LCA as a tool for targeted GHG mitigation in Australian cropping systems

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ABSTRACT

Australian agricultural industries contribute approximately 14.6% of net annual national greenhouse gas (GHG) emissions, with N_2O emissions from agricultural soils the second greatest source of these emissions. Given that 25 M ha of land in Australia is cropped, the technical potential for GHG emissions reduction in Australian grain production systems is substantial. The New South Wales Department of Primary Industries (NSW DPI) has developed research capacity in Life Cycle Assessment (LCA) to assess this mitigation potential. In this paper we provide insights into the regionally-specific approach that we are taking, not only to provide credible management options at a grain grower level and ensure that detailed data are available for analysis by participants in the downstream supply chain, but also to provide data which, in an aggregated form, will underpin market access and inform national policy development. We report on initial NSW DPI studies and discuss a new project, funded by the Grains Research and Development Corporation (GRDC), to determine emissions reduction opportunities for each of Australia's agro-ecological zones. Initial studies show total emissions from wheat production in the order of 200 kg CO_2-e per tonne, with values ranging down to 140 kg CO_2-e per tonne. In one study, replacing synthetic nitrogenous fertiliser with biologically fixed N reduced emissions to 33% of prior values. The new project is particularly concerned with developing accurate foreground data by triangulating several sources of published literature (including official statistics) and conducting 'ground-truthing' through panels of regionally-based advisors to increase data specificity. The LCAs and associated mitigation strategies will be underpinned by a median and relevant distribution of values for inputs, practices and yields, with system assumptions clearly documented.

Keywords: cropping, grain production, mitigation, agriculture, emissions

1. Introduction

It can be said with 95% certainty that anthropogenic emissions of the greenhouse gases (GHG) CO_2, N_2O and CH_4 are the primary driver of climate change (IPCC 2013). Australian agriculture industries contributed approximately 79.5 Mt CO_2-e or 14.6% of net annual national greenhouse gas (GHG) emissions in 2010, with N_2O emissions from agricultural soils the second greatest source of emissions after those from livestock methane (Australian Government 2013).With approximately 25 M ha of Australian farming land cropped, the technical potential for GHG emissions reductions in grain production systems in Australia is substantial. All industries have a responsibility to contribute to the reduction of emissions to minimise the impacts of climate change, including agriculture.

The application of Life Cycle Assessment (LCA) to agricultural systems is now relatively widespread (Roy *et al*. 2009) and country-specific life cycle inventories are being developed to increase the applicability of LCAs, e.g. The Australian Agricultural Life Cycle Inventory (Eady *et al*. 2013). Australia has considerable intra- and inter-regional variation in landscape and climate, aspects which determine the most profitable functional production unit. This variation, coupled with methodological issues associated with attributing emissions accurately and accounting for the flow-on effects arising as a consequence of recommended practice changes, creates challenges for LCA practitioners. Also, data gaps exist when attempting to apply published regionally-specific Emissions Factors (EFs). In this paper, we discuss existing studies by the NSW Department of Primary Industries (NSW DPI) and a new project, which we will lead, to explore mitigation options for grain production across Australia.

2. Australian cropping systems

Australia is a relatively large landmass, with climatic zones ranging from wet tropics to temperate semi-arid plains (Williams *et al*. 2002). Australia also has high seasonal climatic variability driven in South-eastern Australia by the El Nino - Southern Oscillation and the Indian Ocean Dipole (Cai *et al*. 2011). Grain cropping is a major agricultural land use occupying approximately 25 Mha, with an estimated annual production of approximately 44 Mt (ABARES 2013). The Grains Research and Development Corporation (GRDC) has determined agro-ecological zones for their industry by using a similar framework to Williams *et al*. (2002), who considered climatic, agronomic and ecological factors. The GRDC's agro-ecological zones have been fine-tuned for relevance to regional grain growing systems and the geographical constraints of those systems (Figure 1), providing suitable biophysical boundaries for LCA studies. The GRDC is one of the primary providers of research funding for the Australian grains industry, raising funds through grower levies and federal government co-contributions.

