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An ILCD database of three pesticides for the kiwifruit industry

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Contents

Executive summary

An ILCD database of three pesticides for the Kiwifruit industry

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Project and Client

This is an output of a MAF-NZLCM-ZESPRI project for the New Zealand kiwifruit industry. The project is being undertaken on behalf of ZESPRI Group Ltd. and subsidiaries (ZESPRI) and The Ministry of Agriculture and Forestry (MAF). The work is led by New Zealand Centre for Life Cycle Management (NZLCM) in collaboration with The New Zealand Institute for Plant & Food Research Limited (PFR), AgResearch Limited, Landcare Research, Massey University and Scion.

This report focuses on compiling **I**nternational Reference **L**ife **C**ycle **D**ata System (ILCD)-compatible Life Cycle Inventory (LCI) datasets for the production of one herbicide, one insecticide and one fungicide, which are relevant for kiwifruit production systems in New Zealand. These LCIs will be available for New Zealand practitioners to use in future carbon footprinting and/or LCA studies of New Zealand horticultural systems.

The work for this report was carried out by PFR under a subcontract to NZLCM.

Objectives

- To scan confidential spray diaries of kiwifruit orchards from 2009/10 and choose three common and representative pesticides; a herbicide, a fungicide and an insecticide.
- To contact the suppliers of the chosen pesticides and determine the offshore production sites of the active ingredients, the sites of formulation, and the transport to the port of Auckland, New Zealand.
- To estimate the New Zealand weighted average values for greenhouse gas (GHG) emissions from ‘cradle to New Zealand port’ using data from existing LCIs on the production of the selected three pesticides combined with data from the New Zealand chemical industry on the offshore production and formulation sites and the associated transport to New Zealand.
- To describe lessons learned as a result of compiling the ILCD-compatible datasets and the subsequent review process.

Methodology

- We scanned 40 spray diaries from New Zealand kiwifruit orchards in these regions to choose three representative pesticides. No confidential quantitative spray diary information is released; rather an assessment was made to determine which were the major agrichemicals in the three pesticide categories. We then conducted a survey of pesticide suppliers that consisted of interviewing representatives of New Zealand chemical industry relevant for kiwifruit production to determine the offshore production sites of the active ingredients, the sites of formulation, and the transport to the port of Auckland, New Zealand. We completed the survey by contacting the chemical industry by email and telephone.

- For compiling ILCD-compatible datasets on the GHG of three pesticides, we followed the ILCD handbook (International Reference Life Cycle Data System (ILCD) 2010) using the information from our survey, and additional information (e.g., concentration of active ingredients, formulation) from product labels, and via the use of Life Cycle Inventory (LCI) databases published by the Swiss Centre for Life Cycle Inventories, ecoinvent v.2.2. (2010).

- The functional unit in this report is a kilogram of the formulated product used in New Zealand kiwifruit production systems and imported to New Zealand.
- On the basis of our assessment of the pesticide use profile, we quantified a GHG inventory for the glyphosate herbicide, diazole-fungicides and thiacloprid-insecticides used in kiwifruit production systems. We considered the formulated pesticide product as imported to New Zealand and stored at an Auckland distribution centre.
- We also determined the Global Warming Potential (GWP100) for the three formulated and imported pesticides using the IPPC characterization factors (Intergovernmental Panel on Climate Change (IPCC) 2007) and using the list of greenhouse gases given in the LCA-software GaBi2007.

Key results

Herbicides

- We chose glyphosate as active ingredient representative of herbicides used in New Zealand kiwifruit production systems. Glyphosate is the major herbicide used, and we considered the three major importers of this product from the total of four suppliers of glyphosate to the kiwifruit industry. Our focus was also on the suppliers to the Bay of Plenty region where the dominant fraction of New Zealand’s kiwifruit is grown.
- The database from the Swiss Centre for Life Cycle Inventories, ecoinvent v.2.2. (2010) contains a LCI dataset for the production of glyphosate including materials, energy uses, infrastructure and emissions at a regional storehouse in Europe. About 24 and 76% of glyphosate used in New Zealand kiwifruit orchards is produced in the US and China, respectively. Emissions associated with electricity usage during active ingredient production were corrected with emissions based on local electricity datasets (China, US) taken from ecoinvent v.2.2. (2010), meaning that a weighted average for China and US datasets was used.
- Information on where the products are formulated and about overseas freight truck transport from the factory to the ports, as well as transport on ocean freight ship to Australia (Brisbane) or Auckland, New Zealand were based on information provided by the respective New Zealand chemical industries. Glyphosate is either transported as active ingredient (85%) or as formulated product (15%) to Auckland, New Zealand. About 1.5% of the entire glyphosate used in New Zealand kiwifruit production is manufactured in the US and subsequently formulated in Brisbane (Australia). On average (analysis of 40 spray diaries of kiwifruit orchards), 1 kg formulated product contains 0.36 kg active ingredient. Glyphosate is formulated as emulsifiable oil.
- The Global Warming Potential (GWP100) for a kg of imported, formulated and packaged glyphosate is 14.74 CO_2-e. The contributions of transport, packaging and formulation to the total GWP for the imported and formulated product are 31%.

Fungicides

- We chose iprodione as active ingredient representative for fungicides used in New Zealand kiwifruit production systems. Iprodione-based products are used to control sclerotinia, botrytis and fruit rots in kiwifruit production. We considered the one dominant company who distributes these products. The other one is a small supplier.

- Iprodione can be chemically classified as diazole-compound. The database from the Swiss Centre for Life Cycle Inventories, ecoinvent v.2.2. (2010) contains a LCI dataset for the production of diazole-compounds including materials, energy uses, infrastructure and emissions at a regional storehouse in Europe. All iprodione used in New Zealand kiwifruit orchards is produced in Europe.

- Overseas freight train transport from Leverkusen to the port in Hamburg, as well as transport on ocean freight ship to Australia (Brisbane), where the products are formulated, and subsequent ocean freight ship of formulated products from Brisbane to Sydney, and from Sydney to Auckland, New Zealand, were based on information provided by the agrichemical industry (personal communication). On average, a kg of the formulated products contains 0.75 kg active ingredient according to product labels. Iprodione is formulated as granules.

- The Global Warming Potential (GWP100) for a kg of imported, formulated and packaged glyphosate is 17.37 CO_2-e. The contribution of transport, packaging and formulation to the total GWP for the imported and formulated product is 16%.

