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Thomas S, van der Weerden T, Rollo M, Laubach J

June 2016















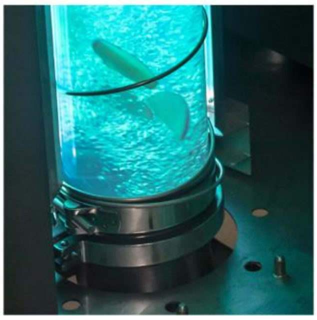


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EXECUTIVE SUMMARY

Methodology and implications of incorporating irrigation into New Zealand's Inventory

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June 2016

In this report prepared for MPI we assess the likely impact that the inclusion of irrigation would have on New Zealand's greenhouse gas inventory, and analyse the feasibility of incorporating irrigation into the inventory, considering both activity data and changes to methodology, and emission factors for nitrous oxide.

Our review of the available nitrous oxide (N_2O) emission data found that there are only a handful of relevant field experiments and modelling studies to base any refinement of the inventory. The focus of the review was on direct emissions from pasture, the largest source of New Zealand N_2O emissions. Due to the lack of studies for dung or fertiliser on pasture, findings from the review are restricted to emissions from urine and the emission factor for urine (EF_3 – urine). Key findings were that: greater N_2O emissions have been observed due to increased frequency in irrigation although not in all studies; larger emissions occur from poorly drained soils than more freely drained soils; emissions from irrigated, freely drained Canterbury soils may be less than the New Zealand default value; and there are no studies where the emissions factor for urine (EF_3) from dryland and irrigated pasture are compared.

When we considered the availability of the relevant activity data we found that there are limited quantitative data on the amounts and type of irrigated land use. The best information is from the Agricultural Production census but has limited coverage from 1990 to now. Approximately 80% of irrigation occurs in Canterbury and Otago. Irrigation has increased steadily since 1990. Most of the irrigated land occurs on freely drained soils although there is limited information on the areas of different soil classes that are irrigated. There is good quantitative information for the number of animals by land use and regions from the Agricultural Production census and surveys. However, there is a lack of information on the amount of excretal-nitrogen (NEX) distributed between irrigated and dryland systems.

We developed a simple spreadsheet model to help assess the impact of including irrigation into the inventory using activity data identified from the review and a range of EF_3 values. Data were input from all regions in New Zealand, although we applied modified irrigation EF_3 values and activity data for Canterbury and Otago only. Key findings were that Canterbury and Otago currently contribute about one-quarter of New Zealand N_2O emissions with the greatest proportion from irrigated dairy farms and that increasing the emission factor for irrigation will increase N_2O emissions. The impact on total New Zealand N_2O emissions is likely to be small based on comparison of inferred EF_3 (Total N_2O emissions/Total excretal nitrogen [NEX] for New Zealand). For example, doubling the default EF_3 value for irrigated pastoral land in Canterbury and Otago would increase the inferred emission factor for the whole of New Zealand by 3%. In other words, direct N_2O emissions from urine and dung would increase by 3%. Selection of appropriate EF_3 values for the modelled scenarios was challenging. Emissions from

Canterbury freely drained soils estimated using EF_3 from SLMACC (Sustainable Land Management and Climate Change programme) funded field trials or modelling were lower than using the New Zealand default EF_3 value. This is largely due to low emission factors for the freely drained soils that are dominant in Canterbury and Otago. EF_3 (urine) used in some scenarios was greater than the default value for dung, although this is unlikely in reality.

Our spreadsheet model was developed to fit with the current inventory methodology. It included additional functionality based on the total and regional area of irrigation, land use information, soil type, greater NEX inputs due to irrigation and could be input in monthly periods. Some or all of these factors could be feasibly incorporated into the inventory. Although, the simplest approach would be to adjust the EF_3 to incorporate the additional effect of irrigation.

It is our assessment that there is currently insufficient justification or supporting information for incorporating irrigation into the inventory. Our reasoning is that an EF_3 value for irrigation would be highly uncertain and that the increase in emissions would likely be relatively small. Evidence of effects of irrigation on emissions is highly variable based on a few studies. More information is required to understand and quantify this variability. Emissions from freely drained soils, the major irrigated soil type, appears to be much smaller than the New Zealand EF_3 value.
This needs further investigation and needs to be addressed for dryland as well as irrigated soils. There are limited or no data for irrigation derived emission factors from dung and fertiliser. Projections for conversion of dryland to irrigation (a 50% increase in irrigated land) will increase the inferred EF_3.

If irrigation is included in the inventory then we recommend the following activity data sources are used: current methods for estimating NEX, which could be reported regionally; Statistics NZ agricultural production census information and MAF survey information for the area of irrigation; regional information for Canterbury and Otago if no other regional disaggregation is adopted; consideration of disaggregating by soil type and irrigation/dryland. However, this is only likely to be useful if our current inventory approach and understanding of soil type effects on emissions changes.

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1 INTRODUCTION

MPI is required to estimate agricultural sector greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. MPI seeks to continuously improve the accuracy of New Zealand's estimates by undertaking country-specific greenhouse gas emissions research, as encouraged by the UNFCCC. As part of this undertaking MPI required research to:

1. Assess the likely impact that the inclusion or irrigation would have on New Zealand's greenhouse gas inventory.
2. Analyse the feasibility of incorporating irrigation into the inventory, considering both activity data and changes to methodology, and emission factors for nitrous oxide (N_2O).

We have brought together a small team of experts in N_2O Inventory methodology, including the model development, quantifying N_2O emissions and EF_3 responses to irrigation, soil and management. Our experts are from Plant & Food Research, AgResearch and Landcare Research.

Key steps of the project were:

- The preliminary collation of relevant activity and emission data by the authors.
- A coarse assessment of how incorporation of irrigation might affect the National Inventory using a spreadsheet model.
- A 1-day workshop for the authors and Joel Gibbs (MPI) to review the first two steps and provide the basis for a report to MPI.
- A report reviewing the available emission and activity data, revised modelling analysis based on the workshop, including an assessment of how irrigation might affect the inventory and values for emission and activity data.

This report is the output of step 4.

In Section 2 we review the available data for assessing the effects of irrigation on N_2O emissions, including published and unpublished scientific literature, and collation of available activity data required to quantify national N_2O emissions. In Section 3 we describe a spreadsheet model developed for this study to enable us to assess the impact of including the irrigation in to the national inventory. A number of assumptions are described and justified.
In Section 4 we discuss the key findings and provide recommendations for the inclusion of irrigation into the inventory.

2 REVIEW OF DATA SOURCES

2.1 New Zealand Inventory alignment

New Zealand's N_2O inventory is estimated from the results of a series of calculations that apply one or more functions or emission factors (EFs) to a range of agriculturally related activity data to estimate the amount of N_2O emitted from an agricultural source. Emissions from these sources are then aggregated to produce a total N_2O emission. For example, the direct N_2O emissions from animal urine, the biggest single source of agricultural N_2O emissions, are calculated by applying an emission factor EF_3 (urine) to the amount of urine-nitrogen (N) excreted (NEX) by animals.

The EF_3 (urine) for New Zealand is 1% of the total urine-N excreted for all pastoral systems and is based on a large number of field measurements (Kelliher et al. 2014). NEX is calculated using New Zealand parameterised models based on animal productivity information. The value for EF_3 (urine) differs from dung, EF_3 (dung), which is 0.25% (Kelliher et al. 2014).

Changes in national emissions are reported through annual emission data back to a reference year of 1990.

Currently the effect of irrigation on N_2O emissions are not reflected in the national inventory.

2.2 Emission factors

We have searched and reviewed the national and international literature. In addition we sought information from researchers who have been involved in relevant New Zealand studies. The results of this search are a few relevant studies that we have summarised below.

For each study we report key information to enable an assessment of the relevancy and appropriateness of emission factors, specifically EF_3 for urine. These EF_3 values are either directly reported or we have derived them from the data. In addition to EF_3 values we report the environmental (location, soil and climate, including season) and experimental or modelling conditions (treatments, plot size, irrigation management, length of experiment). The studies are summarised in Table 1.

2.2.1 Field experiments

Firstly, we have summarised the findings from a series of experiments that were funded through MPI's Sustainable Land Management and Climate Change (SLMACC) Programme between 2013 and 2015. This programme aimed to address the lack of New Zealand information on emissions from irrigated pastoral systems. The focus of the research was to provide irrigation management option for farmers to reduce their emissions, but also to provide information to inform the agricultural inventory of appropriateness of the current EF_3 for irrigated farming.

