrogen input from stubble incorporation. The factor is measured experimentally as the difference between the mean annual emissions rates on farmed and non-farmed sites, on the same soil type and on similar parent ecosystems.

Table 3. Basic assumptions for the GRDC Northern Region, utilised in this project for the estimation of greenhouse gas emissions from the grains industry.

GRDC Northern Region				
Location	**Soil details**	**Sowing**	**Fertiliser**	**Fallow Management**
Darling Downs (Dalby) Wheat-long fallow Sorghum-long fallow	Waco Black earth Rooting depth 1.5 m PAWC 287 mm Available water 47 mm NO_3-N 14 kg/ha Residues 6.4 t/ha C:N in residues 80 Roots 2 t/ha C:N in roots 40	Window: Wheat: 25 May – late Jul Sorghum: 21 Sept – 5 Jan if PAW > 50% PAWC and rain within 4 days is more than 20mm	Applied pre-sowing Wheat: 55 kg N/ha in Feb/Mar Sorghum: 75 kg N/ha in Jul/Aug	Zero till
Western Downs (Miles) Opportunity cropping Wheat-long fallow Sorghum double cropped to chickpea or long fallow wheat	Brigalow/belah grey clay (Warra) Rooting depth 1.2 m (chickpea 0.9 m) PAWC 194 mm Available water 46 mm NO_3-N 18 kg/ha Residues 4.2 t/ha C:N in residues 80 Roots 1.5 t/ha C:N in roots 40	Window: Wheat: 15 May – 15 Jul Chickpea: 1 May – 30 Jun Sorghum: 15 Sept – 31 Jan with PAW > 75% PAWC (140 mm) and rain within 4 days is more than 15mm	Only applied to wheat 23 kg N/ha as urea at sowing	Zero till
Walgett (a) Wheat after sorghum- long fallow (b) Wheat after chickpea	Coolibah grey clay Rooting depth 1.2 m PAWC 187 mm Available water for sorghum 43mm, for chickpeas 70 mm NO_3-N 17 kg/ha Residues 4.2t/ha Sorg. 2. t/ha Chick. Residue C:N 80 Sorg, 30 Chick. Roots 1.75 t/ha Sorg., 1 t/ha Chick Root C:N 40 Sorg. 20 Chick.	Window: 14 May – 15 June with PAW > 110mm and rain within 4 days > 10 mm or sow on 15 June if PAW > 80 mm Note: approx 30% of wheat crop might be planted early (from 20 April) using late maturing varieties.	Following sorghum – long fallow: None Following chick: 55 kg N/ha as urea in April	Reduced tillage with 2 or 3 cultivations before sowing

The soil disturbance emission factor for crops was derived from an experiment at Werrimull in the Northern Mallee where the annual emission from a wheat crop was compared with that from undisturbed Mallee woodland in an adjacent site. The soil disturbance emission factor for pastures was derived from a comparison of two forest sites with a legume pasture site. The forest sites were the Boola Boola State Forest in Gippsland (Khalil et al., 1991) and the Wombat state forest (Meyer et al., 1997); the legume pasture was at Book Book near Wagga Wagga (Galbally et al., 1994). The data is summarised in Table 5.

Table 4. Basic assumptions for the GRDC Western Region, utilised in this project for the estimation of greenhouse gas emissions from the grains industry.

GRDC Western Region				
Location	**Soil details**	**Sowing**	**Fertiliser**	**Fallow Management**
Buntine Wheat after lupins	Sand Rooting depth 2.1 m PAWC 79 mm Available water 21 mm NO_3-N 29 kg/ha Residues 2.5 kg/ha C:N in residues 25 Roots 1.2 t/ha C:N in roots 25	Window: 15 May – 30 June with moisture in 5-10 cm soil (PAWC in layer 1 > 0.5) and rainfall within 3 days higher than 10 mm	Sowing: 40 kg N/ha as MAP/DAP	Residues not burnt No tillage
Wickepin Wheat after lupins	Loamy sand Rooting depth 1.5 m PAWC 82 mm Available water 14 mm NO_3-N 25 kg/ha Residues 2.5 kg/ha C:N in residues 25 Roots 1.2 kg/ha C:N in roots 25	Window: 1 May – 30 June with moisture in 5-10 cm soil (PAWC in layer 1 > 0.5) and rainfall within 3 days higher than 10 mm	Sowing: 20 kg N/ha N as MAP/DAP Topdress at 30 DAS: 30 kg N/ha as urea	Residues not burnt. 1 cultivations prior to sowing
Grass Patch Wheat (barley) after wheat	Water-logging duplex soil Rooting depth 0.9 m PAWC 68 mm Available water 12 mm NO_3-N 17 kg/ha Residues 3.5 t/ha C:N in residues 80 Roots 1.5 t/ha C:N in roots 40	Window: 1 May – 15 July with moisture in 5-10 cm soil (PAWC in layer 1 > 0.5) and rainfall within 3 days higher than 15 mm	Sowing: 15 kg N/ha as MAP/DAP Topdress at 30 DAS: 30 kg N/ha as urea	Residues not burnt No tillage
Grass Patch Wheat (barley) after wheat	Loamy sand Rooting depth 2.1 m PAWC 100 mm Available water 28 mm NO_3-N 28 kg/ha Residues 3.5 t/ha C:N in residues 80 Roots 1.5 t/ha C:N in roots 40	As above	As above	As above

No overseas studies on paired sites we know of are relevant to Australia, and modelling studies in Australia either have not been validated sufficiently for this investigation.

We recommend that a soil disturbance emission factor of 0.25 kg N ha^{-1} is used in this study until new measurements for the Australian agro-ecosystems becomes available

- Emission factor for fertilisers

  Emissions from fertiliser addition is the amount of fertiliser nitrogen lost from the system as N_2O. It is defined as the difference in mean emissions of N_2O during crop production between a non-fertilised and fertilised site. Ideally the duration of the measurements should be a year or more because applied fertilisers can accumulate in the soil with repeated applications. The emission factors for fertiliser addition to crops and pastures have been reviewed in several publications (Bouwman 1996, 2001; Dalal et al. 2003), and independently for this project. Even though the available data sets are limited, explicit estimates of fertiliser N_2O loss as a fraction of the fertiliser addition (i.e. fraction of fertiliser N lost corrected for background emission rate) are available to calculate more precisely the emission factors.

