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Life cycle assessment of greenhouse gas emissions from agriculture in relation to marketing and regional development

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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 is still in progress in June 2005. This preliminary analysis of the initial results was produced to keep stakeholders informed as to the emerging outcomes.

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 and this study has focused on them.

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 as a first step towards greenhouse gas mitigation. 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 (N_2O) because the use of fertiliser has been shown to emit N_2O, which is a strong greenhouse gas with a global warming potential of 310. The maize industry uses high rates of fertiliser inputs and crop production occurs at times of the year that favour high rates of N_2O production from soils. However, despite the high global warming potential associated with fertiliser 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 report we present our current progress towards answering 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.

The project comprised:

- Life-cycle analysis from raw materials to end product. Prioritisation and assessment of these results in terms of ranked emission sources; and
- On-farm measurements of nitrous oxide emissions from fertiliser applications and different crop management options.

Life-cycle assessment design

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 emissions 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.

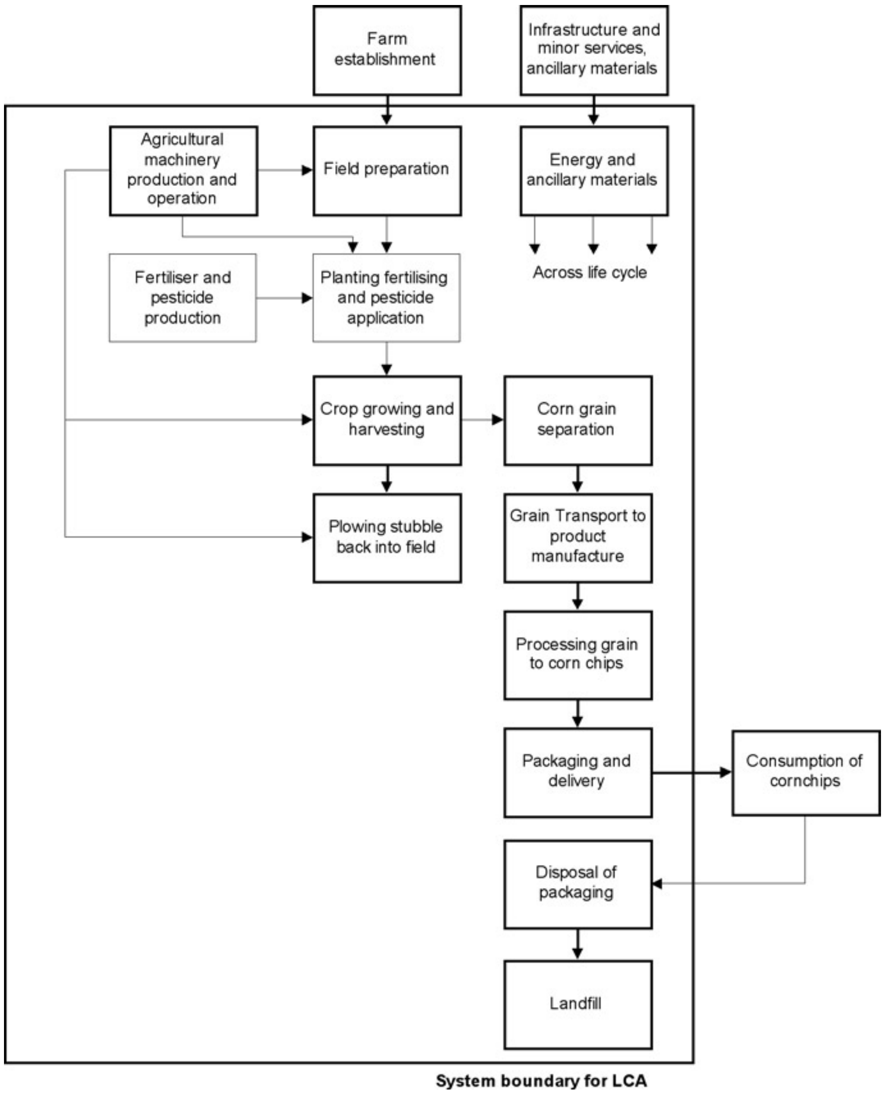

Figure 1. *System boundary for life cycle analysis for corn-chip production*

Data requirements

The study is concerned with global warming impacts arising from substances that have quantified global warming potentials, the gases carbon dioxide (CO_2), methane (CH_4) and N_2O. 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 widely on a regional basis so that we cannot, 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.