Grains cropping in Australia primarily occurs where rainfall is < 650 mm, although can occur in high (> 650 mm) rainfall areas. Winter crops such as wheat, barley, oats and canola, with smaller areas of legumes (*e.g.* lupins, peas and vetch), are primarily grown in regions with a typical winter dominant rainfall pattern (*i.e.* southern Western Australia (WA), South Australia (SA), some parts of Victoria and southern New South Wales (NSW)) (ABS 2013). Whilst winter grain crops are also grown in northern NSW and southern Queensland (Qld), summer grain crops, such as chickpeas, sorghum and sunflowers are also grown, to capitalise upon high levels of sub-soil moisture during mid-spring and a greater proportion of rainfall in summer. In tropical zones (*e.g.* WA Ord and Central and Far North Qld) sugarcane dominates, with grain crops grown in rotation as a break crop for disease control. Where irrigation is available, systems are modified to meet market demand, with crop production primarily limited by the capital infrastructure of the enterprise.

Australian agriculture is supported by an effective financial assistance of 0.15% of national gross domestic product (GDP), which is relatively small compared to the European Union (0.73%) and the USA (1%) (OECD 2013). Cropping, sheep and cattle enterprises are aggregated for Australian national economic reporting purposes and receive approximately a third of this assistance (Productivity Commission 2013).