Effects of irrigation frequency (return interval) and soil type on N_2O emissions

The first set of plot-scale studies were conducted in the autumn of 2013 at Lincoln, Canterbury and East Tieri, Otago, to investigate the effect of irrigation frequency on N_2O emissions and EF_3 from urine amended pasture (Thomas et al. 2013c). Previous land use for the Canterbury site was irrigated sheep pasture, while there had been no irrigation at the Otago site that was used for sheep and beef grazing.

The effects of high frequency (intervals of 3 days) to low frequency irrigation (about every 14 days) were investigated on soils of contrasting drainage characteristics (freely drained [Canterbury] and poorly drained [Otago]) soils. The selected frequencies were based on representative intervals for centre pivot or large gun type irrigators (e.g. rotorainers). At both sites rainfall was excluded from the plots using open-sided greenhouses. Synthetic urine was applied at a rate of about 600 kg N/ha to simulate cow urine (Kool et al. 2006), whereas control plots received no urine. Overhead spray irrigation was applied at low application rates of 6 and 11 mm/hour at amounts to replenish water used since the last irrigation. Nitrous oxide emissions were measured using manual and automated gas chambers (van der Weerden et al. 2013) and were conducted for 8 weeks (Otago) and 15 weeks (Canterbury).

The key findings from this study were firstly that more frequent irrigation increased both the N_2O emissions and EF_3, and secondly that the magnitude of emissions was strongly affected by the soil drainage class. Nitrous oxide emissions from the freely drained soils were 2.5, 1.8 and 1.1 kg N/ha from urine plots and 0.5, 0.2 and 0.2 kg N/ha from the control plots irrigated at high, moderate and low frequency, respectively. Emissions from the poorly drained Otago soils were 21.1 and 17.6 kg/ha from the urine plots and 0.3 and 0.2 from the control plots for the high and low frequency irrigation, respectively.

Emission factors for the freely drained soils were low compared with the default EF_3 for New Zealand (1%) and increased from 0.2 to 0.4% for the low frequency and high frequency irrigation, respectively. In contrast, EF_3 for the poorly drained soils were greater than the default factor and increased from 2.7 for the low to 3.4% for the high frequency irrigation.

These results have not yet been published in international journals. They have been presented at the New Zealand Soil Science Society (NZSSS) conference in 2014 and the GGAA 2016 conference in Melbourne in February 2016 (Clemens et al. 2014; Thomas et al. 2016a). They have also been reported to MPI in reports (Thomas et al. 2013c) and two NZOnet meetings (Thomas et al. 2015a; Thomas et al. 2013a). A manuscript is being prepared and should be submitted to an international journal later this year.

Two small-plot chamber studies with cow urine and controlled irrigation were undertaken by Owens et al. (2016a, b). The first was for one month in late summer on a freely-draining Lismore soil in Canterbury, on pasture of a commercial dairy farm. This is the first study in which soil oxygen levels at four depths were measured concurrently with N_2O emissions. Irrigation frequencies of once per 3 d and once per 6 d were compared. The differences in N_2O emissions and soil oxygen contents between the two frequencies were not significant, and an emission factor of 0.09% was found for both. In this experiment, soil oxygen contents never dropped below 15% except briefly immediately following the urine application, which differs from the subsequent irrigation application in that oxygen is consumed chemically by the urea hydrolysis.

The second study (Owens et al. 2016b) was for 8 weeks in July–August on a poorly drained soil near Lincoln University. The site received irrigation and rainfall a few times at irregular intervals, leading to a wider range of soil moisture and soil oxygen concentrations than in the first study. The main finding is that N_2O fluxes remain very small while the relative soil gas diffusivity exceeds a value of 0.006 but increase strongly for values below this threshold. Soil gas diffusivity is reduced when soils are saturated and draining. Poorly drained soils will drain more slowly. The overall emission factor for N_2O from urine in this experiment was 2.1%.

A 3-year long paddock-scale study was undertaken at the same mid-Canterbury farm as the experiment of Owens et al. (2016a), with data from the first year published in Laubach et al. (2016) and analysis of the whole set of results in preparation. Using two complementary micrometeorological methods, total N_2O emissions were derived on a daily basis and accumulated to annual sums. These sums were interpreted in relation to known fertiliser application and estimated excreta deposition (based on the removed biomass, which was regularly measured). The inferred EFs (for urine, dung and fertiliser combined) were 1.2, 1.6 and 1.5% for the 3 years if natural background was assumed negligible, or 0.4, 0.9 and 0.8% if the emissions from a neighbouring unfertilized dryland pasture were subtracted as a "control". The EFs for urine alone must have been somewhat higher than these numbers if it is generally the case that the EFs for urea and dung are less than that for urine (Kelliher et al. 2014).

Internationally, there is one other paddock-scale study of N_2O fluxes from irrigated dairying (Phillips et al., 2007). This experiment ran for 2 years at a dairy farm in SE Australia that used flood irrigation every 7 to 10 d over the summer half of the year. The emission factors were not inferred on an annual basis, but for each of 13 grazing events with associated fertiliser application. These inferred emission factors for "grazing" (urine, dung and fertiliser combined) were 0.23% on average (significantly greater on two occasions).

Effects of grazing timing after irrigation on poorly drained soil

A field plot trial was established on the same site used for the Year 1 trial at the East Taieri site on the poorly drained soil (Thomas et al., 2013c). A fully replicated design was implemented beneath two tunnel houses to exclude rainfall similar to the earlier experiment. The aim was investigate the relationship between the period between irrigation and grazing and soil damage and N_2O emissions from urine applied to soil. The main treatments were urine (applied at a rate of 600 kg N/ha; (Kool et al. 2006)) and a control with no urine. Grazing was withheld for 0, 2 and 6 days after irrigation as split plots. Grazing was simulated by treading the plots using a mechanical compaction machine applying a pressure to the soil equivalent to a standing cow and applying urine immediately after (Thomas et al. 2014). After the simulated, irrigation was applied to all plots every 7 days. Nitrous oxide emissions were made for 12 weeks using the same methodology described for the earlier experiment.

The key findings were that grazing immediately after irrigation (18.1 kg N/ha) and 2 days later (17.7 kg N/ha) produced N_2O emissions greater (P = 0.002, d.f. = 23) than those grazed 6 days after irrigation (14.3 kg N/ha). The grazing treatment resulted in soil compaction. Loss of macropores was inversely related to the time of grazing after irrigation. Compaction affected emissions from the control plots (no urine), but these remained low (0.06 to 0.5 kg N/ha) in comparison to the urine-amended plots. Although EF_3 was less affected by the compaction (P = 0.26, d.f. = 11), these were greater than the default value for New Zealand, ranging from 1.7 to 3.4% for the plot grazed at 6 and 0 days after irrigation (Thomas et al. 2014) and are similar to those reported from the previous field trial.

Effect of irrigation intensity on N_2O emissions

A randomly designed, replicated lysimeter experiment was conducted in the autumn of 2014 to investigate the effect of irrigation intensity on both direct and indirect N_2O emissions from leached N (Thomas et al. 2014). Twenty-four lysimeters containing a freely-drained soil were collected from adjacent to the previous SLMACC field trial at Lincoln. The lysimeters were then installed at the Plant & Food Research lysimeter facility at Lincoln. Rainfall was excluded using an automatic rainshelter. Irrigation was applied to each lysimeter using individual nozzles. Treatments were three irrigation intensities (12, 25 and 50 mm/h) applied with or without synthetic urine (Kool et al. 2006) at a rate of 600 kg N/ha. Irrigation was applied when the soil water deficit reached 10 to 15 mm at an amount to bring the soil back to field capacity. N_2O was measured for 15 weeks using manual chambers.

Irrigation intensity did not affect the total emissions or EF_3. After 15 weeks the emissions from the urine amended lysimeters ranged between 3.0 and 3.3 kg N/ha for the 12 mm/h and 50 mm/h treatments, respectively, while the emissions from the control lysimeters ranged from 0.06 to 0.11 kg N/ha for the 12 mm/h and 50 mm/h treatments, respectively. These are in reasonably close agreement with the previous field plot study on the same soil a year earlier, 2.5 kg N/ha for the frequently applied treatment. EF_3 was approximately 0.5%.These results have not yet been published in international journals but have been presented at the NZSSS conference in 2014 (Fraser et al. 2014) and reported to MPI (Thomas et al. 2014).

