Life Cycle Assessment of grain cropping

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Abstract

Life cycle assessment (LCA) is a relatively recent framework that was developed to estimate the environmental impacts of industrial production processes and systems. The framework is now being applied to agricultural systems, including cropping systems, to identify opportunities for more environmentally-sustainable production. This purpose of this paper is to provide an overview of the application of LCA to grain cropping systems. Research at NSW DPI has focused on using LCA to estimate greenhouse gas (GHG) emissions from grain production systems for different regions of NSW as part of an industry-funded climate mitigation research program. The emission profiles suggest that GHG emissions in the systems modelled thus far are primarily the result of the production and application of synthetic N fertilizers, direct losses of nitrous oxide (N_2O) via denitrification of soil mineral N and dissolution of lime. The emissions intensities of crops also differ between regions primarily due to rainfall patterns and soil type, the type of fertiliser used, levels of inputs and yields. LCA, however, can provide a more holistic view of environmental impacts by also estimating effects on indicators such as eutrophication, land-use change and ecological toxicity. The reporting of numerous indicators allows potential perverse impacts to be assessed from applications of potential mitigation strategies. For example, increasing the proportion of legumes in a cropping rotation may reduce GHG emissions for that land area. However, the action may also result in land-use change to maintain supply of products displaced by including legumes in the rotation. Emissions associated with this land-use change such as sequestration or emission of soil or biomass carbon, may also affect the overall environmental impact.

Key words

Life Cycle Assessment, grains, environmental improvement, variability, indirect land-use change

Introduction

Life Cycle Assessment (LCA) is a framework originally developed to assess the environmental impact of industrial production systems, and to examine the effect of changes to the system. The application of LCA in recent years has included the assessment of the environmental impact of agricultural systems for the production of food, fibre and fuel (Harris and Narayanaswamy, 2009). As is indicated by the name, LCA usually examines the entire lifecycle of a product from production to disposal (cradle-to-grave). However due to lack of control a farmer has on the fate of his produce once it leaves his farm, agricultural LCAs usually model a cradle-to-gate system. Data included in a cradle-to-gate grain crop model includes the production, transport and use of all inputs (e.g. herbicide, fertiliser, fuel) and the area of land required to produce the crop. Processing a LCA model produces indicators. Many indicators are available but commonly used indicators include climate change, human toxicity, ecological toxicity and eutrophication. These indicators are estimated from emissions to air, water and soil and emissions are generally calculated using emissions factors (EFs). Emissions factors are categorized as Tier 1 (global values, spatially coarse), Tier 2 (country- or region-specific, higher spatial and temporal resolution) and Tier 3 (highest resolution values resulting from modeling and comprehensive field sampling) (IPCC, 1997).

Where LCA is used to examine changes to a cropping system, indicators such landuse, water use and indirect land-use change (iLUC; Schmidt et al., 2015) also become important. For example, consideration of iLUC means that where a cropping system is altered to replace a cereal crop with a legume crop in a rotation, it assumes that land elsewhere is converted from pasture to cropland to ensure that supply of the cereal crop is maintained.

A LCA model generally examines the impact of producing a functional unit (e.g. a tonne of wheat at the farm gate). Where product mass is used as a functional unit, it is important to ensure that product quality is considered (Charles et al., 2006) as product quality determines the end use of the product. Ensuring quality is comparable is particularly important when using LCA to compare the impacts of different cropping systems.

A number of ISO standards relevant to LCA are available. ISO 14044:2006 deals with LCA processes including allocation and critical review, and ISO 14071:2014 provides additional guidance on critical review and reviewer competencies. Compliance with the ISO standards provides the rigour and transparency required for end users to have a high level of confidence in the results of the LCA study.

Results

NSW DPI researchers (Muir et al., 2014b, Muir et al., 2014a) have been using LCA to estimate the carbon footprints of crop and identify opportunities for GHG mitigation in NSW grain cropping systems. This work has shown that GHG emissions from the production and use of N fertilisers are the primary driver for the carbon footprint of wheat in north-west and south-east NSW (Figure 1), and that lime, where used, also makes a considerable contribution. On-farm GHG emissions associated with N fertiliser-use include direct losses of nitrous oxide (N_2O) via the processes of nitrification and denitrification, carbon dioxide (CO_2) from hydrolysis of urea when used and CO_2 from the dissolution of lime where used. Figure 1 demonstrates how the emissions profile of wheat can differ as a result of fertiliser type, yield, previous crop and region, noting that these four variables are dependent. Nevertheless, other research supports the key finding that N fertilisers make considerable contributions to the overall carbon footprint of crops (Barton et al., 2014, Biswas et al., 2008, Biswas et al., 2010, Brentrup et al., 2004, Wang and Dalal, 2015). Fertiliser N is also a key contributor to other indicators such as eutrophication, human toxicity and ecological toxicity (Figure 2) but can have a positive impact on land use through its positive effect on yield.