Insecticides

- We chose thiacloprid as active ingredient representative for insecticides used in New Zealand kiwifruit production systems. Thiacloprid-based products are used in kiwifruit production to control the broad spectrum of sucking and chewing insects encountered in kiwifruit orchards. We considered the only supplier of these products.

- The database from the Swiss Centre for Life Cycle Inventories, ecoinvent v.2.2. (2010) contains a generic LCI dataset for the production of insecticides including materials, energy uses, infrastructure and emissions at a regional storehouse in Europe. All thiacloprid used in New Zealand kiwifruit orchards is produced in Europe.

- Overseas freight train transport from Leverkusen to the port in Hamburg, as well as transport on ocean freight ship to Australia (Brisbane), where the products are formulated, and subsequent ocean freight ship of formulated product from Brisbane to Sydney, and from Sydney to Auckland, New Zealand were based on information provided by the agrichemical industry (personal communication). One kg of formulated product contains 0.48 kg active ingredient according to product labels. Thiacloprid is formulated as emulsifiable oil.

- The Global Warming Potential (GWP100) for a kg of imported, formulated and packaged glyphosate is 19.17 CO_2-e. The contribution of transport, packaging and formulation to the total GWP for the imported and formulated product is 9%.

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1. Introduction

1.1 Context of this project

The need for a New Zealand Inventory Database study to support GHG footprinting and LCA studies conducted in New Zealand has been recognized. This project is part of a study analysing the feasibility and methodology for such an Inventory Database. Moreover, LCANZ has endorsed the International Reference Life cycle Data System (ILCD) data format as preferred option for such a New Zealand Inventory Database. More details on the methodology, aim and scope of this study are given in the project proposal.

1.2 Goal and scope

Environmental assessments of pesticides are generally restricted to emissions of active ingredients during the orchard phase (Birkved & Hauschild 2006). The environmental impacts of pesticides associated with the production of the active ingredient, the formulation and the transport of pesticides are generally neglected. The use of life cycle greenhouse gas (GHG) inventories for the production of active ingredients, the formulation and packaging of pesticides and the transport into the country of use could render environmental assessments of pesticides more comprehensive, and easier to carry out. The datasets produced in this study could be used for carbon footprint studies of New Zealand kiwifruit production systems which use imported pesticides. The specific objectives of this report are:

- To scan the spray diaries from kiwifruit orchards over the year 2009/10 and choose three representative pesticides; an herbicide, a fungicide and an insecticide (Section 2).
- To contact the suppliers of the chosen pesticides and determine the offshore production sites of the active ingredients, the sites of formulation, and modes of the transport to the port of Auckland, New Zealand (Section 4).
- To estimate the New Zealand weighted average values for greenhouse gas (GHG) emissions covering ‘cradle to New Zealand port’ using data adapted from existing LCIs on the production of the selected three pesticides, combined with data from the New Zealand chemical industry on the offshore production and formulation sites and the associated transport to New Zealand (Section 5).
- To determine the Global Warming Potential (GWP100) of the three imported, formulated and packaged pesticides used in New Zealand kiwifruit orchards (Section 6).

2. Selection of representative pesticides

From an assessment of 40 spray diaries of kiwifruit orchards for 2009/2010, the choice of representative pesticides became reasonably straightforward. The spray-diary information revealed the dominant pesticide in each of the three categories.

2.1 Herbicides

Glyphosate is the only active ingredient used as herbicide in kiwifruit production systems in New Zealand. In total, in the 40 orchards surveyed, 20 applications had been made in the reference year, with an average application rate of 369 mL ha^{-1}. Six different products had been used, which are provided through four New Zealand distributors. Three of the four distributors accounted for the majority of the supply of glyphosate for use in kiwifruit orchards. We concentrated on these three suppliers.

The database from the Swiss Centre for Life Cycle Inventories, ecoinvent v.2.2. (2010), contains an LCI dataset for the production of glyphosate including materials, energy uses, infrastructure and emissions at a regional storehouse in Europe. The pesticide inventories in the ecoinvent database have been established according to guidelines for LCI formulated by Frischknecht et al. (2007) and Hirschier et al. (2004). In the document 'Life cycle inventories of pesticides' accompanying the Swiss database, the following details on glyphosate production are provided (Sutter, 2010): "Glyphosate ($C_3H_8NO_5P$; CAS No.: 1071-83-6) is produced in three steps from phosphorus trichloride (Unger 1996: 276-279, 1052-1062):

$$PCl_3 + 2\ CH_2O \rightarrow CH_2Cl_3OP$$
$$CH_2Cl_3OP + H_2O \rightarrow CH_4ClO_3P + 2\ HCl$$
$$CH_4ClO_3P + C_2H_5NO_2 \rightarrow C_3H_8NO_5P + HCl$$

A precursor that is used for the glyphosate production is glycine ($C_2H_5NO_2$). Glycine ($C_2H_5NO_2$) is produced in two steps from acetic acid (Unger 1996: 276-279, 1052-1062):

$$C_2H_4O_2 + Cl_2 \rightarrow C_2H_3ClO_2 + HCl$$
$$C_2H_3ClO_2 + NH_3 \rightarrow C_2H_5NO_2 + HCl.\text{"}$$

Glyphosate belongs to the chemical class of phosphonates. The LCI is for the so-called glyphosate "tech" (95% pure isopropylamine salt).

Glyphosate was selected as the herbicide for this project, and the greenhouse gas emissions associated with the supply by the three major suppliers were calculated.

2.2 Fungicides

Four different active ingredients have been used as fungicides in the reference year in the 40 representative kiwifruit orchards we observed: iprodione, trifloxystrobin, copper hydroxide, methoxyfenozide.

- Iprodione: Ten applications have been made with an average rate of 49 g ha^{-1}. Iprodione is used for the control of sclerotinia, botrytis and fruit rots.
- Trifloxystrobin: Ten applications have been made with an average application rate of 11 g ha^{-1}.
- Methoxyfenozide: A single application.
- Copper: A single application.