2.2.2 Modelling approaches

Effects of irrigation frequency, grazing timing, soil type and climate on N_2O emissions – modelling approach

APSIM (Agricultural Production Systems Simulator) model (Keating et al. 2003) was used to simulate the effect of six different irrigation management scenarios on N_2O emissions from urine patches (600 kg N/ha) and non-urine areas on pasture of three different soil types (Thomas et al. 2015b; Thomas et al. 2016b). These were deep poorly drained (Otokia), deep well drained (Templeton) and shallow well drained (Eyre) soils. The effects of different climate and rainfall regimes were simulated using 20 years of data from two climate stations (Lincoln and Hororata, Canterbury).

Key findings were that soil type, urine and the timing of urine application had the greatest influence on the variation of N_2O emission. Irrigation had a lesser effect on the total variation, but it significantly affected emissions ($p<0.001$). Importantly it is the only factor that could be managed to reduce the emissions (the interaction between irrigation and timing of urine deposition was not significant). Greatest N_2O emissions were predicted from the poorly drained soil (average annual of 9.3 kg N/ha, range 1.6 to 23 kg N/ha), while emissions tended to be similar from the two well-drained soils (average annual of 3.0 kg N/ha, range of 1.2 to 5.8 kg N/ha). Similarly, EF_3 for the poorly drained soil was larger than the freely drained soil. The average annual EF_3 for the poorly and freely drained soils were 1.4% and 0.47% respectively, while during the irrigation period this increased to 1.6 and 0.48%. The range of EF_3 was large between months and years (Figure 1).

When compared with the previous SLMACC-funded experiments, measured EFs for the freely Canterbury drained soil were within the range predicted by the modelling. The prediction of emissions from the poorly drained soil tended to be lower than observed in the field plot.

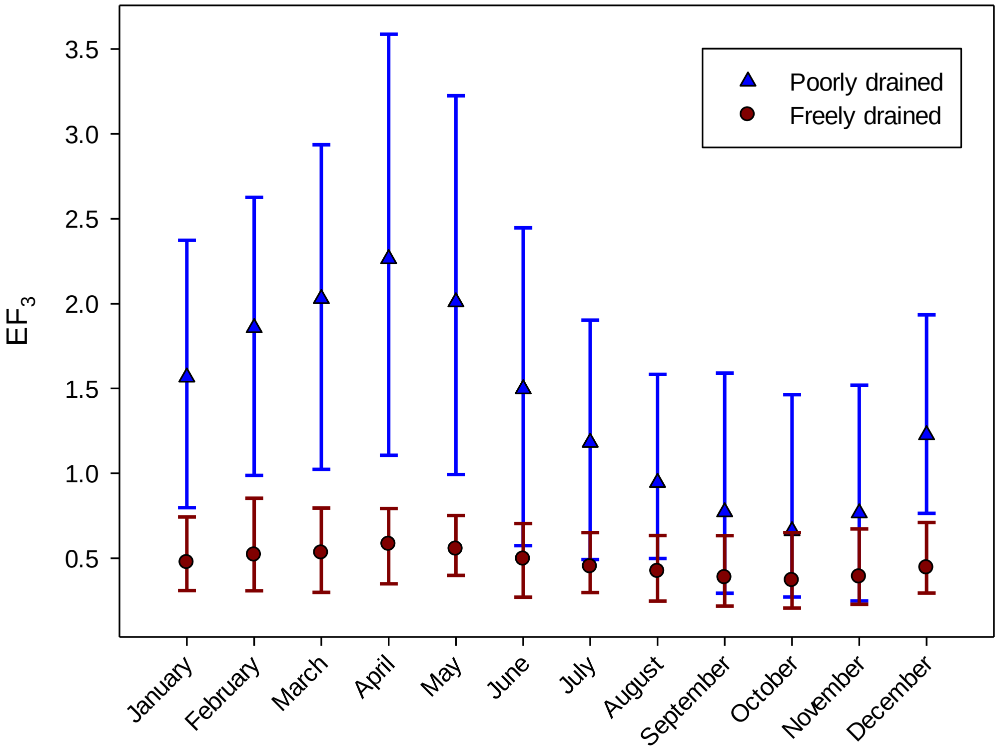

Figure 1. Effect of the timing of urine deposition on EF_3 for poorly and freely drained soils. Bars represent the maximum and minimum of monthly EF_3 values over 20 years based of APSIM simulations of six irrigation management scenarios run with climate data from a low and high rainfall site across the Canterbury Plains. Symbols are the mean of these data.

These results have not yet been published in international journals but have been presented and reported at the 2016 Fertiliser Lime Research Centre Workshop (Thomas et al. 2016b).

2.3 Summary of review of irrigation effects on EF_3

- Increase in N_2O emissions and EF_3 have been observed due to increased frequency in irrigation although not in all studies. Modelling studies indicate that increasing irrigation increases N_2O emissions.
- Larger emissions occur from poorly drained soils compared to more freely drained soils.
- Modelling indicates there are temporal differences in EF_3.
- EF_3 from field studies and modelling indicate that EF_3 may be much lower from irrigated, freely drained Canterbury soils than the New Zealand default value, although not in all studies.
- EF_3 from field studies and modelling indicate that EF_3 for poorly drained soils may be greater than the New Zealand default EF_3 value.
- There is no information comparing dryland and irrigated pastures on EF_3.
- There is a lack of information about the effect of different irrigation systems on N_2O emissions.

Table 1. Summary of studies to estimate EF_3 for irrigated soils.

	Study Main treatments	Region	Land use	Soil type Drainage Type	Season/length of study	Irrigation system/ management	Study type (measurement/ modelling)	EF_3 %	Findings and comments
1	(Thomas et al. 2013b)	Canterbury	Dairy/sheep & beef	Freely Eyre	Late-summer/ autumn	Low intensity sprinklers 3 to 15 d	Small plot Synthetic urine Manual & autochambers	0.2 to 0.4	N_2O emissions reduced with frequency of irrigation Statistical analysis. Paper in draft.
2	(Thomas et al. 2014)	Canterbury	Dairy/sheep & beef	Freely Eyre	Late-summer/ autumn	Variable – deficit trigger 3 to 7 d	Lysimeter Synthetic urine	0.5	Not affected by irrigation intensity Statistical analysis.
3	(Owens et al. 2016b)	Canterbury	Dairy	Freely Lismore	Late-summer/ autumn 1 month	3 to 6 d	Small plot Real cow urine	0.09	Not affected by irrigation frequency. Soil oxygen remained > 15 % Statistical analysis, paper accepted.
4	(Owens et al. 2016a)	Canterbury	Pasture (grazed & mowed at various times)	Poorly Wakanui	Winter 8 weeks	Manual, irregular, to create range of soil water content	Small plot Real cow urine	2.1	N_2O emissions occur when relative soil gas diffusivity is less than 0.006 Statistical analysis, paper submitted
5	(Laubach et al. 2016)	Canterbury	Dairy	Freely Lismore	3 years	Centre Pivot 3d	Paddock scale micromet	0.5 to 1.6	On irrigated pasture, N_2O emissions relatively steady over time, strong pulse events rare. Published paper for first year of data, more in preparation.
6	(Thomas et al. 2013b)	Otago	Dairy/sheep & beef	Poorly Otokia	Late-summer/ autumn	Low intensity sprinklers 3 and 14 d	Small plot Synthetic urine Manual & autochambers	2.7 to 3.4	N_2O emissions reduced with frequency of irrigation. Statistical analysis Paper in draft.
7	(Thomas et al. 2014)	Otago	Dairy/sheep & beef	Poorly Otokia	Late summer	Low intensity sprinklers 7 d	Small plot Synthetic urine Manual & autochambers	1.8 to 3.3	Withholding grazing reduced emissions Statistical analysis.

	Study Main treatments	Region	Land use	Soil type Drainage Type	Season/length of study	Irrigation system/ management	Study type (measurement/ modelling)	EF_3 %	Findings and comments
8	(Phillips et al. 2007)	Southeast Australia	Dairy	Poorly. Red-brown earth (yellow/red Sodosol)	2 years	Flood irrigation 7 to 10 d	Paddock scale micromet EFs determined for 13 grazing events	0.23	These soils are different in physio-chemical properties to irrigated soils in New Zealand. Irrigation by flood of poorly drained soils is not practiced in New Zealand.
9	(Thomas et al. 2016b)	Canterbury	Dairy	Freely Eyre Templeton	Monthly for 2 years	6 soil moisture deficit triggers	Modelled 20 years climate data for two Canterbury sites	0.37 to 0.58	N_2O emissions reduced with increasing soil water deficit triggers. Low emissions.
10	(Thomas et al. 2016b)	Otago/ Canterbury	Dairy	Poorly Otokia	Monthly for 2 years	6 soil moisture deficit triggers	Modelled 20 years climate data for two Canterbury sites	0.66 to 2.26	N_2O emissions reduced with increasing soil water deficit triggers. High emissions.
13	NZ EF_3 trial data set	Canterbury	Dairy/ sheep and beef	Freely, imperfectly drained			Non-irrigated summer scenario for Canterbury	0.4 to 3.85 Arithmetic mean = 0.8	Large emission was from a Lismore lysimeter.