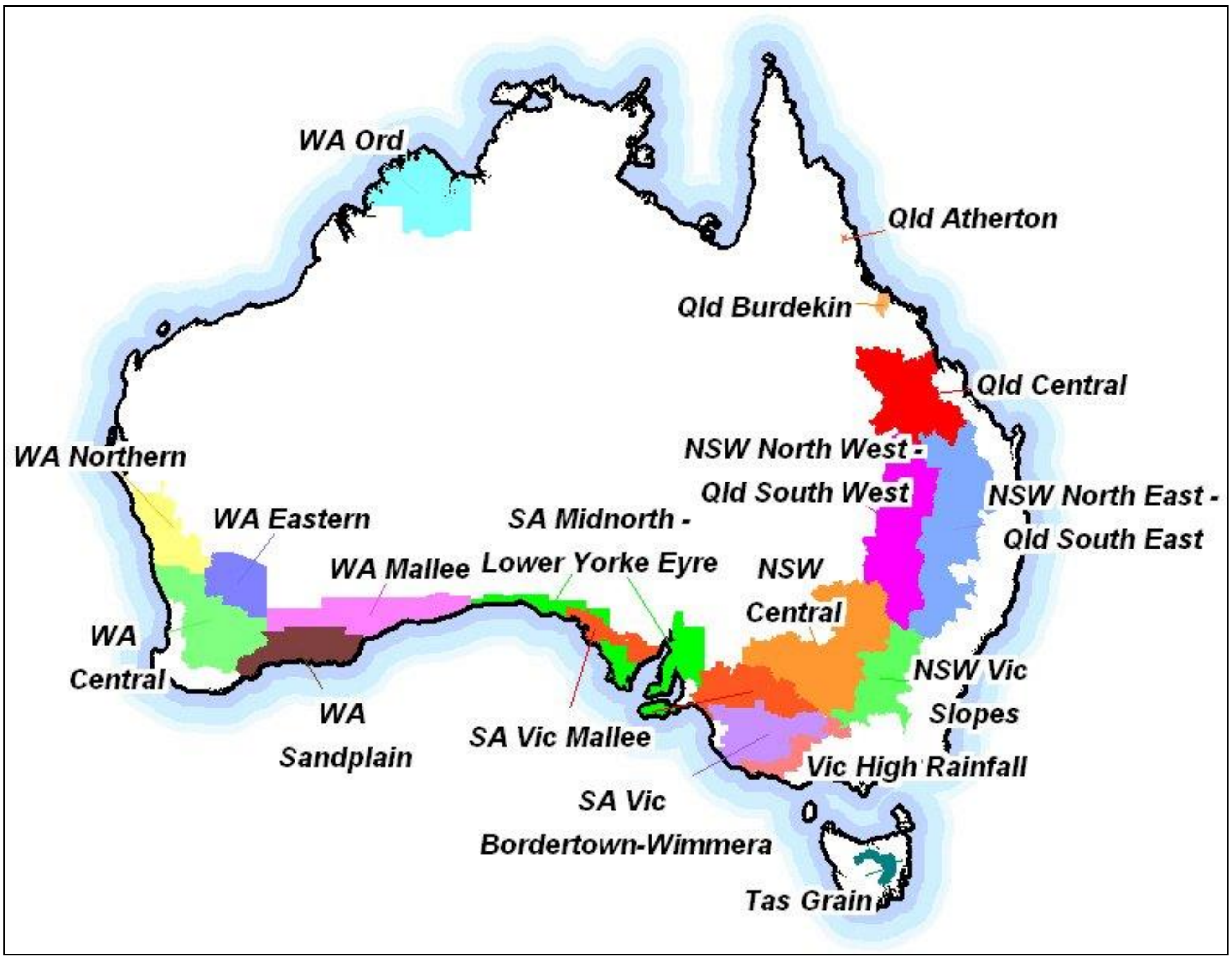

Figure 1. Map of Australia showing the GRDC agro-ecological zones.

The scale of enterprise varies between regions (Table 1) with larger grain growing holdings in WA, compared with other States and Territories of Australia. Scale plays an important role, with larger farms generally more profitable due to economies of scale in purchasing inputs, machinery size and labor costs.

Table 1. Holding area, numbers of holdings and average holding area of cropping properties in the States and Territories of Australia (ABS 2013).

State	Area of holding (ha)	Number of holdings	Average area of holdings (ha)
WA	8 543 799	8 112	1053
SA	4 048 970	9 384	431
NSW	6 931 906	18 069	383
Vic	3 818 961	12 448	306
Qld	2 898 356	11 596	249
Tas	70 581	1 415	49
NT	11 084	238	46

3. Data sources and quality

As with any modeling approach, the quality of input data is a key determinant of the quality of an LCA. In terms of foreground data, LCA research being conducted by NSW DPI takes the approach of triangulating several sources of published literature and then conducting 'ground-truthing' with advisors, primarily agronomists and economists. Official statistics, such as from ABS (2013) and ABARE (2013) are included, for attributes for which they are available, along with State-specific official crop statistics reports which provide total tonnages aligned with area sown. However, these data are often not collected at a sufficiently fine scale, do not cover all attributes necessary to conduct LCA and do not universally provide enterprise-specific ranges to enable sensitivity testing. Another key source of data has been annual gross margins, published by NSW DPI, which forecast yield and profit for given inputs and management actions. However, modifications to these data have also been necessary to account for long-term trends.

A new project, funded by GRDC, has a specific budget allowance for panels of regionally-based advisors to fine-tune data and by involving them in the LCA process, they will be well informed to extend findings to their grain grower clients. These advisors have a large client base with approximately half of all grain growers employing advisors in some areas. We are confident that their client data and production knowledge is strongly representative of common practice. Regionally-specific data will be made available for attributes such as the quantities of fertilizer, diesel and herbicide used. The LCAs and associated mitigation strategies will be underpinned by a median and relevant distribution of values for inputs, practices and yields, with system assumptions clearly documented. Sensitivity analysis is then conducted and individual attributes which show significant variation, due to biophysical or management differences, further investigated. For example, we are currently testing the effect of different assumptions about tractor engine capacity, source of inputs, such as herbicides, and use of lime and fertiliser. Whilst larger engines consume more diesel, they enable faster completion of farm practices. Also, biophysical modelling could be beneficial to account for differences in denitrification for a given quantity of N applied, in a specific climatic zone, on different soil types. The degree of interdependence varies between attributes, so we have tested variables independently across a representative range and then discussed linkages.

Emissions from biological processes within agricultural systems have been calculated using EFs obtained preferentially from published field measurements (Schwenke *et al*. 2012), then tier 2 data e.g. from the National Inventory Report (Australian Government 2013) and then tier 1 data (Eggleston *et al*. 2006). The approach of adopting published data where they are more specific than default EFs is consistent with the National Inventory Report (Australian Government 2013). However, Australian coverage of data from published field measurement is not complete, so where emission reduction strategies are being tested through comparative LCA, some standardisation of factors is necessary. Background emissions data about the manufacture and transport of agricultural inputs have been preferentially sourced from the Australasian LCI database (Life Cycle Strategies Pty Ltd 2013) which has been adjusted for Australian conditions, followed by data from Ecoinvent (Hischier *et al*. 2009).