The database from the Swiss Centre for Life Cycle Inventories, ecoinvent v.2.2. (2010) does not contain datasets for the production of any of the fungicides relevant for New Zealand kiwifruit production systems. Sutter's (2010) accompanying report explains that the limited number of LCIs for individual pesticides is due to the constant changes in the pesticide market. The Swiss ecoinvent database of pesticides attempted to include only the most relevant active ingredients for agricultural production systems in Switzerland. However, in the report, several other active ingredients are classified into 16 different chemical classes (e.g., triazines, diazoles). For the production of active ingredients belonging to any of these chemical classes, an average LCI dataset is provided and is based on the individual LCIs for a number of active ingredients representing the respective chemical class.

For example, the active ingredient iprodione belongs to the chemical class of diazole-compounds. Diazole-compounds are a group of pesticides with a ring consisting of three carbon atoms and two nitrogen atoms ($C_3H_4N_2$) and are produced by adding a diazole ring to a halo-compound (Sutter, 2010). The dataset for diazole-compounds in the ecoinvent 2.2. (2010) database was calculated from the arithmetic mean of all inputs and outputs of the production of prochloraz and metazachlor, including materials, energy uses, infrastructure and emissions at a regional storehouse in Europe. The unit-process raw data for the production of diazole-compounds are listed in the supporting report (Sutter, 2010; Table 2.49).

The only other fungicide relevant for New Zealand kiwifruit production that is classified in the report by Sutter (2010) is trifloxystrobin. It is classified as dinitroaniline-compound (Sutter, 2010), which is, to the best of our knowledge, incorrect. Trifloxystrobin belongs to the relatively new chemical class of fungicides strobilurin (http://sitem.herts.ac.uk/aeru/footprint/en/).

Accordingly, the active ingredient iprodione was chosen as the representative fungicide for this project.

2.3 Insecticides

High diversity of active ingredients used in kiwifruit orchards was found for insecticides. Six different active ingredients had been used by kiwifruit orchardists to control insect pests in the reference year.

- Mineral oil, with 85 applications (average application rate: 823 mL ha^{-1}), was the most frequently applied insecticide. There are two suppliers of mineral oil.
- The next most frequently applied compound is *Bacillus thuringiensis* (or Bt), a Gram-positive soil-dwelling bacterium, commonly used as a biological alternative to pesticides. *Bacillus thuringiensis* had been applied up to 50 times, and there are three main suppliers in New Zealand.
- Emamecetin benzoate (one supplier) had been applied up to 25 times (between 0.1 and 0.2 g ha^{-1}) to control leaf roller.
- Spirotetramat (one supplier): 21 applications (6.73 g ha^{-1})
- Methoxyfenozide: 15 applications (7.3 g ha^{-1})
- Thiacloprid (one supplier): 10 applications (15.6 g ha^{-1})

None of these six insecticides is listed in the Swiss database ecoinvent. Thiacloprid is classified as diazole-compound (Sutter, 2010). According to the IUPAC chemical classification, thiacloprid is a neonicotinoid insecticide (http://sitem.herts.ac.uk/aeru/footprint/en/index.htm). We, thus, did not use the suggested average LCI for the production of diazole-compounds, but instead applied the generic average LCI for insecticides proposed in Sutter's report (2010) for non-classified insecticides. This LCI is the arithmetic mean of all inputs and outputs of the production of the following insecticides: alpha-cypermethrin, beta-cyfluthrin, chlorpyrifos, chlorpyrifosmethyl, cypermethrin, dimethoate, lambda-cyhalothrin, lufenuron, parathion-methyl, phosalone, and pirimicarb (Sutter, 2010).

The active ingredient thiacloprid was chosen as the representative insecticide for this project.

3. Formulation and packaging of pesticides

Pesticides applied in agricultural systems are not used in the form of pure active ingredients, but rather as formulated pesticide products. For example, the active ingredient glyphosate is a broad-spectrum non-selective herbicide used in agriculture and forestry, as well as in urban, domestic, industrial and aquatic environments all over the world. It is one of the most sold and widely used pesticides worldwide. Monsanto's patent for this active ingredient has expired. Accordingly, glyphosate is marketed by various chemical companies in different solution strengths under many different trade names. In New Zealand, for example, the glyphosate products include Roundup® Transorb®, Roundup® Renew, Lion® Herbicide and Polaris™.

Our task was to compile three ILCD-compatible datasets for the production of three pesticides. The functional unit is a kilogram of the formulated product. As well as the active ingredient, ingredients such as surfactants are added to produce the formulated product; however, these are not disclosed by the industry. Readily available information, however, includes the type of formulation (emulsifiable oil, wettable powder or granules), and the concentration of active ingredient in a product. The only available estimate of the energy requirements for the formulation and packaging of pesticides is provided in Green (1987). Energy involved in the packaging of the formulated pesticide amounts to about 2 GJ per tonne of pesticide according to Green (1987).

We translated these energy requirements into carbon dioxide emissions following others (Saunders et al. 2006; Wells 2001). Carbon dioxide is released when carbon is oxidised during the burning process of fuels. The emissions are primarily dependent on the carbon content of the fuel. The molecular weight ratio of carbon dioxide to carbon is 3.67. Thus, multiplying the weight of carbon by 3.67 gives the quantity of carbon dioxide emitted when the carbon is oxidised. According to Baines (1993) the quantity of carbon dioxide emitted from New Zealand diesel, petrol and oil is 68.7, 66.6, and 35.9 g CO_2 MJ^{-1}. Wells (2001) chose a translation factor of 64 g CO_2 MJ^{-1} based on the assumption that all energy used for the production, packaging and distribution of agrichemicals is based on fossil fuels. Like others (e.g., Saunders et al. 2006) we adapted this factor. This approach does not allow a disaggregation of the emissions into the different greenhouse gases.

3.1 Glyphosate

Glyphosate is formulated as an aqueous concentrate. Green (1987) estimated the energy requirement for emulsifiable oils to be 20 GJ per tonne of pesticide. In absence of energy requirement estimates for aqueous concentrates and considering that these data are rough estimates only, we used the energy requirement for emulsifiable oils as best estimate available for glyphosate formulations. Assessing 40 spray diaries from the kiwifruit industry revealed that the average application of 1 kg of formulated product contains 0.36 kg glyphosate.

3.2 Iprodione

Iprodione is formulated as granules, and requires between 10 and 20 GJ per tonne of pesticide depending on whether ‘microgranules’ are produced, or not (Green 1987). We chose 15 GJ per tonne of pesticide as the average energy requirement. A kg of formulated product contains on average 0.75 kg iprodione.