Table 5. Effects of land disturbance on N_2O emissions from soil (Galbally et al. 1992; Meyer et al. 2001)

Undisturbed system	Emission (kg N ha^{-1} y^{-1})	Disturbed system	Emission (kg N ha^{-1} y^{-1})	Enhanced Emission (kg N ha^{-1} y^{-1})
Mallee (Bilbul Sth)	0.18	Mallee (Bilbul Sth)	0.42	0.24
Forest (Boola Boola, Wombat)	0.16	Wagga Wagga	0.41	0.25

Measured emission factors for both background and fertilised emission rates, 384 measurements, range from 0 to 14.7% with a mean of 1.25% (the figure currently used for Australia). We have stratified this data set for the current study using the following selection criteria:

- The crop is a cereal for grain production;
- The fertiliser is an inorganic nitrogen type (ammonium, nitrate or urea);
- No nitrification inhibiters are applied;
- The length of the measurement period exceeds 100 days. It is known that N fertiliser can reside in some form in the soil for long periods; certainly the effect can last for several years as can be shown in fertiliser trials where yield responses to N fertiliser addition rates become apparent and reproducible only after 3 years or more.

When the first three rules are applied and the data set is reduced to grain crops only, the mean emission factor remains unchanged from that of the full set. However, the range declines and the median increases from 0.5% to 0.7%. This data set includes a number of experiments in which measurements were conducted for a relatively short period of a few weeks following fertiliser addition. Removing all experiments of less than 100 days reduces the data set to 56, with increases in both mean and median to 1.5 and 1.0% respectively. The frequency distribution is now somewhat bimodal with modes at 0.5% and 1.9% (Figure 1, Table 6).

Table 6. The effect of classifying the international emissions database for cereal grain production

Class	All data	N_2O Emission factor (%fertiliser-N) Grains only	Grains only
		Inorganic N, no nitrification inhibitors	Inorganic N, no nitrification inhibitors Period >100days
Mean	1.25	1.25	1.52
Stdev	2.08	1.51	1.75
Median	0.50	0.70	1.00
Max	14.7	7.35	7.35
Min	0.0	0.00	0.00
N	384	85	56

Most of the measurements are from northern Europe, Canada, and USA, and the majority (80%) were fertilised with ammonium nitrate fertilisers and the soil textures ranged from sandy loam to clay. As a first approximation we used the median value of the grains data set (1.0%) as a suitable estimate for the case studies in this spreadsheet that are meant to be typical or “median” cases.

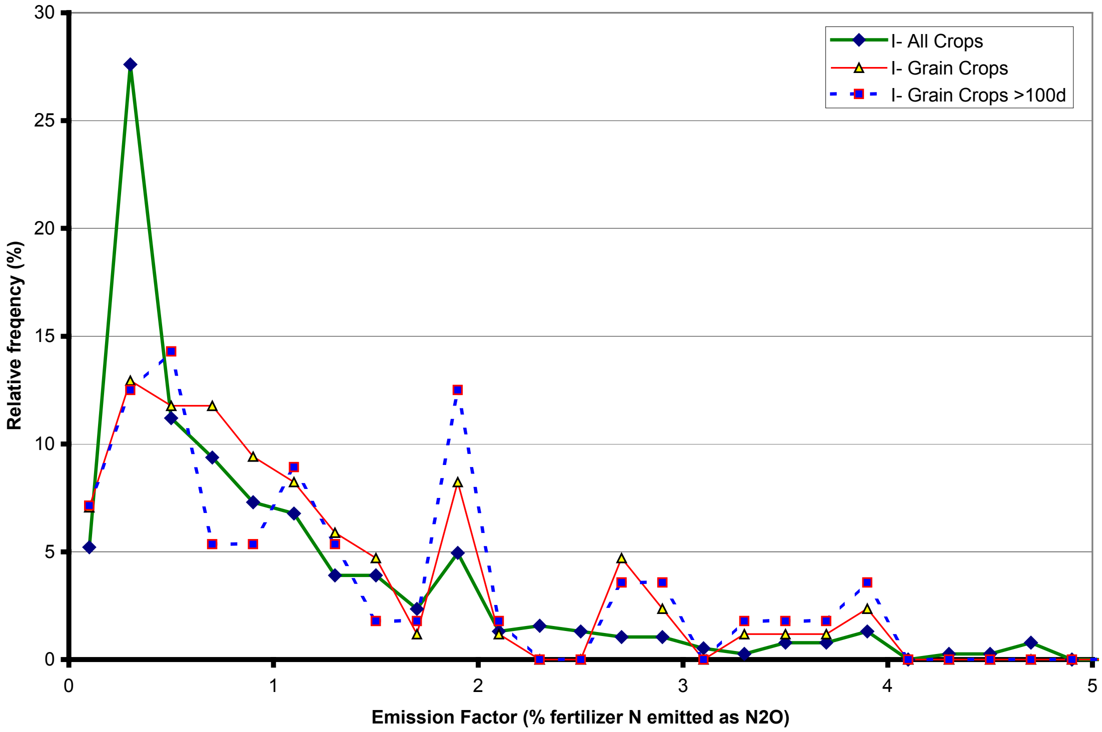

Figure 1. Frequency distribution of the N_2O emission factors from the international literature

We recommend taking the median value of the grains data set in this study (1.0%) as the emission factor from fertilisers while information from Australian farming systems is produced

Uncertainty analysis

Due to the lack of measurements the emission factors reported herein present a high level of uncertainty.

We recommend that the emission factors reported herein should be further contrasted against measurements of greenhouse gas emissions from Australian farming systems

To assess the impact of uncertainty on these emission factors a sensitivity analysis was produced using the Grains Greenhouse Accounting Framework developed in this project. Using this tool we evaluated the change in total farm emission in each of the case studies in the three GRDC regions after varying a:

- ±10% the soil disturbance factor;
- ±10% the emission factor for emissions from fertilisers.

The sensitivity analysis (Table 7) indicates that estimated changes in total farm emissions were not proportional to the changes in the emission factors. A 10% change in the emission factors produced changes that ranged from 1.8 up to 6.3% in farm emissions. Total farm emissions were more sensitive to changes in the soil disturbance factor, and the impact varied across the different regions and within regions. The highest impact on total farm emissions was estimated for the Darling Downs after changing the fertiliser emission factor. In the Darling Downs up to 63% of the farm emissions originate from the use of fertilisers while in the rest of the regions and case studies emissions from fertilisers were never higher than 34%.

Table 7. Sensitivity analysis to a 10% change in the soil disturbance and fertiliser emission factors on total farm emissions for the different case studies in the three GRDC regions.

