Update of the carbon footprint of fertilisers used in New Zealand

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1. Executive Summary

The aim of the study reported here was to update the estimates of the average carbon footprint of a range of fertilisers used in New Zealand (NZ) by Ballance Agri-Nutrients and Ravensdown based on local production and importation data for 2018/19. Results are compared with estimates from a previous carbon footprint study of NZ fertilisers in 2010.

Data was provided by both fertiliser companies on the sources of raw materials for production of single superphosphate (SSP) in NZ and on sources of imported fertilisers. Some updated input and SSP processing data were also provided, otherwise it was assumed to be the same as for the earlier 2010 study. Life cycle assessment methodology was used to account for all sources of greenhouse gas (GHG) emissions in calculation of the carbon footprint of fertilisers, including that for transportation to an NZ port. For imported fertilisers, estimates were based on a recent regional analysis of fertilisers globally by Fertilizer Europe.

For imported fertilisers to an NZ port (weighted for the two companies and sites of importation), the carbon footprint of ammonium sulphate, calcium ammonium nitrate, diammonium phosphate, triple superphosphate, and muriate of potash (KCl) was 0.77, 1.14, 1.28, 0.38 and 0.45 kg CO_2equivalent/kg, respectively. The main contributor was manufacturing emissions, although transportation was significant for some fertilisers (e.g. 44% of total for KCl). Values were lower than for the earlier study, due to greater efficiency of production and transportation and differences in source of fertilisers.

Urea had a carbon footprint of 0.97 kg CO_2equivalent/kg, which is a weighted value for different sources of imported urea to an NZ port and locally-produced urea at Kapuni and is 8% lower than for the 2010 estimate. This excludes CO_2 emissions from soil after application of 0.73 kg CO_2equivalent/kg and N_2O emissions after application to soil of 1.4 kg CO_2equivalent/kg.

The carbon footprint of SSP for 2018/19 was 0.156 kg CO_2equivalent/kg, compared to 0.216 kg CO_2equivalent/kg for the 2010 study, with lower emissions mainly due to differences in the phosphate rock (PR) source and shipping efficiencies. Emissions from shipping of PR and sulphur to NZ were the largest contributor to the carbon footprint of SSP, at 62% of the total. Other contributors were PR mining & beneficiation, internal transport, energy for production and CO_2 release from carbonate in PR at 25, 2, 2 and 9%, respectively.

When this data was used in analysis of the carbon footprint of milk for the average NZ dairy farm for 2016/17, it revealed that N fertiliser and non-N fertilisers (P, K, S) used on the dairy farm (milking platform) contributed 7.4 and 0.6% to the total, respectively. The N fertiliser-related emissions included those from soil after fertiliser application. For the average North Island hill country sheep and beef farm, the contribution from N and non-N fertiliser to total farm GHG emissions were 2.8 and 1%, respectively.

2. Introduction

Previous New Zealand (NZ) greenhouse gas (GHG) emission studies have shown that fertilisers can make a significant contribution to the carbon footprint (i.e. total GHG emissions) of a product (e.g. milk, meat, fibre) from the cradle-to-farm-gate stage. For example, in an earlier study of the carbon footprint of milk produced in NZ, nitrogen (N) and non-N fertilisers contributed an average of 12% and 2% to the carbon footprint of milk (Ledgard et al., 2011). Those estimates were based on data from the calculated carbon footprint of fertilisers produced in NZ and/or imported into NZ in 2008-2009. Since that time, there have been changes in the source of raw materials and levels of fertiliser production in NZ. Similarly, changes in other contributors such as the fuel efficiency of transportation and emissions associated with the production of electricity in NZ have occurred. At that time, the carbon footprint of imported fertilisers was based on relatively old 2006 European data on fertiliser production from the European Fertiliser Manufacturers Association.

Estimation of the carbon footprint of fertilisers to account for the total GHG emissions requires application of life cycle assessment (LCA) methodology. This captures all GHG emissions, including those from the extraction of raw materials, transportation and production of inputs used through all stages of the life cycle (e.g. IDF, 2015).

The aim of this study was to provide an update on the carbon footprint of fertilisers used in NZ in 2018, based on data provided by Ballance Agri-Nutrients and Ravensdown on the source of imported fertilisers or phosphate rock for production of single superphosphate (SSP) in NZ, as well as some updates on fertiliser production data. Additionally, the effects of this update on the relative contribution of fertilisers to the carbon footprint of milk and sheep meat produced in NZ was estimated and compared with that for the earlier fertiliser data.

