Carbon Footprint of New Zealand Arable Production – Wheat, Maize Silage, Maize Grain and Ryegrass Seed

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Authorship

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The report has been peer reviewed by Dr Wahidul Biswas and Associate Professor Michele Rosano from the Centre of Excellence in Cleaner Production, Curtain University, Australia.

List of Abbreviations

Energy and Power

J	joule	basic unit of energy
kJ	kilojoule	1,000 joules
MJ	megajoule	1,000,000 joules
W	watt	basic unit of power = 1 joule per second
kW	kilowatt	1,000 watts
kWh	kilowatt-hour	3.6 MJ

Others

CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
Defra	Department for Environment Food and Rural Affairs (UK)
EF	emission factor
FAR	The Foundation of Arable Research
GHG	greenhouse gas
GWP	global warming potential
ha	hectare (10,000 square metres)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardization
kg	kilogram
LCA	Life cycle assessment
l	litre
LUC	land use change
MAF	Ministry of Agriculture and Forestry
MfE	Ministry for the Environment
N_2O	nitrous oxide
PAS	Publicly Available Specification
t	tonne (1,000 kg)

Conversions

1 ha = 2.47 acres

1 l petrol = 0.90 l diesel (diesel equivalents on an energy basis)

1 kJ = 239 calories

1 kW = 1.34 horse-power

Note on statistics

All data is presented as the mean of the survey data. References to 'national' or 'regional' results do not imply a New Zealand national average, or a whole region average. These statistics instead refer to the 'surveyed national' or 'surveyed regional' results.

Executive Summary

Introduction

This report presents a greenhouse gas (GHG) life cycle assessment (LCA) of one tonne of arable product to the farm gate in New Zealand. Sector-specific methodologies and guidance for the measurement of on-farm GHG emissions were developed for arable production. The report is based on the internationally recognised Publicly Available Specification (PAS) 2050 and ISO standards 14040:2006 and 14044:2006 methodologies.

This study represents the first detailed look at the GHG emissions from arable crop production in New Zealand. The data was collected from a series of ten in-depth interviews and surveys, conducted with significant New Zealand arable growers. The information collected covered the resource inputs and production for the 2008/09 season. Accordingly, the small sample size and short monitoring period means that this report offers only a preliminary glimpse into this important New Zealand industry. Naturally, within any production system there is variability in the collected data. Such variability was expected in a review that attempted to encompass each major New Zealand growing region, four crops, and the varied climate experienced by each and the different management practices preferred by the growers. This report establishes a benchmark crop specific carbon footprint, identifies potential efficiency gains for the arable industry, and provides guidance for areas of future study.

Methodology

This report uses LCA methodology to measure the resource use and greenhouse gas emissions of four arable crops. The partial LCA represents a 'cradle to farm-gate' analysis of all resources and processes that contribute to the production of one tonne of wheat, maize silage, maize grain and ryegrass seed and the associated greenhouse gas emissions.

The production information used in this report is based on ten face-to-face surveys conducted with growers. The survey included wheat, maize and ryegrass seed growers in the main growing regions of New Zealand, who are members of the Foundation for Arable Research. Resource inputs included fuel, electricity, fertiliser and agrichemical use.

The environmental outputs measured were the emission of the three main GHGs CO_2, CH_4 and N_2O. GHG emissions associated with each resource is calculated and attributed to each crop to generate a crop specific carbon footprint.

Discussion and Results

The GHG emissions of each arable crop were broadly similar when compared on a per hectare basis, ranging from 2,190 – 2,820 kg CO_2-equivalent (CO_2e)/ha (Table E. 1).

Table E. 1 Arable industry GHG emissions per tonne and per hectare.

	GHG Emissions (kgCO_2e)	
	per tonne	**per hectare**
Wheat	340	2,820
Maize silage	125	2,190
Maize grain	190	2,380
Ryegrass seed	1,325	2,190

The distribution of GHG sources was broadly similar for each arable crop. This was typified by nitrogen fertiliser (both through its manufacture and field emissions following application) making up on average 60% of all farm GHG emissions. Field emissions following nitrogen fertiliser application is the single largest source of GHG emissions (33% in wheat) and is highly dependent upon the chosen field emission factor (EF_1), which for this study used the default IPCC figure of 1.0%. However in Australia EF_1 has been found to range from 0.03% in dryland crops to over 2.1% in irrigated crops. Altering EF_1 would either lower the current total wheat GHG emissions by 33% or increasing them by 45%. The use of site specific soil emission factors would significantly improve the robustness of the final result.

Energy (fuel and electricity) contributed less than 20% of total emissions. The GHG emissions from wheat production are a good illustration of what is typical amongst the arable industry and is shown here in Figure E. 1.

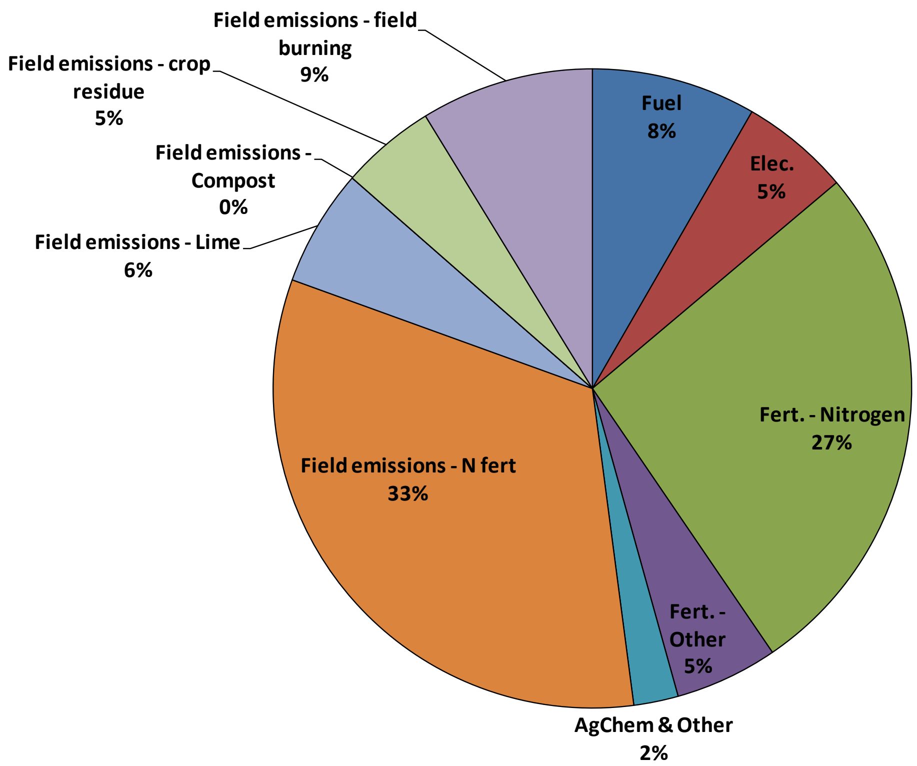

Figure E. 1 Distribution of GHG emission sources from New Zealand wheat production.

The effects of any land use change, such as converting from long-term pasture to arable cropping, can have a significant effect on soil carbon levels and resultant GHG emissions. Data from New Zealand's GHG National Inventory 1990 – 2007 (MfE, 2009) estimate GHG emissions resulting from LUC may be as high as 7,900 kgCO_2e/ha/yr. This is approximately three times as high as all other GHG sources combined and therefore could have a significant impact on the carbon footprint of arable crops. However, little data exists to accurately track soil carbon during arable production. An analysis of New Zealand's wheat growing area since 1935 suggests that the vast majority of the arable growing area has been in long-term production and the soil is therefore unlikely to be experiencing any significant net change in carbon levels.

The accuracy and representativeness of future LCAs can be improved in two ways. Firstly quantitatively: data from more producers, over several seasons, and across a greater geographical region, will allow a more robust statistical analysis of the collected data. This pilot study drew data from ten farms and limits the ability to draw many conclusions beyond establishing a suitable LCA methodology and first set of benchmarks. The variability in any study with a low subject number means it is difficult to describe an 'average' operation for consideration by other farmers. Secondly qualitatively, any LCA is only as accurate as the data that has been used to construct it. Improved recording of resource inputs will be reflected in greater accuracy. Additionally, where specific emission factors are unavailable then country default values, as prescribed by the IPCC, are used. The greatest area of uncertainty is likely to be the field emissions of nitrous oxide resulting from the application of nitrogen fertiliser.

To further improve the representativeness of this dataset increased arable production monitoring is required, incorporating operations from throughout New Zealand. A system of integrating resource use and financial records would deliver a very powerful and practical tool for optimising production and profitability.

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1. Introduction

This project has developed sector-specific methodologies and guidance for the measurement of on-farm GHG emissions associated with arable production. The project will support the Foundation of Arable Research to operate in markets with credibility and where necessary using internationally recognised, transparent and validated GHG footprinting methodologies for the production and supply of products.

This report describes a pilot study, undertaken to establish a partial life cycle assessment (LCA) using internationally prescribed protocols for four crops: wheat, maize silage, maize grain and ryegrass seed. This report uses the UK's Publicly Available Specification (PAS) 2050, for GHG emission measurement of goods and services (BSI, 2008); GHG Protocol Product and Supply chain Initiative (World Resource Institute); ISO 14040 and 14044 protocols. In addition, it provides details of methodological issues that arise when modelling GHG emissions within these crops. The data used to produce this pilot study is generated from the detailed analysis of ten arable grower operations from throughout New Zealand.

It is important to study the environmental impact of the arable sector to identify potential areas of inefficiency to help optimise profitability and address the increasing consumer awareness of carbon emissions. Applying internationally recognised standards insures that such a study is done in a credible way. This pilot study represents the first time such an analysis has been undertaken for the arable sector in New Zealand. Similar studies have already been completed on arable production in other countries and where possible will be discussed in this report. Within New Zealand, LCAs have previously been completed for over 80% of New Zealand's primary production including kiwifruit, pipfruit, onion, berryfruit, dairy, lamb, and merino wool sectors.

The results presented in this report show the life-cycle impact of producing a tonne of arable product on surveyed New Zealand farms, in terms of GHG emissions. The grower surveys that this LCA is built upon were conducted in person and provide a robust inventory of each grower's inputs. The relatively small sample size however, limits the conclusions that can be drawn from this study regarding the industry as a whole. While it has outlined methods and guidance for measuring the arable sector's carbon footprint, comparisons with LCA's from other sectors or overseas studies should be treated with caution until a more robust appraisal can be completed.

This work was carried out by AgriLINK New Zealand, and undertaken for the Foundation of Arable Research and the Ministry of Agriculture and Forestry.

1.1. Background

1.1.1. The New Zealand arable industry

The arable industry is a vibrant and successful sector within the New Zealand economy, covering small and large grain crops and crops grown for seed production. Maize represents 30% of the arable industry; wheat 20% and grass seed 20%. New Zealand exports over $70 million of wheat based products around the world. Seed production has developed to a $115 million export industry. Maize silage is an important feed supplement in the New Zealand dairy industry and maize grain is used in a wide range of animal feeds and human food products such as cornflakes, cornflower and other starch products. The arable industry is a land intensive activity and emits significant amounts of GHGs and as such its effect on the environment needs to be understood. At present the environmental impact of the New Zealand arable industry has been described through case study analysis (Barber, A., *et al*., 2004; and Nguyen, M. L. and Haynes, R. J., 1995). While these provide detail analysis of resource use within specific farm environments they are not intended to describe the complete life cycle of arable products or be applicable to the entire industry.

1.1.2. Life cycle assessments

The Food Miles initiative focussed on the distance food travelled from the site of production to the consumer. It is interesting to note that the region of production seems to only be important for food – there is no strong evidence that consumers consider region of production for other items such as cars, whiteware, china etc. (Schlich and Fleissner, 2005). While Food Miles became very topical, it has largely been derided as a poor environmental indicator. The focus has subsequently shifted to examining a products' full life cycle, often termed a 'cradle to grave' analysis.

Farming systems need to be studied in a holistic way to capture a range of interlinking factors. This adds a level of complexity that is not always easily dealt with. An LCA provides the techniques to assess this by reporting the environmental impacts associated with a product and its entire production system. An LCA includes an inventory of material and energy inputs and identifies the potential impact these have on the environment, particularly in regard to GHG emissions. According to PAS and ISO guidelines an LCA is made up of the following four phases: definition of the goal and scope of the study, a detailed inventory of inputs and outputs to the environment, an assessment of the impact this has on the environment, and an interpretation of the results. This interpretation is often carried out at each phase, with the results of one phase influencing each subsequent phase.

The goal and scope of an LCA defines the functional unit of the product. In this way the system boundary can be defined along with its related inputs and outputs. The complex inventory involves defining the energy and raw material requirements for each input and their subsequent release into the environment, as well as any assumptions that have been made. This data needs to encompass all the activities within the system boundary. After definition of the inventory an assessment can be made on the impacts these have on the environment. This assessment measures the impact of the system, taking into account the prescribed goal of the study.

While LCAs have been applied extensively to industrial products and processes, its application to agriculture and the food chain has been quite recent. This study therefore undertook the process of developing an LCA for wheat, maize silage, maize grain and ryegrass seed, the four key arable crops of the New Zealand arable industry. This report defines the methodological aspects and begins to define a dataset encompassing all production inputs, up to a state suitable for storage. It is expected that the customer will develop the remainder of the life cycle analysis based on their own product use and disposal systems.

1.2. Literature review

1.2.1. Life cycle assessments - vegetable and arable industry

A small number of LCA studies have been undertaken on vegetable and arable cropping. However, most do not specify detailed energy consumption or GHG emission figures. This prevents any meaningful comparisons between different studies or with this arable study. Several studies of wheat production in Europe, utilising LCA principles were found, these often isolated an aspect of production to study and used modelled data to determine emissions. This allowed researchers to consider different fertiliser products and rates of application, and then model the impact on production (Charles, *et al*., 2006). Extrapolating these findings to other parts of the world is inappropriate due to differences in crop type, soil, climate and management practices. Several LCAs of the Australian arable industry have been completed and published (Biswas, *et al*., 2008, Biswas, *et al*., 2010). These were undertaken to quantify the environmental emissions from grain production in the Australian food supply chain and where possible identify pollution 'hot spots' (Biswas W. and John M., 2009). These studies identified the large contribution of N_2O emissions from fertiliser production and field emissions as significant contributors of total GHG emissions. These studies also show the effect of climate on the arable carbon footprint and the impact of using regional specific emission factors versus IPCC default values.