GRDC region	Case study	±10% Soil disturbance factor	±10% Fertiliser emission factor
Western			
	Buntine	±2.8%	±3.0%
	Wickepin	±3.2%	±4.5%
	Grass Patch	±3.4%	±4.3%
North			
	N NSW	±2.8%	±4.2%
	W Downs	±2.2%	±5.5%
	D Downs	±6.3%	±2.7%
South			
	Mallee	±1.8%	±4.4%
	S Mallee	±2.9%	±3.3%
	Wimmera	±2.0%	±3.8%

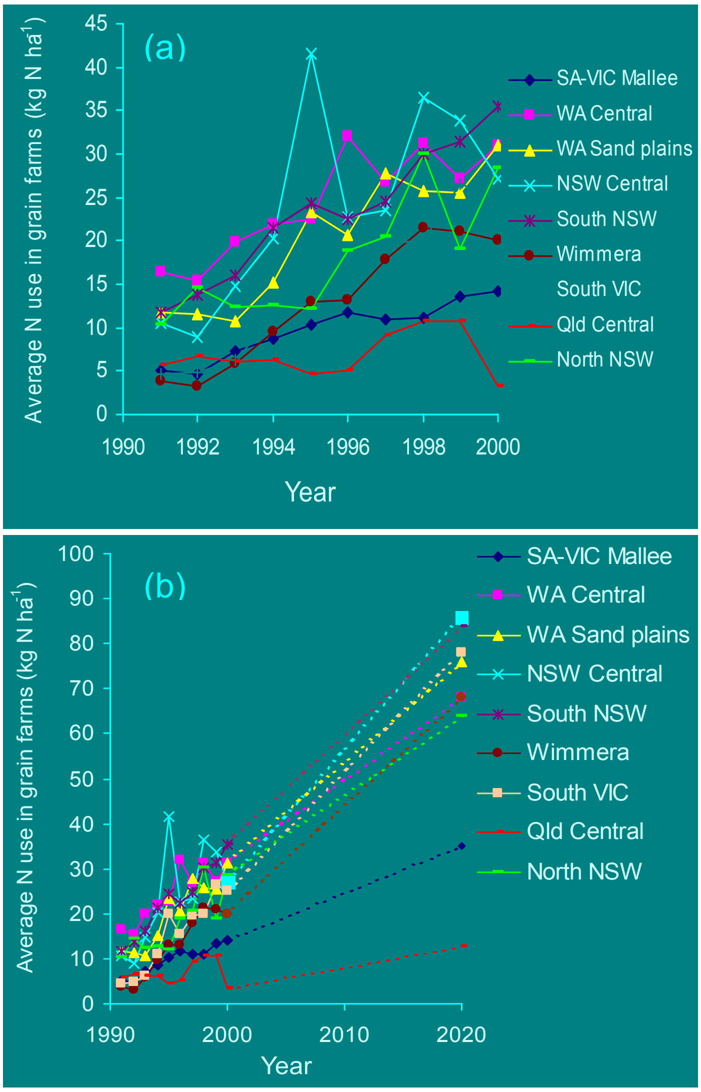

Figure 2. Average N use (kg N ha^{-1}) in grain farms for different regions in Australia (a), and (b) linear interpolation of the average N use between the years 2003 and 2020.

The impact of trends in N fertilisers use

Trends in the average per farm use of N in grain farms in the three GRDC regions were derived from a data series 1990-2000 (Ag@ccess, Abare 1999). Using this data series the change in the use of N fertilisers between 2003 and 2020 was predicted assuming linear extrapolations (Figure 2a and b). This exercise does not attempt to forecast future fertiliser use and consequently emissions from the use of N fertilisers, but to evaluate the potential sensitivity to a linear increase in the use of N. It is important to notice that linear extrapolations as done here might not be appropriated due to non-linearity in some of the regions i.e. Central Qld and Central NSW (Table 8). After deriving the trends, potential changes in emissions (tCO_2-eq ha^{-1}) were estimated using the Grains Greenhouse Accounting Framework developed in this project (Table 8). Assuming linear increases in N use the biggest changes in estimated emissions from the use of N fertilisers can be expected in the Wimmera and high rainfall zone of south Victoria, and the smallest changes from central Western Australia, and the south Australian and Victorian Mallee. Caution is required when interpreting this result as this is a direct correlation to already medium to high levels of fertiliser used in the Wimmera and high rainfall zone of South Victoria.

Table 8. Estimated change in average farm N use (grains farming) and emissions (tCO_2-eq ha^{-1}) from fertilisers assuming a linear increase in the use of N fertilisers between the years 2003 and 2020

Region	**N use kg N ha^{-1}**			**tCO_2-eq ha^{-1}**		
	R^2	2003	2020	2003	2020	% change
Southern						
Mallee	0.91**	17.5	35	0.085	0.170	99
Wimmera	0.93**	29	68	0.141	0.331	134
Southern Victoria	0.9**	34	78	0.165	0.379	129
Western						
Central WA	0.78**	37	68	0.180	0.331	83
Sand plains	0.87**	37	76	0.180	0.370	105
Northern						
Central Qld	0.07	8.6	12.6	0.042	0.061	46
North NSW	0.69**	32	64	0.156	0.311	100
Central NSW	0.5*	43	86	0.209	0.418	100
South NSW	0.95**	42	84	0.204	0.409	100

* Significant at 5% level of probability
** Significant at 1% level of probability

The impact of climate variability

The Agricultural Production Systems Simulator (APSIM) was used to investigate the variability in denitrification for the case studies in Tables 1 and 2. The cropping systems model, APSIM (Keating et al, 2003; see also web site www.apsim-help.tag.csiro.au) is a modelling framework that permits the simulation of a diverse range of cropping systems. APSIM v2.1 modules have been used in this study. APSIM simulates total denitrification, the algorithm in the SOILN2 module (Probert et al. 1998) being responsive to soil moisture, temperature, nitrate in a soil layer, and soil organic matter. No attempt is made within APSIM to partition total denitrification into the component gases (NO, N_2O, N_2) or to simulate the losses that occur during nitrification.

In the simplest cases, the cropping system simulated was a single crop with initial conditions specified to represent a particular crop sequence. By re-initialising the model each year corresponding to the time of harvest of the (presumed) previous crop, the weather files for each location were sampled so that output was obtained for up to 45 years, all with identical starting conditions (water and mineral N, soil organic matter, residues and roots from previous crop) (see GRDC Southern Region and GRDC Western Region in Table 2).

For the GRDC Northern Region, more complex cropping patterns were simulated. At the Walgett location, two cropping systems were compared: (1) wheat following a long fallow after sorghum with the simulations being re-initialised in January to mimic the harvest of the sorghum crop; thus there was a fallow period of at least 16 months prior to sowing wheat. (2) wheat after chickpea with re-initialisation in November and ~7 month fallow prior to sowing wheat. On the Darling Downs a fixed rotation was used, re-initialised after the wheat crop (November); after a fallow of ~10 months sorghum could be planted from September; subsequently there was a long fallow of at least 12 months before sowing wheat. On the Western Downs an opportunity cropping system was simulated, re-initialised after the wheat crop (November). After a fallow of at least 10 months, sorghum was sown in a window between September and January; when weather conditions allowed, chickpea was sown after a short fallow followed by wheat, otherwise there was a long fallow after sorghum to the next wheat crop.