3. Methods

3.1 Goal and Scope

The goal of this project is to provide the NZ fertiliser industry with information on the GHG emissions associated with the production and use of fertilisers on NZ farms. Additionally, a goal is to use this data to determine the contribution of fertilisers to the total carbon footprint of typical NZ dairy and sheep meat products. Use of data from this project will also enable the fertiliser industry to examine the "hot-spots" in GHG emissions throughout the life cycle in the production and use of fertilisers in the primary sector.

The scope of the current study covers estimation of the GHG emissions associated with the production and delivery of the main fertilisers used on NZ farms to sites of NZ manufacturing (for SSP) or to a 'typical' NZ port for imported fertilisers.

3.2 System boundary

The system boundaries relating to the fertilisers covered all stages from cradle-to-NZport for imported fertilisers and from cradle-to-manufacturing-plant-gate for SSP and urea that is manufactured in NZ. Thus, they included resource use and emissions associated with the extraction of all raw materials, beneficiation, all transportation stages, and the fertiliser manufacturing process.

To provide context for the fertiliser GHG emissions relative to the life cycle of an agricultural product, the updated data from this study was used in the AgResearch carbon footprint model for milk for the cradle-to-farm-gate stage (Figure 1).

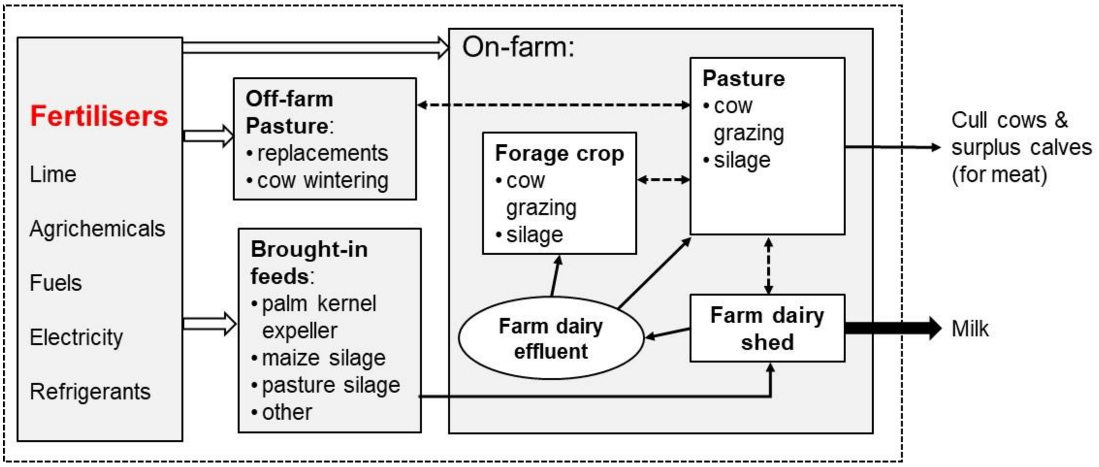

Figure 1: Simplified flowchart of the "cradle-to-farm-gate" for an NZ dairy farm system

3.3 Functional unit

The functional unit of this study was one kg of fertiliser.

3.4 Life Cycle Inventory data

3.4.1 Imported fertilisers

Details of the total GHG emissions associated with the manufacturing of a range of fertilisers for different countries or regions globally were obtained from Brentrup et al. (2018). These were estimated using Fertilizer Europe's carbon footprint tool, based on primary data from Fertilizer Europe members for 2014. It covers a range of different fertilisers used in NZ including urea, ammonium sulphate (AS), calcium ammonium nitrate (CAN), diammonium phosphate (DAP), triple superphosphate (TSP), and muriate of potash (KCl).

3.4.2 Urea

Data on raw material and energy use from the previous study were used to calculate GHG emissions associated with production of urea from the Kapuni plant for 2018/19.

Data from the NZ plant was used in conjunction with data for urea produced in a ‘typical’ plant according to the region or country from which the urea was sourced, using data from Brentrup et al. (2018). This data-set was then used to calculate an NZ weighted average based on information provided by both companies on the relative amounts of urea from the different sources for 2018/19. This calculation accounted for GHG emissions associated with transport of imported urea from overseas manufacturing plants to an NZ port.

3.4.3 NZ single superphosphate

Data was provided by both NZ fertiliser manufacturers on the sources of phosphate rock (PR) and sulphur (S) used for production of SSP. The process of extraction of the raw materials in the country of origin was assumed to be the same as in the earlier study. Data on shipping routes for raw materials from source to NZ port were estimated after feedback from the companies.