Biswas, *et al*., (2008) found a 40% lower carbon footprint for wheat production when using a site specific N_2O emission factor (0.02% - low rainfall area) compared to the IPCC default (1.0%). Barker-Reid *et al*., (2005 – cited in Dept. CCEE, 2011) reported low N_2O emissions from a rainfed wheat crop in a temperate region of south-eastern Australia of 0.06 – 0.11%. Cultivation practice and residue management may also impact on the rate of N_2O emissions from soil. Wang *et al.* (cited in Dept. CCEE, 2011) found N_2O emission factors for no-till rainfed wheat of between 0.5% (residue burned) and 0.8% (residue retained) compared to cultivated wheat at 0.9% (residue burned) and 1.2% (residue retained). However this contrasts with Abdalla *et al*., (2010) who found that reduced tillage did not reduce soil N_2O emissions compared to conventional cultivation and may in fact be increasing soil N_2O emissions.

The Australian National Inventory Report 2009 (Dept. CCEE, 2011) uses N_2O emission factors for synthetic fertiliser of 0.3% for non-irrigated crops and 2.1% for irrigated crops. Horticulture and vegetables has an emission factor of 2.1% (based on total fertiliser N applied). A sensitivity analysis has been completed using a range of emission factors (Section 6.6).

1.2.2. Life cycle assessments - bread

Narayanaswamy *et al*. (2004) developed, amongst a range of environmental indicators, a carbon footprint for Western Australian grain products, with one of the functional units being one loaf of bread (Table 1.1). As one of the most comprehensive and transparent studies of this type, their post farm gate inputs and emissions have been used in this study to extend the on-farm wheat emissions through to a loaf of bread (see Section 6.1.1).

Table 1.1 Western Australian LCA for bread ($kgCO_2e$).

	Australian bread	
	per loaf†	**per kg bread**
Pre-farm and farming	0.37	0.55
Storage & processing	0.63	0.92
Retail & consumption	1.25	1.84
Transport	0.04	0.05
Total	2.28	3.35

Source: Narayanaswamy *et al.* (2004)
†681 g loaf of white bread

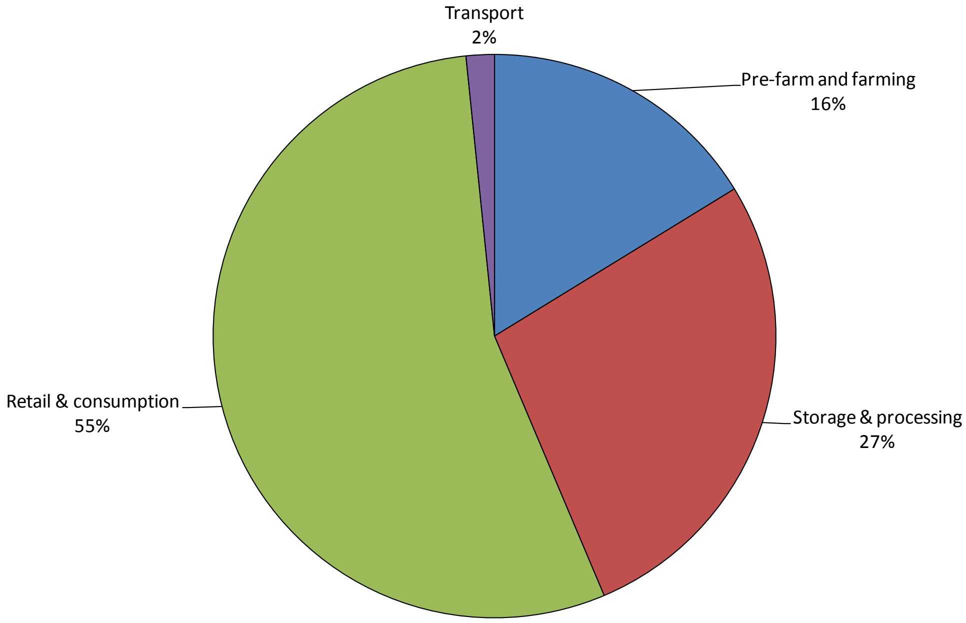

Figure 1.1 GHG emissions along the Australian bread supply chain.

Western Australia average wheat production yields are 2.0 – 2.5t/ha from dryland production; Narayanaswamy *et al*. (2004) used an average of 2.1 t/ha. The on-farm GHG emissions of Australian grown wheat is 0.55 $kgCO_2e/kg$. It takes 690 g of harvested wheat to produce a 681 g white loaf; with water being the other main ingredient by weight.

1.2.3. UK winter wheat (milling) production

Energy inputs and GHG emissions from UK wheat production have been described and are detailed below (Lillywhite *et al.*, 2007, Table 1.2). However, there is insufficient detail to allow a full understanding of how these figures were determined. For example, the total energy inputs appear low, considering the fuel and nitrogen inputs. Additionally, caution must be exercised when comparing figures between LCAs. Firstly, methodologies will invariably differ; assumptions and how resources are tracked will affect the final reported figures. Secondly, the conditions and environment that characterise the LCA system may be considerably different.

Table 1.2 UK wheat production and resource use (per ha).

	UK	Units
Marketable crop	7.8	t/ha
Fuel use	110	l/ha
Nitrogen	220	kgN/ha
Drying	500	MJ/ha
Energy	19,545	MJ/ha
GHG emissions	1,550	$kgCO_2e/ha$

The UK wheat study used modelled fuel use by Williams *et al*. (2006). Accurately modelling fuel use is extremely difficult and previous studies conducted by the authors have found very poor correlations between modelled fuel use and recorded actual fuel use, with models tending to underestimate actual fuel use.

The results from the Defra project (Defra, 2009); on a per tonne basis for feed wheat and forage maize are shown in Table 1.3.

Table 1.3 UK Feed Wheat, and Forage Maize production and resource use.

	Units	UK Feed Wheat	UK Forage Maize
Primary energy use	MJ/t	2,260	1,880
Field work component	%	36%	33%
Crop storage & drying or cooling	%	6%	2%
Pesticide manufacture	%	8%	4%
Fertiliser manufacture	%	51%	61%
GHG emissions	$kgCO_2e/t$	731	577

The Defra project studied feed wheat, whereas this study has included all wheat crops grown on farm, with no differentiation for feed wheat or milling wheat. Milling wheat requires higher protein levels to meet manufacturer's requirements so inputs will be different between the two crops and may include different varieties. One of the key differences is the increased nitrogen usage in milling wheat, which is the highest contributor to the New Zealand wheat crop emission profile. Differentiating inputs for the two end uses would be a useful future study.

1.2.4. Reduced Tillage

There has been much debate about tillage methods and their effect on GHG emissions. A number of studies suggest by moving from conventional tillage methods to the various forms of conservation tillage may lead to an increase in soil organic matter, therefore more soil carbon sequestration.

Based on the default figures in New Zealand's GHG National Inventory 1990 – 2007 (MfE, 2009) the carbon stock in grassland is 105 tC/ha (385 tCO_2/ha). A change to cropping on mineral soils overtime reduces the soil carbon levels to 65 tC/ha (240 tCO_2/ha). Therefore there appears to be scope for increasing crop soil carbon levels, which may have a significant effect on farm GHG emissions. The effect of different land use management techniques on soil carbon mineralisation is modelled in the National Inventory (MfE, 2009). A switch from the national default full crop tillage land management factor (F_{MG}) to reduced tillage increases the baseline soil carbon levels to 70 tC/ha (257 tCO_2/ha) and no-tillage further increases carbon levels to 75 tC/ha (274 tCO_2/ha). The difference in sequestered carbon between full cultivation and no-tillage is equivalent to 12 years of GHG emissions from wheat production (discussed further in Section 5.9). Some arable growers have adopted conservation tillage methods and successfully established commercial arable crops. In addition to the increased soil carbon, reduced tillage would also lower fuel use.

Koga (2006) used the life cycle inventory analysis to calculate the GHG emissions from arable farming in Hokkaido, Japan. Here conventional tillage was compared with reduced tillage (no ploughing) and calculated an 18% reduction in GHG emissions on the Andosol soil type for winter wheat, due to less fuel usage and lower soil organic matter decomposition. Using their measured results and the 1999 and 2001 IPCC numbers, they calculate the annual soil CO_2 emission rate for cropping on the Andosol soils of 3,810 $kgCO_2$/ha/year for reduced tillage and 4,910 $kgCO_2$/ha/year for conventional tillage - a difference of 22%. They also comment that "any cultivation of the Andosol soils results in rapid decomposition of soil organic matter and considerable emissions of CO_2 from the soil". Other researchers (Lal 1997; Lal and Kimble 1997; Paustian *et al*. 1997; and Robertson *et al*. 2000) agree that the rate of soil organic matter oxidisation is influenced by different tillage systems. While conservation tillage systems will enhance carbon sequestration in soils, it requires completely different management systems to be successful and is not just a matter of 'parking the plough in the shed'.

2. LCA methodology

In general this report follows the LCA methodology described in the PAS 2050 but has also been informed by aspects of the ISO standards (14040 series). The PAS 2050 standard was chosen based on consistency with previous MAF commissioned LCA studies in the kiwifruit, pipfruit and lamb industries.

2.1. Study objectives

The goal of this arable carbon footprinting project is to work towards development of sector-specific methodologies and guidance for the measurement, management and eventual reduction of GHG emissions associated with wheat, maize and ryegrass seed crops.

There are two specific objectives:

1. To develop a robust resource input inventory to begin establishing benchmark figures;
2. To create agreed methodology for measuring GHG emissions in the arable sector.

The wider context for the research is to ensure that the New Zealand arable industry can operate in markets with credibility and, where necessary, using internationally recognised, transparent and validated GHG footprinting methodologies for the production and supply of products.

2.2. Functional unit

The PAS 2050 specifies that a functional unit should be defined that describes the unit of analysis for any study. In turn, this defines the system boundary by the resources, services and practices that together produce the functional unit. For the arable industry, it is a specified weight of harvested product at the farm gate. For this study, the functional unit is taken as:

- 1 tonne of wheat,
- 1 tonne of maize grain (harvested weight),
- 1 tonne maize silage (wet weight),
- 1 tonne ryegrass seed.

2.3. System boundary

The system boundary defines the processes and input/output components that have been taken into account in the life cycle study. For this study the system boundary extends from extraction of raw materials from the ground, through field cultivation and harvest to produce one tonne of stable product (Figure 2.1). The system boundary is essentially the same for each functional unit; however the maize grain system boundary excludes drying after harvest due to a lack of reliable data. Results from other LCA studies into bread manufacture have been used to illustrate an expanded system boundary to include storage, distribution, retailing, consumer use and disposal. This is discussed in Section 6.1.1.

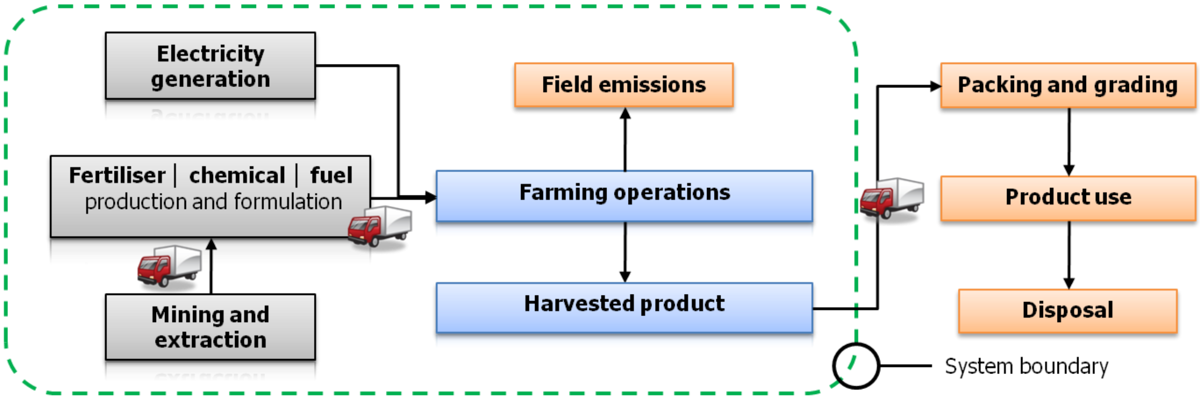

Figure 2.1 Processes and inputs/outputs included within the system boundary.

2.3.1. Components included within the System Boundary

The system defined in this life cycle study includes the impacts associated with:

- The extraction, refinement, formulation, packaging and transport to the farm of fuel, fertiliser and agrichemicals,
- Fuel use on the farm: this includes all types of fuel that the farmer purchases (excluding private use), as well as the estimated fuel use by contractors. Activities carried out by contractors included, but not limited to, drain, water race and silt trap cleaning; fertiliser application; shelter trimming and spraying; planting and harvesting of crops,
- On-farm electricity use, predominantly for irrigation. Electricity included fugitive losses in conversion and distribution.

Greenhouse gas emissions the result of resource use included the three key gases CO_2, CH_4 and N_2O. Including carbon dioxide emissions from:

- Direct energy sources, including all types of fuel used on farm, diesel used by contractors and in transportation, electricity used by the farm,
- Electricity, including the energy inputs to deliver it to the farm,
- Fertilisers and agrichemicals, including manufacture and delivery,
- Limestone quarrying and processing, and carbon emissions from the reaction with the soil,
- Changes in soil carbon due to land use change. This has been investigated through a sensitivity analysis (Section 5.9.1).

Methane and nitrous oxide emissions from:

- Resource inputs,
- Nitrous oxide emissions from direct and indirect inputs of synthetic fertiliser and indirect emissions from leaching,
- Field burning of agricultural crop residues.

2.3.2. Components excluded from the System Boundary

The components of the life cycle which have been excluded are:

- All processes in the production chain beyond the farm gate,
- Drying of seed crops,
- Farm capital such as sheds and implements, (investigated, see Section 5.8)
- Carbon sequestered in soil (other than through land use change).

2.3.3. The 'farm gate'

While completing the surveys it became clear that the farm gate did not always share a common definition. For each operation and even each crop within an operation, the farm gate was a moving point. The farm gate was therefore standardised as the point of harvest.

2.3.4. Bread LCA

Data for the illustrative expanded life cycle of wheat to bread was taken from Sustainable Engineering Group and Muresk Institute at Curtin University (Narayanaswamy *et al*. 2004).

3. Data

Data quality is a critical issue in LCA studies. The following aspects must be taken into consideration: time-related coverage, geographical coverage, type of technology, variability of data values, completeness, representativeness, consistency, reproducibility, sources and uncertainty (ISO14044, Section 4.2.3.6.2).

PAS 2050 defines two types of data: primary and secondary. Primary data is a quantitative measurement of activity from a product's life cycle and equivalent to the site-specific data described in ISO14044. Secondary data are data obtained from sources other than direct measurement of the processes included in the life cycle of the product, typically taken from sources such as the European Reference Life Cycle Data System (PAS 2050).

