FEBRUARY 2016

SOIL CARBON AND GREENHOUSE GAS EMISSIONS FACT SHEET

GRDC
Grains Research & Development Corporation
Your GRDC working with you

NORTHERN, SOUTHERN AND WESTERN REGIONS

IMPROVED GRAIN YIELDS FROM BEST PRACTICE CROPPING CAN BENEFIT SOIL CARBON AND LOWER GREENHOUSE GAS EMISSIONS

Accounting for the greenhouse gas emissions from broadacre grain cropping involves the use of life cycle assessment (LCA) methodology, an internationally recognised method for assessing the environmental impact of products and production systems.

KEY POINTS

- Climate change is linked to increasing levels of greenhouse gases in the Earth's atmosphere.
- The major greenhouse gases in grain production are nitrous oxide and carbon dioxide.
- Grain cropping, embracing best management practices, could become part of the solution to elevated greenhouse gas emissions.
- Life cycle assessment (LCA), a methodology for determining the environmental footprint of products and production systems, is now being applied to agriculture.
- At first glance, the use of nitrogenous fertilisers appears to be the major source of greenhouse gas emissions in grain cropping.
- However, when potential changes in soil carbon stocks are included in LCAs of N-fertilised and N-fixing legume crops, a different picture emerges.
- Farming practices that improve the productivity and profitability of grain crops can also benefit soil carbon stocks.

Australia produces 40 to 45 million tonnes of grain annually from about 23 million hectares, much of which is exported. Grain production not only directly sustains the livelihoods of an estimated 27,000 farmers in Australia but also underpins the livelihoods of many hundreds of thousands of other people throughout regional Australia who are linked to grain production and grain producers through provision of goods and services. Current predictions are that climate change associated with increased greenhouse gas emissions will impact on Australian agriculture. Higher overall temperatures are likely to occur, with more hot extremes, fewer colder extremes and changes to rainfall patterns.

Current detailed accounts or inventories of greenhouse gas emissions associated with each and every aspect of grain production are being produced. It may be the case that widespread adoption of best management practices in grain cropping will result in not only an increase in on-farm productivity and profitability but in a significant reduction in associated emissions and contribute to meeting Australia's emissions reduction targets. In effect, grain cropping becomes part of the solution to increasing greenhouse gas emissions.

What are the greenhouse gases associated with grain production?

The most abundant greenhouse gases associated with grain cropping are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Greenhouse gases

Level 4, East Building | 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604 | **T** +61 2 6166 4500 | **F** +61 2 6166 4599 | **E** grdc@grdc.com.au | **W** www.grdc.com.au

Monitoring greenhouse gas emissions from crops at the NSW Department of Primary Industries at Tamworth. The gases are collected in either automated chambers (above left) or static (manual) chambers (above right).

absorb and redirect some of the Earth's outgoing radiation (heat) back to the earth; that is, they trap heat, causing increased temperatures with potential impacts on global weather. Nitrous oxide is a minor atmospheric gas, but a potent greenhouse gas with a global warming potential about 300 times that of carbon dioxide. Emissions of nitrous oxide are strongly associated with the production, transport and use of fertiliser N. Methane is another greenhouse gas linked to agriculture and is primarily associated with animal production and paddy rice culture. Methane has a global warming potential 25 times that of carbon dioxide. Greenhouse gas emissions are usually expressed as carbon dioxide equivalents or CO_2-e (based on their global warming potential).

The Australian Government Department of the Environment has determined that agricultural industries directly contribute 81 million tonnes CO_2-e annually or 15 per cent of national greenhouse gas emissions, which total 547 million tonnes CO_2-e. Although exact figures are not published, it is likely that grain cropping accounts for about 10 million tonnes CO_2-e annually.

Life cycle assessment: an accounting method for greenhouse gas emissions

Life cycle assessment (LCA) has become an increasingly common approach across different industries, including agriculture, for environmental (including carbon footprint) impact assessment, particularly related to greenhouse gas emissions. Its use is recommended and supported by Australia's grains industry. In grain production, the sources of greenhouse gas emissions are nitrous oxide and carbon dioxide from the soil, transport and on-farm energy use and material inputs, e.g. fertilisers and pesticides.

