LIFE-CYCLE ASSESSMENT OF GREENHOUSE GAS EMISSIONS FROM IRRIGATED MAIZE: THE LIFE-CYCLE ANALYSIS

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Abstract

The life-cycle analysis of this multi-institutional project concentrated on determining the greenhouse gas emissions involved in pre-farm, on-farm and post-farm activities involved in the use of maize for the manufacture of corn chips.

When the emissions are all expressed in terms of CO₂-equivalents (CO₂-e), then pre-farm emissions comprise about 5% of the life-cycle emissions, on-farm activities comprise about 27%, and post-farm activities account for about 68% of life-cycle greenhouse gas emissions.

We have used a box of ten 400 g packets of corn-chips as the functional unit. The single largest source of greenhouse emissions is the emission of nitrous oxide on the farm as a result of fertilizer application (0.12 kg CO₂-e per box). The next largest is the electricity used during the manufacture of the corn-chips. This accounts for 0.09 kg CO₂-e per box of corn chips. The manufacture of the box itself is the third largest source of greenhouse gas emissions, being 0.06 kg CO₂-e per box.

The greenhouse gas emissions from fertilizer application are primarily nitrous oxide (N₂O), which has a global warming potential of 310. In irrigated farm systems these emissions, when converted to CO₂-e equivalents, are about two and a half times as large as the greenhouse gas emissions as a result of the energy use in pumping water. Greenhouse gas emissions from the use of tractors on the farm are about one-third of the emissions from pumping water.

Introduction

The Grains Research and Development Corporation and the Australian Greenhouse Office contracted CSIRO, the CRC for Greenhouse Accounting and the University of Melbourne to undertake a study to examine the “cradle to grave” emissions of greenhouse gas from irrigated maize. This study started in November 2003 and ran until December 2005.

Agricultural industries comprise a supply chain extending from the pre-farm inputs to post-farm processed products. While the production of the crop is often the most visible aspect of the production chain, it may not be the major component in terms of the requirements for energy and fuel. Neither is it necessarily the major source of unwanted by-products such as environmental pollutants. Increasingly, greenhouse gases are emerging as by-products of major concern.

Current practice is to assess the components of the production chain, sector by sector and to identify the greenhouse gas emissions in each sector in isolation. A more cost-effective approach may be to identify the major emission sources that are amenable to greenhouse gas mitigation regardless of where they lie in the chain. This is the province of life-cycle assessment.

Within the farm sector, irrigated summer cropping has been identified as a potentially strong emitter of greenhouse gases, particularly of nitrous oxide (N₂O) because the use of fertilizer has been shown to emit N₂O, which is a strong greenhouse gas with a global warming potential of 310. The maize industry uses high rates of fertilizer inputs and crop production occurs at times of the year that favour high rates of N₂O production from soils. However, despite the high global warming potential associated with fertilizer emissions, it is not clear that in the whole supply chain crop production is the dominant greenhouse gas emissions source; there may be larger emission sources in the energy-intensive, post-farm processing stages of the supply chain.
The irrigated maize industry provides an excellent test case for examining the utility of life-cycle assessment for identifying and ranking emission sources, and assessing which of these sources are suitable candidates for practical emission reduction strategies. This study was designed to examine the issue and in this and the accompanying papers we present our results and current answers to the questions.

Scope and aim of this project

Australian maize is used to make corn-chips, corn flakes and starch while sweet corn is sent to market with little further processing. This work has concentrated on the supply chain associated with corn-chip manufacture. Maize production for corn-chips, the most energy intensive of the product streams comprises 5-7% of the Australian maize industry. Much of this production comes from farms that are irrigated and intensively managed and therefore less subject to climatic variability than rain-fed cropping systems.

Life-cycle assessment design

Life cycle analysis (or assessment) is a method of evaluating the impact, the use or manufacture of a particular product or material has on the environment (Jönson 1996, Consoli 1993). It has been defined by the Society of Environmental Toxicology and Chemistry as:

“...an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing of materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and final disposal. LCA only addresses environmental impacts and not other consequences of human activities such as economic and social effects...”