3.1.1. Primary data - grower surveys

The grower production information used in this report is based on ten face-to-face surveys conducted with growers. The survey included growers in the three main growing regions Waikato, Hawke's Bay and Canterbury, who are members of the Foundation for Arable Research.

The survey group included eight who grew wheat, five maize silage, three maize grain, and seven ryegrass growers. The survey group farmed 2.0% of the wheat area and 1.7% of the maize grain area grown in New Zealand in the 2008/09 season. A robust analysis of the detailed survey data therefore provides an accurate description of the surveyed farming operations. However, extending these findings to a full LCA description of the New Zealand arable sector should be limited due to the small sample size and small representation of total New Zealand grain production.

The production area surveyed in each region is not proportional to the national distribution of production for these crops. In this initial project, it was decided that it was important to work with innovative growers to understand any crop differences and methodological issues.

Most growers found it challenging to complete the survey, with most taking between six to 15 hours. All growers have mixed growing operations and this added complexity to the survey. The majority of growers grow at least two of the studied crops, and several growers grow three or four of these crops.

The most difficult information to retrieve was fuel use, and often represented a best estimate because records were seldom kept on the quantity of fuel used for each crop (fuel use records were aggregated for the whole farm). Where fuel use was estimated from the financial accounts (2 farms), knowing the average price reduced the level of accuracy. The timing of fuel deliveries on the shoulder of the recording year, and the level in the fuel tank can influence the quantity of fuel attributed to a crop (these issues are often more significant for the small operations).

Some agrichemicals are applied to specific paddocks or even parts of a paddock to deal with specific issues, i.e. not blanket application. This made determining a typical programme more challenging. It would be possible to enter total spray use and therefore determine an average, however this would have taken considerably longer and was not justified for a component that represents less than 4% of on-farm GHG emissions.

For two growers it was not possible to obtain details of their electricity use, so this was estimated.

Where water use for irrigation was not metered a best estimate was made.

3.1.2. Secondary data

An estimate of energy inputs and GHG emissions resulting from arable machinery production and maintenance was provided from a previous FAR energy report (Barber, 2004).

The average energy costs of manufacturing fertiliser nutrient components was based on Ledgard and Boyes (2008) and Wells (2001).

For each agrichemical the manufacturing energy, associated emissions, chemical formulation, packaging and transport emissions were determined from the published report by Green (1987), where this was not available the average for the chemical type was used.

3.1.3. Additional data – emission factors

Emission factors for each input are detailed in the appropriate section or are as per the New Zealand Energy Data File (MED, 2010). In this pilot study all forms of nitrogen fertiliser are attributed with the same GHG emission factor for production and field emissions. Considering the large effect that N_2O is likely to have on total GHG emissions then generating manufacturing specific and environmental specific emission factors is something that should be considered in the future.

3.2. Attributional and consequential LCA

A potentially important decision concerns whether a consequential or attributional study is considered appropriate. Consequential studies generally address 'What if?' questions and aim to describe the effect of changes within a life cycle. Attributional studies describe the current (or past) situation. This study falls into the latter category, and is an awareness-raising study to develop a methodology that will allow the measurement of on-farm GHG emission resulting from arable production.

3.3. Allocation of GHG emissions

Arable production systems are multi-functional and generate multiple products. Typically, growers produce several different crops for financial diversification and crop rotation as part of soil, water and disease best management practices. Therefore, inputs and emissions need to be allocated between the various products. Following PAS 2050 guidelines, each farming operation was divided into sub-processes based upon the functional units defined in this study and the farmer's best estimates. This approach avoids the less favoured approach of allocation based on economic value, it does however assume an accurate allocation by the farmer.

Farmer estimates were often based on the crop area as a percentage of the total production area and a feel if that crop typically required more or less fuel than the farm average. In addition, most operations included a component of livestock. Allocation to livestock was based on the growers' best estimate. As a check this was compared to the All Class Average sheep and beef farm inputs per stock unit obtained from Barber and Pellow (2008). On average, the farmers' estimates were the same as the modelled number, with nine of the ten farmer estimates ranging between 94% and 109% of the modelled amount.

Straw and hay as a co-product

Both wheat and ryegrass seed can have straw or hay as a co-product. Not all farms harvested hay, but where they did the GHG emissions were allocated between the grain, seed and hay. Following PAS guidelines, this was done on the basis of system boundary expansion, where the grain or ryegrass seed was given a credit per tonne of harvested hay. The hay emissions were determined using the data from two farms in this study that provided robust financial data. Here it was found that, based on economic allocation, 5% of emissions should be allocated to straw. Consequently the GHG emissions and primary energy of hay was found to be 34 kgCO_2e/t hay harvested and 290 MJ/t hay respectively. These figures were then applied to the wheat and ryegrass seed hay from each farm that produced these co-products.

4. Reference period - seasonal product

In line with PAS 2050 guidelines, where a product is made available on a continuing basis, the assessment of GHG emissions shall cover at least one year. Where a product is differentiated by time (e.g. seasonal products), the assessment of GHG emissions shall cover the particular period associated with the production of the product (see PAS 2050 Section 7.6). New Zealand arable crops are a seasonal product. As such, farm surveys covered all operations over a growing season from June to May.

4.1. Calculating GHG emissions

GHG emissions were calculated from the resource use inventory and multiplied by their appropriate emission factor. For example diesel has an LCA emission factor of 3.13 kgCO_2e/L (see Table 5.4) multiplied by the quantity of fuel in the inventory.

Nitrogen fertiliser has both a manufacturing GHG emission factor and further emissions once applied to the soil. The quantity of nitrogen applied is multiplied by the emission factors described in Sections 5.3 and 5.5.

Given that this study only considered two environmental impact categories (resource use and GHG emissions) the analysis was conducted using an excel model developed specifically for this project.

5. Life cycle inventory

5.1. Farm description

Regional distribution

Wheat is grown in all regions of New Zealand, although very little is grown north of Hawkes Bay and Manawatu. Maize silage crops are grown as far south as South Canterbury, whereas maize grain is grown predominantly in the North Island and a small area is grown in North and Central Canterbury. Ryegrass seed crops are grown in the Hawke's Bay and Canterbury. Data for this report did not distinguish production inputs between different varieties, nor for different end uses. Future studies could examine the difference in inputs for milling and stockfood wheat uses. For example, milling wheat requires more inputs and uses different varieties, resulting in different management techniques and yields.

Size and yields

The surveyed farm areas and crop production are described in Table 5.1. Wheat operations are described for the surveyed national totals and compared to operations surveyed in Canterbury; as well as the national statistics from the survey period, collected by Statistics New Zealand. Maize and ryegrass seed operations are only described by the surveyed area and production. Regional reporting is limited to Canterbury due to the small survey size and to maintain confidentiality; no national census statistics are recorded for these crops.

Following the life cycle impact assessment the farming operations with the minimum and maximum GHG emissions (per tonne of product) were identified and are presented below and throughout the inventory section of this report. These minimum and maximum farms have been used to provide a gauge on the survey group's variability, and as a potential guide towards areas of improvement. As these farms have been selected based on their total GHG emissions, some of the individual inputs will not be the highest or lowest surveyed GHG emissions. In some cases the maximum figure may be below the average simply because that farm, while having the highest GHG emissions overall, had low emissions for a particular input. For the same reason, in some cases the minimum figure for an individual input may be higher than the average.

Table 5.1 Area and crop production of surveyed farms.

Crop	Survey size	Total area (ha)	Productivity (t/ha)		
			Average	Minimum emitter[1]	Maximum emitter[1]
Wheat	8	840	8.8	10.0	5.4
Canterbury	6	590	9.2	9.7	6.5
National census 2008	-	*42,326*	*8.1*	-	-
Maize silage	6	120	17.9	21.0	16.0
Maize grain	3	390	12.8	14.0	10.8
Ryegrass seed	7	400	1.7	1.9	0.9
Canterbury	*6*	*360*	*1.8*	1.9	0.9
Total farm size	10	6,000	-	a	a
Canterbury	*6*	*1,810*	-	a	a

1. per tonne

a. confidential to ensure that the farms cannot be identified.

5.2. Farm fuel and electricity use

In the main body of the report the results are presented for wheat. The corresponding results for the other three crops can be found in the appendix.

Diesel, petrol, oil, and electricity use includes all fuel purchased by the grower and their agricultural contractors (Table 5.2 and 5.3). Data is presented for the survey average and the Canterbury region, as well as the minimum and maximum GHG emitting farming operations.

Table 5.2 Wheat growing operation fuel and electricity use (per ha).

	Units	Survey Average	Minimum emitter	Maximum emitter
Field operations (diesel equivalent)	L/ha	77	82	75
Canterbury	*L/ha*	*75*	*87*	*75*
Electricity	kWh/ha	830	45	3,865
Canterbury	*kWh/ha*	*990*	*20*	*3,865*

Table 5.3 Wheat growing operation fuel and electricity use (per t).

	Units	Survey Average	Minimum emitter	Maximum emitter
Field operations (diesel equivalent)	L/t	9.1	8.2	14.6
Canterbury	*L/t*	*8.3*	*9.0*	*8.2*
Electricity	kWh/t	94.4	4.3	118.3
Canterbury	*kWh/t*	*105.4*	*2.0*	*1.7*

5.2.1. Data

Total fuel use was determined from the grower surveys where the grower provided their annual fuel use in litres or in two cases dollars. Generally, this information covered a range of company activities and crops. Many of the growers could not accurately disaggregate total fuel use by crop type. Given the range of crops grown, and timing overlaps this made allocating fuel more difficult. Additionally, not all the activities are conducted by the grower; where contractors were used their fuel consumption was estimated based on the activity, time taken and area covered. The Canterbury fuel use figure is slightly higher than a previously published estimate of 65 l/ha (Safa, M., *et al*., 2010).

Electricity use for irrigation was very difficult to determine for most growers. For many, a single irrigation bore, pump and meter is used for several crops during the season. Some growers were unable to apportion electricity use between the irrigation system, animal water reticulation system, workshop and office as there is only one meter – therefore determining usage relating to the arable operation was difficult.

There is considerable variability in the fuel use figures and even more so for electricity. However, variability is inherent in many previous primary sector carbon footprinting studies, even those with large sample sizes (Mithraratne, *et al*., 2008 and Hume *et al*., 2009).

Table 5.4 describes the primary energy and life cycle GHG emission factors for fuel and electricity.

Table 5.4 Fuel and electricity primary energy and GHG emissions.

	Units	Primary Energy (MJ/unit)	GHG (kgCO_2e/unit)
Diesel	Litre	46.3	3.13
Petrol	Litre	42.3	2.74
Electricity (2009)	kWh	8.6	0.19

Source: Barber, 2011

5.2.2. Methodological issues

Several growers commented that they were surprised at their fuel use per hectare. Newer tractors display fuel usage during tractor operation, so they know what their usage typically is for a given job. What is often harder to monitor is the fuel used to monitor crops and in miscellaneous travel that is required to grow a crop successfully. For several growers this has sparked interest in undertaking more detailed tracking of their fuel use in the coming season. This may identify where the balance of the fuel is used, highlighting possible gains in efficiency.

To identify any obvious potential efficiency gains management systems of dryland compared to irrigated crops and minimal tillage systems versus conventional tillage were considered. However, the survey group numbers were too small to provide recommendations from this analysis. It did however suggest that this area requires further research to understand the impacts of different management systems, efficiency of energy inputs obtainable and resultant GHG emissions.

Allocation

Total fuel and electricity use for the farm was recorded and allocated to each arable crop based on the farmer's best estimate. The fuel and electricity use per tonne was determined by dividing the per hectare inputs by the harvested tonnes per hectare of each crop.

Variability between operations

There is considerable difference in fuel usage between farms. This will be explained by inaccuracies in data collection, farm scale, and efficiencies in fuel use, including how equipment is setup, operated, age etc. This variability may also result from the large difference in environments that the surveyed farms are operating under. Larger surveys may identify if this variability is correlated to regional differences. It is also likely that this variability is a measure of differences in farm management practices. If so then this raises the possibility of increasing resource efficiency through knowledge of farmer best practices.

5.2.3. Recommendations

The large differences observed between some farms' use of fuel suggests that individual grower practices can have a pronounced effect on the carbon footprint for arable crops. More fuel use information and a focus on collecting more accurate information is needed to better understand how much of this variability is due to grower practices versus differences in data collection, recording and climate.

More accurate and consistent water use records are required that show both the total farm water use and the quantity of water applied to each crop type. With this information electricity use could be more accurately allocated to each crop type.

5.3. Fertiliser and limestone production and use

Most growers use a combination of synthetic and mineral fertilisers and lime. The main nutrient elements are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and magnesium (Mg). Lime is applied to the soil for calcium and pH control, however not all growers apply it before planting each crop.

5.3.1. Data

Fertiliser use was collected and reported in their different nutrient components.

Table 5.5 shows the average energy costs of manufacturing each nutrient component based on Ledgard and Boyes (2008) and Wells (2001). These are average figures taken from a range of different fertiliser production methods. Urea is the predominant form of nitrogen, accounting for 96% of the nitrogen applied to wheat (maize silage = 52%, maize grain 69%, and ryegrass seed = 81%), and has been used as the basis for all nitrogen applications in this study. A New Zealand specific fertiliser study is currently underway that will enable more accurate GHG emission factors to be used in the future.

Wells (2001) determined the CO_2 emissions for sulphur and magnesium based on the average CO_2 emissions of 0.06 kg CO_2 per megajoule of embodied primary energy. Consequently, the GHG emissions for these two nutrients were increased to 0.064 $kgCO_2e/MJ_{primary}$ to account for the small quantity of CH_4 and N_2O released from the various fuel types during fertiliser manufacture.

The field emission of nitrous oxide and carbon dioxide after nitrogen and limestone application is described in Sections 5.5 and 5.6 respectively.

Table 5.5 Energy requirements and GHG emissions to manufacture fertiliser components.

Component	Energy cost (MJ/kg)	GHG ($kgCO_2e/kg$)
N (urea – N) [a]	51	4.01
P [a]	39	3.18
K [a]	10	0.74
S [b]	5	0.32
Mg [b]	5	0.32
Lime stone	0.6	0.041

[a] Ledgard and Boyes (2008)
[b] Wells (2001)

Fertiliser use data was collected in the grower surveys and is reported in the different nutrient components. Table 5.6 gives the total quantity of nutrients applied nationally and in Canterbury, to wheat per hectare, and Table 5.7 as per tonne of harvested product.

Table 5.6 Quantity of nutrients applied to wheat (per ha).