TABLE 1 Grain yields, fertiliser N inputs and total pre-farm + on-farm greenhouse gas emissions for N-fertilised wheat and N-fixing field peas.

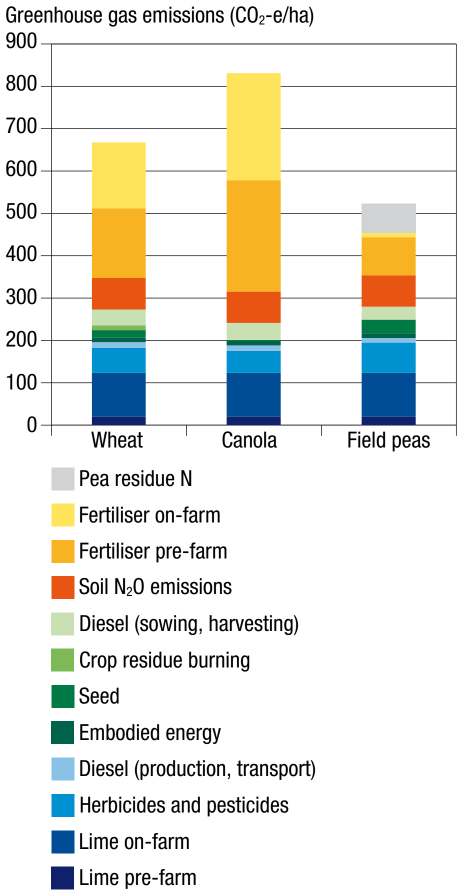
Crop	Yield (t/ha)	Fertiliser N inputs (fixed N for field peas) (kg N/ha)	Total GHG emissions (kg CO_2–e/ha)	Total GHG emissions (kg CO_2–e/t grain)
Wheat	3.0	60	676	225
Canola	2.0	100	841	420
Field peas	1.8	(100)	530	294

Life cycle assessments for grain cropping can include emissions from the manufacture and transport of raw materials, the creation of the product, transport and use of the product through to disposal of waste products. In most cases, however, only the pre-farm and on-farm emissions are counted because of the diversity of uses of grains post-farm. The functional unit is usually a unit of grain (tonne) or sometimes land (hectare). The outputs of greenhouse gas LCAs are expressed as carbon dioxide equivalents or CO_2-e. Another term used, when all components of the emissions profile are combined, is the carbon footprint. Other impact categories, such as ecotoxicity and eutrophication of water sources, are often included but here we are focusing wholly on greenhouse gas emissions.

Monitoring greenhouse gas emissions during grain cropping

Greenhouse gas emissions are monitored either continuously using automated chambers or at specific time points using static chambers (see photos above). The automated chambers are preferred because large spikes of greenhouse gas emissions may be missed when using static chambers, leading to underestimation of total emissions. In the automated chamber system, samples of the atmosphere in the chambers are channelled through flexible gas hoses to a gas chromatograph located nearby for measurement. The chambers illustrated in the photo above and associated chromatograph are set up to measure nitrous oxide, methane and carbon dioxide.

FIGURE 1 Inventory of greenhouse gas emissions associated with the production of N-fertilised wheat and canola and N-fixing field peas in the Wagga Wagga region of NSW.



Case study: grain cropping in southern NSW

The case study involves N-fertilised wheat and canola and N-fixing field peas in the Wagga Wagga region of south-eastern NSW[1]. Grain yields of the various crops and inputs of fertiliser N (wheat and canola) and legume-fixed N (field pea) are shown in Table 1. Using LCA methodology, the area-based greenhouse gas emissions for production of the individual crops were estimated to range from 530 kilograms CO_2-e/ha for field peas to 841kg CO_2-e/ha for canola. Emissions cover the full 12 months, from sowing of the crops through to the end of the post-crop (summer) fallow. The greatest source of emissions was the production, transport and use of N fertiliser, with an almost 50:50 balance of pre-farm emissions (essentially production and transport of the fertilisers) and on-farm emissions from the soil as carbon dioxide and nitrous oxide emissions (Figure 1). As a consequence, greenhouse gas emissions were lowest for field pea (no fertiliser N). Note that the greenhouse gas emission values in Table 1 do not include estimates of the carbon dioxide associated with possible soil carbon changes during production of these crops.