For the systems involving rotations/long fallows, the simulations were repeated starting in consecutive years so that multiple phases of the rotations were simulated.

Denitrification in APSIM occurs under anoxic conditions and is particularly sensitive to soil water content that limits diffusive fluxes of O_2 and emissions of denitrification gases. Models of denitrification tend to be highly sensitive to the threshold water content that determines the moisture content above which denitrification occurs. In APSIM SoilN2, it is assumed the threshold is at the drainage upper limit (DUL), which is supported by the studies of de Klein and van Logtestijn (1996). Others have suggested that the threshold should be defined in terms of water filled pore space (WFPS), though there is no general agreement as to what WFPS is appropriate, and whether there is a value that can be applied across different soil types. De Klein and van Logtesteijn (1996) reviewed the literature and suggested the threshold WFPS decreases, as soil texture becomes finer.

WFPS is defined as volumetric water content as a proportion of total porosity, the later usually being calculated on the basis that the soil solids have an absolute density of 2.65 g cm^{-3}.

In view of these considerations, the outputs of the model are reported using the following variates:

- total denitrification as predicted by APSIM. This provides an "integrated" estimate that involves more than simply how wet the soil is; for example it considers the presence of nitrate in the soil layers.

- the number of days when the soil water content of the 0-20 cm layer of soil is higher than 75% WFPS. This estimate is merely an indication of how often the soil would be sufficiently wet to cause denitrification – how much gas was evolved would depend on whether nitrate was present to be denitrified.

In summarising the output, the cropping season has been divided into the fallows (from harvest or re-initialisation until sowing) and in-crop; where there were a significant number of seasons when the model predicted no crop would be sown, the extended fallow until the expiry of the sowing window is reported.

The output from the simulations are set out in Table 9 which reports the minimum, maximum and mean for each of the variates in the Northern (a), Southern (b) and Western (c) case studies. In addition, information is included on crop yields to enable the simulations to be tested against the information collected from farmers' groups. This provides some measure of "ground-truthing" for the simulations. In most of the case studies the agreement with the yield estimates obtained from farmers' groups was very good. The only major disparity was for the chickpea crops in the opportunity cropping system on the Western Downs where the mean predicted yield was 1.8 t ha^{-1} compared with the survey value of 1.0 t ha^{-1}. The yields for the other crops were much closer (wheat predicted 2.4, survey 2.6; sorghum predicted 3.8, survey 3.5). It is to be noted that the rules used to determine when to double crop from sorghum into chickpea resulted in chickpea being sown in 57% of years; these would have been the most favourable years in terms of soil water. To illustrate the results, the denitrification data for selected case studies is shown in Figure 3 as cumulative probability functions (CDFs), representing the probability of exceeding any given denitrification.

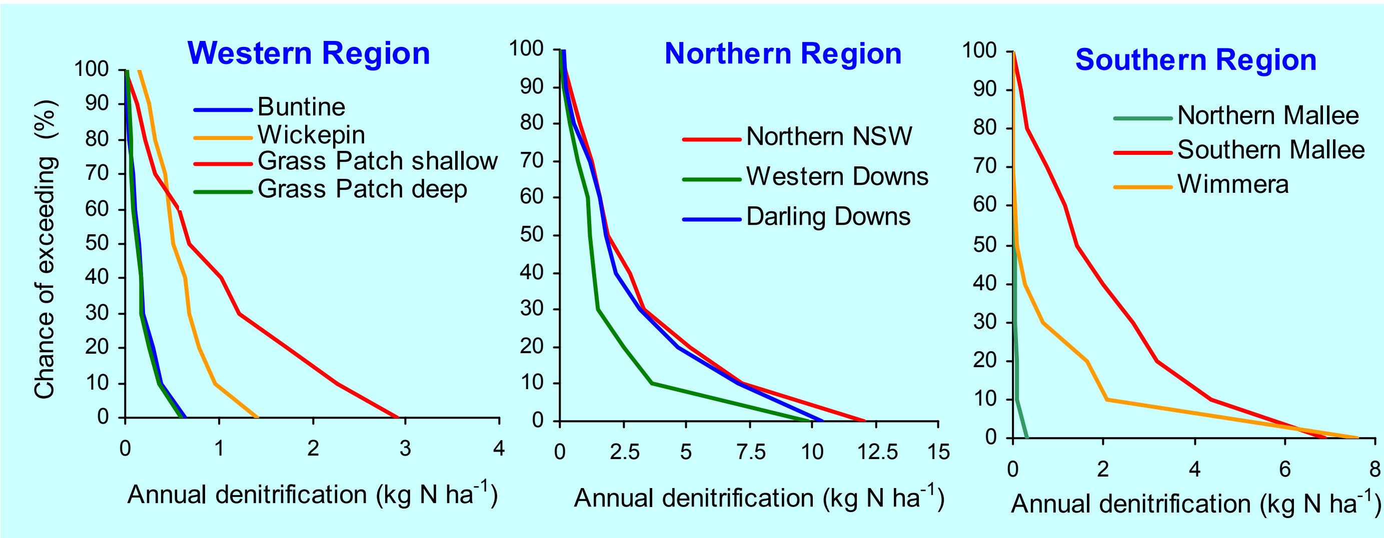

Figure 3. Probability of exceeding any given denitrification value simulated by APSIM for the each of the case study in the three GRDC regions.

Table 9a. Predicted denitrification (kg N ha^{-1}) and number of days per season when soil water content of upper soil layers (0-20 cm) is above 75% of WFPS for the various case studies. Based on weather records for 1957-2001.