Generic data on the manufacturing process for SSP was provided for each of the five main SSP plants in NZ for the 2018-2019 year. This included data on the average quantities of PR and S used relative to the SSP produced. Sulphur is used to produce sulphuric acid at all plants except one, where the acid was imported from Tasmania and was derived from a waste byproduct (no allocation was made to account for this product) of a zinc smelting process. The sulphuric acid is reacted with PR to form SSP. The latter reaction is exothermic and consequently electricity data included consumption of electricity as well electricity generated and fed back into the NZ grid (data based on NZ grid mix; MBIE, 2018). Some specific energy use data was provided but otherwise it was assumed to be the same per tonne SSP as in the previous study.

The results for superphosphate are based on an update of the earlier model used in 2010, with current emission factors for electricity, diesel, shipping and truck transport (for NZ and for countries from which raw material was derived).

Data from each plant was used to determine total GHG emissions per kg SSP produced. This was used in conjunction with data on the quantities of SSP produced at each plant to calculate an NZ weighted average.

3.4.4 Transportation

Transportation emissions included that for transporting the raw materials from site of extraction to local port and for shipping to the NZ port. For SSP, it also covered transportation from the NZ port to the manufacturing plant.

For the imported fertilisers and raw materials, expert opinion from the NZ fertiliser companies was used to define the mode of transport from the different manufacturing or extraction sites to the local port for export and the route of transport used. Emission factors for the relevant modes of transport in the different countries were derived from the Ecoinvent version3.5 database using SimaPro LCA software (version 8.5).

Shipping distances from overseas ports to the NZ ports associated with the main fertiliser plants were calculated using http://www.searates.com/. The emission factor used for shipping was 0.0089 kg CO_2-equivalents/t.km from the Ecoinvent database.

For SSP, previous data was used on the mode of transport from the NZ port to the manufacturing site and the route of transport used.

3.5 Contribution of fertilisers and lime to GHG emissions from NZ dairy, sheep and beef production

Data from NZ weighted-average GHG emissions for the different fertilisers described previously were used in the AgResearch LCA dairy model to determine the carbon footprint of milk (e.g. Ledgard et al. 2019). This included data on fuel use and GHG emissions from the transportation of fertilisers from plants or ports to example farms across all dairying regions of NZ and on application to pasture. It also included CO_2 released from soil after application of urea according to IPCC (2006). An average NZ carbon footprint of milk was based on integration of emissions calculated for dairying in each region across NZ and weighted according to relative milk production across the regions (DairyNZ/LIC, 2018). Regional DairyNZ DairyBase (https://www.dairynz.co.nz/business/dairybase/) data was used to obtain other farm data such as that for the rates of fertilisers applied and levels of brought-in feeds used.

A sheep and beef LCA model has also been developed and it was applied using data for the average North Island sheep and beef farm (Beef+LambNZ Class 4) for 2015/16 provided by Beef+LambNZ. The model was revised to account for the updated fertiliser production emissions from this report. These LCA model analyses were used to evaluate the relative contribution from production of fertilisers to the carbon footprint of the livestock products.

3.6 Calculation of GHG emissions

The GHG emissions and carbon footprint were calculated according to Stocker et al. (2013) in carbon dioxide equivalents (kg CO_2eq). This used Global Warming Potential (GWP) factors for a 100-year time horizon (GWP_{100}) of CO_2 1, nitrous oxide (N_2O) 265, biogenic methane (CH_4) 27.75 and fossil CH_4 30.5.

4. Results and Discussion

4.1 Imported fertilisers

A summary of results for the carbon footprint of the different imported fertilisers is presented in Table 1. The highest GHG emissions per kg product were from the N-based fertilisers, which is associated with the relatively high energy requirements for ammonia production (e.g. EFMA, 2000). It was least for TSP, with relatively low energy requirements for manufacturing, and for KCl which is extracted from soil reserves and undergoes no manufacturing.

For all fertilisers, the GHG emissions associated with their production has decreased compared to that from the earlier study. This is associated with improvements in manufacturing efficiency. For example, the GHG emissions per kg N associated with production of ammonium nitrate in Europe has decreased by 60% from 1990 to 2014 (Brentrup et al., 2018). In Table 1, the results for urea are a weighted average for the urea imported from overseas and include shipping-related emissions, as well as that for urea produced at Kapuni in NZ.