Grain cropping and changes in soil carbon

Carbon is released from soil organic matter as carbon dioxide during mineralisation at a C:N ratio of about 11:1, equivalent to 40.3 kg CO_2 for each kg N (a unit of C is multiplied by 44/12 to convert to CO_2). The same stoichiometry (measure of elements) of 11:1 applies to the incorporation of carbon and nitrogen into soil organic matter during the decomposition of crop residues. The relative amounts of carbon (and nitrogen) that are concurrently released from and immobilised into soil organic matter during a specific time-frame will determine the net changes in soil carbon. The Department of the Environment published guidelines for estimating changes in soil carbon stocks with cropping are too broad to be useful at the individual paddock level. As a consequence, many of the reports of LCAs for grain cropping assume a neutral effect of cropping on soil carbon, although not in all cases. Even small changes in soil carbon can have a profound impact on estimated greenhouse gas emissions for a particular crop or cropping sequence.

Implications of soil carbon changes for overall greenhouse gas emissions

In our case study, as little as a 200kg/ha increase in soil carbon (equivalent to 733kg CO_2-e/ha) during the year in which the crops were grown would essentially offset all other pre-farm and on-farm greenhouse gas emissions (as shown in Figure 1). On the other hand, a 200kg/ha reduction in soil carbon would essentially double the total production of greenhouse gas emissions associated with the crops.

Many published scientific studies, such as the large Australian study of Dr Murray Unkovich and colleagues[2], inform us that well fertilised wheat and canola crops will normally produce substantially more biomass than field pea growing in the same soil and environment. This is because field pea uses as much as 30% of its carbon to maintain N fixation activity. We would also expect that the wheat would produce more grain than the canola, but less residue carbon, because of its higher harvest index, i.e. the proportion of total above-ground biomass that is harvested as grain.

What this means is the canola is likely to return more residue carbon back to the soil than wheat with field pea returning the least. Modelling indicates a potential increase in soil carbon of 200 kg/ha for the 2.0 tonne/ha canola crop, an increase in soil carbon of just 20 kg/ha for the 3.0 tonne/ha wheat and a loss of soil carbon of 200 kg/ha for the 1.8 tonne/ha field pea.

Combining the modelled soil carbon data with the total pre-crop + in-crop greenhouse gas emissions allows us to more fully determine the carbon footprints of the three crops (Table 2). Canola was the largest emitter before accounting for potential changes in soil carbon. When modelled changes were included in the LCAs, canola had the smallest, rather than the largest, carbon footprint (final column, Table 2). Conversely, field peas went from being the smallest emitter to the largest when the soil carbon changes were included.

This is a somewhat surprising outcome because there is a general belief that one way of reducing greenhouse gas emissions is to replace or partly replace crops that rely on inputs of fertiliser N with nitrogen-fixing legume crops.

The carbon footprint of the different sources of crop N

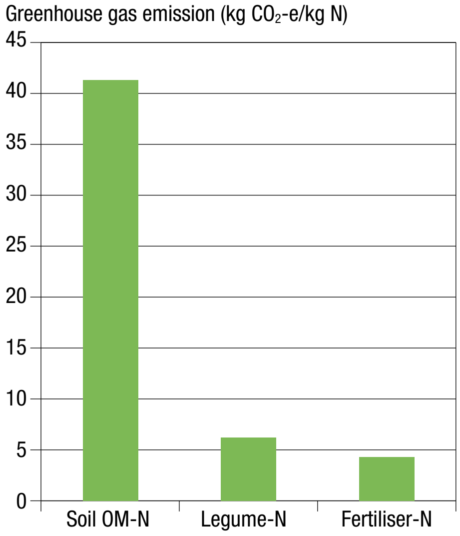
Rather than fertiliser N having a heavy carbon footprint, the opposite may be true. When considered more broadly to include soil carbon changes, industrially produced fertiliser N appears to be highly efficient in terms of greenhouse gas emissions. For the Wagga Wagga case study, 4.3kg CO_2-e was emitted for each kg fertiliser N used (Figure 2). This was substantially less than the emissions calculated for the N fixation inputs of the field peas (6.2kg CO_2-e/kg N). The largest