2.4 Activity data – sources and availability

Based on our review of the effects of irrigation on N_2O emissions and key factors affecting the emission factors, we have assessed the sources and availability of relevant information on irrigated areas, the areas of this under various pastoral land use and the proportion of that might be associated with different soil drainage characteristics.

We have also investigated how NEX can be associated with these different categories. NEX is related to the animal type, type, number and dry matter intake and is already calculated for use in the inventory. We have commented on the availability of the activity data over time and their reliability and robustness. In the first instance we have looked at the availability of information from the Agricultural Production census and surveys conducted by Statistics NZ which are typically the preferred source of data for the inventory.

2.4.1 Irrigation, pastoral land use and soil information

Historically there has been a lack of good quantitative information for the area and type of land irrigated as reported by a number of authors (Aqualinc 2010; Ministry of Agriculture and Forestry 2004; Saunders & Saunders 2012). Agricultural Production censuses of 2002, 2007 and 2012 have collected information about the type of irrigation and associated land uses (Figure 2). An additional source of historical data is a MAF survey (MAF Irrigated Area Surveys) in 1985 reported in a Lincoln Environmental report (Lincoln Environmental 2000). To address the gap in information, surveys of the areas consented by for irrigation have been conducted (Figure 2). These include Ministry for the Environment commissioned studies in 1999, 2006 and 2010 (Aqualinc 2010; Lincoln Environmental 2000).

The consent approach results in an over-estimation of the areas actually irrigated. For example, New Zealand's total consented area was 940,000 ha in 2006 and 1 million ha in 2010 (Figure 2). These numbers are about 40% larger than the Statistics NZ census values. This is largely due to areas that have consent to irrigate but have no existing irrigation infrastructure. Current annual Statistics NZ Agricultural surveys conducted do not capture the areas irrigated.

The total irrigation area in New Zealand in 2012 was estimated to be greater than 720,000 ha and has been steadily increasing over the last three decades. Between 2007 and 2012 an additional 102,000 ha was irrigated; 60% of this occurred in Canterbury. Overall most of the irrigation in New Zealand is in Canterbury and Otago, it was estimated that 81% of all irrigation occurred in these regions (Lincoln Environmental 2000). Based on the census data, between 2002 and 2012 the area irrigated in Canterbury increased by 15,760 ha/year and by 2,500 ha/year in Otago.

Irrigation expansion is expected to steadily continue. Approximately 350,000 ha of new irrigation has been identified for development by 2025, approximately 50% more than the current area (NZIER 2010). A large proportion of this is expected to be for pasture.

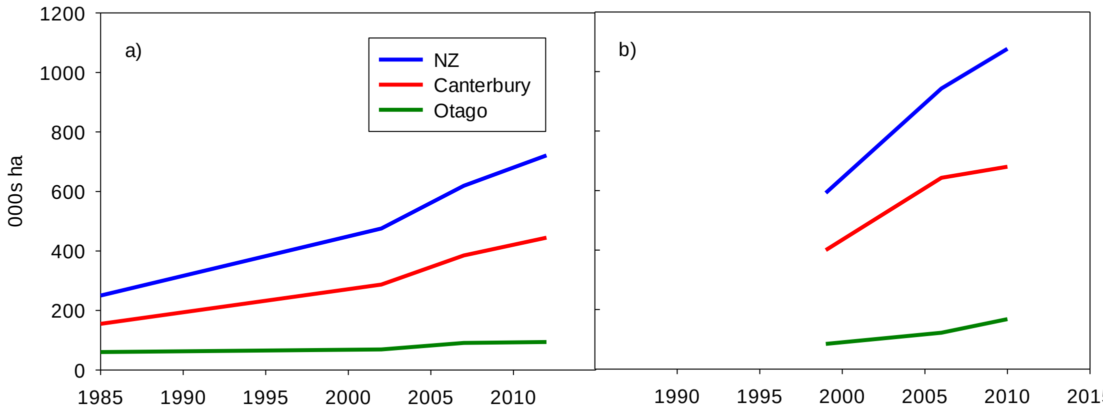

Figure 2. Estimated total irrigated areas in Canterbury, Otago and New Zealand from a) Agricultural Production census (2002, 2007 and 2012) and survey (1985) and b) from surveys for consented irrigation areas in 1999, 2006 and 2010 (Aqualinc 2010; Lincoln Environmental 2000).

There is very limited information to estimate the areas of different pastoral farming that are irrigated. The best current information is from the 2012 agricultural production census. For each region and pastoral land use category the total land area, the area irrigated and the number of animals can be estimated (Table 2 & Table 3). Similar information should be available from the earlier 2002 and 2007 censuses. Prior to this it was estimated that in Canterbury, the area of dairy pasture under irrigation increased four-fold between 1985 and 1999 to 34% of the total irrigated area in Canterbury (Ministry of Agriculture and Forestry 2004). By 2012 this had increased to more than 50% of the land irrigated in Canterbury.

The way that the data are recorded by both land use area and animal numbers means that some interpolation is required, i.e. there are additional land use categories such as Sheep & Beef and Mixed Cropping are irrigated but there is no specific information on the associated type or number of animals. However, these areas are relatively small compared with dairying, sheep and beef farms (Table 2). For example, we assume mixed cropping has a typical arable rotation including ryegrass or clover every 2 out of 6 years and these might be grazed by sheep or cattle.

Table 2. Statistics NZ 2012 Agricultural Production Census – pastoral land in Canterbury and Otago and estimated NEX based on animal numbers.

	Canterbury			Otago			Canterbury	Otago
Land use	Total Land area (ha)	Total irrigated	% Irrigated	Total Land area (ha)	Total irrigated	% Irrigated	Total NEX (000s kg N)	Total NEX (000s kg N)
Dairy	332,769	231,835	70%	127,458	32,253	25%	138,000	38,200
Sheep	1,059,178	36,777	3%	1,238,711	36,586	3%	97,008	96,914
Beef	168,134	35,165	21%	54,424	4,927	9%	36,159	22,306
Sheep & beef	567,533	16,395	3%	522,342	6,343	1%		
Deer	84,715	5,474	6%	48,565	3,456	7%	8,662	4,549
Mixed	88,578	35,383	40%	6,486	1,323	25%		
Total	**2,903,823**	**444,777**		**2,521,651**	**93,874**		**279,829**	**161,969**

Another approach to estimate the area of irrigated land use is by remote sensing. Pairman et al. (2011) used this approach to identify irrigated paddocks from satellite images collected from 2008 to early 2011. They were able to correctly classify 76% of all irrigated land using NDVI sensing and 89% of the irrigated pastoral land. Cropping paddocks were more difficult to identify as their NDVI also depends on their growth stage and the specific crop type.

Carrick et al. (2013) estimated there was a total of 143,000 ha on very freely drained stony soil in Canterbury in 2012, with about 12,000 ha in Otago. In Canterbury, of the 302,000 ha of irrigated land that could be detected with analysis of satellite images collected from 2008 to early 2011 (Pairman et al. 2011), 196,000 ha occurs on stony soils.

Apart from this study by Carrick et al. (2013) there is no published or readily available information on the area of these land uses related to the underlying soils.

2.4.2 Estimation of NEX from animal numbers and distribution information

There is good information on the regional numbers and distribution of animals based on agricultural production data fromfrom Statistics NZ from census and surveys (Table 3, Figure 3 to Figure 6). This information is currently used for the estimation of NEX in the inventory. Because of the high proportion of irrigation in Canterbury and Otago we report data from these regions.

Changes in animal numbers and distribution are of relevance for the impact of irrigation on N_2O emissions, in particular the increase in irrigated dairying. Nationally, the number of dairy cows increased from 5.3 million in 2007 to 6.4 million in 2012. Regions that had significant shifts in dairy numbers over this period included Canterbury, with an increase of 445,000 dairy cattle, Southland, with an increase of 238,000, and Otago, with an increase of 118,000.