4. The application of LCA to Australian cropping systems

Several LCA studies have been completed for cropping systems in the State of NSW, *e.g.* Brock *et al*. (2012a). Some of these studies and a new funded project are discussed below.

4.1. Aims

The purpose of NSW DPI's LCA studies is to develop an understanding of the various components of emissions profiles for a given functional unit and through comparative LCA, identify practice changes that will target emissions reduction hotspots. For example, the substantial contribution of emissions from both manufacture and use synthetic nitrogenous fertilisers led to testing of the effects of supplying crop N requirements from biologically-fixed N (Brock *et al*. 2012b), resulting in emissions reduction to 33% of prior values.

4.2. Methods

Cradle-to-gate attributional LCAs for wheat production in Central Zone (East) NSW (Brock *et al*. 2012a), and wheat-wheat, canola-wheat and chickpea-wheat rotations in North-East (NE) NSW and North-West (NW) NSW (Muir *et al* 2013), have been developed using SimaPro v7.3.3 (Goedkoop *et al*. 2008). Input data were sourced as per Section 3 above. Pre-farm emissions data were included for the production and transport of all inputs, with the exception of wetting agents, as their contribution to overall emissions profiles were considered to be negligible. On-farm, direct N_2O emissions from the use of synthetic nitrogenous fertilizers were included, as were indirect emissions from the re-deposition of volatilized N as NH_3. N_2O from leaching and runoff of nitrogenous fertilisers were not included as these processes were deemed not to occur, due to soil type and climate, for consistency with the National Inventory Report (NIR) (Australian Government 2013). Direct CO_2 emissions from the hydrolysis of urea were included, as were CO_2 emissions from the dissolution of lime.

Whilst emissions from herbicides used during the pre-crop fallow were included, N_2O and CH_4 emissions from the decomposition of stubble were only included post-crop, as this is when they are attributable to the functional unit. However, residue emissions were excluded where they could result in double-counting with experimental field chamber data, with field-based N_2O EF as high as 0.45%, compared to the current Australian default value of 0.3%. Following our decision rule (consistent with the NIR), to adopt local published values, ahead of NIR data, ahead of IPCC data, it will be necessary to include low EF values obtained from soil with a low clay content in WA, in the future work discussed in Section 4.4 of this paper.

Given that consideration is being given to lowering the Australian default value of 0.3%, for WA or on a wider basis, the 0.3% value is a better estimate for Australia than the 1% IPCC default value. The 0.3% value is in between the 0.45% that has been adopted for some existing studies in NSW and a lower value that will be included for future studies for WA, so will provide a useful standardised value if we wish to hold this attribute constant during comparison of other variables. However, if the next NIR (Australian Government) includes a lower value for Australia, then we will adjust our assumptions accordingly. Stubble burning is not considered common practice in these regions, so was also excluded. All above- and below-ground sequestered carbon (C), remaining after harvest, was considered to be re-emitted through decomposition of crop residues, with soil C flux in a steady state. Emissions from combustion of diesel in tractors for cultivation, sowing and spraying of farm chemicals were included, as were emissions from harvesting and on-farm cartage.

4.3. Results

The emission intensity for one tonne of wheat grown in Central Zone (East) NSW and yielding 3.5 t ha^{-1}, was calculated as 200 kg CO_2-e (Brock *et al*. 2012a). The largest contributors to emissions were the production of fertilizer and lime, and N_2O and CO_2 emissions from these inputs (Figure 2). Opportunities to modify the emissions profile through changes to inputs and practices were discussed, ranging from improved fertiliser management to replacing cultivation with herbicide application.