LCA is an attempt to quantify the environmental impact that is brought about by the use of a product. LCA measures the impact at all stages of a products life; from procurement of raw materials through to manufacture, transport, use and final disposal or recycling. For this reason, LCA is commonly referred to as a “cradle-to-grave” assessment of a product. LCA considers all inputs (such as materials used and energy required for manufacture) and outputs (such as products, by-products and emissions to air, water and soil) in producing a product (Frühwald 2005).

Boundaries

The purpose of the life cycle assessment is to understand how different activities in the various stages of the life cycle contribute to the cumulative greenhouse results for products and services we consume. To do this the production of corn-chips is broken up into many individual processes and activities, from tractor operations on farms, through to the packaging and distribution of corn-chips. A summary of the processes which are included in the study are shown in Figure 1.

All the processes within the system boundary shown in Figure 1 are included in the study, while the processes on the outside of the boundary are excluded because their impact is either small or not relevant to the study.
Table 1. Activities and corresponding data sources

<table>
<thead>
<tr>
<th>Activity</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission from field through planting, fertilising, growing and field preparation</td>
<td>On-farm measurement program</td>
</tr>
<tr>
<td>Fuel use, fertilizer use, pesticide use, water use</td>
<td>Survey with farmers, Department of Agriculture reports</td>
</tr>
<tr>
<td>Fertilizer production</td>
<td>Centre for Design LCA database based on European fertilizer manufacturers’ data or local data if available</td>
</tr>
<tr>
<td>Electricity and fuel production</td>
<td>Centre for Design LCA database based on National Greenhouse Gas Inventory, Australian Bureau of Agricultural and Resource Economics, and Electricity Supply Association of Australia</td>
</tr>
<tr>
<td>Agricultural machinery impacts</td>
<td>Input-output environmental impact model based on Australian National Accounts</td>
</tr>
<tr>
<td>Transport emissions and energy use</td>
<td>Apelbaum Associates and National Greenhouse Gas Inventory</td>
</tr>
<tr>
<td>Corn-chip manufacture</td>
<td>Data provided by producer in Bendigo</td>
</tr>
<tr>
<td>Packaging material and landfill disposal</td>
<td>Centre for Design LCA database</td>
</tr>
</tbody>
</table>
Data requirements

The study is concerned with global warming impacts arising from substances that have quantified global warming potentials, the gases carbon dioxide (CO₂), methane (CH₄) and N₂O. This simplified the level of data collection required. Data sources used for the study are acquired from primary data collection, published local studies and overseas data, with the greatest emphasis being placed on activities which have significant contributions to the overall greenhouse emissions.

For many data sources, generic emission factors can be used, but soil emission rates vary very widely on a regional basis so that we can not, with confidence, use overseas data and apply them to Australian conditions and farming practice. Table 1 outlines some of the data sources used in the study.

On farm measurements

On-farm measurements of N₂O emissions from nitrogen fertilizer applied to maize crops were conducted at Commins Brothers property at Whitton, NSW (34.5°S 146.2°E). The measurements were conducted on a site, already established for 5 years, to investigate the interactions between nitrogen and stubble retention on soil carbon dynamics. The fluxes of N₂O and CO₂ were measured on three of the established treatments:

- Zero N fertilizer application and stubble removed by burning;
- 300 kg N ha⁻¹, stubble removed by burning; and
- 300 kg N ha⁻¹, stubble mulched an incorporated into the soil.

The on-farm measurements are reported in more detail in the accompanying paper.

In addition it was recognized that farms may use different irrigation techniques, different soil management techniques, and different fertilizer application techniques to that used on the field site. A forum of stakeholders was held in February 2005 and their responses to a questionnaire were used to determine the representative average value to use for input variables. The divergence amongst the answers was also used to provide information with which to quantify the uncertainty analysis.