Table 1: Carbon footprint of imported fertilisers (kg CO_2eq/kg), showing relative contribution from production, local transport (within country of production to their port) and shipping to an NZ port. Data for urea is weighted for imported urea and urea produced at Kapuni in NZ.

	Urea	**DAP**	**TSP**	**AS**	**CAN**	**KCl**
2018/19:						
Production	0.88	1.13	0.27	0.69	0.95	0.25
Local transport	0	0.05	0.01	<0.01	<0.01	0.06
Shipping	0.09	0.10	0.10	0.07	0.19	0.14
TOTAL	**0.97**	**1.28**	**0.38**	**0.77**	**1.14**	**0.45**
2008/09:						
Production	0.94	0.91	0.35	0.47	1.66	0.36
Local transport	0	0.01	0.00	0.01	0	0.05
Shipping	0.12	0.20	0.25	0.12	0.27	0.17
TOTAL	**1.06**	**1.12**	**0.60**	**0.61**	**1.93**	**0.58**

The contribution to the carbon footprint of fertilisers from shipping of product to NZ also decreased across all fertilisers. This was partly associated with lower GHG emissions per t.km from shipping used in the environmental databases, presumably reflecting greater efficiency of energy use by ship transport. In some cases, lower shipping emissions were associated with closer sourcing of fertilisers, e.g. all TSP was sourced from Asia in 2018/19 instead of the Middle East in 2008/09 at almost half the shipping distance.

4.1.1 NZ single superphosphate

Separate analyses were made for each of the five NZ manufacturing sites and a weighted average was calculated according to data on the SSP production from each site for 2018/2019. The weighted average GHG emissions per t SSP for 2018/19 was 28% lower than that for 2008/09 (Table 2). This was mainly due to lower emissions for the PR mining and shipping stages. Lower emissions for the PR mining stage relate to changes in countries where PR was purchased, with only some countries requiring beneficiation of PR and the associated energy use and GHG emissions. Additionally, there was a large difference in internal transportation emissions associated with delivering the extracted PR to the nearest port, which was included in the PR mining stage.

Total emissions from shipping of PR and S to NZ were the largest contributor to the carbon footprint of SSP, at 62% of the total. Much lower shipping emissions in 2018/19 were a result of a combination of lower shipping emissions per t.km associated with more efficient shipping and changes in the sources of PR with the average shipping distance to PR to NZ ports being 7% less in 2018/19 than in 2008/09.

Table 2: Total greenhouse gas emissions in kg CO_2-equivalents/kg superphosphate covering the cradle-to-manufacturing-plant-gate in New Zealand. It represents a weighted average for superphosphate produced across the manufacturing plants of Ballance Agri-Nutrients and Ravensdown.

Stage of production	2018/19 estimate	2008/09 estimate
PR mining & beneficiation (including transport to port)	0.039	0.048
Train transport of S in Canada	0.003	0.002
Shipping of raw materials (PR, S and H_2SO_4) to NZ port	0.096	0.148
Truck transport of raw materials to plant	0.001	0.001
Net electricity and fuel use at plant	0.003	0.003
CO_2 release from CO_3 in PR	0.014	0.014
TOTAL	**0.156**	**0.216**

The contribution from within-country transport of raw materials and energy (electricity and fuel) use for manufacturing of SSP were minimal contributors (<5% in total) to the carbon footprint of SSP. Release of CO_2 from carbonate in the PR (based on an average of 2.3% content) was estimated to contribute 9% to total GHG emissions.

There was only a very small variation between SSP plants in total GHG emission intensity, ranging from 0.153 to 0.163 kg CO_2-e/kg SSP. This was influenced by variation in shipping distances for raw materials and energy use associated with manufacturing. The estimates from this study are higher than those for SSP of 0.08-0.13 kg CO_2-e/kg SSP across different regions of the world (including 0.11 for Oceania) by Brentrup et al. (2018). However, the SSP analysis given in the latter summary was 7.8%P, which if adjusted to 9.1%P as used for NZ SSP, would increase the range to 0.10-0.13 kg CO_2-e/kg SSP. In addition, the latter study may not have included the CO_2 released from PR on processing.