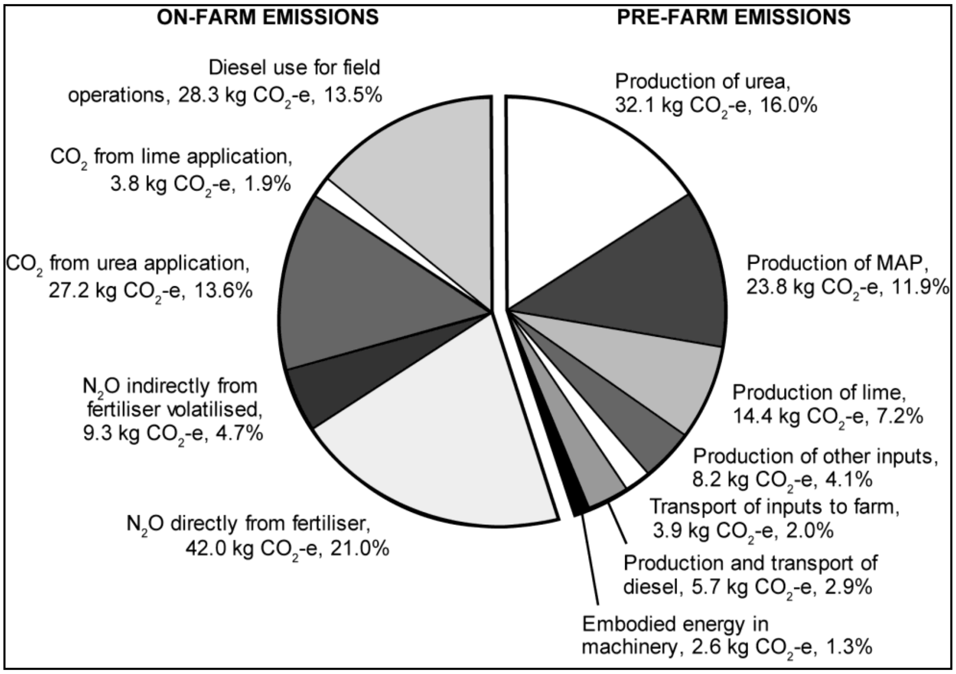

Figure 2. On-farm and pre-farm GHG emissions (CO_2-e) for a tonne of wheat from cradle-to-gate in Central Zone (East) NSW.

Similar studies by NSW DPI, funded by the GRDC (Muir *et al*. 2013), have provided estimated emissions intensities of short fallow wheat production in North East (NE) NSW following wheat (at 218.9 kg CO_2-e), following canola (at 185.3 kg CO_2-e) and following chickpea (at 139.1 kg CO_2-e per tonne of wheat), with 130, 130 and 80 kg N ha^{-1}, respectively. A tonne of wheat grown after chickpeas had an intensity that was approximately 80 kg CO_2-e lower than that grown after wheat. These reductions were primarily driven by the lower quantity of synthetic nitrogenous fertiliser applied (Figure 3). Similar impacts were found for the North West (NW) NSW where a tonne of short fallow wheat grown after chickpeas (at 140.7 kg CO_2-e) was calculated to have an emissions intensity that was approximately 50 kg CO_2-e lower than wheat grown after a wheat crop (at 192.5 kg CO_2-e) (Figure 4). The reduction of emissions intensity of approximately 30 kg CO_2-e/t for wheat following canola for both districts was the result of higher crop yields, given the same fertiliser inputs as wheat following wheat, with a total for one tonne of wheat following canola in NW NSW of 166.1 kg CO_2-e.

When long fallow wheat after sorghum was considered for NE NSW, emissions were found to be 143.4 kg CO_2-e per tonne of wheat (Muir *et al*. 2014a). These emissions are similar to wheat from short fallow after chickpeas but, despite 106 kg N/ha applied, the emissions intensity was much reduced by the higher yield (3.5 t/ha) obtained, compared with 3 t/ha in the short fallow. Emissions were 139 CO_2-e/t for long fallow wheat grown in more arid NW NSW and planted with a total of 32 kg N/ha (Muir *et al*. 2014b). Again a combination of lower N fertiliser application and greater grain yield of 2.4 t/ha reduced the emissions intensity compared with short fallow wheat (1.7-2 t/ha). LCAs are currently being finalised for the pre-crop, grown in rotation with the cereal, and as the product is usually marketed for human consumption, rather than used within the same production system, its emissions profile will be reported separately. This approach is discussed further in Section 5.1 below.