	Average kg/ha	Minimum emitter	Maximum emitter
Nitrogen	192	100	240
Canterbury	*200*	*190*	*240*
Phosphorus	30	14	0
Canterbury	*35*	*78*	*0*
Potassium	26	45	0
Canterbury	*18*	*0*	*0*
Sulphur	46	1	0
Canterbury	*55*	*101*	*0*
Magnesium	8	0	0
Canterbury	*11*	*0*	*0*
Lime - soil	432	15	385
Canterbury	*529*	*559*	*385*
Compost	0	0	0
Canterbury	*0*	*0*	*0*

No wheat growers used any form of compost on their crops. However chicken manure was used by maize grain and silage operations.

Table 5.7 Quantity of nutrients applied to wheat (per t).

	Average kg/t	Minimum emitter	Maximum emitter
Nitrogen	23	10	43
Canterbury	*22*	*20*	*28*
Phosphorus	3	1	3
Canterbury	*4*	*8*	*4*
Potassium	3	5	10
Canterbury	*2*	*0*	*8*
Sulphur	5	0	8
Canterbury	*6*	*10*	*5*
Magnesium	1	0	0
Canterbury	*2*	*0*	*8*
Lime - soil	51	1	49
Canterbury	*59*	*58*	*79*

Variability between growers

Fertiliser application varied between growers, which are to be expected with different management systems, production plans, soil types and climatic conditions observed across the survey group. Nitrogen was applied reasonably consistently; with an average national application rate of 192 kg N/ha. No differentiation was made between milling and stockfeed wheat crops which will influence these numbers and should be investigated in future studies.

5.3.2. Methodological recommendations

Infrequent activities should be identified and their associated GHG emissions allocated across all subsequent harvests until the activity is repeated. For example, lime may be applied one year (year 1) yet have benefits for several years after application (year 2 onwards). If all the GHG emissions associated with its application are allocated to the harvested crop in year 1, this effectively disadvantages the year 1 harvest and advantages the subsequent harvests.

For this study, grower survey figures for lime application were given for the whole farm and proportioned out on an area basis. Also, frequency of application was recorded and calculated back to an average annual application rate.

5.4. Agrichemicals production and use

All surveyed growers used agrichemicals, predominantly fungicides, herbicides and insecticides. Other, minor chemical groups, include plant growth regulators, foliar fertilisers and various miscellaneous items.

5.4.1. Data

Tables 5.8 and 5.9 outline the average quantity of agrichemicals applied to wheat per hectare and per tonne. This data was derived from the surveyed grower's spray diaries.

Table 5.8 Quantity of agrichemical applied for wheat production (per ha).

	Average l/ha	Minimum emitter	Maximum emitter
Herbicide	3.7	3.0	2.2
Canterbury	*3.8*	*1.1*	*2.2*
Fungicide	5.6	25.7	2.3
Canterbury	*2.2*	*1.7*	*2.3*
Insecticide	0.5	0.0	0.0
Canterbury	*0.6*	*0.0*	*0.0*
Plant Growth Regulators	0.6	0.0	0.0
Canterbury	*0.7*	*0.0*	*0.0*

Table 5.9 Quantity of agrichemical applied for wheat production (per t).

	Average l/t	Minimum emitter	Maximum emitter
Herbicide	0.5	0.3	0.7
Canterbury	0.4	0.1	0.8
Fungicide	0.7	2.6	1.0
Canterbury	0.3	0.2	0.7
Insecticide	0.1	0.0	0.1
Canterbury	0.1	0.0	0.2
Plant Growth Regulators	0.1	0.0	0.1
Canterbury	0.1	0.0	0.2

For each agrichemical the manufacturing energy, associated emissions, chemical formulation, packaging and transport emissions were determined from the literature, where this was not available the average for the chemical type was used (Green, 1987)[1].

5.4.2. Variability between operations

The least variable agrichemical input nationally was herbicides. The average national application rate was 3.7 L/ha, and 0.5 L/t.

Application of the other agrichemicals was more variable. Not all growers used insecticides and plant growth regulators. Of those who did, application rates were very low.

5.5. Field emissions –nitrous oxide (N_2O)

In most soils, an increase in available nitrogen enhances nitrification and denitrification rates, which then increase the production of N_2O, along with indirect emissions from leaching. The following nitrogen sources are included in the methodology for estimating N_2O emissions from soils:

- Synthetic nitrogen fertilisers,
- Organic nitrogen applied as fertilisers (e.g., compost),
- Nitrogen in crop residues (above ground) for wheat and maize grain.

Field emissions of N_2O arise from synthetic fertiliser use and the decomposition of crop residues left on fields. As specific emissions factors have yet to be determined, all nitrogen

[1] A second publication of agrichemical emission factors presents manufacturing GHG emissions for agrichemicals based on Gaillard et al. (1997) (Jancovici 2005). For fungicides the Green (1987) and Gaillard et al. (1997) average emission factors were very similar. The Green (1987) average herbicide manufacturing emission factors were higher, and so the use of them in this report is conservative. For consistency GHG emission factors from Green (1987) are used throughout this report.

inputs are treated the same and a New Zealand-specific emission factor of 0.01 kgN_2O-N/kgN (Kelliher and de Klein, 2006) is applied to calculate total direct emissions from non-organic soils, generalised Equation 1. As mentioned previously, N_2O emissions have a global warming potential 298 times as great as CO_2. Emission factors specific for each nitrogen source and site would greatly increase the accuracy of calculated on-farm GHG emissions. See the literature review on this issue (Section 1.2.1) and the sensitivity analysis (Section 6.6).

$$\text{Direct soil emissions} = \text{kgN} \times EF_1 \times 44/28 \times GWP_{N2O} \quad (1)$$

5.5.1. Data

Soil emissions from synthetic nitrogen fertiliser

The quantity of synthetic nitrogen fertiliser used is shown in Table 5.6 and 5.7.

Nitrous oxide emissions from the application of synthetic nitrogen fertiliser were determined based on the methodology and default emission factors in the New Zealand GHG Inventory (MfE, 2007). The content and format of the New Zealand GHG Inventory is prescribed by the IPCC (IPCC, 1996; 2000; 2003).

Nitrous oxide comes from both direct and indirect sources. Direct sources include soil emissions from synthetic nitrogen fertiliser applied on the farm. Indirect sources include the volatilising and leaching of synthetic nitrogen fertiliser. Additional indirect emissions occur from atmospheric deposition in which soils emit ammonia (NH_3) and oxides of nitrogen (NO_x) that react to form nitrous oxide in the atmosphere.

Nitrous oxide emissions from soils were estimated (in kgCO_2e) by summing the various emission components in Equations 2, 3 and 4, and emission factors from Table 5.10.

$$\text{Direct soil emissions } (SE_{DIRECT}) = \text{kgN applied} \times (1-Frac_{GASF}) \times EF_1 \times 44/28 \times GWP_{N2O} \quad (2)$$

$$\text{Indirect soil emissions } (SE_{INDIRECT}) = \text{kgN applied} \times Frac_{GASF} \times EF_4 \times 44/28 \times GWP_{N2O} \quad (3)$$

Indirect leaching soil emissions (SE_{LEACH})

$$= \text{kgN applied} \times (1-Frac_{GASF}) \times Frac_{LEACH} \times EF_5 \times 44/28 \times GWP_{N2O} \quad (4)$$

$$\text{Total SE} = SE_{DIRECT} + SE_{INDIRECT} + SE_{LEACH}$$

Table 5.10 Relevant factors for use in evaluating nitrous oxide emissions from soil**.**

	Description	Default value
GWP_{N2O}	Global warming potential of nitrous oxide (IPCC Fourth Assessment Report, 2007)	298
EF_1	Emission factor for direct emissions from N input to soil	0.01
EF_4	Emission factor for indirect emissions from volatising nitrogen	0.01
EF_5	Emission factor for indirect emissions from leaching nitrogen	0.0075
$Frac_{GASF}$	Fraction of synthetic N fertiliser emitted as NO_x or NH_3	0.1
$Frac_{LEACH}$	N input to soil that is lost through leaching and run-off	0.07

Source: New Zealand GHG Inventory, MfE, 2009.

Soil emissions from crop residue

The quantity of crop residue left after harvesting wheat was calculated based on the crop yield, less any residue burned or removed as the co-product wheat straw. This was based on the methodology described in the New Zealand GHG Inventory (MfE, 2009) where it was pointed out that an area for future improvement could be changing the method for how wheat residue is calculated.

Maize grain growers mulched or slashed their crop residue after harvest so the quantity of reside was calculated based on their yield. Wheat and maize grain growers utilised a range of systems to deal with their crop residue.

The quantity of crop residue left after maize silage and ryegrass harvest was considered negligible and has been treated as zero.

The quantity of nitrogen in the wheat and maize grain crop residue was calculated based on the factors used in the New Zealand GHG Inventory (MfE, 2009). Equation 5 was then used to determine the quantity of N_2O emissions converted into CO_2e values.

$$\text{Direct soil emissions} = \text{kgN in crop residue} \times EF_1 \times 44/28 \times GWP_{N2O} \quad (5)$$

5.6. Field emissions – lime (CO_2)

In addition to mining, transport and manufacturing GHG emissions, when limestone (calcium carbonate $CaCO_3$) or dolomite (calcium magnesium carbonate $CaMg(CO_3)_2$) is applied to the soil CO_2 is released over time. This rate is based on the IPCC guidelines, and assuming 90% purity, equals 0.396 kg CO_2/kg limestone and 0.429 kg CO_2/kg dolomite.

5.7. Field emissions – field burning of crop residues

Some farmers burn their wheat crop residues, some of which was picked up in the surveys. Maize residues are not burned in New Zealand.

The burning of crop residues is not a net source of CO_2 because the carbon released to the atmosphere during burning is reabsorbed by the crop the following season. However the burning process also releases CH_4 and N_2O, which needs to be accounted for.

The emissions from burning crop residues are estimated using Equations 6, 7 and 8 and factors described in the revised 1996 IPCC guidelines.

Carbon released = annual production (t) × ratio of residue to crop production × average dry matter fraction of residue × fraction oxidised × carbon fraction (6)

CH_4 emissions = carbon released × emissions ratio × 16/12 (7)

N_2O emissions = carbon released × N/C ratio × emissions ratio × 44/28 (8)

Based on the factors used in the New Zealand GHG Inventory (MfE, 2009) wheat has a residue to crop ratio of 1.3 and a dry matter fraction of 0.83. 90% of the residue is oxidised and the carbon fraction of the residue is 0.49. For the N_2O emissions the nitrogen to carbon ration (N/C ratio) is 0.01.

Converted into CO_2e values, when a wheat crop's residues are burned in the field it releases 97 $kgCO_2e$/t wheat produced.

5.8. Machinery, production and maintenance

GHG emissions associated with farm capital (equipment, buildings etc.) manufacture and maintenance are excluded from the PAS 2050. However, as these items are included in ISO 14044 and maybe included in future revisions of PAS 2050, an assessment of farm capital is included here.

New Zealand specific data on total energy use during arable production, including farm capital manufacture and maintenance, has been collected previously (Barber, 2004). This has been updated using the most recent energy and GHG emission factors and used as the basis for this assessment. Allocating these emissions over the working life of the capital results in 125 $kgCO_2$/ha/yr. Based on a farms' yield, this per hectare emission factor can be converted into GHG emissions per tonne of production. For the surveyed wheat operations this equates to 14.2 $kgCO_2$/t, making up 4% of total GHG emissions.

Not collecting information on capital equipment during grower surveys had the benefit that it significantly shortened the survey, consequently improving uptake by growers.

5.9. Changes in soil carbon

Soils are an important part in the carbon cycle and changes in soil carbon can influence GHG emissions. Greenhouse gases emissions can result from soil carbon losses, caused by land use changes (LUC). Currently there is considerable uncertainty about how to representatively measure, track and account for changes in soil carbon. For this reason, emissions and sequestration arising from changes in soil carbon, outside of an LUC, are excluded from PAS. The inclusion of carbon storage in soils will be considered further in future revisions of PAS (PAS 2050, Section 5.6, Note 2).

5.9.1. Land use change (LUC)

A land use change from grassland to cropping can lead to a decrease in the carbon content of soil over many years. This can occur through greater oxidisation of soil carbon by increased tillage and decreased carbon inputs. PAS 2050 (Section 5.5) requires the inclusion of all direct LUC occurring on or after 1 January 1990. One-twentieth (5%) of the potential emissions arising from the LUC shall be included in the GHG emissions of these products in each year over the 20 years following the change in land use. Where the land use has not changed in 20 years then PAS, and the New Zealand GHG Inventory, assume that the soil carbon levels remain the same.

Methodological issues and data

PAS 2050 lists default LUC emission factors for selected countries. For example, converting between grassland and annual cropping has associated GHG emission of 2.2 tCO_2e/ha/yr in Australia and Canada, 1.9 tCO_2e/ha/yr in the United States and as high as 7.0 tCO_2e/ha/yr in the UK.

Where a country specific figure has not been included in the PAS Appendix the country specific IPCC guidelines must be followed. Based on the default figures in New Zealand's GHG National Inventory 1990 – 2007 (MfE, 2009) the net carbon stock change, per hectare of land converted from grassland to cropland, on mineral soils is 2.0 tC/ha/yr or 7.3 tCO_2/ha/yr. Nitrous oxide emissions from the mineralisation of this organic matter adds a further 0.6 tCO_2e/ha/yr. Total GHG emissions from converting grassland to crop production is thus 7.9 tCO_2e/ha/yr. Therefore, LUC can be a very significant source of emissions, being more than double all other on-farm emissions combined.

The area of wheat production has been recorded by Statistics New Zealand since 1935. Wheat production in the middle of the 20th century was characterised by large changes in cropped area and production, both increasing fivefold between 1957 and 1969. However since 1969 the area has decreased significantly. From 1990 the area devoted to wheat production has oscillated between 40,000 and 55,000 hectares (Figure 5.1). However total production in 2010 matched that of 1969, from just a third of the land.

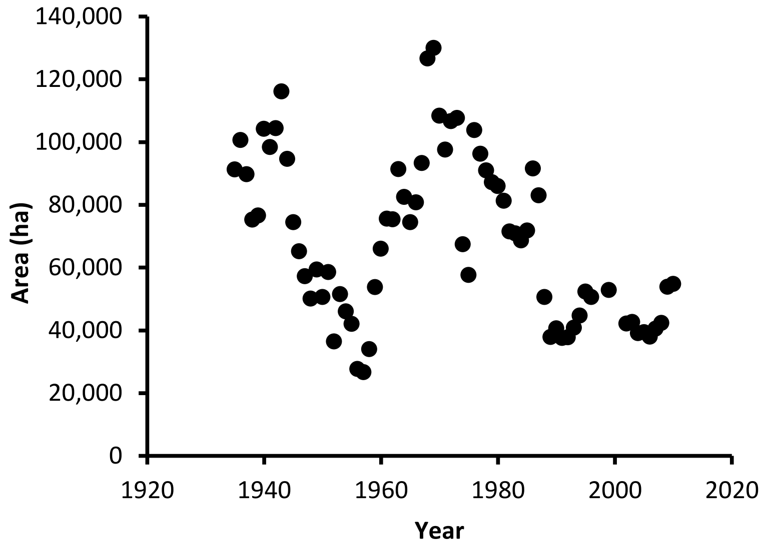

Figure 5.1 New Zealand wheat production area since 1935 (Statistics New Zealand).