Northern Region

Darling Downs: Wheat – sorghum rotation

	Fallow 1	Sorghum	Fallow 2	Wheat
Denitrification (kg N ha^{-1})				
Min	1.4	0.5	1.1	0.0
Max	26.2	21.3	36.8	10.6
Mean	9.5	6.3	13.2	2.8
N° of days WFPS > 75%				
Min	73	15	46	4
Max	367	77	476	95
Mean	247	47	326	51
Grain yield (t ha^{-1})		2.4 - 7.2		1.85 - 5.4

Western Downs: Opportunity cropping (sorghum, chickpea, wheat)

	Fallow 1	Sorghum	Fallow 2	Chickpeas	Fallow 3	Wheat
Denitrification (kg ha^{-1})						
Min	0.8	0	<0.1	0	0.3	0
Max	12.4	11.3	1.7	2.8	12.6	10.8
Mean	4.2	1.6	0.6	0.6	5.1	2.0
N° of days WFPS > 75%						
Min	71	7	1	26	19	0
Max	296	91	125	105	323	85
Mean	161	42	63	67	141	42
Grain yield (t ha^{-1})		1.5 – 7.7		0.8 – 2.7		0.8 – 5.1

Walgett: after sorghum

	Fallow	Wheat	not sown[1]
Denitrification (kg ha^{-1})			
Min	2.9	0	0
Max	34.1	14.2	11.9
Mean	13.7	3.3	4.0
N° of days WFPS > 75%			
Min	16	0	0
Max	93	46	47
Mean	46	11	20
Grain yield (t ha^{-1})		0.8 – 3.9	

Walgett after chickpeas

Denitrification (kg ha^{-1})			
Min	0.3	0	0
Max	12.0	11.9	3.1
Mean	4.0	3.1	0.5
N° of days WFPS > 75%			
Min	1	0	0
Max	38	46	6
Mean	15	10	1
Grain yield (t ha^{-1})		0.8 - 3.6	

[1] not sown before planting window expired.

Table 9b. Predicted denitrification (kg N/ha) and number of days per season when soil water content of upper soil layers (0-20 cm) is above 75% of WFPS for the various case studies. Based on weather records for 1957-2001.

	Southern region		
Northern Mallee: wheat after wheat			
	Fallow	Not sown[1]	Wheat
Denitrification (kg ha^{-1})			
Min	0	0	0
Max	0.31	0.12	0.11
Mean	0.05	0.05	0.03
N^{o} of days WFPS > 75%			
Min	0	0	0
Max	0	0	0
Mean	0	0	0
Grain yield (t ha^{-1})			0.61 – 1.34
Southern Mallee: Wheat (barley) after wheat			
	Fallow	Not sown[1]	Wheat
Denitrification (kg/ha)			
Min	0.01	0	0
Max	3.7	0.16	6.9
Mean	0.5	0.03	1.9
N^{o} of days WFPS > 75%			
Min	0	0	0
Max	44	0	94
Mean	6	0	32
Grain yield (t ha^{-1})			0.94 – 4.2
Wimmera: Wheat after lentils			
	Fallow	Not sown[1]	Wheat
Denitrification (kg ha^{-1})			
Min	0	0	0
Max	2.1	0	7.6
Mean	0.1	0	0.9
N^{o} of days WFPS > 75%			
Min	0	0	0
Max	13	0	106
Mean	1	0	14
Grain yield (t ha^{-1})			1.6 – 5.4

[1] not sown before planting window expired.

At all locations, there is considerable year-to-year variation in predicted denitrification and number of "wet days". At all sites there are some years when denitrification is predicted to be extremely small. The number of "wet days" is very dependent on the soil type; on the deep sand or loamy sand in WA, the soil is never wet above 75% WFPS; in contrast the clay soils of the GRDC Northern Region can be above 75% WFPS for much of the year, especially during fallow periods.

The largest denitrification losses were predicted for the wheat-sorghum rotation on the black earth on the Darling Downs. This cropping system had high inputs of fertiliser, but also had long fallow periods between the crops.

Table 9c. Predicted denitrification (kg N ha^{-1}) and number of days per season when soil water content of upper soil layers (0-20 cm) is above 75% of WFPS for the various case studies. Based on weather records for 1957-2001.

	Western region	
Buntine: Wheat after lupins		
	Fallow	Wheat
Denitrification (kg ha^{-1})		
Min	0	0
Max	0.49	0.65
Mean	0.08	0.17
N° of days WFPS > 75%		
Min	0	0
Max	0	0
Mean	0	0
Grain yield (t ha^{-1})		0.63 – 3.6
Wickepin: Wheat after lupins		
	Fallow	Wheat
Denitrification (kg ha^{-1})		
Min	0	0.16
Max	0.62	1.45
Mean	0.10	0.59
N° of days WFPS > 75%		
Min	0	0
Max	0	0
Mean	0	0
Grain yield (t ha^{-1})		1.7 – 4.8
Grass Patch: Wheat (barley) after wheat		
a) water-logging duplex soil		
	Fallow	Wheat
Denitrification (kg ha^{-1})		
Min	0	0
Max	3.3	2.9
Mean	0.50	0.96
N° of days WFPS > 75%		
Min	0	0
Max	8	2
Mean	0.4	0.1
Grain yield (t ha^{-1})		1 – 4.9
b) loamy sand, rooting depth 2.1m		
Denitrification (kg ha^{-1})		
Min	0	0.01
Max	0.7	0.6
Mean	0.10	0.16
N° of days WFPS > 75%		
Min	0	0
Max	0	0
Mean	0	0
Grain yield (t ha^{-1})		1 – 4.9

In general denitrification losses were larger in the fallows than during the growth of the crop. Water use by the crop is obviously a contributing factor, but the relative length of the fallow and cropping period varies between the different cropping systems.

The relative importance of fallow versus fertiliser is shown by the two cropping systems simulated at Walgett, NSW. Denitrification is predicted to be greater in the system where wheat followed sorghum after a long fallow where no fertiliser is used compared with wheat after chickpea with 55 kg ha^{-1} of fertiliser N. The wheat crops grown in both systems have similar yields implying they have similar N supplies. The build up of N through mineralisation during the long fallow when the soil can be wet for extended periods clearly leads to larger denitrification losses than when fertiliser is applied at sowing.

The winter cropping systems of GRDC Southern and Western Regions have smaller predicted denitrification losses than in the Northern Region. Several factors would seem to be contributing – crops are usually growing at the wettest time of year, which is also the coldest time of year, and any fertiliser that is used is applied at sowing or as split-dressings. As expected denitrification was greater on the water-logging duplex soil at Grass Patch than for the other two case studies in WA (and compared to a loamy sand at the same location). Even for the water-logging soil, losses were predicted to be rather small. It should be noted however that mean annual rainfall at Grass Patch is only 380mm and water-logging may become a more serious issue in higher rainfall areas closer to the coast.

It can be expected high season-to-season variability in greenhouse gas emissions from cropping systems, particularly of nitrous oxide.

The highest rates of N_2O emission occur during denitrification under anoxic conditions; thus there is likely to be a strong dependence on rainfall pattern and the soil's susceptibility to water-logging.

Mitigation options

The main greenhouse gases associated with the grains industry in Australia (excluding rice) are carbon dioxide (CO_2) and nitrous oxide (N_2O).

1. Potential management practices for reducing CO_2 emissions from the grain industry.

   The three main options identified by the International Panel for Climate Change for the mitigation of CO_2 emissions from agriculture are:

   (i) Reduction of agricultural-related fossil fuel consumption.