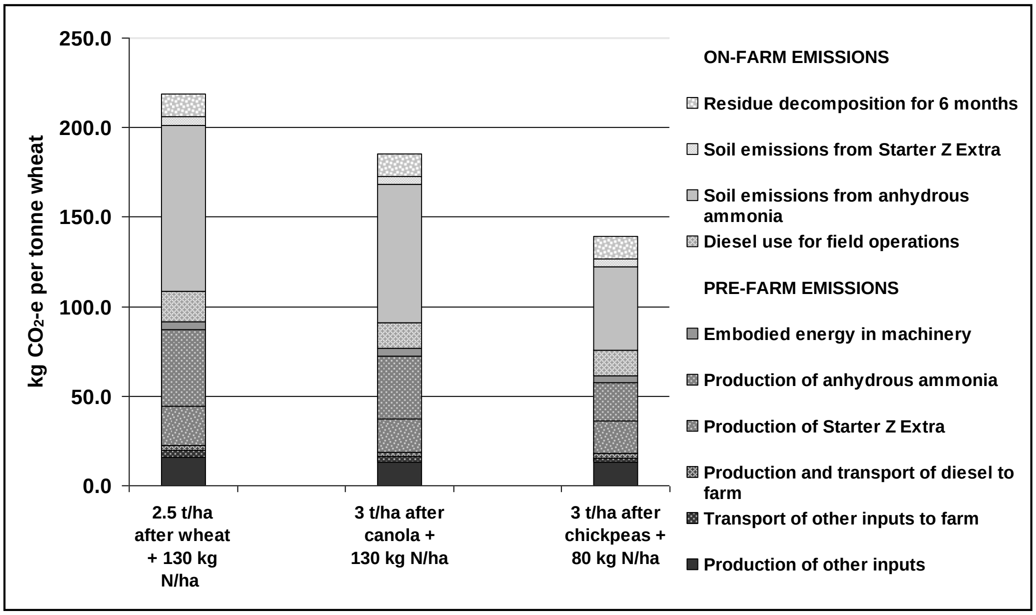

Figure 3. Characterization of GHG emissions for a tonne of short fallow wheat grown in NE NSW in either a wheat-wheat, canola-wheat or chickpea-wheat rotation, with 130, 130 and 80 kg N ha^{-1} applied respectively as combined anhydrous ammonia and Starter Z Extra. Crop yields used in calculations are stated for each rotation.

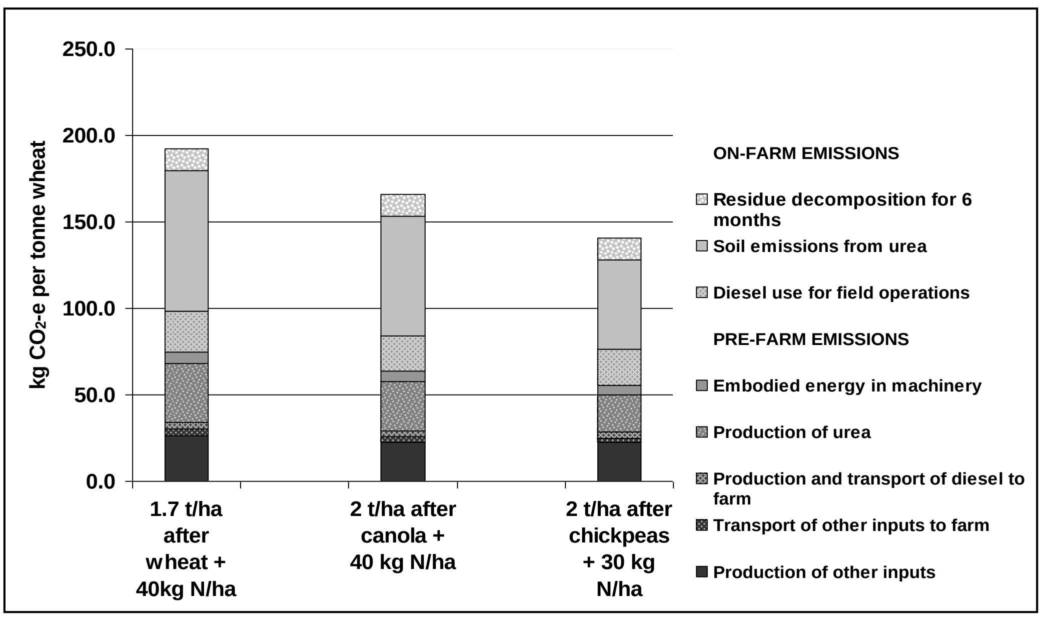

Figure 4. Characterization of GHG emissions for a tonne of short fallow wheat grown in NW NSW in either a wheat-wheat, canola-wheat or chickpea-wheat rotation, with 40, 40 and 30 kg N ha^{-1} as urea respectively. Crop yields used in calculations are stated for each rotation.