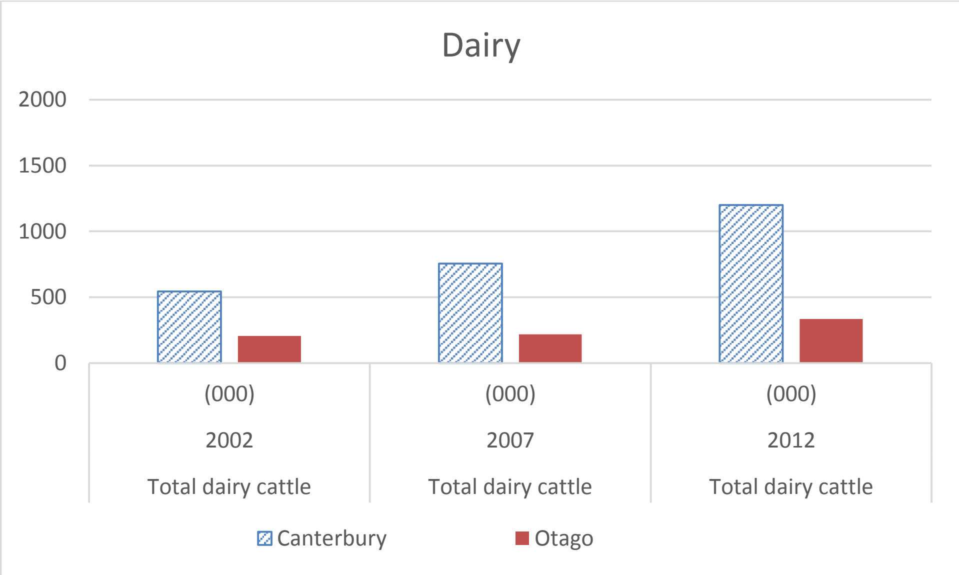

Figure 3 . Changes in dairy cow numbers between 2002 and 2012 from Agricultural production census (Statistics NZ).

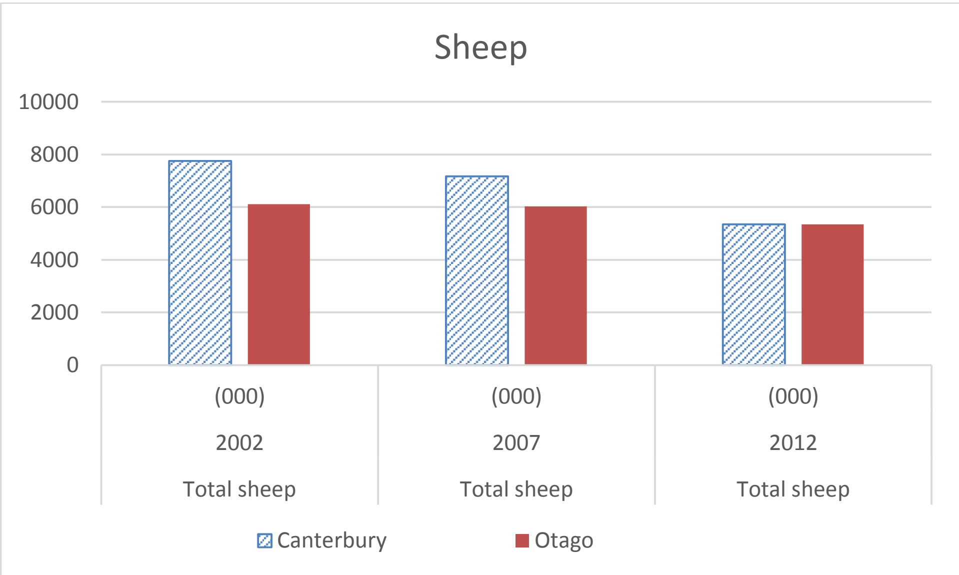

Figure 4. Changes in sheep numbers between 2002 and 2012 from Agricultural production census (Statistics NZ).

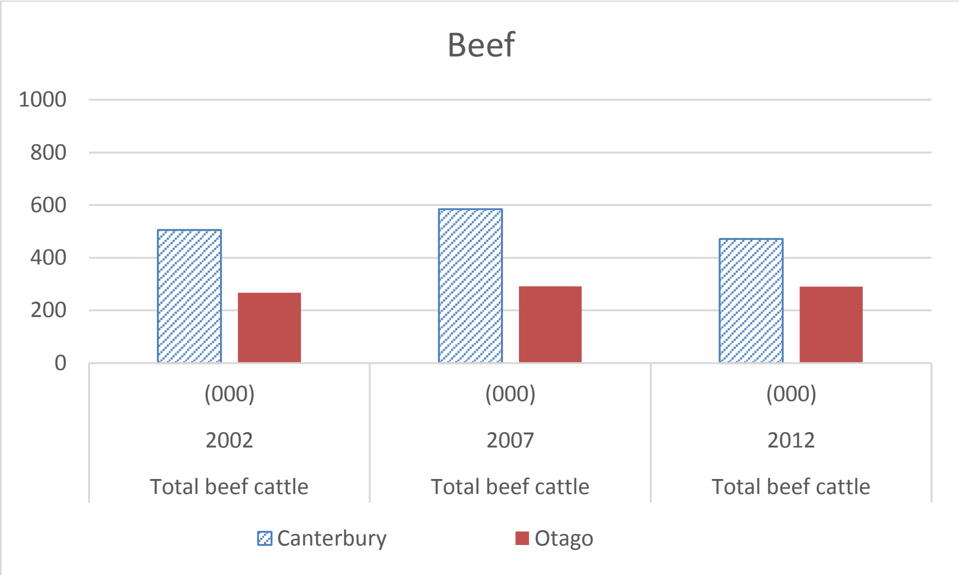

Figure 5. Changes in beef cattle numbers between 2002 and 2012 from Agricultural production census (Statistics NZ).

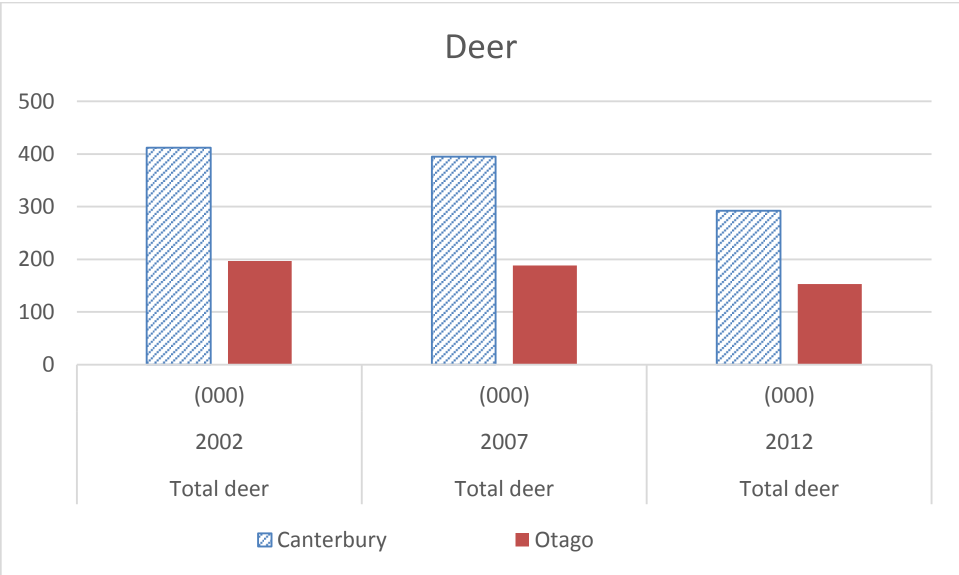

Figure 6. Changes in deer numbers between 2002 and 2012 from Agricultural production census (Statistics NZ).

However, the number of animals that are grazed on irrigated and non-irrigated land are not recorded. Therefore, additional information is required to estimate the NEX inputs between these systems. We suggest this can be done by proportioning NEX based on the relatively greater production and carrying capacity of irrigated land compared with dryland.

Table 3. Regional changes in sheep, dairy, beef and deer numbers between 2002 and 2012.