This suggests that the majority of the current wheat crop is planted on land that has been in arable production for greater than 20 years. Therefore this study has assumed that there are no GHG emissions as a result of LUC.

However, an LUC can still have a large effect on the GHG emissions of individual operations that choose to convert pasture to arable cropping. This is likely to only represent a small proportion of the national arable crop and have a minimum effect on total industry GHG emissions. A sensitivity analysis was therefore conducted to assess the effect on GHG emissions of converting from long-term pasture to arable production.

LUC sensitivity analysis

A sensitivity analysis was conducted based on the average wheat operation, emitting 2.8 tCO_2e/ha and converting a proportion of the farm from long-term pasture into wheat production. GHG emissions the result of LUC were based on New Zealand's GHG National Inventory 1990 – 2007 (MfE, 2009) of 7.9 tCO_2e/ha (Table 5.11).

Table 5.11 The effect of LUC on the GHG emissions of a wheat operation.

Land use change	(% of cropped area)	0%	10%	20%	40%	80%
LUC GHG emissions	(tCO_2e/ha)	0	0.8	1.6	3.2	6.4
% Increase of wheat GHG emissions		0%	28%	56%	112%	224%

This analysis shows that any LUC can generate a large increase in GHG emissions for the 20 years following the change.

6. GHG Life Cycle Impact Assessment

The results in this section are for baseline scenarios for the four crops – wheat, maize silage, maize grain, and ryegrass seed. Results represent the 'average' GHG emissions per functional unit. However, as mentioned in the Life Cycle Inventory, considerable variability exists within the collected data. Therefore, while these results accurately describe the distribution and GHG emissions from each operation and GHG emissions for each functional unit, the small sample size, data quality and regional influences limits its ability to accurately describe each sector of the New Zealand arable industry as a whole.

6.1. Wheat production

The distribution and quantity of GHG emissions due to wheat farm operations are shown in Figure 6.1 and 6.2.

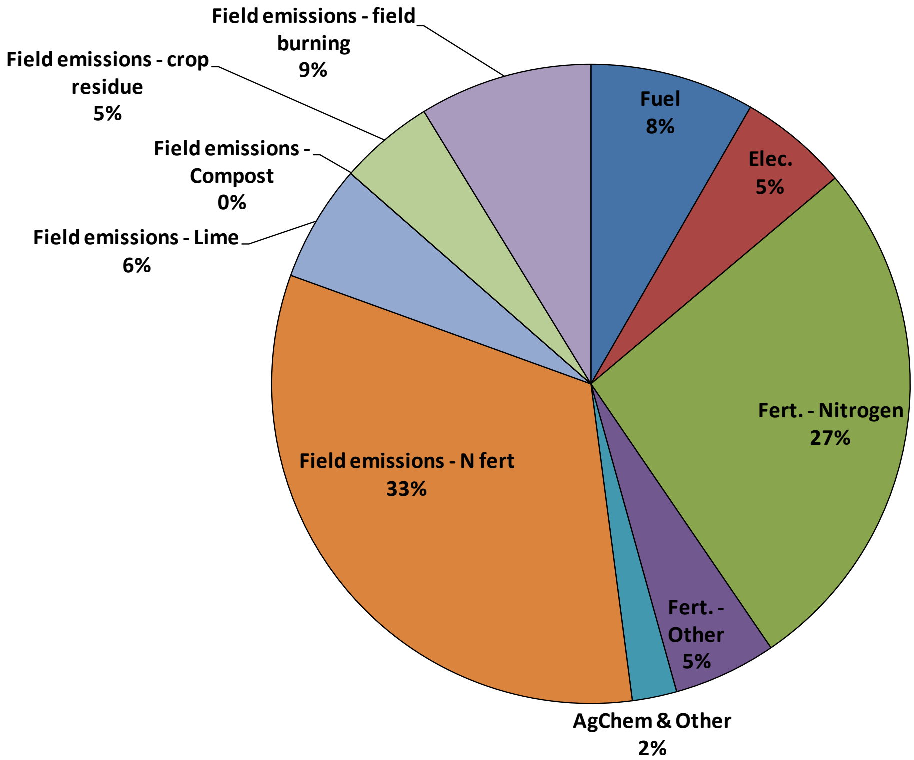

Figure 6.1 Distribution of GHG emissions from surveyed wheat production operations.

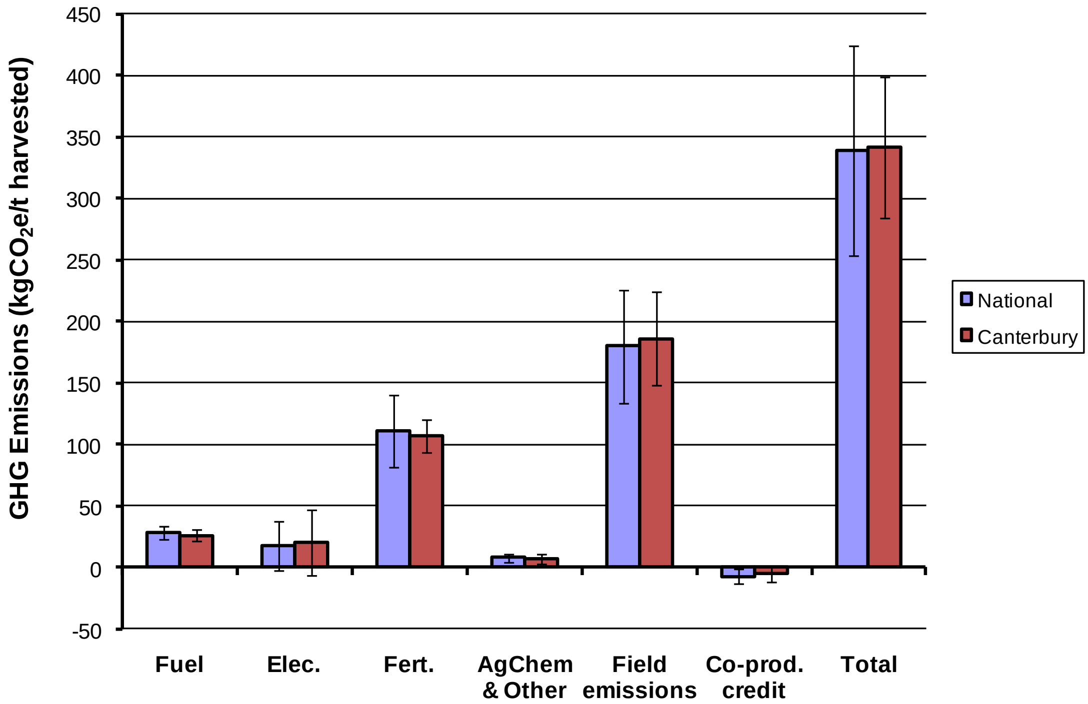

Figure 6.2 Quantities of GHG emissions from surveyed wheat production operations (per t).

Total wheat GHG emissions for the survey are 345 $kgCO_2e/t$ harvested, less a small credit for displacing hay production of 7 $kgCO_2e/t$, resulting in net emissions of 340 $kgCO_2e/t$ harvested (Figure 6.2) and ranged between 130 and 530 $kgCO_2e/t$ (Table 6.1). The highest emitting crop was due solely to a very low yield that season (Table A.1) as GHG emissions per hectare for this farm were equal to the national average. The lowest emitting farm had a combination of high yields and low inputs, particularly nitrogen (Table A.2 and A.4). It was the lowest both per hectare and per tonne of wheat.

On a per hectare basis, average total GHG emissions for wheat production is 2,885 $kgCO_2e/ha$, with a credit of 70 $kgCO_2e/ha$ for hay or straw as a co-product, resulting in net emissions of 2,820 $kgCO_2e/ha$. Total GHG emissions ranged between 1,300 and 3,700 $kgCO_2e/ha$ (Table 6.1). The highest emissions per hectare were due to very high electricity use (Table A.2). The lowest Canterbury wheat farm had close to average inputs, they are a dryland farm so had low electricity use, and they did not burn their crop residues. Combined with high yields this farm also had the lowest emissions of the Canterbury farms per tonne of wheat (Table A.1).

Table 6.1 Wheat GHG emissions

	Average	Minimum emitter	Maximum emitter	Average	Minimum emitter	Maximum emitter
		Per hectare			Per tonne	
National	2,820	1,300	3,700	340	130	530
Canterbury	*3,060*	*2,540*	*3,700*	*340*	*260*	*445*

When compared to previously published LCAs, the GHG emissions per tonne of harvested product are broadly in line with what has been reported in Australia (Biswas, *et al*., 2008, Biswas, *et al*., 2010); however, as mentioned previously one can only cautiously compare results between LCAs. Differences in nitrogen manufacturing and field emission factors, along with what has been included in the inventory, and how these inputs were determined, have a significant bearing on the final result.

The main driver for the minimum emitting farm was very low nitrogen use (Table 5.6).

Fuel and electricity use contribute 8% and 5% respectively of on-farm GHG emissions. Fuel was reasonably consistent, and electricity varied widely. While this was partly driven by having irrigated and dryland (non-irrigated) wheat, even when taking only irrigated operations into account electricity use varied between 235 to 4,880 kWh/ha.

The majority of emissions are derived from fertiliser manufacture and the associated fertiliser field emissions, at 32% and 39% respectively. The highest GHG emitting nutrient (manufacture and field emissions) is nitrogen (84% of fertiliser emissions) followed by lime (9%), phosphorus (5%), and potassium (1%).

Fifty nine percent of the emissions profile is generated by synthetic nitrogen fertiliser, of which 45% is from manufacturing with the remaining 55% in the form of field emissions once the fertiliser is applied to the soil. Of the field emissions, 86% occur where N_2O is emitted directly to the atmosphere through microbial nitrification and denitrification. However there is considerable uncertainty around the soil emission factor which can vary widely. In the future site specific soil emission factors should be used (when they become available) that takes into account nitrogen fertiliser type, crop management, soil type and climate. FAR has several initiatives to optimise nitrogen use.

Following PAS 2050 guidelines, capital is not included within this analysis. However, as it is included as part of the ISO 14044 methodology, and is likely to be included in future revisions of PAS 2050; its effect is addressed here. As discussed in Section 5.8, farm capital would likely add 125 $kgCO_2$/ha (or 14.2 $kgCO_2$/t wheat produced). This represents a 4% increase in on-farm GHG emissions.

6.1.1. Bread LCA

GHG emissions along a complete bread supply chain have been used to illustrate environmental impacts (Narayanaswamy *et al*. 2004). Using the on-farm results from this study and the post-farm gate resource use inputs from the Narayanaswamy *et al*. (2004) study reveals New Zealand's lower on-farm emissions (due to higher productivity) and significantly lower consumer emissions (due to lower electricity emissions) when compared to results from Australia (Figure 6.3).

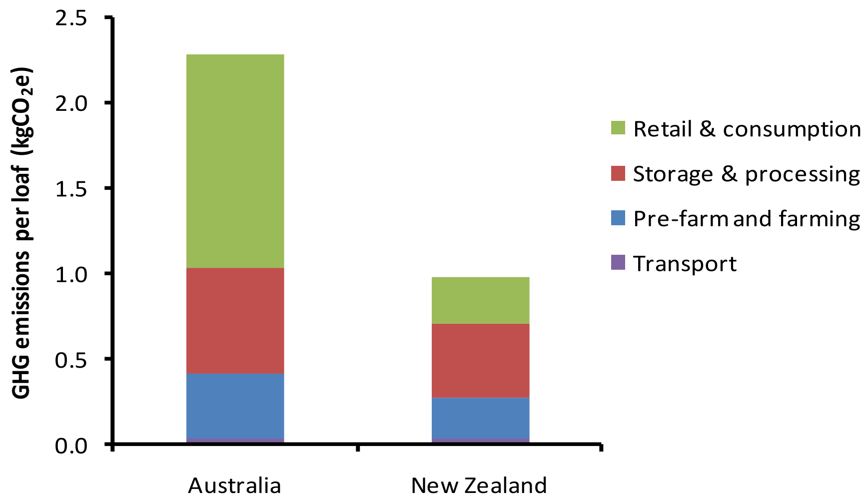

Figure 6.3 Quantity and distribution of GHG emissions along the bread supply chain in Australia and New Zealand.

6.2. Maize silage production

The distribution and quantity of GHG emissions due to maize silage production are shown in Figure 6.4 and 6.5.

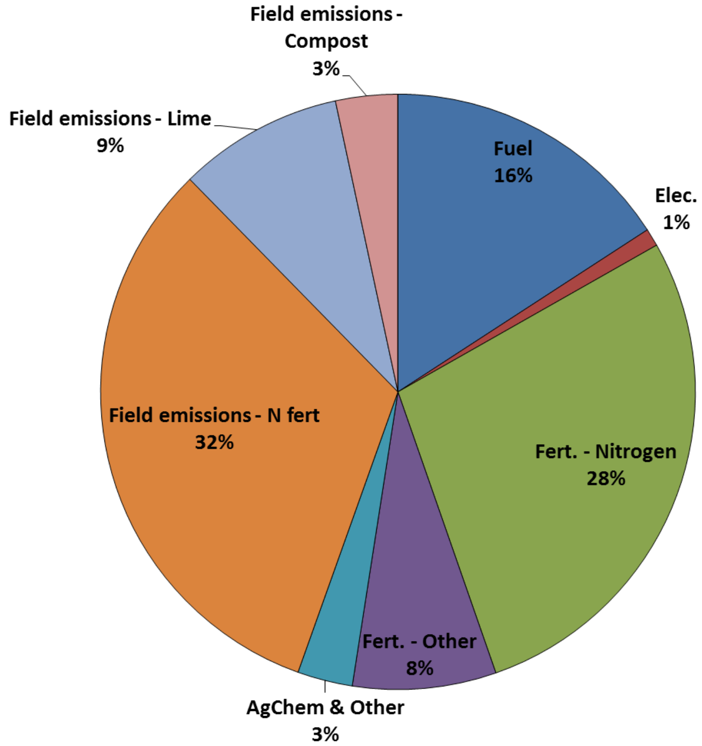

Figure 6.4 Distribution of GHG emissions from maize silage production.