   (ii) Production of biofuels to replace fossil fuels.

   (iii) Creation and strengthening of carbon (C) sinks in the soil.

   Only option (iii) will be examined here.

   A key process is carbon sequestration. Soil carbon sequestration is where, by management of crops, cultivation and fertiliser use, the soil carbon content increases through plants removing atmospheric carbon dioxide. Provided the carbon storage in the soil is long term, this sequestration helps reduce the rate of increase of atmospheric carbon dioxide.

   The reports on the impacts of land management on soil carbon vary greatly. Nevertheless, the general consensus is that some management practices may lead to increased soil C sequestration.

   Table 10 shows the potential soil sequestration of different management practices.

Table 10 Potential greenhouse reduction due to management practices in the Australian grain industry (the rainfed cereal belt)*

Changes of management practice	**Potential reduction of CO_2 emission ($tCO_2eq\ ha^{-1} year^{-1}$)**
Ley-pasture rotation (vs continuing cereal cropping)	1-5
Cereal-grain legume –other crop rotation (vs continuing cereal cropping)	0.8-3
No-till and crop residue retention (vs conventional tillage)	0-4
Fertiliser and, manures, irrigation (vs none fertiliser and none irrigation)	0-2

*Adapted from Dalal and Chan (2001).

2. Potential mitigation options for N_2O emissions from the grains industry

Like other agricultural systems, nitrous oxide emissions from the grains industry arise as a result of the soil processes of denitrification and nitrification. Mitigation options aim to reduce the rates of these processes and ensure that nitrogen is emitted as harmless N_2 rather than N_2O. Denitrification and nitrification are affected differently by many soil and climatic factors. Options that decrease opportunity for episodic denitrification events will presumably decrease N_2O emissions. Decreasing N_2O loss due to nitrification is a much greater challenge in contrast to denitrification. As a result, experimental evidence of the impact of mitigation options on N_2O emissions is limited. The main nitrous oxide mitigation options suggested and their potential for reducing nitrous oxide emissions are presented in Table 11.

More efficient use of soil and applied N: Provided that edaphic and environmental conditions are conducive, maintaining low soil nitrate concentrations will diminish N_2O loss due to denitrification. Shorter fallow periods before cropping, good crop growth and / or good water use efficiency and partition of N applications (split N application) during cropping will expose fewer nitrates for reduction to N_2O.

More efficient management of soil water. Since maximum denitrification rates are commonly observed when soil water-filled pore space is > 80%, minimising the time a soil is saturated should limit denitrification and the accompanying production of N_2O. As an example, rise bed techniques have the potential to significantly increase crop N demand reducing losses by denitrification. The impact of losses of N in the drainage and run off water would need to be quantified.

Table 11. Estimates of potential reductions of N_2O emissions from Australia's grain industries by implementing various mitigation options.

Practices	Measures	Potential to reduce denitrification losses (%)	Estimate of potential reduction of N_2O emission (tCO_2-eq ha^{-1} $year^{-1}$)
Improve N fertiliser management/ match N supply with crop demand	application schemes	5 - 30%	0.5-2.8
	-match N application to reduced gas production goals		
	-use controlled release fertilisers and nitrification inhibitors	10-35%	0.9-3.3
	-match fertiliser type to seasonal conditions	5-15%	0.3-0.9
Improve crop management	-optimise irrigation and drainage (prevent large groundwater fluctuations or flooding)	15-80%	0.9-5.1
	-use N fixing crops		
	-Breed cultivars that improve N use efficiency		
	-minimise fallow periods by growing cover crops	5-10%	0.3-0.6
	-prevent soil compaction		
	-adequate P (P-fertiliser)	5-15%	0.3-0.9
GIS based decision support mode	BMPs to the local conditions, optimal application rate, timing and methods of N fertiliser	25-35%	0.9-3.0

[1] Assuming average of 80 kgN/ha/year is used, 25% of total denitrification as N_2O.

Altering soil conditions. Soil management techniques that improve infiltration and reduce soil compaction have also the potential to reduce waterlogging and denitrification process.

Optimal application rate, timing and methods of N fertiliser. It has been demonstrated that application of N fertiliser to match the crop demands, deep placement of N fertiliser and appropriate application rates increased efficiency of N fertilisers and reduced the denitrification losses for the irrigated cotton and wheat (Chen *et al.* 1994; Cai *et al.* 2001).

Use of nitrification and urease inhibitors. Good control of N losses has been achieved by using urease and nitrification inhibitors.

Grains Greenhouse Accounting Framework

This project has developed a user-friendly Excel based tool (Figure 4, 5 and 6) that allows the user to:

(i) estimate farm emissions using an updated set of emission factors;

(ii) compare the calculated emissions with those expected in each GRDC region;

(iii) evaluate the impact of climate variability on greenhouse gas emissions;

(iv) read general information explaining what are GHG emissions, why they are important, what are their sources, how they can be estimated and what would be mitigation options.

The potential users of the tool include farmers, research and extension staff, and policy makers. This tool has combined the results outlined in the document into an accessible piece of software, making the research available to a wide range of people.