4.4. Future work

The GRDC has funded NSW DPI to develop GHG emissions mitigation strategies for the Australian grains industry. This project will involve determining the emissions intensity for a functional unit of the primary grains crop grown in each GRDC agro-ecological zone and for a crop grown in rotation with the primary crop. LCA will be applied to determine emissions intensities and also explore alternative systems and practices that will result in emissions reduction for the same functional unit. It is anticipated that GHG emissions reduction strategies will focus on reducing emissions from the manufacture and use of nitrogenous fertilizers. A possible strategy to achieve this will be by increasing legume rotations into cropping systems to biologically fix N, through rhizobial activity. Emissions reductions may also be achieved by managing excess nitrates in the soil available for denitrification. Possible strategies to achieve this may include splitting fertilizer applications to tailor N availability to crop requirements, using variable rate fertilizer applications to match N application to yield potential and sowing cover crops during the traditional fallow period to 'tie-up' soil nitrates. The effect of different N_2O EFs on this analysis is discussed in Section 5.1 below. The potential to gain minor emissions savings from reductions in fossil fuel use in farm machinery and more energy efficient production of inputs will be examined. The work will also provide a framework for testing future management practice recommendations from an emissions perspective.

Life Cycle Strategies will build non-GHG impact categories, such as land use, water use, eutrophication and ecotoxicity into the LCAs, so that NSW DPI can test for potential unintended consequences of recommended practice changes. The Commonwealth Scientific and Industrial Research Organization (CSIRO) will contribute by developing an impact category to examine the effect of LCA scenarios on soil health. Development of the impact category has commenced and Life Cycle Strategies Pty Ltd will integrate this impact category into the Australian Agricultural Life Cycle Inventory.

Cotton production systems in northern NSW and southern Qld include cereal and legume crops in their rotations and cotton seed is itself a grain. Initial LCA work (Tan *et al*. 2013) has established preliminary emissions profiles for Australian cotton lint and seed production, with separate funding secured by NSW DPI to continue this work. Studies into rice production are also underway (Suenaga *et al*. 2014).

5. Application of results

5.1. On-farm constraints and trade signals

Abovementioned practice change recommendations identified, to date, by NSW DPI researchers include incorporating legumes into cropping rotations, using split fertiliser applications, using nitrogenous fertilisers that have lower emissions potential, growing cover crops during traditional fallow periods, using variable rate fertiliser technology to manage excess nitrates in soils and exploring potential reductions in diesel use. Also, measures to improve productivity tend to provide a net reduction in emissions intensity. Whilst there is some uncertainty about N_2O EFs, with some published factors based on short-term trials, we believe that there are sufficient emerging Australian data from which to test practice change options. NSW DPI has adopted published N_2O EFs, including 0.45% (Schwenke *et al*. 2012) and 0.3% (Australian Government 2013) and will adopt lower published values for WA, where clay content and in some instances rainfall is lower. Current EFs are adequately representative for determining the relative benefit of different practice change options. Values for the absolute benefit can then be refined over time, with emerging data and potential revision to the NIR default values. In the meantime, we will continue to discuss the consequence of choosing different factors, as per Brock *et al*. (2012a) where the sensitivity of the emissions profile to choice of EF was discussed.

In particular, use of biologically-fixed N has the potential to reduce N_2O emissions, primarily through reduced emissions from the manufacture and use of nitrogenous fertilisers. The practical application of these findings by Australian farmers is, however, somewhat constrained. Farmers tend to tailor their systems to manage economic and agronomic risks to maximise profit and current enterprise mix reflects a robust consideration of these factors. Growing legumes (such as chickpeas, peas and lentils) poses different agronomic risks than growing cereals. Sowing time is more critical for legumes, to minimize the risk of frost damage and heat stress, and legumes are more susceptible to fungal diseases. However, adoption may increase with improvements in skill and technology, and will be driven by increased prices for synthetic fertilisers and market pressures for low-emissions intensity products.