Life-cycle analysis

The basic lifecycle analysis was for irrigated maize supplied to corn-chip producers. It was assumed that:

1) approximately 50% of the crop was produced by conventional cultivation (i.e. with stubble burned) and 50% with stubble incorporated; and
2) the irrigation water was supplied by gravity feed from irrigation channels, not from bores

The unit in which emissions are reported is g CO₂-equivalents per packet of corn-chips.

With these assumptions it was found that for the corn-chip production chain the total net emissions per 400 g packet of corn-chips reaching the domestic market were 0.52kg CO₂-e. This comprised 68% CO₂, 30%, N₂O and 2% CH₄. By sector 6% of emissions were pre farm, 36% were on farm and 58% were post farm.

Looking at the entire supply chain, the major sources are shown in Figure 3. Nitrogen fertilizer application is the largest single contributor however post farm activities are more significant in aggregate to the on farm and pre farm inputs. In order of rank, the main emission sources were N₂O from fertilizer application (25%), electricity for chip production (17%), canola oil (9%), transport of chips to market (9%), production of the box for transporting the corn-chips (8%), water pumping (7%), natural gas for chip processing (6%), and the corn-chip packet (4%).
Life-cycle assessment

One of the purposes for a lifecycle assessment of the maize industry is to identify areas in which to apply cost effective strategies to control and reduce greenhouse gas production. The reductions may consist of new technologies applied to the areas that were identified, or the reductions may consist of improved efficiencies of production using current technologies. In our study of the corn-chip industry, stubble management has emerged as a key issue. If the 50% of farms that we assume currently burn stubble were to implement stubble incorporation then, in the absence of other changes to the supply chain, total emissions decrease by 27%. In absolute terms, our measurements indicate the greenhouse gas emissions from farms that produce maize using stubble incorporation are 56% lower than emissions from farms that burn their stubble when the soil carbon changes are included (Figure 3).

Among post-farm processes, the packaging and transport components of corn-chip production were substantial sources of greenhouse gases comprising 24% of total life-cycle emissions.
Surprisingly, packaging (i.e. the box for transporting the corn-chips and the corn-chip packet) was the third largest emission source, but only marginally greater than the transport of grain from farm to factory and the transport of product to market. The potential to improve efficiencies in these areas should be investigated in the development of industry-wide mitigation strategies.

**Discussion and conclusions**

The relative importance of on-farm emissions to total lifecycle emissions depends strongly on the production chain into which the product is being directed. For example, another market for maize is starch production. This industry requires less energy (per kg maize) than corn-chip production and has lower post-farm emissions of greenhouse gases. As a result the relative contribution of on-farm emissions to the complete lifecycle is substantially greater for starch production (58%) compared to corn-chips (36%), (Figure 4) and, from the industry perspective, implementing greenhouse gas mitigation options on-farm is a worthwhile greenhouse gas reduction measure.

![Figure 3. Comparison of lifecycle emissions of greenhouse gases between different types of crop management regimes on a per hectare basis.](image)

The pumping of water represents a significant energy use and consequent greenhouse contribution, particularly if the water is being drawn from deep bores. With reduced water availability, water may be drawn from further down in the water table increasing greenhouse emissions associated with water supply. In addition to this, the additional infrastructure required on-farm for water treatment and water storages can be substantial. From our analysis, pumping irrigation water from deep wells currently causes almost three times the greenhouse gas emissions than arise from irrigating from surface waters.

The lifecycle analyses and supporting measurements show that on-farm emissions arising from nitrogen fertilizer application to irrigated crops is the major single emission source. Overall, post-farm emissions associated with production (energy and oil), packaging and transport account for most of the greenhouse gas production. There appears to be substantial potential to reduce emissions on-farm through stubble management. The substantial post-farm emissions indicate that there is also scope for exploring practical mitigation options in relation to transport and packaging.

![Figure 4. Comparison of lifecycle emissions of greenhouse gases for different uses of corn chips. Emissions are given per kg of corn chips.](image)
Acknowledgements

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References