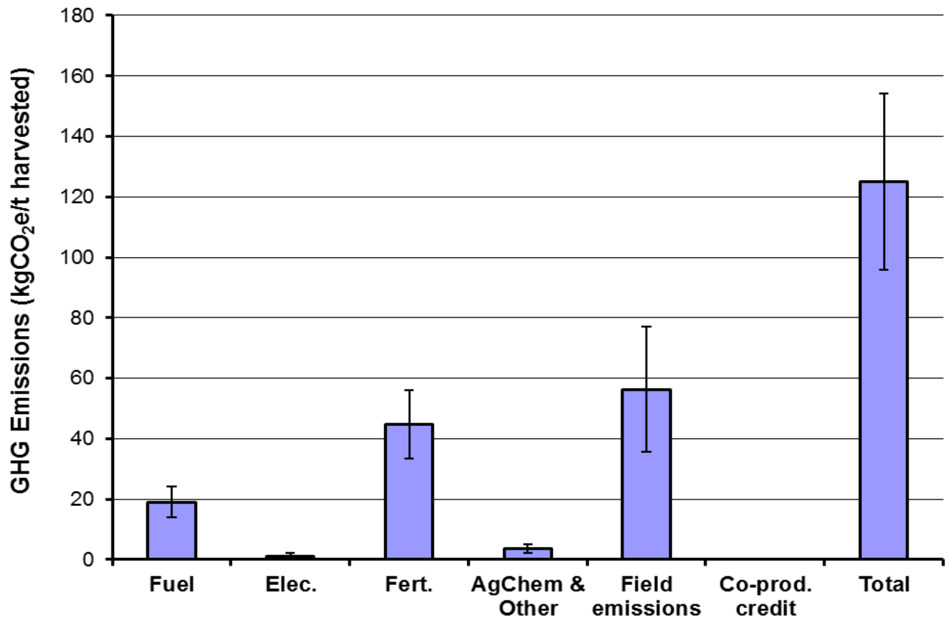

Figure 6.5 Quantities of GHG emissions from maize silage production (per t).

Total maize silage GHG emissions for the survey are 125 kgCO_2e/t harvested (Figure 6.5) and ranged between 95 and 170 kgCO_2e/t (Table 6.2). The lowest emitting farm had high yields at 21.0 t/ha, along with average resource use inputs except for lime which was very low and consequently field emissions were approximately half of the average operation. On a per hectare basis, average total GHG emissions for maize silage production is 2,190 kgCO_2e/ha and ranged between 1,640 and 2,710 kgCO_2e/ha (Table 6.2). The lowest emitting farm per hectare had both low fuel use and nitrogen inputs (Table A.7). Due to their lower than average yields they were 19% above the minimum emitting crop at 110 kgCO_2e/t.

Table 6.2 Maize silage GHG emissions

	Average	Minimum emitter	Maximum emitter	Average	Minimum emitter	Maximum emitter
		Per hectare			Per tonne	
National	2,190	1,640	2,710	125	95	170

Fuel and electricity use contribute 16% and 1% respectively of on-farm GHG emissions.

The majority of emissions are derived from fertiliser manufacture and the associated fertiliser field emissions, at 36% and 41% respectively. The highest GHG emitting nutrient (manufacture and field emissions) is nitrogen (78% of fertiliser emissions) followed by lime (13%), phosphorus (6%), and potassium (2%).

Sixty percent of the maize silage emissions profile is generated by synthetic nitrogen fertiliser, of which 46% is from manufacturing with the remaining 54% in the form of field emissions once the fertiliser is applied to the soil. However there is considerable uncertainty around the soil emission factor which can vary widely. In the future site specific soil emission factors should be used (when they become available) that takes into account nitrogen fertiliser type, crop management, soil type and climate. FAR has several initiatives to optimise nitrogen use.

Following PAS 2050 guidelines, capital is not included within this analysis. However, as it is included as part of the ISO 14044 methodology, and is likely to be included in future revisions of PAS 2050. As discussed in Section 5.8, farm capital would likely add 125 kgCO_2/ha (or 7.0 kgCO_2/t maize silage produced). This represents a 5% increase in on-farm GHG emissions.

While it was assumed that no land had been converted from long term pasture to cropping in the past 20 years (see Section 5.9.1) where this may have occurred, it would significantly increase GHG emissions. If 20% of land had been converted total maize silage GHG emissions would increase by 75%.

6.3. Maize grain production

The distribution and quantity of GHG emissions due to maize grain production are shown in Figure 6.6 and 6.7.

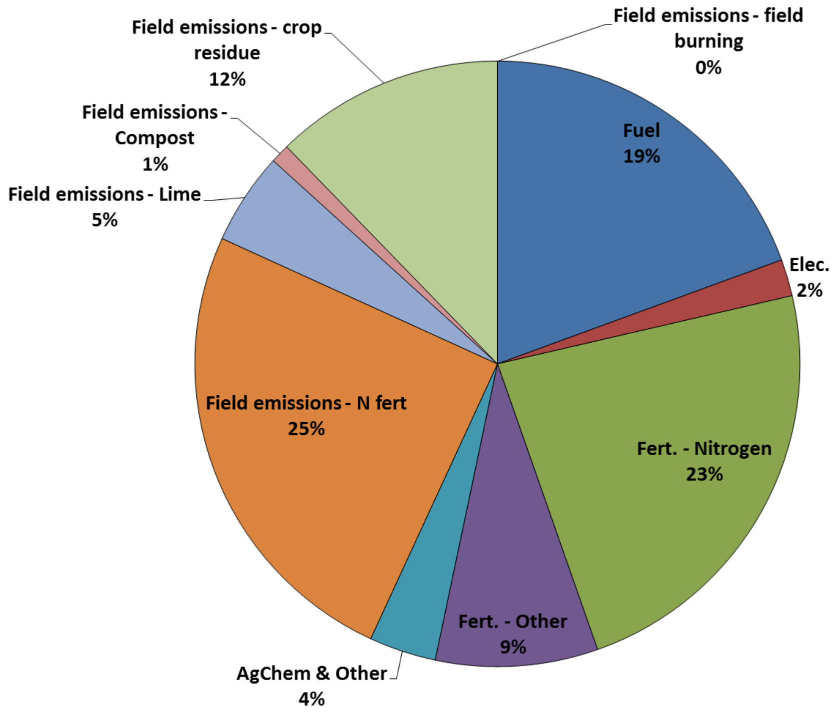

Figure 6.6 Distribution of GHG emissions from maize grain production.

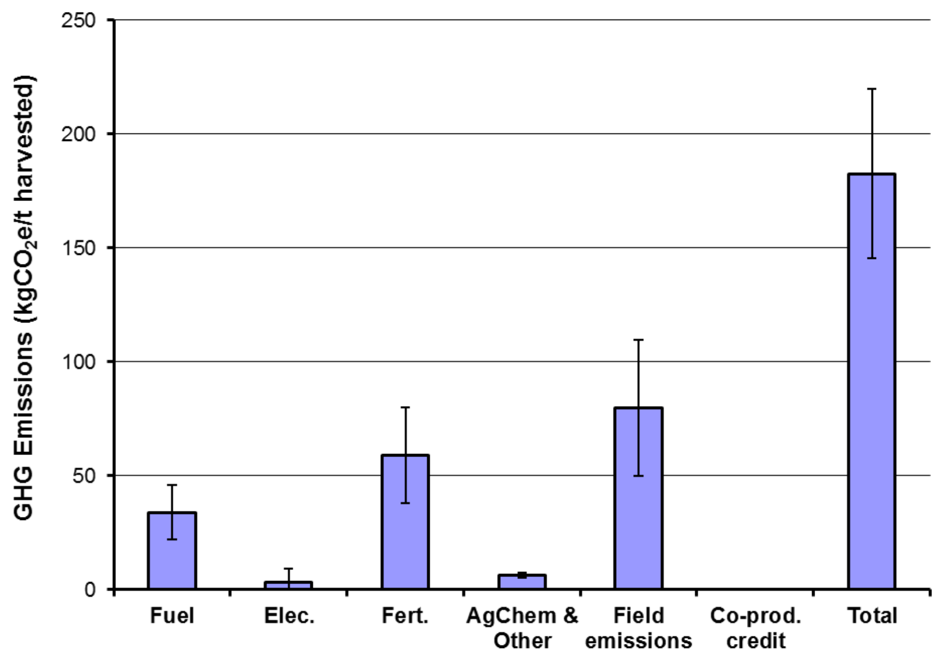

Figure 6.7 Quantities of GHG emissions from maize grain production (per t).

Total maize grain GHG emissions for the survey are 190 kgCO_2e/t harvested (Figure 6.7) and were tightly ranged between 170 and 220 kgCO_2e/t (Table 6.3). The minimum maize grain crop had slightly above average yields (Table A.9). On a per hectare basis, average total GHG emissions for maize silage production is 2,380 kgCO_2e/ha and was tightly ranged between 2,330 and 2,440 kgCO_2e/ha.

Table 6.3 Maize grain GHG emissions

	Average	Minimum emitter	Maximum emitter	Average	Minimum emitter	Maximum emitter
		Per hectare			Per tonne	
National	2,380	2,330	2,440	190	170	220

Fuel and electricity use contribute 19% and 2% respectively.

Like the other New Zealand arable crops, the majority of emissions are derived from fertiliser manufacture and the associated fertiliser field emissions, at 32% and 30% respectively. This represents the lowest contribution by fertiliser, with high energy and crop residue field emissions making significant contributions at 21% and 12% respectively. The highest GHG emitting nutrient (manufacture and field emissions) is nitrogen (78% of fertiliser emissions) followed by lime (9%), phosphorus (9%), and potassium (3%).

Synthetic nitrogen fertiliser is the single largest source of GHG emissions, contributing just under half (48%) of all on-farm emissions of which 48% is from manufacturing with the remaining 52% in the form of field emissions once the fertiliser is applied to the soil. However there is considerable uncertainty around the soil emission factor which can vary widely. In the future site specific soil emission factors should be used (when they become available) that takes into account nitrogen fertiliser type, crop management, soil type and climate. FAR has several initiatives to optimise nitrogen use.

Following PAS 2050 guidelines, capital is not included within this analysis. However, as it is included as part of the ISO 14044 methodology, and is likely to be included in future revisions of PAS 2050; its effect is addressed here. As discussed in Section 5.8, farm capital would likely add 125 kgCO_2/ha (or 9.8 kgCO_2/t maize grain produced). This represents a 5% increase in on-farm GHG emissions.

While it was assumed that no land had been converted from long term pasture to cropping in the past 20 years (see Section 5.9.1) where this may have occurred, it would significantly increase GHG emissions. If 20% of land had been converted total maize silage GHG emissions would increase by 70%.

6.4. Ryegrass seed production

The distribution and quantity of GHG emissions due to ryegrass seed production are shown in Figure 6.8 and Figure 6.9.

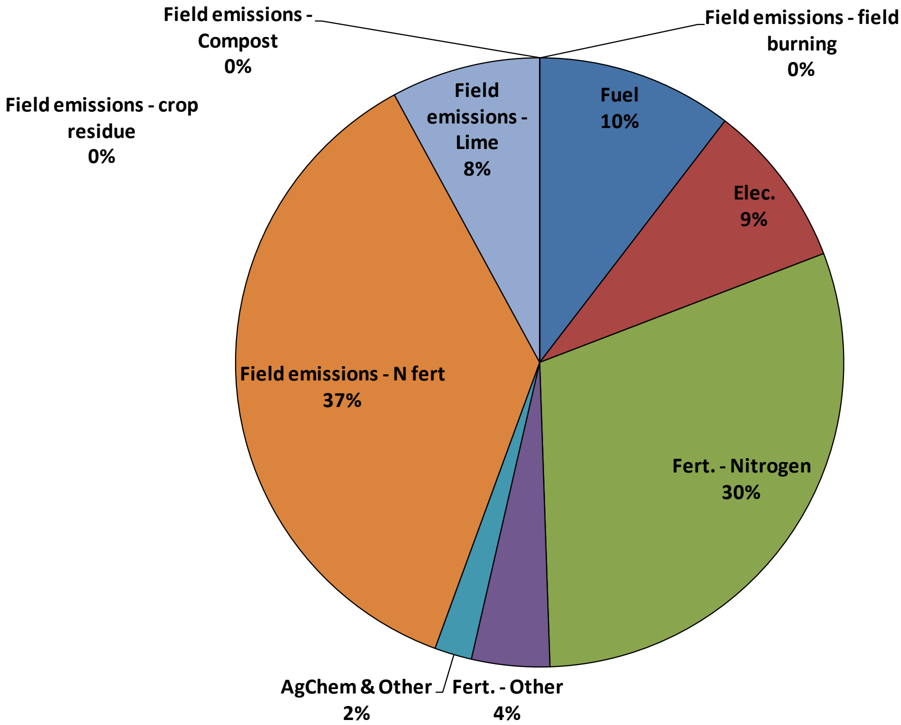

Figure 6.8 Distribution of GHG emissions from ryegrass seed production.

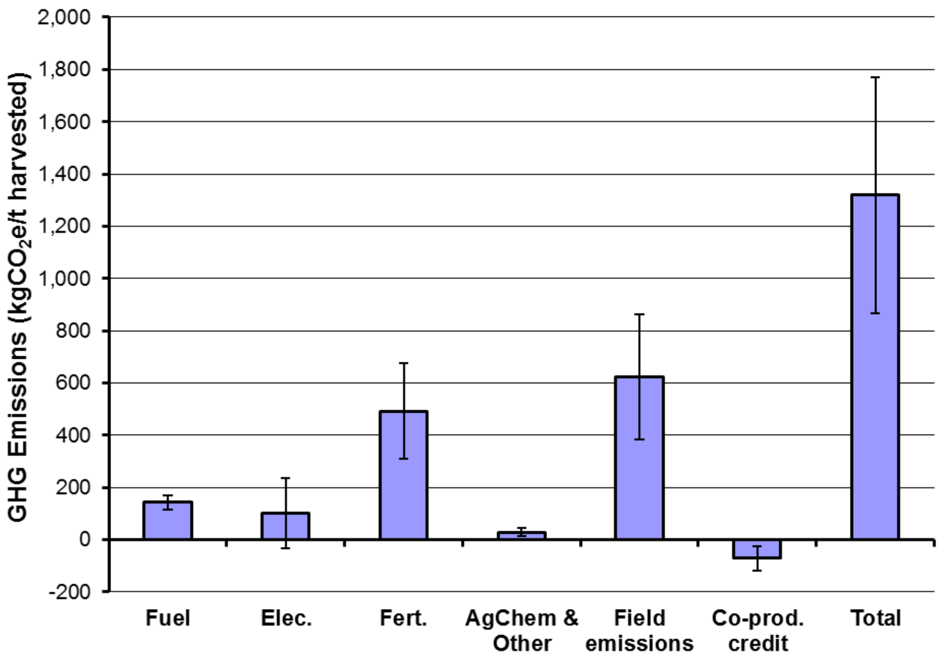

Figure 6.9 Quantities of GHG emissions from ryegrass seed production (per t).