Results from this study can be used to compare the GHG efficiency of fertilisers on a unit nutrient basis. Based on this, the total GHG emissions for NZ-average SSP (to the manufacturing-plant-gate) or TSP (based on the NZ average TSP from overseas sources to the NZ port) equated to 1.71 or 1.85 kg CO_2-e/kg P. This ignores the fertiliser value of the S contained in these products (which is roughly ten times higher per kg P for SSP than for TSP) and indicates greater GHG efficiency for the NZ average SSP. This also applies when other fertilisers are compared that vary in their associated S content. For example, the carbon footprint of urea (including the CO_2 emissions following application to soil, equivalent to 0.73 kg CO_2-e/kg urea or 1.59 kg CO_2-e/kg N) is 3.69 kg CO_2-e/kg N (based on 46%N), while that for ammonium sulphate is 3.83 kg CO_2-e/kg N (based on 20%N), but the latter contains 23% S while urea contains no S.

4.2 Contribution of fertilisers to GHG emissions from NZ dairy, sheep and beef production

Recent research examined the carbon footprint of milk from the average NZ dairy farm for 2016/17 (i.e. cradle-to-farm-gate stage; Ledgard et al. 2019). The average rate of N, P and K applied in fertilisers on the milking platform was 140, 27 and 28 kg/ha/year, respectively. The N fertiliser and non-N fertilisers (P, K, S) used on the dairy farm (milking platform) were estimated to contribute 7.4 and 0.6%, respectively, based on the updated 2018/19 fertiliser carbon footprint data. Corresponding estimates for N fertiliser and non-N fertilisers (P, K, S) based on the previous fertiliser data (for 2008/09) were 7.7 and 0.8%, respectively. Thus, these updated results led to a reduction in the calculated cradle-to-farm-gate carbon footprint of NZ milk for 2016/17 of about 0.5%. Note that these N fertiliser emissions included N_2O emissions (direct and indirect) from fertiliser-N after application to soil, CO_2 released from urea after application to soil, and the manufacturing emissions. These estimates do not include emissions from fertilisers used on the area for grazing replacements, wintering cows off and where crops were grown for production of brought-in feeds. The latter would add approximately 1% to the total fertiliser-related contribution (from N and non-N fertilisers).

Preliminary analyses have been made of the total GHG emissions and carbon footprint of products from the average North Island sheep and beef farm (Beef+LambNZ Class 4) for 2015/16. This indicated that N fertiliser and non-N fertilisers contributed 2.8% (including from N_2O and CO_2 emissions after application to soil) and 1.0% to the total farm GHG emissions (using the updated fertiliser GHG emission factors). This was associated with application rates of N, P and K at 12, 17 and 10 kg/ha, respectively. Note that the percentage contribution values given for fertilisers included emissions associated with fertiliser transport and application (representing 0.2% of the total contribution).

This project was based solely on assessing the total GHG emissions associated with the production of a range of fertilisers across the cradle-to-NZ-port for imported fertilisers and cradle-to-manufacturing-plant-gate for SSP and urea that is manufactured in NZ. It used LCA methodology and increasingly studies applying LCA examine a range of environmental impact categories. For example, the current European Product Environmental Footprinting initiative, which may require suppliers of products to Europe to have information on the footprint covering approximately 16 “impact categories” (including climate change, ozone depletion, human health toxicity, freshwater ecotoxicity, freshwater and marine eutrophication and acidification, as well as resource use categories of land use, water use and non-renewable resource depletion; EC, 2018). The extraction of raw materials, manufacturing and delivery of fertilisers may contribute directly or indirectly to a range of these other resource use and environmental impact categories (including for example from the production of TSP and associated phospho-gypsum, by-products and wastes). It is recommended that further research is carried out to assess these direct and indirect impacts from production of the key fertilisers used in NZ. Such information will be required by producers of agricultural products for access into some markets in future, e.g. Europe.

Table 3: Summary of the carbon footprint of NZ-average milk for 2016/17 showing the main contributing factors. The fertiliser contributions are based on use of the updated fertiliser LCA data presented in this report, with previous fertiliser LCA data in brackets.

	kg CO_2-equivalents/kg milksolids
Animal methane (enteric fermentation)	6.79
Animal methane (manure management)	0.11
Animal excreta/effluent N_2O	1.20
Production & transport of brought-in feeds	0.49
Electricity	0.14
Fuel use on-farm	0.05
Lime	0.06
N_2O from soil from N fertiliser after application	0.33
N fertiliser production (including CO_2 from soil after application)	0.39 (0.42)
Non-N fertiliser production	0.06 (0.08)
Other (e.g. crop residues, off-farm replacements inputs, transport including fertilisers to farm)	0.14
TOTAL	**9.76** (9.81)

5. Acknowledgements

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