	Total sheep					Total dairy cattle					Total beef cattle					Total deer				
	2002	2007	2012	02-07	07-12	2002	2007	2012	02-07	07-12	2002	2007	2012	02-07	07-12	2002	2007	2012	02-07	07-12
	(000)	(000)	(000)	(%)	(%)	(000)	(000)	(000)	(%)	(%)	(000)	(000)	(000)	(%)	(%)	(000)	(000)	(000)	(%)	(%)
Northland	522	534	441	2.3	-3.1	405	367	398	-9.4	-3.7	468	496	381	5.8	4.1	23	8	5	-67.7	-8.0
Auckland	368	288	205	-21.9	3.5	150	113	117	-24.5	-6.0	172	157	117	-9	-1.4	20	12	13	-39.3	-14.1
Waikato	2,592	2,660	1,777	2.6	8.4	1,663	1,669	1,832	0.4	0.3	667	677	506	1.5	-0.8	143	117	81	-18.5	-2.6
Bay of Plenty	415	385	323	-7.2	-3.2	331	299	312	-9.8	0.8	135	120	93	-11.2	-0.4	73	54	42	-25.6	-8.5
Gisborne	1,679	1,825	1,547	8.7	-2.8	13	8	17	-37	13.1	310	287	268	-7.3	-2.7	26	27	17	3.7	8.7
Hawke's Bay	3,789	3,624	3,262	-4.3	-8.2	89	80	93	-9.9	2.2	556	438	471	-21.2	-7.9	127	88	70	-30.2	-0.9
Taranaki	698	656	434	-5.9	23.7	652	590	604	-9.5	-1.6	127	137	104	7.5	14.5	11	4	4	-58.6	60.5
Manawatu-Wanganui	6,564	6,747	5,613	2.8	-2.5	417	393	475	-5.6	-5.8	726	681	580	-6.2	-1.6	147	104	74	-29.4	2.4
Wellington	1,813	1,822	1,665	0.5	-5.5	111	93	108	-16.5	0.4	181	156	140	-14	-6.4	27	16	14	-41.7	28.7
Total North Island	**18,440**	**18,542**	**15,267**	**0.6**	**-2.0**	**3,832**	**3,613**	**3,958**	**-5.7**	**-1.2**	**3,343**	**3,148**	**2,660**	**-5.8**	**-1.4**	**598**	**430**	**320**	**-28**	**0.3**
Tasman	356	348	277	-2.2	-4.0	67	64	72	-5.4	6.0	49	51	40	4.9	5.3	32	21	16	-35.9	-8.2
Nelson	11	8	6	-31.1	-6.7	C	2	C	C	C	3	1	C	-50.9	C	2	C	C	C	C
Marlborough	785	579	547	-26.3	-5.3	33	24	33	-26.5	-16.3	72	66	60	-9.3	0.1	23	C	C	C	C
West Coast	93	54	58	-41.5	-43.4	125	152	174	22.3	3.0	39	30	29	-22.2	-9.5	33	42	34	25.5	-4.2
Canterbury	7,758	7,167	5,348	-7.6	-2.4	543	755	1,200	39.1	8.7	505	585	471	15.7	4.7	412	395	292	-4.1	-1.4
Otago	6,121	6,031	5,343	-1.5	-0.3	205	218	336	6.6	9.2	267	292	290	9.5	-4.8	197	188	153	-4.4	-6.5
Southland	5,951	5,662	4,356	-4.8	0.8	356	433	671	21.5	-8.2	204	208	172	1.9	-2.4	352	308	238	-12.5	-7.1
Chatham Islands	57	69	59	21.3	12.8	C	-	C	C	C	9	12	C	34.3	C	-	-	0	-	0.0
Total South Island	**21,132**	**19,918**	**15,995**	**-5.7**	**-1.0**	**1,330**	**1,648**	**2,488**	**23.9**	**3.4**	**1,148**	**1,245**	**1,075**	**8.5**	**0.2**	**1,050**	**966**	**741**	**-8**	**-4.5**
Total New Zealand	**39,572**	**38,460**	**31,263**	**-2.8**	**-1.5**	**5,162**	**5,261**	**6,446**	**1.9**	**0.6**	**4,491**	**4,394**	**3,734**	**-2.2**	**-1.0**	**1,648**	**1,396**	**1,061**	**-15.3**	**-3.0**

2.4.3 Accounting for increased pasture production due to irrigation to adjust NEX

There is limited data on the relative response of pasture to irrigation compared to dryland conditions (Martin et al. 2006). The best source of information is from the long-term sheep-grazed, border-dyke irrigation trial on freely draining Lismore soils at Winchmore, Canterbury. Monthly data have been collected from 1960 enabling comparison between dryland and irrigation treatments (Table 4 and Figure 7; from van der Weerden et al. (2009)). There were 5 treatments: dryland, irrigate at either 10%, 15% or 20% of the available soil moisture content, and 3-weekly irrigation if available soil moisture was above 20%. Assuming irrigation is applied to maximise production based on these treatments, irrigation produces 1.7 times greater production compared to dryland. However, yields of 17 t/ha were measured from spray irrigated dairy pastures in Canterbury (Martin et al. 2006) indicating that irrigated production is likely to be greater from more intensively managed irrigated farms than observed at Winchmore.

Table 4. Monthly pasture production data (kg DM/ha) from the Winchmore Long-term Irrigation trial 1960–2003.

	Soil moisture content treatment				
1960-2003	Dryland	10%	15%	20%	3-weekly
Jul	268	246	241	248	251
Aug	290	268	259	266	269
Sep	933	930	938	939	959
Oct	1687	1704	1775	1810	1844
Nov	1187	1466	1619	1774	1757
Dec	594	1328	1481	1711	1621
Jan	434	1299	1409	1676	1510
Feb	333	1010	1126	1334	1217
Mar	465	851	959	1085	1051
Apr	393	513	571	639	625
May	282	327	335	391	374
Jun	255	250	246	270	263
Total	7119	10191	10960	12143	11741

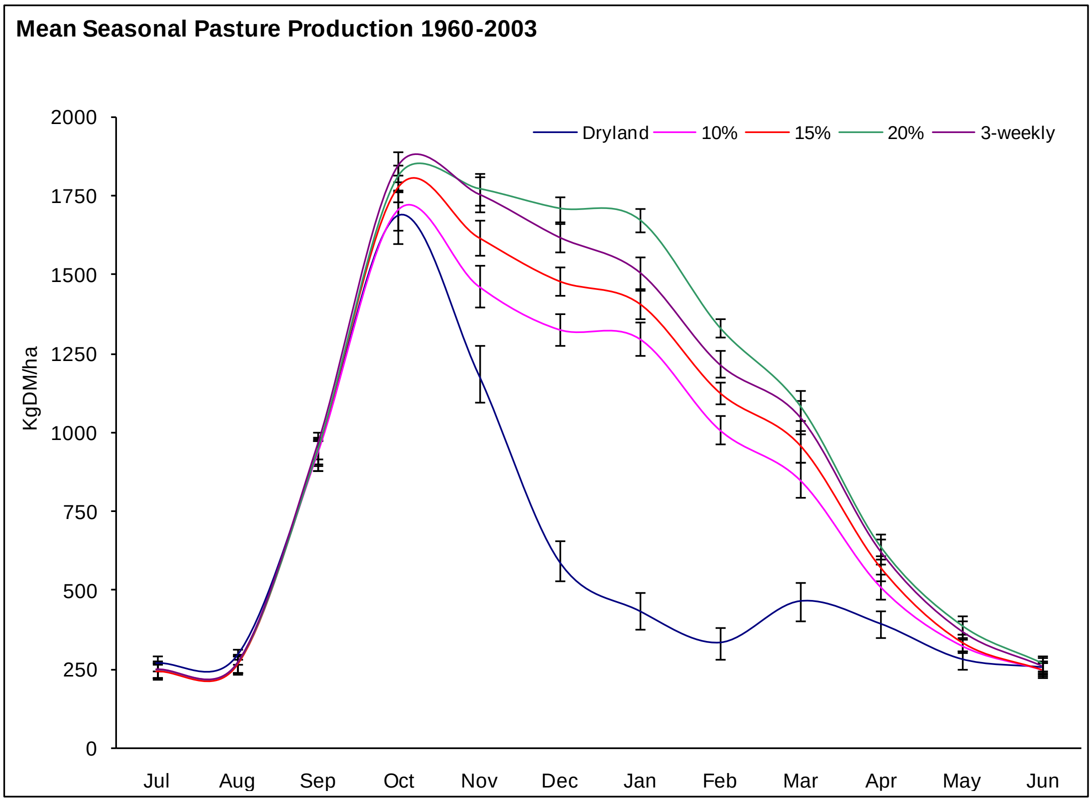

Figure 7. Monthly pasture production data (kg DM/ha) from the Winchmore Long-term Irrigation trial 1960-2003. Error bars show the standard error of the mean.

Effects of irrigation on pasture production have been measured in another field trial (LUCI North Otago trial) on an imperfectly draining soil (van der Weerden et al. 2009). Irrigation was applied by sprinklers applied every 7–14 days from October to April. Mean annual pasture yield data for 3 full years (July to June) are presented in Table 5.

Table 5. Mean annual pasture yield (kg DM/ha) from N fertilised plots from LUCI North Otago trial.