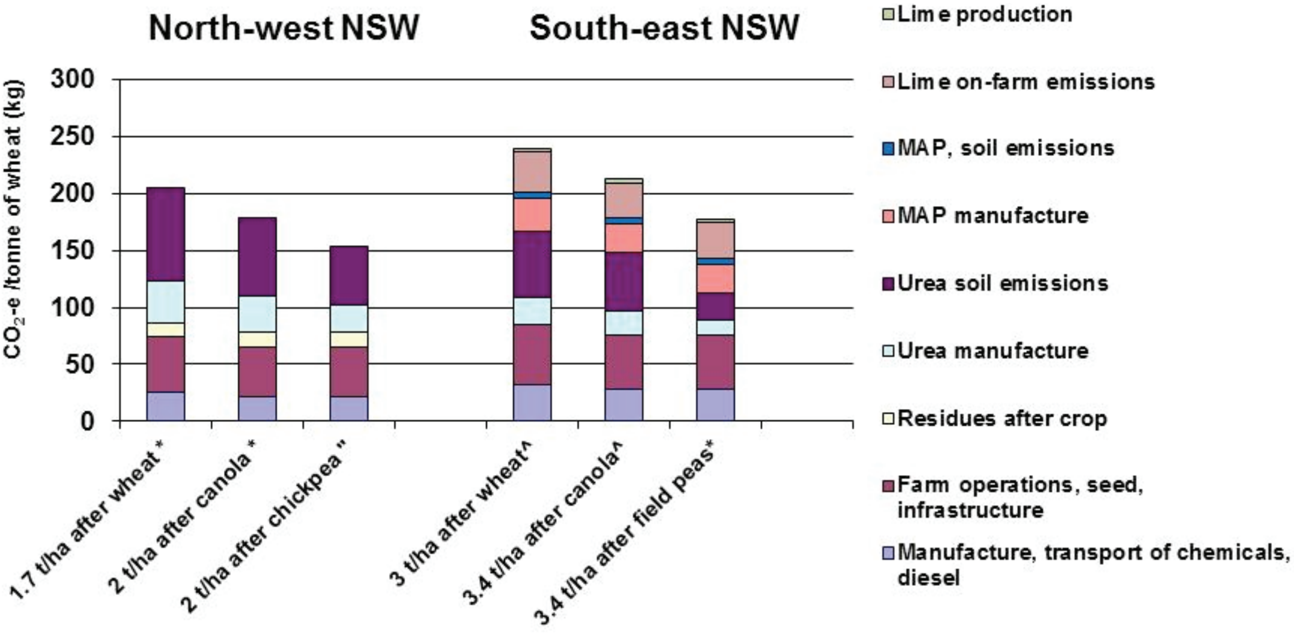

Figure 1. GHG emissions profile of short fallow wheat-wheat, canola-wheat and chickpea-wheat rotations in north-east and wheat-wheat, canola-wheat and field pea-wheat in south-east NSW. Labels followed by; * = 40 kg N/ha as urea applied, " 30 kg N/ha as urea applied, ^ 60 kg N/ha as urea and MAP, ' 40 kg N/ha as urea and MAP.