3.3 Thiacloprid

Thiacloprid is sold as an emulsifiable oil, and thus has the same energy requirements as glyphosate. According to the analysis of the spray diaries from 40 kiwifruit orchards, 1 kg of formulated product corresponds on average to 0.48 kg of active ingredient.

4. Survey of suppliers

The suppliers of glyphosate, iprodione and thiacloprid were contacted to determine the offshore production sites of the active ingredients, the sites of formulation, and the mode of transport to New Zealand. All suppliers were forthcoming with information, even if sometimes their information was average estimates. Furthermore, they noted that from time to time different sources were used for active ingredients as market and prices fluctuated. As well, sometimes if there were greater demand, air freight rather than shipping might be used to get product to New Zealand, albeit in small quantities, say 2-3% of the annual import. The companies asked that there be a degree of confidentiality about the detailed location of sources of product, although they were happy for the final footprint results to become available. Therefore, the information is aggregated for all suppliers of pesticides containing the respective active ingredient considered.

4.1 Glyphosate

The majority (76%) of the glyphosate salt (‘tech’ – 95% pure) comes from China. The remaining 24% of the total glyphosate salt imported to New Zealand comes from St Louis, Missouri in the US. About 85% of the glyphosate salt is then formulated in Auckland, New Zealand. About 10% of the product formulation is carried out in Sydney, Australia. The remainder of the glyphosate herbicides (5%) is formulated in China.

The location of glyphosate production in China is centred around Shanghai (Figure 1).

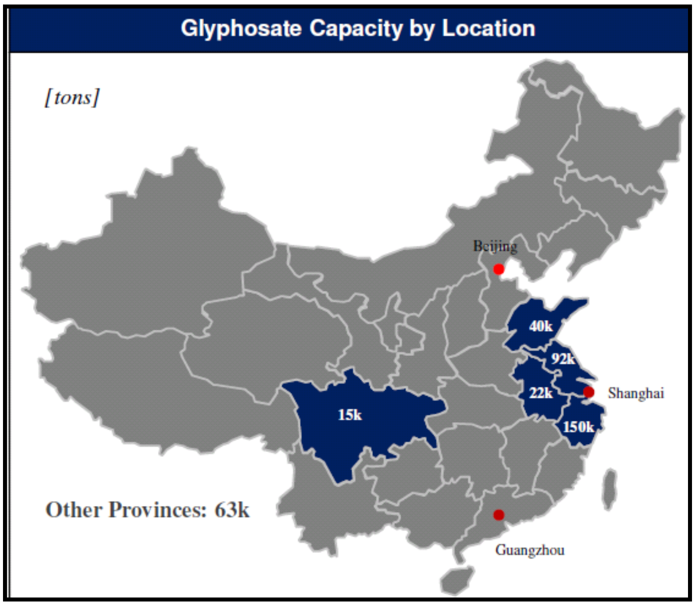

Figure 1: Locations of glyphosate production in China (http://www.jkprofile.com/blog/wp-content/uploads/2010/02/Chinese-Glyphosate-Industry.pdf).

4.2 Iprodione

The active ingredient iprodione comes from Germany and France, and probably is dominated by supply from Leverkusen. Transport to the port in Europe is by rail. The formulation is carried out in Australia, at either of the agrichemical company sites in Melbourne or Brisbane. Some 75% of the products used in formulation are thought to be sourced within Australia. The final product is 25% weight/volume (w/v) Iprodione, with 30-60% w/v being paraffin oil, and there is about 10% w/v of various surfactants in the formulated product. The formulated product is then shipped either to Auckland or Christchurch.

4.3 Thiacloprid

The active ingredient thiacloprid comes from Germany and France, and probably the majority comes from Leverkusen. Transport to the European port is by rail. The formulation is carried out in Australia, either in Melbourne or Brisbane. Some 75% of the products used in the formulation are thought to be sourced in Australia. The product is then shipped either to Auckland or Christchurch.

5. Life Cycle Inventories

The LCIs of pesticide production from the Swiss ecoinvent database cover the ‘cradle to manufacturing gate’ stage. According to the publishers, the LCIs include the production of an active ingredient, the chemical class of active ingredients, or pesticide class, taking account of materials, energy uses, infrastructure and emissions at a regional storehouse in Europe.

5.1 Glyphosate

An LCI for the production of the active ingredient glyphosate in Europe is available in the ecoinvent database, and was used as our base data. Our survey of pesticide suppliers revealed that 24 and 76% of all glyphosate used in New Zealand kiwifruit production systems is produced in the US and in China, respectively. The electricity used during the manufacturing process, as provided in the ecoinvent database, was corrected according to the individual country-specific situation. The emissions associated with electricity usage during glyphosate production in Europe (high voltage, production RER, at grid) were replaced by emissions associated with electricity production in China (electricity mix, CN), or the US (electricity mix, US). All data were taken from ecoinvent v.2.2 (2010). This approach assumes that the production of glyphosate follows the same series of chemical reactions, and that the operations involved such as heating, cooling, stirring, distilling, filtering, drying, are conducted in the same way causing the same emissions. This assumption may not be valid as the environmental requirements and regulations may differ between countries.

Data from the New Zealand chemical industry on the sites of glyphosate formulation and the transport to New Zealand were used to determine overseas truck transport, and ocean freight transport to New Zealand at the port of Auckland. Glyphosate used in New Zealand kiwifruit orchards is transported either as active ingredient (85%), or as formulated product (15%) to Auckland, New Zealand. Only, about 1.5% of the entire glyphosate used in New Zealand kiwifruit production is manufactured in the US and subsequently formulated in Brisbane (Australia). For ocean transport, data for the transoceanic freight ship (50,000 dwt) from the ecoinvent database were used (Spielmann et al. 2007). Shipping distances were taken from www.maritimechain.com. For the overseas truck transport, the EURO 3 vehicle was chosen (16 t - 32 t) (Spielmann et al. 2007). All transport distances are summarized in Table A1 (Annex). The concentrations of glyphosate in the various herbicide products were considered during the transport of the formulated products. Emissions from the formulation and packaging were modelled as has been described above (see Section 3). Table A2 (Annex) presents the 'cradle to New Zealand port' greenhouse gas LCI of the imported formulated herbicides containing glyphosate used in New Zealand kiwifruit orchards. An overview of the relevant processes of the active ingredient glyphosate from 'cradle-to New Zealand port' is provided in Figure A1 (top; Annex).