Total ryegrass seed GHG emissions for the survey are 1,390 $kgCO_2e/t$ harvested, less a small credit for displacing hay production of 70 $kgCO_2e/t$, resulting in net emissions of 1,320 $kgCO_2e/t$ harvested (Figure 6.9). Of all the crops investigated ryegrass had the greatest spread, ranging between 425 to 2,205 $kgCO_2e/t$ (Table 6.4). The lowest emitting farm and crop had a combination of low inputs combined with above average yields (Table A.12, A.13 and A.14). The highest emissions per tonne were due solely to low yields that year as emissions per hectare were just below the average. On a per hectare basis, average total GHG emissions for maize silage production are 2,290 $kgCO_2e/ha$, with a credit of 105 $kgCO_2e/ha$ for hay or straw as a co-product, resulting in net emissions of 2,190 $kgCO_2e/ha$ and ranged between 820 and 3,910 $kgCO_2e/ha$. The lowest emissions per hectare were driven almost solely by very low nitrogen inputs along with the fact that it was a dryland farm so electricity use was very low. Likewise the highest emissions per hectare were due to high nitrogen inputs but almost just as significantly high electricity use for irrigation (Table A.13).

Table 6.4 Ryegrass seed GHG emissions

	Average	Minimum emitter	Maximum emitter	Average	Minimum emitter	Maximum emitter
		Per hectare			Per tonne	
National	2,175	820	3,910	1,320	425	2,205

Fuel and electricity use contribute 10% and 9% respectively of on-farm GHG emissions.

As for the other New Zealand arable crops, the majority of emissions are derived from fertiliser manufacture and the associated fertiliser field emissions, at 34% and 44% respectively. This represents the highest proportion of GHG emissions from fertiliser use. The highest GHG emitting nutrient (manufacture and field emissions) is nitrogen (85% of fertiliser emissions) followed by lime (11%), phosphorus (3%), and potassium (1%).

Sixty seven percent of the ryegrass emissions profile is generated by synthetic nitrogen fertiliser, of which 45% is from manufacturing with the remaining 55% in the form of field emissions once the fertiliser is applied to the soil. However there is considerable uncertainty around the soil emission factor which can vary widely. In the future site specific soil emission factors should be used (when they become available) that takes into account nitrogen fertiliser type, crop management, soil type and climate. FAR has several initiatives to optimise nitrogen use.

Following PAS 2050 guidelines, capital is not included within this analysis. However, as it is included as part of the ISO 14044 methodology, and is likely to be included in future revisions of PAS 2050; its effect is addressed here. As discussed in Section 5.8, farm capital would likely add 125 $kgCO_2/ha$ (or 73 $kgCO_2/t$ ryegrass seed produced). This represents a 6% increase in on-farm GHG emissions.

While it was assumed that no land had been converted from long term pasture to cropping in the past 20 years (see Section 5.9.1) where this may have occurred, it would significantly increase GHG emissions. If 20% of land had been converted total ryegrass GHG emissions would increase by 73%.

6.5. Hotspot analysis

Based on the minimum and maximum GHG emitting crops an analysis was conducted to identify what the drivers were behind these results. Not surprisingly yield and nitrogen are the two key components in determining crop performance from a GHG perspective.

Table 6.5 Hotspot analysis of the minimum and maximum carbon footprints

	Minimum GHG Emitting Crop		Maximum GHG Emitting Crop	
	Per tonne	Per hectare	Per tonne	Per hectare
Wheat	(02) High yield. Low N and lime.	(02) Very low N and lime.	(03) Low yield. Average inputs.	(04) Reasonably high water use, consequently high elec. Above average N.
Maize silage	(02) High yield. Low lime. (High diesel).	(10) Below average fuel use and low N.	(08) High N. Below average yields.	(08) High N inputs. All other inputs = average.
Maize grain	(03) High yield.	(03) All farms in a very tight range. Lower N.	(10) Slightly higher N and lime. Lower yields.	(02) All farms in a very tight range. Higher fuel and N, offset by lower lime.
Ryegrass seed	(06) Low N. Above average yield.	(06) Very low N.	(07) Low yield. Average inputs.	(04) High water use, consequently very high elec. High N >50% above regional average.

Note: Numbers in the brackets refer to the farm number. Their detailed inputs and yields can be seen in the appendix.

6.6. Sensitivity analysis for N_2O field emissions

N_2O is a powerful GHG, with 298 times the global warming potential of CO_2 (IPCC, 2007). The principle source of N_2O in arable production is field emissions following the application of nitrogen fertiliser, which makes up 33% of all wheat production GHG emissions. However, only a generic emission factor could be used in this study to calculate GHG emissions following nitrogen fertiliser application, regardless of the fertiliser type, crop management, climate, or soil type that they were applied to (Table 5.10). Previous studies (see Section 1.2.1) have shown that using site specific emission factors can have a large impact on the carbon footprint of arable products.

A sensitivity analysis was conducted to understand how estimates of total GHG emissions would react to changes in EF_1, the emission factor for direct emissions from nitrogen fertiliser application. Currently this emission factor (1.0%) is prescribed by the IPCC and is detailed in the New Zealand GHG Inventory (MfE, 2009). EF_1 was changed and the effect on total GHG emissions recorded (Table 6.6). See a discussion on the range of emission factors in Section 1.2.1.

Table 6.6 The effect of changing the emission factor EF_1 (the emission factor for direct emissions following nitrogen fertiliser application) on estimated total GHG emissions ($kgCO_2e$/t wheat).

Soil N_2O emission factor (EF_1)	0.03%	0.30%	**1.00%**	1.25%	2.10%
N fertiliser field emissions	19	49	**115**	153	246
Total wheat GHG emissions	230	265	**340**	385	490
Change in total GHG emissions	-33%	-23%	**0%**	13%	45%

This sensitivity analysis reveals how changes in a single N_2O-dependant emission factor can significantly affect the estimate of total GHG emissions. It is therefore apparent that rather than using the international default value, where possible, a regionally specific soil emission factor should be used when assessing GHG emissions from arable production systems. Ideally the soil emission factor should also be adjusting for fertiliser type, irrigation versus non-irrigated land, cultivation practices, and residue management.

7. Discussion

7.1. Project conclusions

This represents a pilot project to develop the methodology of undertaking a partial LCA of arable crops using protocols prescribed in PAS 2050. Four crops were chosen, representing approximately 70% of the arable crops grown in New Zealand. PAS 2050 methodology and inputs, measured during ten farm surveys, were used to calculate GHG emissions resulting from the production of one tonne of each crop, to the farm gate (Table 7.1).

Table 7.1 GHG emissions of surveyed New Zealand arable crops.

	GHG Emissions ($kgCO_2e$)	
	per tonne	**per hectare**
Wheat	340	2,820
Maize silage	125	2,190
Maize grain	190	2,380
Ryegrass seed	1,325	2,190

Fertiliser use, including its manufacture and field emissions following its application, make up between 60% and 80% of all on-farm GHG emissions (Table 7.2). Within fertiliser use the effect of N_2O was pronounced. N_2O is a powerful greenhouse gas, with 298 times the global warming potential of CO_2 (IPCC, 2007). The principle source of N_2O in arable production is through field emissions following the application of synthetic nitrogen fertiliser (Table 7.2). This single largest source of GHG emissions is highly dependent upon the chosen soil emission factor, which for this study used the default IPCC emission factor of 1.0%. However in Australia this emission factor has been found to range from 0.03% in dryland crops to over 2.1% in irrigated crops. Consequently total greenhouse gas emissions could range between 33% lower to 45% higher compared to the results in this study.

Table 7.2 Distribution of GHG emissions sources from arable farming.

	Wheat	Maize silage	Maize grain	Ryegrass seed
Fuel	8%	16%	19%	10%
Electricity	6%	1%	2%	9%
Fertiliser production				
Nitrogen	27%	28%	23%	30%
Other	5%	8%	9%	4%
Agricultural chemicals	2%	3%	4%	2%
Field emissions				
Nitrogen	33%	32%	25%	36%
Lime	6%	9%	5%	8%
Crop residue & compost	5%	3%	13%	0%
Field burning	9%	0%	0%	0%

This pilot study was based on the data gathered from surveying ten arable farming operations from throughout New Zealand. These surveys provided a robust analysis of each operation's inputs and outputs. However, the small sample size limits our ability to extend these results to the arable sector as a whole. A more accurate description of the arable sector will only be possible after a more complete appraisal, surveying a larger proportion of the New Zealand arable crop, using the methodology and suggestions laid out in this report. These preliminary results are therefore only indicative of the potential true values for wheat and maize production in New Zealand. This pilot study has initiated the creation of a robust inventory of arable production inputs and the establishment of benchmark figures.

7.2. Methodological issues

This report followed the LCA methodology described in the PAS 2050. While this allows consistency among MAF commissioned LCA studies, future analysis based on ISO standards may represent the preferred methodology for LCA studies that progress beyond the farm gate and for international comparison. Encouragingly, the PAS 2050 and ISO 14044 protocols are very similar and changing from one method to the other should be completed easily.

Nitrogen fertiliser manufacture and soil emissions following its application are the two largest contributors to arable crop GHG emissions. Therefore, highly accurate data is required to allow confidence about quantitating GHG emissions from this source (and therefore for the functional unit as a whole). In this report the same emission factors were applied to all nitrogen fertilisers, regardless of how they were manufactured. However, different production methods are likely to generate varying levels of emissions. Similarly, the same emission factor was applied for determining N_2O field emissions, resulting from different nitrogen-dependent field applications. This report was therefore unable to take into account the effect of nitrogen source and site differences (soil type, rainfall, irrigation, cultivation practice, and residue management) which are likely to affect the level of N_2O emissions. Ideally product, regional and management specific emission factors would be used. The application of site specific measured N_2O emissions, compared to IPCC default emission factors, has been shown to have a more than 1.5-fold difference on estimated GHG emissions (Biswas, W. K., *et al*., 2011). Encouragingly, New Zealand specific fertiliser emission factors are likely to become available in the future.

Where primary data detailing process inputs was not available these were allocated based on crop area and farmer estimates. The quality of this data could be improved by metering of water use, sub-metering of electricity and detailed record keeping.

Integrating accurate water use records with fuel (diesel and electricity) use for irrigation would be very revealing. Savings in fuel and higher production may be observed with more accurate monitoring and consequently driving improvements in irrigation efficiency such as distribution uniformity, and overall system management.

7.3. Future work

Recommendations for future assessments should be based around two major aspects, improving data quality and increasing sample size. An LCA analysis is dependent upon the quality of the data used to construct it. This pilot study has identified areas where improved data quality will allow a more accurate description of GHG emissions. In particular N_2O emissions that make up a large proportion of total on-farm GHG emissions may be more accurately assessed using manufacturing specific emission factors for nitrogen fertiliser and site specific emission factors for nitrogen dependent field emissions. Data quality would be further improved with accurate quantitative data and its allocation amongst operational processes.

Due to the impact of N_2O emissions further research on applying synthetic versus organic nitrogen on farms could significantly effect on-farm GHG emissions. Such research would likely focus on management factors such as irrigation, application technique and timing; as well as environmental factors such as soil type, pH, and microbial presence.

To establish benchmark figures for the carbon footprint of the New Zealand arable industry any future assessment will be improved by increased sample size, using several seasons, and including grower responses from all arable growing regions throughout New Zealand. In this report wheat production was heavily influenced by growers from Canterbury, which along with the sample size means these results are only indicative of the potential values for other wheat growing regions.

Data for this report did not distinguish production inputs between different varieties or end uses. Future studies could take into account the difference in inputs for milling and stock food wheat, as wheat for milling uses different varieties (resulting in yield differences), different management techniques and higher inputs – particularly nitrogen

The end point for this study was the farm gate. A future study could extend this to consumer use and disposal. For a maize silage crop this would allow analysis of the impact of carting silage – for some crops a considerable distance - from the place of growth to the farm where it is feed out. The grain crop studies (maize, wheat and ryegrass seed), could include storage and transportation. In particular, the effect of transporting wet crops on roads, compared to on farm drying, is expected to make a considerable difference. An expanded study would provide an indication on how much this affects the carbon footprint of the crop.

One of the strengths of an LCA analysis is the identification of inefficiencies and potential 'hotspots' for optimisation. It is envisioned that future LCA work, taking into account the above considerations will allow the discussion of possible cleaner production strategies that could be utilised to lower GHG emissions from arable production.

Future LCA projects will also take into account revisions to the PAS 2050 and ISO standards.

7.4. Grower responses

Grower feedback initiated many discussions on the impacts of these findings and implications for the industry. The most common grower comments and concerns focused on the following aspects:

1. The detailed survey questions prompted the owners to think about all business inputs and if they were being used efficiently. This had implications on how inputs were recorded and tracked.
2. What impact does nitrogen source (organic compared to synthetic) and cultivation techniques have on GHG emissions?
3. Is irrigating a wise use of water? Specifically, is the increase in produce quality and quantity offsetting the increased inputs?

Growers are very keen to see comparison studies undertaken such as:

- Intense, high input systems with low input systems (cut and carry with high yields cropping and high stocking rates; compared to a lower input cropping regime and stock grazing);
- All cropping enterprise with crop rotations compared with a crop and stock farming system;
- Irrigated farming with dryland;
- Full tillage with minimum tillage and no-tillage;
- Conventional production with biological agricultural systems.

Additionally, growers saw a potential advantage in whole farm (corporate) carbon footprints. These could be undertaken to gain an insight into the inputs of each crop or farming enterprise and the resultant GHG emission profiles. The inclusion of water footprints, financial costs, soil health and crop yield information were seen as adding practical and profit-centric recommendations growers are likely to be seeking. Encouragingly, surveyed growers were keen to understand how to use the information gained from their GHG profile to improve their business operation and to mitigate their emissions as well as becoming more energy efficient and profitable. Expanding the analysis beyond energy efficiency will likely encourage more growers to be involved in future projects and improve survey uptake and strengthen statistical analysis.

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Appendix 1. Wheat

Production and resource inputs

Table A.1, A.2 and A.3 summarise the production and resource use inputs for wheat per hectare, while Tables A.4 and A.5 are inputs per tonne. A detailed explanation of the grower survey and methodology can be found in the main report. The national sample size was eight farms; the Canterbury region contained six growers so these results have also been included.