Table 1: Activities and Corresponding Data Sources

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

On Farm measurements

On-farm measurements of N_2O emissions from nitrogen fertiliser 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 five years, to investigate the interactions between nitrogen and stubble retention on soil carbon dynamics. The fluxes of N_2O and CO_2 were measured on three of the established treatments:

- Zero N fertiliser 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.

Comparison between the first two treatments yields the N_2O emissions associated with nitrogen fertiliser addition while comparison between the second and third treatments yields the effect of stubble retention of soil nitrogen loss as N_2O.

Emission rates were measured using an automated chamber methodology described by Meyer et al., 2001. This system measures 24h integrated fluxes continuously through the season and avoids the biases and errors which can arise with intermittent manual flux measurements.

Following a fallow period from the previous harvest the beds were reformed and fertilised (100 kg N ha-1) in late September 2004. The crop was sown in early October. Irrigation commenced at sowing and continued throughout the growing season at intervals of 10-14 days as required until crop maturity in early March 2005. Approximately four weeks after sowing a further 200 kg N ha-1 was applied as a side-dressing of liquid urea. Nitrous oxide emissions were measured continuously on the three treatments from mid June 2004 until harvest in April 2005, except during bed formation, sowing and fertiliser application when the chambers were moved from the beds to allow machine access.

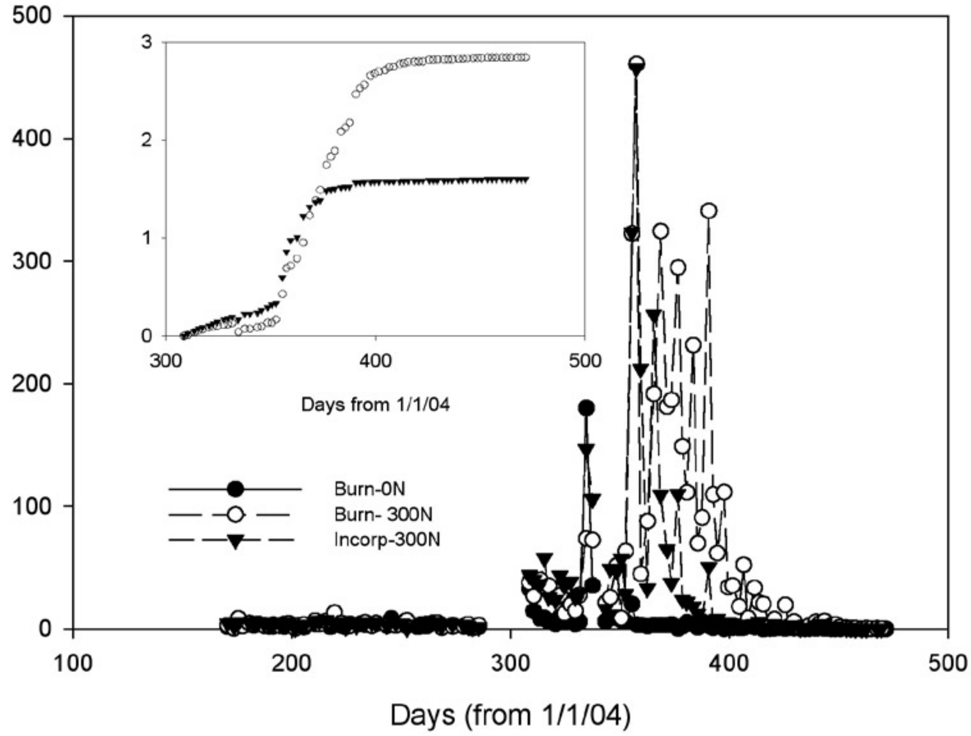

Figure 2. *N_2O emission rates from irrigated maize 2004/2005 season. Treatments are (•) unfertilised, stubble burned; (o) 300 kg N ha^{-1}, stubble burned and (▼) 300 kg N ha^{-1}, stubble incorporated. Inset shows cumulative N_2O N emission as a percentage of applied fertiliser nitrogen.*

Average daily N_2O emission rates during the fallow (3 ng N m^{-2} s^{-1}) are similar to the background emissions from unfertilised pasture and natural soils, with no significant difference between treatments (Figure 2).

The emission rates increased substantially following sowing. In the unfertilised (control) treatment, emissions gradually declined through the cropping season from the maximum which occurred soon after sowing. At crop maturity, emission rates from the control were less than those observed during the fallow. In the fertilised crops, N_2O emissions varied from approximately five times those in the control treatment before irrigation to more than 100 times the control following irrigation. These emissions were larger and more persistent in the treatment where stubble was burned.