5.2 Iprodione

An LCI for the production of the chemical class of diazoles in Europe is available in the ecoinvent database, and was used here as base data for our LCI. The data include the production of diazole-compounds including materials, energy uses, infrastructure and emissions at a regional storehouse in Europe.

Based on information provided by the New Zealand agrichemical industry (personal communication) we considered overseas freight-train transport from Leverkusen to the port in Hamburg, as well as ocean transport by ship to Australia (Brisbane), where the product is formulated. Then we accounted for the subsequent ocean shipping of the formulated product from Brisbane to Sydney, and then from Sydney to Auckland, New Zealand.. For ocean transport, data for the trans-oceanic freight ship (50,000 dwt) were taken from the ecoinvent database (Spielmann et al. 2007). Shipping distances were again taken from www.maritimechain.com. For overseas truck transport, a EURO 3 vehicle was chosen (16 t - 32 t). For overseas rail transport, a freight train RER was used (Spielmann et al. 2007). All transport distances are summarized in Table A1 (Annex).

The resulting LCI represents the situation for iprodione production in Europe, shipped to Australia, where it is formulated, and then subsequently shipped as formulated product to

Auckland, New Zealand. Emissions from formulation and packaging were modelled as has been already described above (see Section 3). The 'cradle to New Zealand port' greenhouse gas LCI of imported formulated fungicides containing iprodione used in New Zealand kiwifruit orchards is presented in Table A3 (Annex). An overview of the relevant processes of the active ingredient iprodione from 'cradle-to New Zealand port' is provided in Figure A1 (middle; Annex).

5.3 Thiacloprid

An LCI for the production of the pesticide class of 'insecticides' in Europe is available in the ecoinvent database, and was used as the base data for our LCI. The data comprise the production of insecticides including materials, energy uses, infrastructure and emissions at a regional storehouse in Europe.

Based on information provided by the New Zealand agrichemical industry (personal communication) we took account of overseas train transport from Leverkusen to the port in Hamburg, as well as transport on by boat to Australia (Brisbane), where the products are formulated. Next we considered emissions during the subsequent ocean shipping of the formulated products from Brisbane to Sydney, and then from Sydney to Auckland, New Zealand. For ocean transport, data for the transoceanic freight ship (50,000 dwt) from the ecoinvent database were used (Spielmann et al. 2007). Shipping distances were also taken again from www.maritimechain.com. For overseas truck transport, the EURO 3 vehicle was chosen (16 t - 32 t). For overseas rail transport, the freight train (Europe) was used (Spielmann et al. 2007). All transport distances are summarized in Table A1 (Annex).

The final LCI represents the situation for insecticides produced in Europe, shipped to Australia, where they are formulated, and subsequently shipped as formulated products to Auckland, New Zealand. Emissions from formulation and packaging were modelled as has been described above (see Section 3). The 'cradle to New Zealand port' greenhouse gas LCI of imported formulated insecticides containing thiacloprid as active ingredient used in New Zealand kiwifruit orchards is presented in Table A4 (Annex). An overview of the relevant processes of the active ingredient thiacloprid from 'cradle-to New Zealand port' is provided in Figure A1 (bottom; Annex).

6. Life Cycle Impact Assessment

The Global Warming Potential (GWP100) of the three pesticides produced in Europe was derived from ecoinvent, and cumulative life cycle impact assessment (LCIA) results (Nemecek et al. 2007) calculated in the ecoinvent datasets. The results for glyphosate, diazole-compounds, and insecticides are shown in Table 1 for the respective ingredients considered in this project: glyphosate, iprodione and thiacloprid. These values were compared to the computed Global Warming Potential values calculated using the LCI provided in the ecoinvent database (cumulative LCI results; (Nemecek et al. 2007)) but separately calculating the GWP results using the IPPC (2007) characterisation factor included in the software package GaBi 2007 (Table 1). The comparison reveals that the ecoinvent LCIA results for glyphosate, iprodione and thiacloprid are 4, 6 and 4% higher than the results using the separately computed values, respectively. The reason for this difference is unclear but it may be due to differences in some of the characterization factors used.

Table 1: Comparison of the ecoinvent database v.2.2. (2010) Global Warming Potential (GWP100) of glyphosate, fungicides of the chemical class diazole-compounds and insecticides (Nemecek et al. 2007) with the calculated GWP using IPCC 2007 characterization factors (Intergovernmental Panel on Climate Change (IPCC) 2007) and the GHG considered in GaBi 2007.

Pesticides	GWP100 in CO_2-eq/kg active ingredient	
	ecoinvent-database	computed using IPCC characterization factors
glyphosate (herbicide)	10.55	10.12
iprodione (fungicide)	16.82	15.72
thiacloprid (insecticide)	16.67	16.00

Table 2 shows Global Warming Potential (GWP100) for the imported formulated products of: herbicides containing glyphosate; fungicides of the chemical class diazole-compounds and insecticides used in New Zealand kiwifruit orchards, using IPCC 2007 characterization factors (Intergovernmental Panel on Climate Change (IPCC) 2007). The Global Warming Potential was highest for the insecticide (19.17 CO_2-e) and lowest for the herbicide (14.74 CO_2-e). It also reveals that the contributions of transport, packaging and formulation to the total GWP for the imported and formulated products ranged between 9 and 31%. It was highest for the herbicide (31%), and lowest for the fungicide (9%).

Table 2: Global Warming Potential (GWP100) for the imported formulated: herbicides containing glyphosate, fungicides of the chemical class diazole-compounds and insecticides used in New Zealand kiwifruit orchards, using IPCC 2007 characterization factors (Intergovernmental Panel on Climate Change (IPCC) 2007).

Pesticides	GWP100 in CO_2-eq/kg formulated pesticide
glyphosate (herbicide)	14.74
iprodione (fungicide)	17.37
thiacloprid (insecticide)	19.17

7. Overall data set quality

The overall data quality of the LCI data set was estimated according to the ILCD handbook ‘Specific guide for Life Cycle Inventory data sets’ (International Reference Life Cycle Data System (ILCD) 2010, pp. 107-109). The goal of this project was to provide New Zealand weighted average values for GHG emissions covering ‘cradle to New Zealand port’ using data adapted from existing LCIs on the production of three selected pesticides used in kiwifruit orchards, combined with data from the agrichemical industry on the offshore production and formulation sites and the associated transport to New Zealand.