Table A.1 Wheat production farm description.

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation	Minimum GHG emitting operation	Maximum GHG emitting operation
			Per hectare		Per tonne	
National						
Farm area	ha	600	a	a	a	a
Wheat area	ha	104	a	a	a	a
Production	t/ha	8.8	10.0	9.0	10.0	5.4
Farm No.	-	-	02	04	02	03
Canterbury						
Farm area	ha	301	a	a	a	a
Wheat area	ha	99	84	51	84	122
Production	t/ha	9.2	9.7	9.0	9.7	6.5
Farm No.	-	-	06	04	06	07

a. Confidential

Table A.2 National wheat resource use inputs (per ha).

National	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	77	82	75
Electricity	kWh	828	43	3,865
Nitrogen	kg	192	100	240
Phosphorus	kg	30	14	0
Potassium	kg	26	45	0
Sulphur	kg	46	1	0
Magnesium	kg	8	0	0
Lime - soil	kg	432	15	385
Compost	kg	0	0	0
Herbicide	L	3.7	3.0	2.2
Fungicide	L	5.6	25.7	2.3
Insecticide	L	0.5	0.0	0.0
Plant growth regulator	L	0.6	0.0	0.0

Table A.3 Canterbury wheat resource use inputs (per ha).

Canterbury	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	75	87	75
Electricity	kWh	990	20	3,865
Nitrogen	kg	200	190	240
Phosphorus	kg	35	78	0
Potassium	kg	18	0	0
Sulphur	kg	55	101	0
Magnesium	kg	11	0	0
Lime - soil	kg	529	559	385
Compost	kg	0	0	0
Herbicide	L	3.8	1.1	2.2
Fungicide	L	2.2	1.7	2.3
Insecticide	L	0.6	0.0	0.0
Plant growth regulator	L	0.7	0.0	0.0

Table A.4 National wheat resource use inputs (per t).

National	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	9.1	8.2	14.6
Electricity	kWh	94.4	4.3	118.3
Nitrogen	kg	23.4	10.0	43.3
Phosphorus	kg	3.4	1.4	3.1
Potassium	kg	3.4	4.5	9.8
Sulphur	kg	5.3	0.1	7.8
Magnesium	kg	1.2	0.0	0.0
Lime - soil	kg	50.7	1.5	49.1
Compost	kg	0.0	0.0	0.0
Herbicide	L	0.5	0.3	0.7
Fungicide	L	0.7	2.6	1.0
Insecticide	L	0.1	0.0	0.1
Plant growth regulator	L	0.1	0.0	0.1

Table A.5 Canterbury wheat resource use inputs (per t).

Canterbury	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	8.3	9.0	8.2
Electricity	kWh	105.4	2.0	1.7
Nitrogen	kg	22.3	19.6	28.3
Phosphorus	kg	3.8	8.1	3.7
Potassium	kg	2.2	0.0	7.5
Sulphur	kg	5.8	10.4	4.6
Magnesium	kg	1.6	0.0	8.0
Lime - soil	kg	59.2	57.6	78.8
Compost	kg	0.0	0.0	0.0
Herbicide	L	0.4	0.1	0.8
Fungicide	L	0.3	0.2	0.7
Insecticide	L	0.1	0.0	0.2
Plant growth regulator	L	0.1	0.0	0.2

Fuel and Electricity

There is very little variability in the fuel use figures. Excluding irrigation electricity use is low, however amongst the irrigated farms it is naturally much higher and varies widely. This is in part due to the small sample size, but also reflects the wide range of water sources and irrigation systems. Large variability is inherent in many of the previous primary sector carbon footprinting studies, even those with reasonably large sample sizes.

The variability if fuel and electricity use can be partially attributed to changes in efficiency, including how equipment is setup and operated, sizing of equipment, and age. Management systems of dryland compared to irrigated crops and minimal tillage systems with conventional tillage were considered. The survey group numbers were too small to provide recommendations from the results. It did however suggest these are areas requiring further research to understand the impacts of the different systems, efficiency of energy inputs obtainable and resultant GHG emissions.

Fertiliser

Fertiliser application varied between growers, which is to be expected with different management systems, production plans, soil types and climatic conditions across the survey group. Nitrogen use was very consistent across all the farms within a range of 180 to 240 kgN/ha, except for one outlier at just 100 kgN/ha. The application of other nutrients was extremely variable. Compost was not used by any of the growers.

Agrichemicals

Herbicide use was reasonably consistent, being the least variable agrichemical. All other agrichemical classes were used and varied widely.

Crop residue and field burning

Crop residue, through its nitrogen content, contributed towards 5% of GHG emissions. Field burning (the carbon released as CO_2 is neutral but burning also releases CH_4 and N_2O) some of the residue contributed a further 9% to total GHG emissions. Field burning only occurred in Canterbury where four of the six farms used burning as part of their crop residue management, covering 45% of the region or 32% nationally.

Appendix 2 Maize Silage

Production and resource inputs

Table A.6 and A.7 summarise the production and resource use inputs for maize silage per hectare, while Table A.8 are inputs per tonne. A detailed explanation of the grower survey and methodology can be found in the main report. The national sample size was six farms; each region contained only two growers and has been omitted for confidentiality reasons.

Table A.6 Maize silage production farm description.

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation	Minimum GHG emitting operation	Maximum GHG emitting operation
			Per hectare		Per tonne	
National						
Farm area	ha	600	a	a	a	a
Maize silage area	ha	20	a	a	a	a
Production	t/ha	17.9	14.7	16.0	21.0	16.0
Farm No.	-	-	10	08	02	08

[a] Confidential

Table A.7 Maize silage resource use inputs (per ha).

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	109	83	105
Electricity	kWh	106	67	8
Nitrogen	kg	149	93	239
Phosphorus	kg	29	48	0
Potassium	kg	48	0	0
Sulphur	kg	21	39	0
Magnesium	kg	6	19	0
Lime - soil	kg	496	636	500
Compost	kg	2,118	0	0
Herbicide	L	5.4	8.9	4.0
Fungicide	L	0.0	0.0	0.0
Insecticide	L	0.0	0.0	0.0
Plant growth regulator	L	0.0	0.0	0.0

Table A.8 Maize silage resource use inputs (per t).

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	6.1	7.1	6.6
Electricity	kWh	6.0	1.4	0.5
Nitrogen	kg	8.8	7.1	15.0
Phosphorus	kg	1.7	0.6	0.0
Potassium	kg	2.4	1.8	0.0
Sulphur	kg	1.3	0.1	0.0
Magnesium	kg	0.4	0.0	0.0
Lime - soil	kg	30.4	0.7	31.3
Compost	kg	96.7	0.0	0.0
Herbicide	L	0.3	0.3	0.3
Fungicide	L	0.0	0.0	0.0
Insecticide	L	0.0	0.0	0.0
Plant growth regulator	L	0.0	0.0	0.0

Fuel and Electricity

There is some variability in the fuel use figures and a little more for electricity. This is in part due to the small sample size, which is further accentuated when the results are subdivided into regional figures. Large variability is inherent in many of the previous primary sector carbon footprinting studies, even those with reasonably large sample sizes.

The variability if fuel and electricity use can be partially attributed to changes in efficiency, including how equipment is setup and operated, sizing of equipment, and age. Management systems of dryland compared to irrigated crops and minimal tillage systems with conventional tillage were considered. The survey group numbers were too small to provide recommendations from the results. It did however suggest these are areas requiring further research to understand the impacts of the different systems, efficiency of energy inputs obtainable and resultant GHG emissions.

It is noted that maize silage fuel use per hectare is approximately 25% less than maize grain. It is thought that this is unlikely, and might simply reflect the small maize grain sample size (3) and issues of allocating fuel use between different crops. Growing the two crops would most likely use very similar amounts of fuel. Differences would arise at harvest time, where if anything maize silage would use more fuel. Further work is needed in this area to improve the level of accuracy of fuel use.

Fertiliser

Fertiliser application varied between growers, which is to be expected with different management systems, production plans, soil types and climatic conditions across the survey group. It was noted that some growers were using lower nitrogen application rates while still achieving good yields, supporting FARs smart nitrogen use programmes. Compost was used by only a few growers. Application of other nutrients was extremely variable.

Agrichemicals

No growers applied fungicides or plant growth regulators. Insecticide applications were highly variable nationally.

Crop residue

Maize silage residues left after harvest was considered negligible.

Appendix 3 Maize Grain

Production and resource use inputs

Table A.9 and A.10 summarise the production and resource use inputs for maize grain per hectare, while Table A. 11 are inputs per tonne. A detailed explanation of the grower survey and methodology can be found in the main report. The national sample size was three farms; the regional data only contained two growers and has been omitted for confidentiality reasons.

Table A.9 Maize grain production farm description.

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation	Minimum GHG emitting operation	Maximum GHG emitting operation
			Per hectare		Per tonne	
National						
Farm area	ha	600	a	a	a	a
Maize grain area	ha	131	a	a	a	a
Production	t/ha	12.8	13.6	14.0	13.6	10.8
Farm No.	-	-	03	02	03	10

[a] Confidential

Table A.10 Maize grain resource use inputs (per ha).

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	143	151	197
Electricity	kWh	233	642	40
Nitrogen	kg	134	106	150
Phosphorus	kg	39	44	13
Potassium	kg	60	87	38
Sulphur	kg	22	20	3
Magnesium	kg	7	0	0
Lime - soil	kg	305	265	15
Compost	kg	333	1,000	0
Herbicide	L	7.3	7.7	6.6
Fungicide	L	0.0	0.0	0.0
Insecticide	L	2.7	4.0	0.1
Plant growth regulator	L	0.0	0.0	0.0

Table A. 11 Maize grain resource use inputs (per t).

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	11	11	7
Electricity	kWh	17	47	2
Nitrogen	kg	11	8	13
Phosphorus	kg	3	3	6
Potassium	kg	5	6	5
Sulphur	kg	2	1	4
Magnesium	kg	1	0	2
Lime - soil	kg	26	20	59
Compost	kg	25	74	0.0
Herbicide	L	0.6	0.6	0.7
Fungicide	L	0.0	0.0	0.0
Insecticide	L	0.2	0.3	0.4
Plant growth regulator	L	0.0	0.0	0.0

Fuel and Electricity

There is some variability in the fuel use figures and a little more for electricity. This is in part due to the small sample size, which is further accentuated when the results are subdivided into regional figures. Large variability is inherent in many of the previous primary sector carbon footprinting studies, even those with reasonably large sample sizes.

The variability if fuel and electricity use can be partially attributed to changes in efficiency, including how equipment is setup and operated, sizing of equipment, age etc. Management systems of dryland compared to irrigated crops and minimal tillage systems with conventional tillage were considered. The survey group numbers were too small to provide recommendations from the results. It did however suggest these are areas requiring further research to understand the impacts of the different systems, efficiency of energy inputs obtainable and resultant GHG emissions.

It is noted that maize grain fuel use per hectare is approximately 30% higher than maize silage. It is thought that this is unlikely, and might simply reflect the small maize grain sample size (3) and issues of allocating fuel use between different crops. Growing the two crops would most likely use very similar amounts of fuel. Differences would arise at harvest time, where if anything maize grain would use less fuel. Further work is needed in this area to improve the level of accuracy of fuel use.

Fertiliser

Fertiliser application varied between growers, which is to be expected with different management systems, production plans, soil types and climatic conditions across the survey group. Compost was used by only a few growers. Application of other nutrients was extremely variable.

Agrichemicals

No growers applied fungicides or plant growth regulators. Insecticide applications were highly variable nationally.

Crop residue

Crop residue, through its nitrogen content, contributed approximately 12% of GHG emissions.

Appendix 4 Ryegrass Seed Crops

Production and resource use inputs

Table A.12 and A.13 summarise the production and resource use inputs for ryegrass per hectare, while Table A.14 are inputs per tonne. A detailed explanation of the grower survey and methodology can be found in the main report. The national sample size was seven farms; of which six were located in Canterbury.

Table A.12 Ryegrass seed crop production farm description.

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation	Minimum GHG emitting operation	Maximum GHG emitting operation
			Per hectare		Per tonne	
National						
Farm area	ha	600	a	a	a	a
Ryegrass area	ha	57	a	a	a	a
Production	t/ha	1.7	1.9	2.0	1.9	0.9
Farm No.	-	-	06	04	06	07

[a] Confidential

Table A.13 Ryegrass seed crop resource use inputs (per ha).

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	76	87	72
Electricity	kWh	1,036	17	5,100
Nitrogen	kg	172	30	281
Phosphorus	kg	18	36	0
Potassium	kg	13	0	0
Sulphur	kg	18	46	0
Magnesium	kg	7	0	0
Lime - soil	kg	455	559	385
Compost	kg	0	0	0
Herbicide	L	3.5	5.9	1.5
Fungicide	L	1.9	2.6	3.6
Insecticide	L	2.0	0.0	0.0
Plant growth regulator	L	1.0	1.0	0.4

Table A.14 Ryegrass seed crop resource use inputs (per t).

	Units	Survey Average	Minimum GHG emitting operation	Maximum GHG emitting operation
Fuel (diesel equivalent)	L	46	45	58
Electricity	kWh	526	9	16
Nitrogen	kg	106	15	197
Phosphorus	kg	12	18	22
Potassium	kg	11	0	56
Sulphur	kg	12	24	28
Magnesium	kg	8	0	58
Lime - soil	kg	279	289	569
Compost	kg	0	0	0
Herbicide	L	2.2	3.1	5.4
Fungicide	L	1.1	1.3	1.5
Insecticide	L	1.4	0.0	3.8
Plant growth regulator	L	1.0	0.5	1.3

Fuel and Electricity

There is some variability in the fuel use figures and a little more for electricity. This is in part due to the small sample size, which is further accentuated when the results are subdivided into regional figures. Large variability is inherent in many of the previous primary sector carbon footprinting studies, even those with reasonably large sample sizes.

The variability if fuel and electricity use can be partially attributed to changes in efficiency, including how equipment is setup and operated, sizing of equipment, age etc. Management systems of dryland compared to irrigated crops and minimal tillage systems with conventional tillage were considered. The survey group numbers were too small to provide recommendations from the results. It did however suggest these are areas requiring further research to understand the impacts of the different systems, efficiency of energy inputs obtainable and resultant GHG emissions.

Fertiliser

Fertiliser application varied between growers, which is to be expected with different management systems, production plans, soil types and climatic conditions across the survey group. It was noted that some growers were using lower nitrogen application rates while still achieving good yields, supporting FARs smart nitrogen use programmes. Compost was used by only a few growers. Application of other nutrients was extremely variable.

Agrichemicals

No growers applied fungicides or plant growth regulators. Insecticide applications were highly variable nationally.