Total emission of N_2O during the crop production, expressed as a fraction of applied fertiliser nitrogen was 2.8% of applied N lost as N_2O in conventional irrigated maize (stubble burning) production (Figure 2, inset). This loss rate is higher than the international average emission factor for all classes of crops (1.25%), but is expected for heavily fertilised, irrigated summer cropping on heavy soils where the combination of high temperature and high water content favour very high rates of denitrification.

Stubble management had a substantial impact on N_2O emissions. Compared to the stubble burned treatment, stubble incorporation reduced the total N_2O emissions by 44% to 1.6% of applied fertiliser nitrogen. Therefore, while irrigated maize production is a substantial source of N_2O, there also appears to be significant potential for reducing N_2O emissions through stubble management.

Lifecycle 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 (ie 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 kg CO_2-equivalents per packet of corn-chips.

With these assumptions it was found that for the corn-chip production chain the total net emissions per 400gram packet of corn-chips reaching the domestic market were 0.52kg CO_2-e. This comprised 68% CO_2, 30% N_2O and 2% CH_4. 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 fertiliser 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 N_2O from fertiliser 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%).

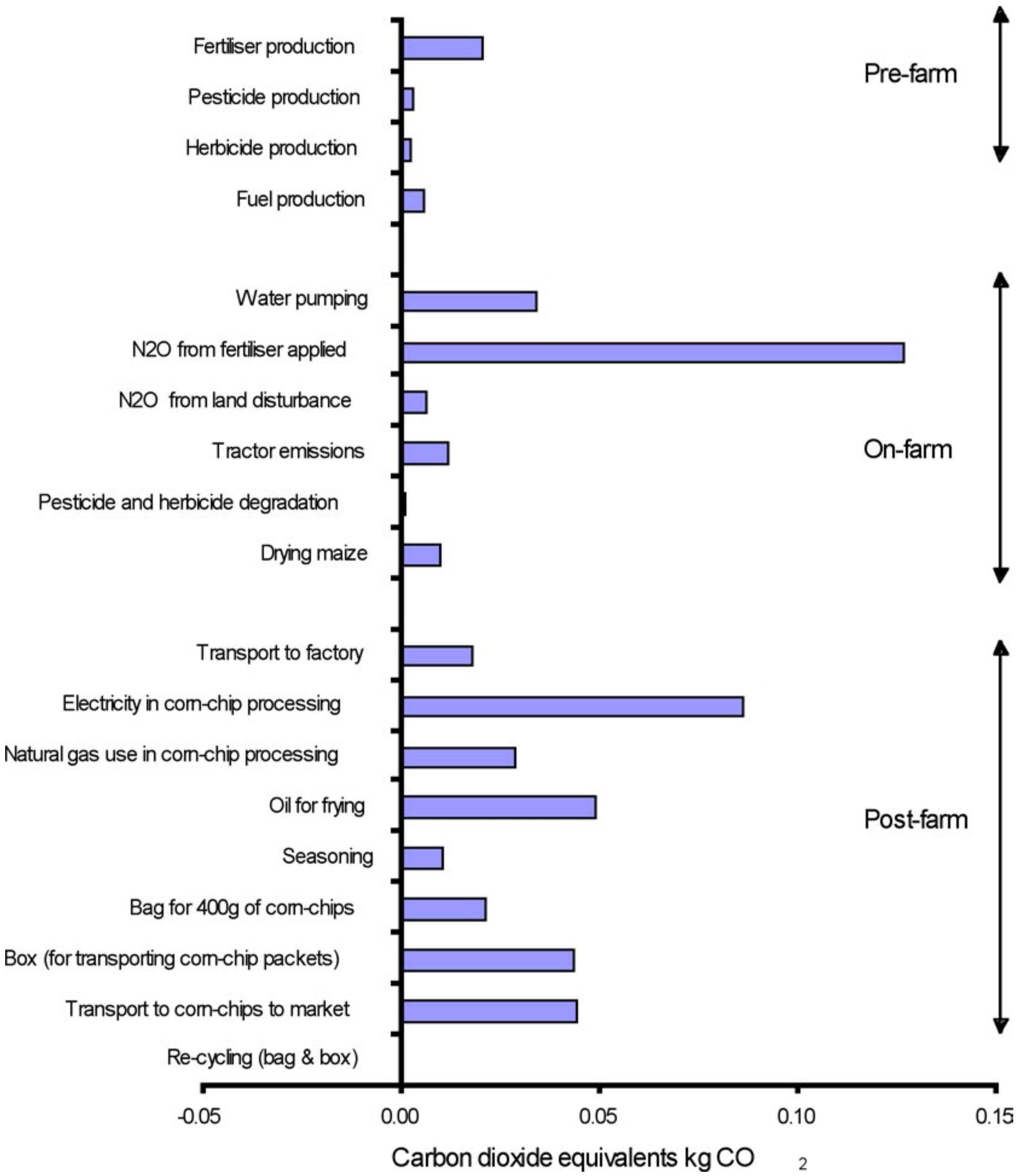

Figure 3: *Contribution to greenhouse emissions for different stages of the life cycle of corn-chips*

Lifecycle 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 implement stubble incorporation then, in the absence of other changes to the supply chain, total emissions decrease by 6.4% and the on-farm emissions decline to 32% of the production chain. In absolute terms, our measurements indicate the greenhouse gas emissions from farms that produce maize using stubble incorporation are 44% lower than emissions from farms that burn their stubble.