According to this goal the inventory data sets have very good geographical and time-related representativeness. The scanning of 40 representative spray diaries guaranteed the relevance of the three pesticides for New Zealand kiwifruit production systems in the reference year. The agrichemical industry provided detailed information on the offshore production sites of the active ingredients, the sites of formulation, and the transport to New Zealand, which assured a very good geographical representativeness of the data sets.

However, the technical representativeness of the inventory data sets ranges from good to fair (Table 3). Only for one of the three selected active ingredients, namely glyphosate, an inventory data set was available (ecoinvent database). The existing data set, however, assumed Europe as the location of production; while glyphosate used in New Zealand kiwifruit orchards is produced in China and the US. Table A5 (Annex) summarizes the assumptions made in the LCI for the active ingredients inclusive of transport, formulation and packaging. Some of these assumptions were already introduced in sections 3 and 5 of this report: The LCI of glyphosate produced in Europe is based on literature data for the active ingredient glyphosate (Sutter 2010), and has the highest data quality of the three GHG inventories used in this study. However, our survey of the major pesticide suppliers in New Zealand revealed that the glyphosate used in New Zealand kiwifruit orchards is not actually produced in Europe, rather it is partly (76%) synthesized in China and partly (24%) in the US. Country-specific LCIs for glyphosate production are not available. We assumed that production and associated emissions are comparable between the different countries, and we only corrected the emissions associated with energy consumption with country-specific electricity data using the weighted average between China and US.

Our LCI of iprodione represents an average LCI for fungicides of the chemical class of diazole-compounds produced in Europe (Sutter 2010). Accordingly, the data quality of this LCI is lower than that of the LCI for the active ingredient glyphosate. However, iprodione is manufactured in Europe, which reduces the uncertainty of its GHG inventory value.

The lowest data quality of our three inventories is for the LCI for the insecticide thiacloprid, as it is derived from the arithmetic mean of several insecticides of different chemical classes produced in Europe. But, similar to iprodione, at least the active ingredient is produced in Europe. In addition, no detailed GHG inventories for the formulation and packaging of pesticides exist. We used the rough energy usage estimations based on formulation type (Green 1987), which had to be converted into CO_2-e. It will be almost impossible to improve the data basis on product formulations, as these formulations are held as corporate secrets by the producers. However, the contribution of formulation and packaging at the overall GHG emissions related to the production of pesticides is thought to be minimal (Green 1987).

Applying Formula 3 from the ILCD-handbook (International Reference Life Cycle Data System (ILCD) 2010, p. 109) , the calculated data quality rating (DQR) for the inventory data set ranges from 3.3 to 3.6, which means that all three data sets can be classified as ‘data estimates’ (Table 3). Overall, the precision uncertainty of the GHG inventories for the three imported and formulated pesticides used in New Zealand kiwifruit orchards is relatively high, which explains the overall data quality rating.

Table 3: Quality rating for the data quality indicators technological representativeness (TeR), geographical representativeness (GR), time related representativeness (TiR), completeness (C), precision uncertainty (P) and methodological appropriateness and consistency (M) according to the ILCD handbook (International Reference Life Cycle Data System (ILCD) 2010, Table 6, p. 108) for the three LCI data sets glyphosate, iprodione and thiacloprid.

Active ingredient	TeR	GR	TiR	C	P	M
glyphosate	2	1	1	2	4	1
iprodione	3	1	1	2	4	1
thiacloprid	4	1	1	2	4	1

8. Life Cycle Interpretation

The GWP of imported pesticides used in New Zealand kiwifruit orchards ranges between 15 and 19 CO_2-e per kg of imported pesticide, and is comparatively high. In contrast, for the fertilizer analysed in the same study by AgResearch, this ranged between 0.3 and 1.9 kg CO_2-e per kg imported fertilizer. The low application volumes of pesticides used in kiwifruit production systems, however, ranging for our three pesticides between 6 and 360 g active ingredients ha^{-1}, render insignificant the contribution of the production/formulation/packaging and import of pesticides to the overall GWP of kiwifruit production.

9. Critical Review (Dr Sarah McLaren, NZLCM)

The resulting ILCD databases and the report were critically reviewed by Dr Sarah McLaren, New Zealand Life Cycle Management Centre. We integrated all her suggestions and clarified some aspects by including additional information, for example, inserting Table A1 summarizing the transport routes and distances used in our calculations, and providing background information on the assumptions made with regard to the emissions related to formulation and packaging of pesticide products. In particular, section 7 'Overall inventory data quality' was added as suggested by the reviewer. This section is structured following the ILCD handbook 'Specific guide for Life Cycle Inventory data sets' (International Reference Life Cycle Data System (ILCD) 2010). The review was done according to ISO 14044 guidelines. In addition, Roger Gilbertson at Zespri reviewed the technical aspects of the report.

10. Lessons learnt and issues encountered

1. Given our close relationship with growers and the industry, we were able to gain access to confidential information from which we could infer what major pesticides were used in kiwifruit production, and the industry was happy to supply us, in confidence, the sources of their products and the sites of their formulations. Detailed information could not, however, be released; rather only generic results are available for dissemination.

2. There is a rapid rate of change in the sites of pesticide production and in the on-orchard use of various products. For example, with Monsanto's patent protection on glyphosate expiring, there has been a large change is where this herbicide is produced and formulated. Furthermore, with pressure on growers to use more sustainable pesticides and reduce spraying, there is a rapid rate of change in product use and application amounts. Thus, the LCI databases will have a reasonably short useful life.

3. The sourcing of product, sites of formulation, and the modes of transport provided to us were as 'average annual' estimates. However, there is quite a degree of year-to-year variation due to supply and demand requirements. For example, one supplier noted that whereas the US-sourced product is normally shipped by sea, during years of high demand, some 2-3% might be brought in by air. Thus, to consider that these results might apply to a given year is incorrect.

4. There is a dearth of detailed information on specific pesticides available. However, it was possible to find specific information about glyphosate 'tech' produced in Europe.

However, the glyphosate used in New Zealand orchards comes either from the US or China. Therefore, we had to infer that the production practices were universal, and that the only difference would be the emissions due to the different energy mixes in China and the US. No specific information was available for the fungicide we considered – Iprodione. Thus, we had to use the emissions values published for the general class of diazole pesticides. For our insecticide of thiacloprid, there was neither specific information nor a generic class value for this neonicotinoid compound available. A generic value for insecticides had to be used. Thus, there are data quality information issues with all three compounds. Even worse, the ecoinvent database lists thiacloprid as a diazole- compound, when in fact it is a neonicotinoid insecticide. So we did not follow ecoinvent's classification, rather we used the generic insecticide values.