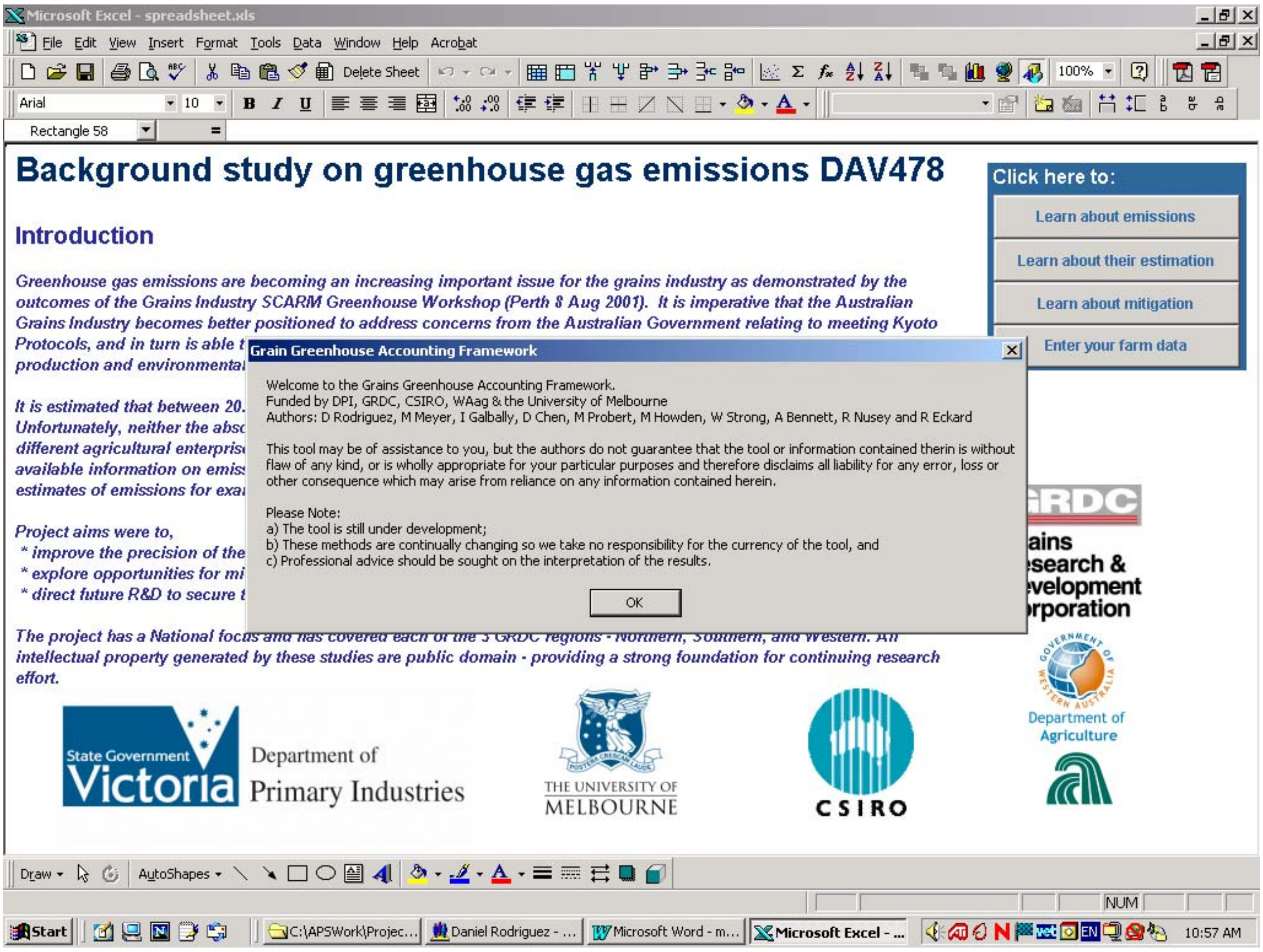

Figure 4. Front page of the updated tool for the estimation of greenhouse gas emissions from the grains industry.

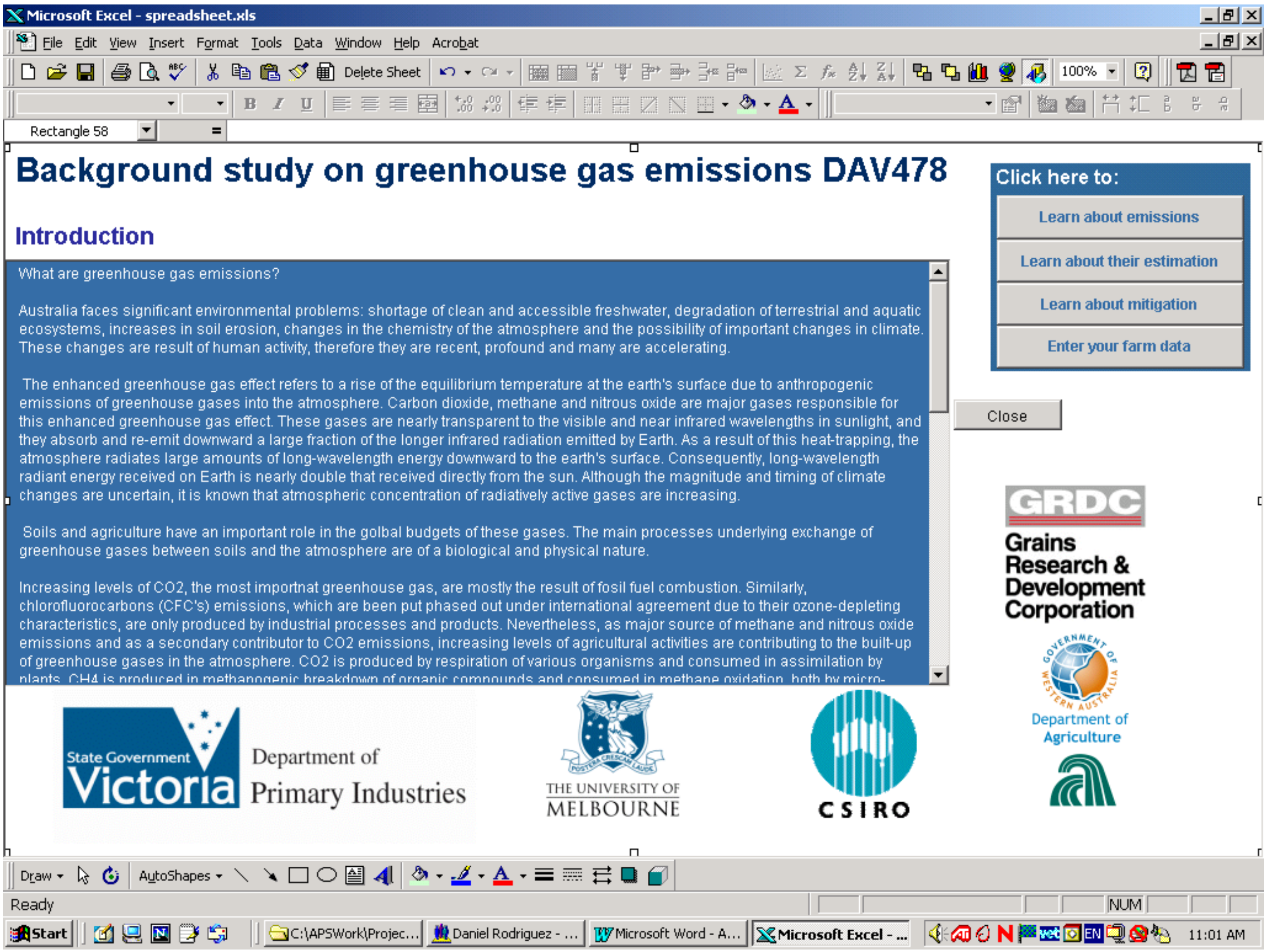

Figure 5. Educational tool with information about the origin of greenhouse gas emissions, methods for their estimation and mitigation options.