Among post-farm processes, the packaging and transport components of corn-chip production were substantial sources of greenhouse gases comprising 24% of total lifecycle emissions. Surprisingly, packaging (ie 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.

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.

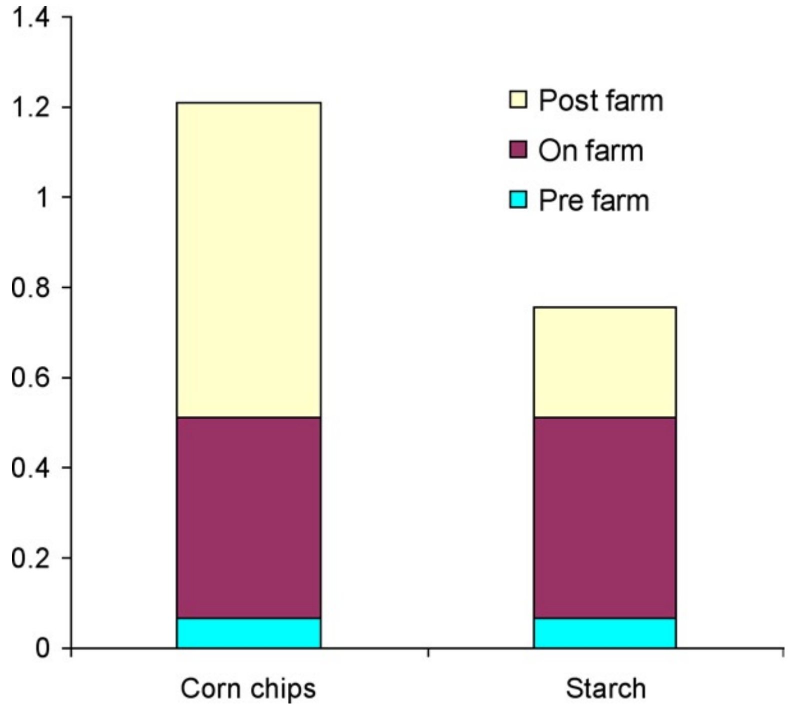

Figure 4: *Comparison of lifecycle emissions between corn-chip production and starch production.*

Future directions and emerging issues

This project is still in progress with several aspects remaining to be completed. These include the detailed assessment of the soil nitrogen cycling processes that control N_2O production and lead to N_2O emissions.

A potentially significant source (or sink) of greenhouse gases has not been included in this lifecycle analysis. This is the soil carbon pool, which changes slowly on an annual basis but which over decades may be substantial. Stubble burning both emits greenhouse gases during combustion and frequently leads to net loss of soil carbon. Preliminary data from the Whitton site indicates that stubble incorporation may be slowly restoring or increasing soil carbon content relative to conventional stubble management (burning). The impact of soil carbon changes on the lifecycle assessment is being investigated and will be discussed in the final report.

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 fertiliser 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.

Though the general areas to target for effective greenhouse gas reduction measures are unlikely to alter, the results are still being analysed and thus the quantitative results and their interpretations may be subject to further refinement.

Reference

Meyer, C. P., Galbally, I. E., Wang, Y. P., Weeks, I. A., Jamie, I. M., and Griffith, D. W. T. (2001). *Two automatic chamber techniques for measuring soil-atmosphere exchanges of trace gases and results of their use in the oasis field experiment.* CSIRO Atmospheric Research technical paper; no. 51. 30 p.