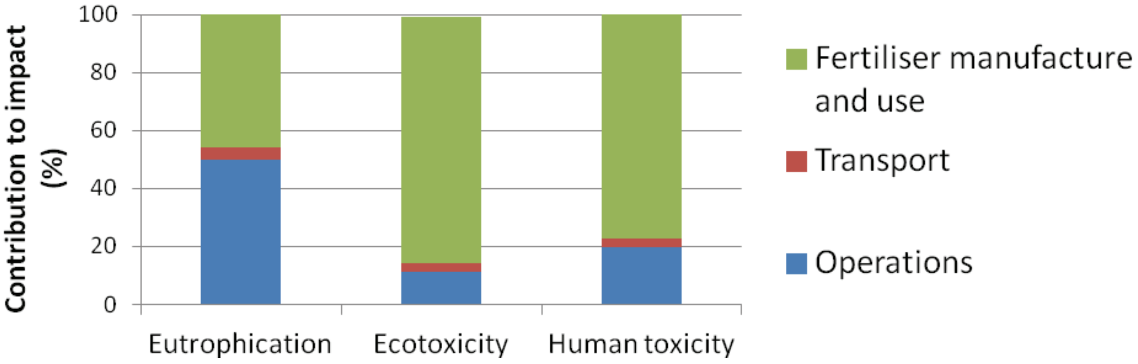

Figure 2. Relative contribution of fertiliser manufacture and use, transport of inputs and fuel, and on-farm operations to the LCA indicators eutrophication, ecological toxicity and human toxicity.

Discussion

A number of key challenges exist with respect to the application of LCA to grain cropping systems. Most LCA studies model the impacts of a representative system for a region of interest (Harris and Narayanaswamy, 2009); however management (e.g. fertiliser use) and biophysical parameters (e.g. rainfall) vary within a region. This means that the accuracy of LCA models based on a representative system for a region is limited. The uncertainty of outputs from these models comes from the impact of biophysical and management variables on emissions (MacKenzie et al., 1997, Mutegi et al., 2010, Chatskikh and Olesen, 2007) and yield. Potential exists to develop models that better explain the variability within a region using validated biophysical models (e.g. APSIM), statistical methods and spatial analysis. For example, numerous runs of biophysical models with different management and biophysical parameters could be conducted across numerous locations in a region. Data for emissions to air, soil and water, and yield could be extracted from the model runs and extrapolated across the region in ArcGIS based on biophysical layers to produce a distribution for each parameter of interest for the region. These distributions could then be used as inputs for Monte Carlo analysis to calculate the permutations of all combinations of the distributions. Using validated biophysical models would ensure perverse outcomes (e.g. high yield with low available N) are not calculated. The benefit of using an approach that provides a distribution of impacts, rather than a representative impact, is that it provides a probability of an impact occurring in the region and range of impacts that could be expected.

iLUC is another important consideration when assessing changes to cropping systems designed to mitigate the impact of production. For example, Barton et al.(2014) concluded that biologically-fixed N in a legume-wheat rotation reduced GHG emissions 35% when compared to a wheat-wheat rotation. What was not considered in that study was the land required to grow wheat to ensure wheat supply did not change. Ignoring this effect implies that the wheat supply is maintained without any changes to existing land uses and that is not possible. Much work has been done in recent years on developing models to account for iLUC in response to changes in agricultural systems (Schmidt et al., 2015). An iLUC model would consider that the displaced wheat would be grown on crop land converted from permanent pasture. This conversion can release large amounts of CO_2-e through the loss of soil organic carbon. Research (Murphy B, 2012) suggests that converting permanent pasture to cropping in the mixed farming region of NSW could release as much as 130 t CO_2-e ha^{-1} from the loss of soil organic carbon. This change would negate some or all of the GHG savings from introducing legumes into a crop rotation.

Background data that comes from databases is often used to build LCA models. Much of this data is derived from processes in Europe and North America. Potential exists to improve these data by examining systems relevant to grain crop systems. For example, current models for fertiliser production use modified data from European plants whereas the actual fertiliser used in Australia is predominantly made in Australian plants. Obtaining data on energy use and by-products from Australian fertiliser production plants has the potential to vastly improve the accuracy of LCA models of Australian grain crops and is important as fertiliser emissions make a considerable contribution to the overall emissions profile of crops (Figure 2).

Conclusion

LCA has proven to be a useful tool for the assessment of the environmental impacts of grain cropping. Results suggest that mitigation of these impacts will revolve around a reduction in the use of N fertilisers. Possible strategies include precision N management, the use of nitrification inhibitors, the inclusion of more N fixing legumes in rotations and/or variable rate technology for N and/or lime applications. More work needs to be done, however, to ensure that LCA models of regional grains systems represent the diversity of management and biophysical variables that exist. Any models also need to consider indirect effects of management decisions, such iLUC, to ensure these impacts are well understood.

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