The availability of markets is less of a constraint on practice change. Whilst prices for legumes are variable, Australia has established markets for both premium grade legumes for human consumption and legumes for stock feed. The legumes are targeted towards the human consumption market, with the stock feed market providing a lower value market if human consumption quality is not achieved. These markets are able to absorb additional production, increasing the chance of meeting the technical potential for mitigation through the adoption of legumes. However, impacts on price may occur, reducing the level of risk that growers will be willing to accept. Issues of leakage may also arise, from foregone cereal production, requiring augmentation elsewhere and reduced demand for legume production by other nations. Use for stock feed is often not within the same farm boundary but where it is, there will be associated livestock emissions, livestock co-products and displacement of other sources of protein as a feed source. These factors increase the need for consequential LCA. We include grain legumes as an additional product to the cereal, in a two-product system. We have trialled substitution of the legumes to focus on emissions from cereal production, attributing emissions from biological fixed N in lieu of those from synthetic fertilisers, with N treated as a legume co-product. However, it was not possible to be certain about market substitution and we now focus on reporting on the two products, with relative economic benefits and find this approach beneficial, especially when contrasting different production systems in comparative LCA.

Economic risk associated with changing aspects of a system such as those discussed here is generally determined by whether the marginal cost is equal to the marginal benefit. Even without a need to acquire capital assets, the marginal benefit and cost will vary between farm enterprise as a result of holding area, climate and soil type. They will also fluctuate from year to year based on factors such as commodity prices and climatic forecasts. In addition, the status of an Australian GHG emissions reduction policy framework is currently evolving. This is resulting in uncertainty which may constrain practice change, especially when coupled with uncertainty about the potential scope of international import penalties and restrictions between specific countries and requirements for Environmental Product Declarations. LCA is being increasingly adopted to underpin market access, for example for canola importation into European Union markets.

5.2. Policy

As discussed by Plevin *et al*. (2013), attributional LCA has limitations when used for policy development. This is because it does not take into account how a system shock, such as a reduction in demand for the nitrogenous fertilizers, due to increased use of biologically fixed N, would affect the demand for and use of these commodities within the entire agricultural sector under different market conditions. A reduction in demand for nitrogenous fertilizers in cropping enterprises may see fertilizer use, and GHG emissions, increase in other enterprises, such as those associated with livestock production. Alternatively, if the relative advantage of biologically fixed N is reduced, due to lower fertiliser prices and/or expected high cereal prices, then opportunistic farmers may increase fertiliser rates to stimulate yields and/or quality. In these cases, consequential rather than attributional LCA becomes important.

Attributional LCA is useful for policy development within a specific industry sector where internal policies will not necessarily have to consider impacts outside the industry. Further, data generated by attributional LCA models may also be indirectly used to develop government policy by providing input data for computer generated equilibrium or partial equilibrium models which aim to inform policy by modeling the impact of system shocks (*e.g.* C price) on the wider economy. In general terms, attributional LCA provides a useful starting point, especially when conducting paired comparisons and understanding likely emissions reduction ‘hot spots’, but needs to be augmented with consequential assessment when considering broader system boundaries, investigating leakage or making final practice change recommendations.

6. Conclusion

Researchers at NSW DPI have demonstrated the ability to use LCA as a tool to estimate emissions intensity from the production of grains crops under different management actions, particularly at a regionally-relevant scale. The information which has been generated is intended to be useful for farmers who wish to change their management practices to minimise GHG emissions for environmental stewardship or in response to policies, such as emissions trading schemes, where those who do not reduce emissions may be disadvantaged. The information is also intended to play a role to inform decision-making in the post farm-gate supply chain where the environmental credentials of products is increasingly being deemed important. Although this information has only received limited use in policy formulation in Australia, so far, LCA is a tool that has the potential to guide long-term management change in agricultural systems, whether by strengthening market signals or informing direct government intervention.

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