5. No specific information was available on the emissions due to formulation and packaging. Furthermore, no specific information was forthcoming on what the actual formulation products were, for these are the trade secrets of the producers. Generic information was simply used for formulation and packaging. It is likely that modern formulation products and processes, along with new packaging practices, would result in emissions that are lower than the 1987 values we used here, namely those published by Green (1987).

6. We then considered the cumulative emissions of the list of gases provided by GaBi 2007 for all three pesticides, and used the IPCC GWP values to determine the LCIA of the pesticides. In comparison with the LCIA values for these products listed in the ecoinvent database, our results were an underestimate by some 4 - 6%. This highlights the need to establish common protocols.

7. We found that product formulation, packaging, and transport accounted for just 9-31% of the emissions from 'cradle to New Zealand warehouse'.

8. Although we found our pesticides to have higher emissions than fertilizer on a per unit weight basis, the amount of formulated product used for pest and disease control means that the emissions from the pesticides used in kiwifruit production is insignificant in the life cycle of a kiwifruit. Nonetheless, the emissions from the application of these pesticides will be important.

9. We found that the greenhouse gas emissions associated with the production, formulation and transport of pesticides were insignificant. This highlights that the focus of the environmental assessment of pesticide usage should be the ecotoxicological impact of pesticides. Whereas currently ecotoxicological assessments mainly concentrate on losses to the environmental compartments air, water and soil following the application of pesticides, it might be worthwhile to consider losses of active ingredients during the production and disposal phase of pesticides as suggested by Müller et al. (2010). Inclusion of upstream (pesticide production related) and downstream (waste related) emissions of pesticides as well as of pesticide production/synthesis related chemicals, including intermediate (synthesis) products and production chemicals such as solvents and catalysts, would be a useful expansion of pesticide risk assessments, making them more comprehensive.

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Annexes

Table A1: Transport distances between the locations of production, formulation and final storage in Auckland used in the calculations for the different active ingredients. For shipping, a trans-oceanic freight ship (50,000 dwt; transport, transoceanic freight ship, OCE, [tkm] (#1968)), for truck transport, a EURO 3 vehicle (transport, lorry 16-32t, EURO3, RER, [tkm] (#7303)), and for rail transport, a freight train (transport, freight, rail, RER, [tkm] (#1983)) were chosen from the ecoinvent database, respectively.

Active ingredient	Route of transport	Mode of transport	Distance (km)
Glyphosate			
	St Louis – New Orleans	truck	1090
	New Orleans - Auckland	ship	14716
	Auckland port to factory in Auckland	truck	25
	within China	truck	200
	Shanghai – Auckland	ship	9532
	Shanghai – Sydney	ship	8584
	Sydney port to factory in Sydney	truck	25
	Sydney – Auckland	ship	2359
	New Orleans - Sydney	ship	16870
Iprodione	Leverkusen – Hamburg	rail	346
	Hamburg – Brisbane	ship	12224
	Brisbane port to factory	truck	25
	Brisbane – Sydney	ship	952
	Sydney - Auckland	ship	2359
Thiacloprid	Leverkusen – Hamburg	rail	346
	Hamburg – Brisbane	ship	12224
	Brisbane port to factory	truck	25
	Brisbane – Sydney	ship	952
	Sydney - Auckland	ship	2359

Table A2: 'Cradle to New Zealand port' greenhouse gas LCI of imported formulated herbicides containing glyphosate used in New Zealand kiwifruit orchards. Greenhouse gases (GHG) included in the table were chosen according to the LCA-software GaBi 2007.

Emissions to air	**kg/kg formulated herbicide**
carbon dioxide (inorganic emissions to air)	1.43E+01
methane (organic emissions to air (group VOC))	3.56E-04
nitrous oxide (laughing gas (inorganic emissions to air))	2.27E-04
dichloromethane (methylene chloride (halogenated organic emissions to air))	9.08E-09
R11 (trichlorofluoromethane (halogenated organic emissions to air))	3.37E-12
R114 (dichlorotetrafluoroethane (halogenated organic emissions to air))	6.36E-08
R116 (hexafluoroethane (halogenated organic emissions to air))	1.71E-07
R12 (dichlorodifluoromethane (halogenated organic emissions to air))	1.14E-09
R114a (tetrafluoroethane (halogenated organic emissions to air))	7.10E-07
R22 (chlorodifluoromethane (halogenated organic emissions to air))	2.94E-07
trichloromethane (chloroform (halogenated organic emissions to air))	1.25E-08
R113 (trichlorofluoroethane (halogenated organic emissions to air))	3.09E-10
Halon (1301) (halogenated organic emissions to air)	2.84E-08
carbon dioxide, land transformation (inorganic emissions to air)	7.95E-03
Sulphur hexafluoride (Inorganic emissions to air)	8.15E-07
R23 (trifluoromethane (halogenated organic emissions to air))	6.61E-10
tetrafluoromethane (halogenated organic emissions to air)	1.34E-06
R152a (difluoroethane (halogenated organic emissions to air))	4.47E-09
Halon (1211) (halogenated organic emissions to air)	7.18E-08
1,1,1, trichloroethane (halogenated organic emissions to air	6.03E-10
carbon dioxide (biotic (inorganic emissions to air))	2.11E-01
methane (biotic (organic emissions to air, group VOC))	3.56E-04
VOC (unspecified (organic emissions to air, group VOC))	3.30E-03
hydrocarbons (unspecified (organic emissions to air, group VOC))	1.58E-03
carbon monoxide	8.08E-03
Emissions to water	**kg/kg formulated herbicide**
VOC (Organic emissions to fresh water)	1.27E-05
VOC (Organic emissions to sea water)	5.54E-06

Table A3: 'Cradle to New Zealand port' green house gas LCI of formulated fungicides containing diazole-compounds as active ingredients used in New Zealand kiwifruit orchards. Greenhouse gases (GHG) included in the table were chosen according to the LCA-software GaBi 2007.