	Cattle	Sheep	Mown	Average
Dryland	6009	6129	6592	6243
Irrigated	10468	13997	13653	12706
Irrigated/Dryland	1.74	2.28	2.07	2.04

Pasture production from the North Otago trial is similar or greater than Winchmore. Focusing on sheep grazing, pasture from the North Otago has a larger response to irrigation than the Winchmore data (2.28 versus 1.70, respectively). This may be due to difference in irrigation type/management (sprinklers delivering 25 mm every 7–14 days at the LUCI trial compared with water applied by flood irrigation when plants may have been water stressed at Winchmore.

The data from these trials indicate that for both freely drained and imperfectly drained soils, pasture production is approximately double that of dryland soils.

2.4.4 Irrigation systems

In Section 2.4.1 we described the challenges with collecting accurate irrigation information. The best source of information on the types of irrigation system or management is from the Agricultural production census. In 2007 approximately 82% of irrigated land used spray (e.g. guns, rotorainers and laterals) and 17% by flood systems (e.g. border dyke) (Table 6).

Table 6. Irrigable land (ha) in Canterbury from 2007 Agricultural Production census (Statistics NZ).

	Total area equipped for irrigation	Irrigable area by flood systems	Irrigable area by spray systems	Irrigable area by micro systems	Irrigable area with systems not specified
Canterbury	385,271	64,386	313,710	5,734	13,237

2.5 Summary of review of irrigation land use activity data

- There is limited quantitative data on the amounts and type of irrigated land use.
- The best information for irrigation areas is from the Agricultural Production census, but has limited coverage from 1990 to current.
- Most of the irrigation occurs in Canterbury and Otago and is approximately 80% of all irrigation, most is in Canterbury.
- Irrigation has been increasing steadily since 1990; much of the increase has been for dairying in Canterbury and Otago.
- Most of the irrigated land occurs on freely drained soils although there is limited information on the areas of different soil classes irrigated.
- There is good quantitative information for the number of animals by land use and region from the Agricultural Production census and surveys.
- There is a lack of information on the amount of NEX distributed between irrigated and dryland systems. We suggest this could be estimated using relative differences between irrigated and dryland production.
- Most irrigation is by spray systems.

3 IMPACT OF INCLUSION OF IRRIGATION INTO INVENTORY

3.1 Modelling approach

The aim of the modelling was to estimate the impact of irrigation-based emission factors and activity data on the New Zealand inventory. The spreadsheet was specially developed to model how changing irrigation-based emission factors and activity data might impact the total N_2O emissions in the New Zealand inventory. We have designed several scenarios using information from our review. These scenarios are focussed on the Canterbury and Otago regions as these account for about 80% of New Zealand irrigated land.

3.1.1 The model

The spreadsheet model was developed by Mike Rollo (AgResearch) who has been responsible for producing models that underpin the current inventory. It is based largely on the current inventory structure with some additional functionality that is either in the current inventory model and not implemented or could be in the future. For example, regional NEX and EF_3 can be included if this level of disaggregation is included in the future.

In brief, the key inputs to model are NEX and EF_3. Annual NEX data is entered by Land use (Dairy, Beef, Deer and Sheep) and 16 regions based on APS census outputs.

NEX tables were populated for the 2002, 2007 and 2012 years and are based on data from the Agricultural Census.

NEX is apportioned between urine and dung based on animal type. The amounts of NEX between irrigated and non-irrigated land uses are modified based on estimated dry matter production from irrigated and non-irrigated land.

EF_3 values are entered for each animal type, soil type (freely and poorly drained) and month combination.

Additional functions were developed to distribute excreta between irrigated and non-irrigated land uses based on proportion of irrigation versus non-irrigated land and proportion of these that were freely or poorly drained.

Outputs:

Monthly and annual NEX and direct N_2O emissions by Regions, Land use, Soil type and Irrigation and Excreta type (dung and urine), and inferred emission factors (N_2O emission/NEX).

3.1.2 Scenarios

Based on our assessment of the available activity and emission data we have made the following assumptions:

- Regions
  - We have disaggregated regional information for two regions – Canterbury and Otago as combined these contain 75% to 81% of the total irrigated area in 2007 and 2012 (Statistics NZ). NEX for other regions is listed in Appendix 1.

- NEX
  - Is proportional to the amount of pasture produced on irrigated compared to dryland pasture. It is assumed that twice as much pasture is produced from irrigated pasture than dryland (Section 2.4.3).
  - The distribution of excreta-N between dung and urine is based on the Tier 2 Inventory model and is split evenly across the year as:

	Dairy	Sheep, beef and deer
Urine	73%	66%
Dung	27%	34%

- Soil types that are irrigated:
  - Soils were categorised into called freely drained and poorly drained soil types. This based on limited data from irrigated soils; however, there was sufficient evidence to suggest that emissions from poorly drained soils are greater than from free draining soils and are likely to increase from irrigation.
  - It was assumed that the majority of irrigation occurs on freely draining soils. For our scenarios we assumed that 80% of irrigation occurs on freely drained soils in the two regions and 20% on poorly drained soils.

- Slope
  - Slope was not included in the model since there is a lack of information on the area and emission measurements from irrigated sloping land. The majority of irrigation occurs on low slope land. Hence it is assumed that there would be no impact on the inventory

- Irrigation types:
  - We have assumed that all irrigation systems have the same effect on direct N_2O emissions.
  - Majority of irrigation of pasture is now spray irrigated.
  - We have no published data on emission from flood irrigated soils or any evidence that different spray type systems directly affect N_2O emissions.

- Irrigation management:
  - Evidence from field experiments and modelling indicates that the frequency of irrigation can impact N_2O emissions.
  - Based on the SLMACC modelling there are differences in at the emissions from low frequency irrigation triggered at large soil water deficits compared with high frequency irrigation that replaced the deficit at each irrigation.

- Emission factors
  - EF_3 for urine and dung were entered although only EF_3 for urine was changed in the model scenarios. As there are no specific data for effects of irrigation on EF_3 for dung this was not adjusted from the default value of 0.25%.
  - Selection of appropriate irrigated and dryland EF_3 data has proved challenging. Field results and the modelling suggest that EF_3 from the freely drained soils in Canterbury are typically lower than the New Zealand default value and also that EF_3 from poorly drained soils may be greater than EF_3.
  - Dryland emission factors:
    - We have assumed that the low frequency irrigation treatments from the SLMACC trials and APSIM modelling are similar to dryland EFs. This is, however, likely to be an overestimate as they produced higher yields than likely from dryland pastures.

- Temporal changes in emission factors
  - We included one scenario where we included monthly EF_3. This was based on APSIM modelling. Dryland values were assumed to be equivalent to the lowest monthly values.
- Years
  - 2002, 2007 and 2012.
  - These are dates when the census was collected providing good data.

3.1.3 Summary of the scenarios.

A brief description of the scenarios and how they are used in our assessment is provided below and through Table 7 to Table 11.

Scenario 1 – "Dryland" or baseline using New Zealand default EF_3**.**

NEX is proportioned between dung and urine. This is the currently how the inventory is calculated without irrigation, i.e. EF_3 is uniformly applied at 1%.

Scenario 2 – Effect of irrigation on increasing emissions from "dryland" Scenario 1 (doubling EF_3).

NEX is proportioned between dung and urine. In this scenario EF_3 was set at 1% for dryland and 2% for irrigation. This is only applied to Canterbury and Otago activity data.

Scenario 3 – Alternative "dryland" baseline incorporating freely draining and poorly draining EFs based on experimental data.

This scenario average EF_3 values for freely and poorly drained soils were based on the low irrigation treatments from the SLMACC field experiments. NEX was proportioned between dung and urine and there was no irrigation EF_3.

Scenario 4 – Effect of irrigation on increasing emissions based on the "dryland" Scenario 3 (experimental data).

NEX proportioned by dung and urine ratio. Feed (and NEX) is proportioned based on additional feed produced from irrigation based on pasture responses described in Table 4. Land use data from 2012 census is applied (Table 2).

Dryland EF_3 for the two soil types were the same used in Scenario 3 (based on low frequency irrigation). Whereas the higher irrigation EF_3s were the same as measured from was the high frequency irrigation treatments form the SLMACC field trials, i.e. approximately 100% and 25% greater for the freely and poorly drained soils respectively.

Scenario 5 –"Dryland" baseline – freely draining and poorly draining EFs (model data).

This is similar to Scenario 3 except the average EF_3 for freely and poorly drained soils based on the low irrigation treatments from the SLMACC modelling was used. NEX proportioned between dung and urine. As this is a dryland type scenario there was no irrigation EF_3.

Scenario 6 and 7 – Effect of irrigation on increasing emissions from Scenario 5 (model data) using average (Scenario 6) and maximum (Scenario 7).