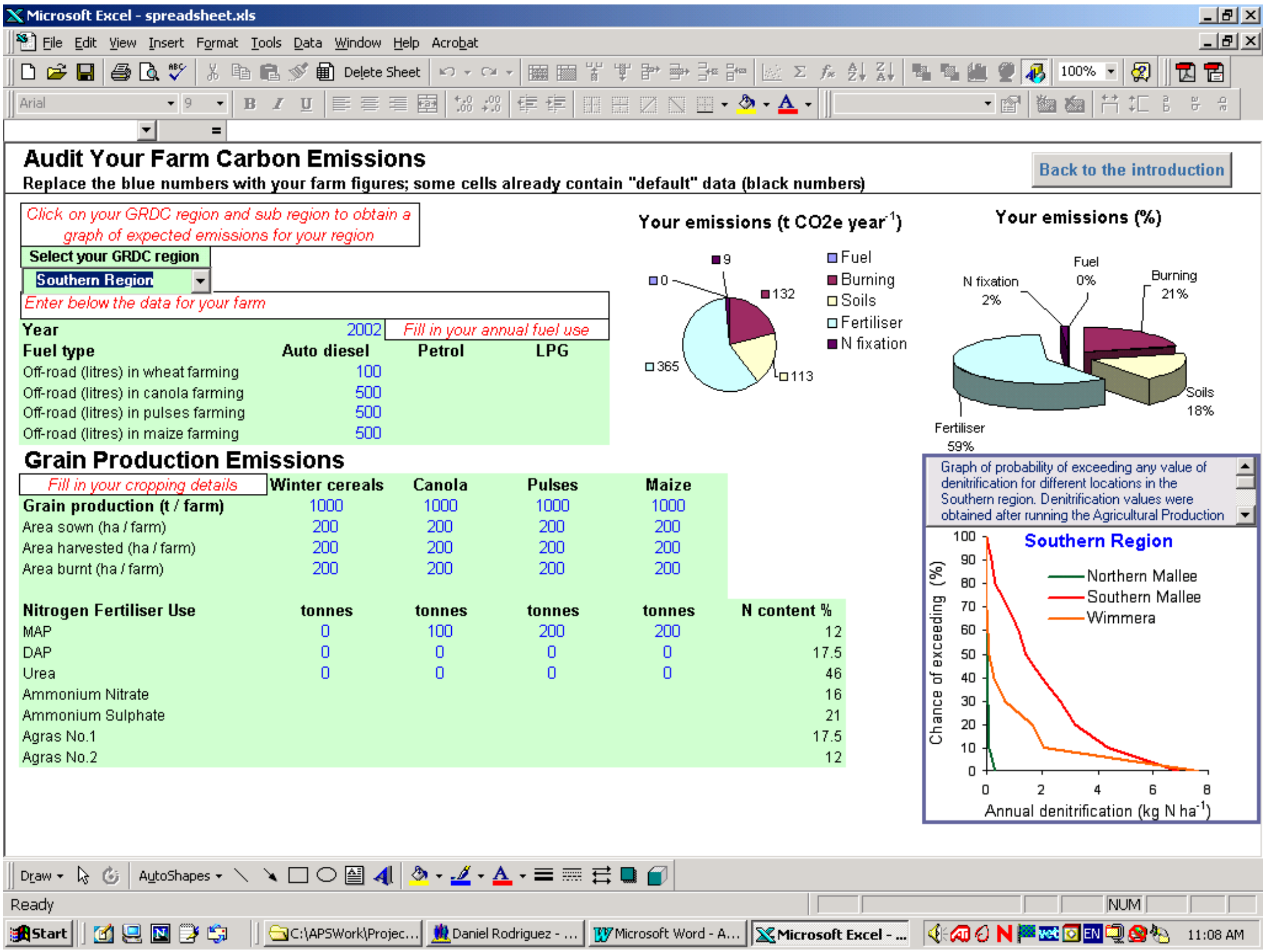

Figure 6. Updated calculation tool for greenhouse gas emissions from the grains industry. This tool allows farmers to estimate their emissions, to compare their emissions with emissions from typical grain enterprises in their region and to learn about seasonal variability in emissions from denitrification.

Conclusions

Emission factors

Emission factors for soil disturbance and for fertiliser application of 0.25 kg N ha^{-1} and 1.0%, respectively, are recommended as appropriate estimates to use for Australian grain production systems. It is imperative that the value of these emission factors is corroborated with measurements of emissions from Australian farming systems, as no overseas study of which we are aware is relevant to Australia.

The impact of climate variability and farming system

Simulation of gaseous N losses to the atmosphere at all locations predicted considerable year-to-year variation, and highlighted northern cropping systems as those most likely to emit N_2O during denitrification events.

The largest denitrification losses were predicted to occur for the wheat-sorghum rotation on the black earths of the Darling Downs (average 32 kg N ha^{-1} over a 3 year rotation). The biggest losses occurred during the fallows with the maximum predicted loss being 37 kg N ha^{-1} during one fallow between a sorghum crop and the next wheat crop.

Smaller losses were predicted from the southern and western farming systems. Several factors are contributing – crops are usually growing at the wettest time of year, which is also the coldest time of year, and small amounts of fertiliser are usually applied.

Uncertainty analysis

The impact of a ±10% change in the soil disturbance and fertiliser emission factors on the total emissions from each of the case studies in this report produced average changes in the emissions of 4 and 3%, respectively. The biggest impact (6%) was observed by varying the fertiliser emission factor in the Darling Downs, however in general terms small variations in the soil disturbance emission factor always had bigger effects than small variations in the fertiliser emission factor.

Trend analysis in the use of N fertilisers

From the trend analysis in use of N fertilisers we concluded that assuming linear increases in N use the biggest changes in estimated emissions can be expected in the Wimmera and high rainfall zone of south Victoria, and the smallest changes from central Western Australia, and the south Australian and Victorian Mallee.

Mitigation options

Changes in the management of a farming system could increase soil carbon sequestration by 0-5 tCO_2-eq ha^{-1} $year^{-1}$. Potential greenhouse reductions due to reduced emissions of nitrous oxide from the Australian grain industry due to better use of fertilisers have been estimated to be 0.5-2.8 tCO_2-eq ha^{-1} $year^{-1}$ after matching N applications to reduce gas production to emission goals; 0.9-3.3 tCO_2-eq ha^{-1} $year^{-1}$ by using controlled release fertilisers and nitrification inhibitors; 0.3-0.9 tCO_2-eq ha^{-1} $year^{-1}$ after matching fertilise type and amount to seasonal conditions.

Needs for further investment

There is urgent need to develop a modelling tool to allow reliable estimates of greenhouse gas emissions from Australian farming systems. This is key to the success of other GRDC funded projects (DAV0039) as short term and limited measurements of greenhouse gas emissions will require to be integrated and extrapolated to account for climatic trends, seasonal variability and changes in management practice.