TABLE 2 Carbon footprints of wheat, canola and field peas (12 months) at Wagga Wagga, NSW, including modelled changes in soil carbon.

Crop	Total GHG emissions (kg CO_2-e/ha)	Changes in soil carbon (kg CO_2-e/ha)	Carbon footprint (kg CO_2-e/ha)[1]
Wheat	676	+73	603
Canola	841	+733	108
Field peas	530	–733	1263

* Calculated as column 2 minus column 3.

FIGURE 2 The carbon footprints of the different sources of N for grain cropping in the Wagga Wagga case study.



emissions by far were associated with the mineralisation of soil organic nitrogen (41.3kg CO_2-e/kg N).

The high carbon cost of liberating soil organic nitrogen also highlights the importance of building nitrogen into soil organic matter and keeping it there. For every kilogram N built into organic matter, 11kg of carbon is sequestered.

Final comment

The readily measured greenhouse gas emissions, particularly nitrous oxide, are less for N-fixing legumes than for N-fertilised crops such as wheat and canola.

However, when emissions associated with potential changes in soil carbon during the period of cropping are included in life cycle assessments, the environmental impacts of the different crops may change, at least in terms of their carbon footprints.

Potential changes in soil carbon that are likely to occur during a 12-month cropping phase will be small and very difficult to quantify against the background levels of around 50 tonnes carbon/ha. What is needed going forward are very precise measurements of soil carbon stocks in medium and long-term field experiments combined with modelling. The fact that N-fixing grain legumes may not have the small carbon footprint they were generally assumed to have does not detract from their economic and agronomic value in grain cropping or their value in other aspects of environmental stewardship, such management of eutrophication of waterways and water sources.

The Department of the Environment guidelines indicate positive effects on carbon levels in soils used for grain cropping of moderate to high inputs (including fertiliser), residue retention, no-tillage and use of rotations for management of diseases, pests and weeds.

Farming practices that improve the productivity and profitability of grain crops can at the same time have positive benefits for soil carbon stocks.

REFERENCES

1 Brock PM, Muir S, Herridge DF, Simmons A (2015) Cradle-to-farm gate greenhouse gas emissions for 2-year wheat monoculture and break crop-wheat sequences in south-eastern Australia. Submitted to *Crop & Pasture Science*.

2 Unkovich M, Baldock J, Forbes M (2010) Variability in harvest index of grain crops and potential significance for carbon accounting: examples from Australian agriculture. *Advances in Agronomy* 105, 173–219.

FURTHER INFORMATION

Pip Brock
NSW Department of Primary Industries, Tocal
02 4916 3940
pip.brock@dpi.nsw.gov.au

Aaron Simmons
NSW Department of Primary Industries, Orange
02 6391 3894
aaron.simmons@dpi.nsw.gov.au

David Herridge
University of New England, Armidale
02 4942 6950
david.herridge@une.edu.au

PROJECT CODE

DAN00160

USEFUL RESOURCES

Wang WJ, Dalal RC, Reeves SH, Butterbach-Bahl K, Kiese R (2011) Greenhouse gas fluxes from an Australian subtropical cropland under long-term contrasting management regimes. *Global Change Biology* 17, 3089–3101.

Acknowledgements: Dr Graeme Schwenke, NSW Department of Primary Industries, Tamworth Dr Sally Muir, NSW Department of Primary Industries, Tamworth.

PRODUCED BY WWW.CORETEXT.COM.AU