Emissions to air	**kg/kg formulated fungicide**
carbon dioxide (inorganic emissions to air)	1.57E+01
methane (organic emissions to air (group VOC))	3.30E-04
nitrous oxide (laughing gas (inorganic emissions to air))	3.92E-03
dichloromethane (methylene chloride (halogenated organic emissions to air))	1.11E-04
R11 (trichlorofluoromethane (halogenated organic emissions to air))	4.79E-12
R114 (dichlorotetrafluoroethane (halogenated organic emissions to air))	6.42E-08
R116 (hexafluoroethane (halogenated organic emissions to air))	2.30E-07
R12 (dichlorodifluoromethane (halogenated organic emissions to air))	1.70E-09
R114a (tetrafluoroethane (halogenated organic emissions to air))	5.52E-07
R22 (chlorodifluoromethane (halogenated organic emissions to air))	4.30E-07
trichloromethane (chloroform (halogenated organic emissions to air))	3.71E-03
R113 (trichlorofluoroethane (halogenated organic emissions to air))	4.43E-10
Halon (1301) (halogenated organic emissions to air)	3.45E-08
carbon dioxide, land transformation (inorganic emissions to air)	4.39E-04
Sulphur hexafluoride (Inorganic emissions to air)	7.70E-07
R23 (trifluoromethane (halogenated organic emissions to air))	9.38E-10
tetrafluoromethane (halogenated organic emissions to air)	1.80E-06
R152a (difluoroethane (halogenated organic emissions to air))	4.55E-09
Halon (1211) (halogenated organic emissions to air)	1.10E-07
1,1,1, trichloroethane (halogenated organic emissions to air	1.66E-11
carbon dioxide (biotic (inorganic emissions to air))	2.28E-01
methane (biotic (organic emissions to air, group VOC))	3.30E-04
VOC (unspecified (organic emissions to air, group VOC))	5.50E-03
hydrocarbons (unspecified (organic emissions to air, group VOC))	1.09E-03
carbon monoxide	7.51E-03
Emissions to water	**kg/kg formulated herbicide**
VOC (Organic emissions to fresh water)	1.54E-05
VOC (Organic emissions to sea water)	5.03E-07

Table A4: 'Cradle to New Zealand port' green house gas LCI of formulated insecticides used in New Zealand kiwifruit orchards. Greenhouse gases (GHG) included in the table were chosen according to the LCA-software GaBi 2007.

Emissions to air	**kg/kg formulated insecticide**
carbon dioxide (inorganic emissions to air)	1.83E+01
methane (organic emissions to air (group VOC))	4.53E-04
nitrous oxide (laughing gas (inorganic emissions to air))	1.29E-03
dichloromethane (methylene chloride (halogenated organic emissions to air))	6.86E-10
R11 (trichlorofluoromethane (halogenated organic emissions to air))	3.43E-12
R114 (dichlorotetrafluoroethane (halogenated organic emissions to air))	9.27E-08
R116 (hexafluoroethane (halogenated organic emissions to air))	1.75E-07
R12 (dichlorodifluoromethane (halogenated organic emissions to air))	1.36E-09
R114a (tetrafluoroethane (halogenated organic emissions to air))	4.96E-07
R22 (chlorodifluoromethane (halogenated organic emissions to air))	4.54E-07
trichloromethane (chloroform (halogenated organic emissions to air))	9.61E-09
R113 (trichlorofluoroethane (halogenated organic emissions to air))	3.10E-10
Halon (1301) (halogenated organic emissions to air)	3.11E-08
carbon dioxide, land transformation (inorganic emissions to air)	2.80E-03
Sulphur hexafluoride (Inorganic emissions to air)	1.15E-06
R23 (trifluoromethane (halogenated organic emissions to air))	6.72E-10
tetrafluoromethane (halogenated organic emissions to air)	1.38E-06
R152a (difluoroethane (halogenated organic emissions to air))	6.76E-09
Halon (1211) (halogenated organic emissions to air)	1.12E-07
1,1,1, trichloroethane (halogenated organic emissions to air	2.22E-11
carbon dioxide (biotic (inorganic emissions to air))	2.91E-01
methane (biotic (organic emissions to air, group VOC))	4.53E-04
VOC (unspecified (organic emissions to air, group VOC))	4.41E-03
hydrocarbons (unspecified (organic emissions to air, group VOC))	1.63E-03
carbon monoxide	4.02E-02
Emissions to water	**kg/kg formulated insecticide**
VOC (Organic emissions to fresh water)	1.45E-05
VOC (Organic emissions to sea water)	5.27E-07

Table A5: Summary of assumptions made for the GHG inventory of the imported formulated pesticides used in New Zealand kiwifruit orchards, and related transport.

Pesticides	Assumptions
Glyphosate (herbicides)	• Spray diaries of 40 kiwifruit orchards were considered as representative of New Zealand kiwifruit production • Glyphosate production in China and US was assumed to follow the same manufacturing process as in Europe (i.e., the same series of chemical reactions, and that the operations involved such as heating, cooling, stirring, distilling, filtering, drying, are conducted in the same way causing the same emissions) in spite of country-specific environmental regulations • No detailed information on the formulation and packaging of glyphosate available; generic energy usage data for formulation of emulsifiable oil (Green, 1987); converted into GHG emissions following Wells (2001)
Iprodione (fungicides)	• Spray diaries of 40 kiwifruit orchards were considered as representative of New Zealand kiwifruit production • No GHG inventory for iprodione available; GHG inventory for diazole-compounds used • No detailed information on the formulation and packaging of iprodione available; generic energy usage data for formulation of granules (Green, 1987); converted into GHG emissions following Wells (2001)
Thiacloprid (insecticides)	• Spray diaries of 40 kiwifruit orchards were considered as representative of New Zealand kiwifruit production • No GHG inventory for iprodione, or chemical class of neonicotinoid-compounds available; GHG inventory for insecticides used • No detailed information on the formulation and packaging of thiacloprid available; generic energy usage data for formulation of emulsifiable oil (Green, 1987); converted into GHG emissions following Wells (2001)
Transport	• EURO 3 truck was chosen for all road transport irrespective of country and potentially varying vehicles • All transport means were assumed to be utilized for other freight transport after delivery of products • Small amount of air transport depending upon demand (but not included in this analysis)

Figure A1: Overview of the relevant processes of the active ingredients glyphosate (top), iprodione (middle), and thiacloprid (bottom) from 'Cradle to New Zealand port'.