To provide an indication of the potential range of EF_3 for irrigated soils these scenarios were run using average and maximum EF_3s from the SLMACC modelling and compared with the non-irrigation scenario (Scenario 5).

Scenario 8 – Effect of irrigation on increasing emissions from Scenario 5 (model data) – monthly data.

This scenario was included to assess whether there might be any benefit in including monthly EF_3s, which might reflect the irrigation season. The data used were the mean values in Figure 1 (Table 11).

Table 7. Annual EF_3 (urine) used in assessment of inclusion of irrigation using an inventory spreadsheet model.

	Canterbury and Otago					NZ	
	Dryland		Irrigated				
Scenario	Freely drained	Poorly drained	Freely drained	Poorly drained	Inferred EF_3 (dung + urine)*	Inferred EF_3 (dung + urine)*	Comments
1	1	1	1	1	0.75%	0.76%	Default EF_3
2	1	1	2	2	0.94%	0.78%	Doubling EF_3 for irrigated land
3	0.2	2.7	0.2	2.7	0.55%	N/A	Baseline based on SLMACC field data (low frequency treatment).
4	0.2	2.7	0.4	3.4	0.61%	N/A	Greater irrigation EF_3 based on SLMACC field data
5	0.4	1.3	0.4	1.3	0.47%	N/A	Baseline based on APSIM modelling (low frequency treatment).
6	0.4	1.3	0.5	1.6	0.51%	N/A	"Average" Irrigation EF_3 based on average effects of irrigation versus low frequency irrigation from APSIM modelling.
7	0.4	1.3	0.85	3.6	0.62%	N/A	High irrigation EF_3 based on maximum of irrigation versus low frequency irrigation from APSIM modelling.
8	0.3 min monthly	0.6 min monthly	See Table 11		0.51%	N/A	Average monthly EF_3 from APSIM modelling.

* Inferred EF_3 = Total N_2O emissions/Total NEX (%). EF_3 for dung is 0.25%. N/A = not applicable. Inferred values for NZ were only calculated for Scenarios 1 and 2 as this allowed comparison with total NZ emissions using the dryland New Zealand default EF_3 (1%) for every region. In the other scenarios the effects of changing the dryland and irrigated values were only applied to the Canterbury and Otago, based on modelling and measurements. Without basis to vary dryland emission factors other regions it was not considered useful to infer or interpret a national emission factor.

Table 8. Summary of assessments using the range of scenarios (Section 3.1.2, Table 7).

				Change in average inferred EF_3 (%)		
Assessment	Description	Scenarios compared	Effect of soil class	Canterbury and Otago	New Zealand	Comment
1	Effect of including an EF_3 for irrigation that is double the New Zealand default value.	1 and 2	No	25	3	Able to compare Scenario 2 against current Inventory factors.
2	Effect of including measured EF_3 values for Canterbury and Otago irrigated soils applied to NEX.	3 (no irrigation) and 4 (irrigation)	Yes	10	N/A	Probably more realistic values for irrigated soils.
3	Effects of including modelled EF_3 values for Canterbury and Otago irrigated soils applied to NEX.	5 (no irrigation), 6 and 7	Yes	7 to 31	N/A	Range of modelled values allows assessment of how emissions might vary depending on climate.
4	Benefits of including monthly EF_3	5 (no irrigation) and 8	Yes	7	N/A	

N/A = not applicable

Table 9. Excretal inputs for scenarios in Section 3.1.2 and Table 7.

		Dairy (000s kg N)			Sheep (000s kg N)			Beef (000s kg N)			Deer (000s kg N)			Total (000s kg N)		
		2002	2007	2012	2002	2007	2012	2002	2007	2012	2002	2007	2012	2002	2007	2012
Urine	Canterbury	44822	62634	100740	87728	79961	64025	24560	28966	23865	8260	7667	5717	165370	179227	194347
	Otago	17009	18177	27886	69213	67290	63963	12978	14480	14722	3761	3652	3002	102961	103600	109574
Dung	Canterbury	16578	23166	37260	45193	41192	32983	12652	14922	12294	4255	3949	2945	78678	83229	85482
	Otago	6291	6723	10314	35655	34665	32951	6686	7460	7584	1938	1882	1546	50569	50729	52396

Table 10. Areas of land irrigated for different land uses from 2012 Census data; inputs for Scenarios 4, 6 to 8 (Section 3.1.2 and Table 7).

	Canterbury		Otago	
Land use	% irrigated area by land use	% of land freely drained	% irrigated area by land use	% of land freely drained
Dairy	70%	80%	25%	80%
Beef	18%	80%	8%	80%
Deer	6%	80%	7%	80%
Sheep	4%	80%	2%	80%

Table 11. Table of Average Monthly emission factors (Scenario 8) (Source: APSIM modelling, (Thomas et al. 2016b)).

		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Dryland	Freely drained	0.4%	0.4%	0.3%	0.3%	0.3%	0.4%	0.4%	0.5%	0.5%	0.5%	0.5%	0.5%
Irrigated	Freely drained	0.5%	0.5%	0.4%	0.4%	0.5%	0.5%	0.5%	0.6%	0.6%	0.6%	0.6%	0.5%
Dryland	Poorly drained	1.1%	0.9%	0.7%	0.6%	0.6%	1.0%	1.4%	1.7%	1.8%	2.1%	1.9%	1.4%
Irrigated	Poorly drained	1.3%	1.1%	0.9%	0.8%	0.9%	1.5%	1.8%	2.1%	2.2%	2.4%	2.1%	1.6%

3.1.4 Results and discussion from the scenarios modelling

In our first analysis we have examined how applying a higher emission factor could affect emissions from Canterbury and Otago, and compared this scenario with national N_2O emissions (Scenarios 1 and 2). Based on the NEX estimates using the default EF_3 value (1%), N_2O emissions for Canterbury and Otago and were 24, 26 and 27% (from 3.0 to 3.4 Gg N_2O-N) of New Zealand's total N_2O emissions in 2002, 2007 and 2012 respectively (Figure 8). This increased to 28, 30 and 33% for 2002, 2007 and 2012, respectively when the EF_3 was doubled for irrigated land in Canterbury and Otago.

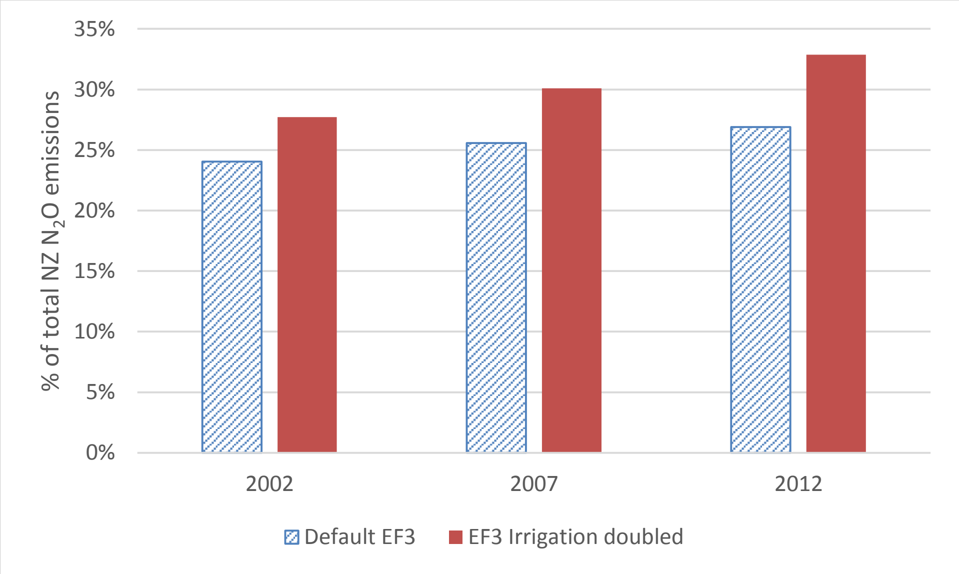

Figure 8. Effect of doubling EF_3 (urine) for irrigated land in Canterbury and Otago on national N_2O emissions between 2002 and 2007 (Scenarios 1 and 2, respectively). Blue bars are the estimated emissions based on applying the default EF_3 value of 1%. Increased emissions are due to applying an EF_3 value of 2% to irrigated land.

Increases in calculated N_2O emissions between 2002 and 2012 reflect both the increase in NEX for the regions and the higher EF_3 value applied to irrigated pasture (Figure 9). Increases in urine-N that drive the increased emissions are due to the greater increase in dairy urine and a greater proportion of NEX due to pasture production (Figure 10).

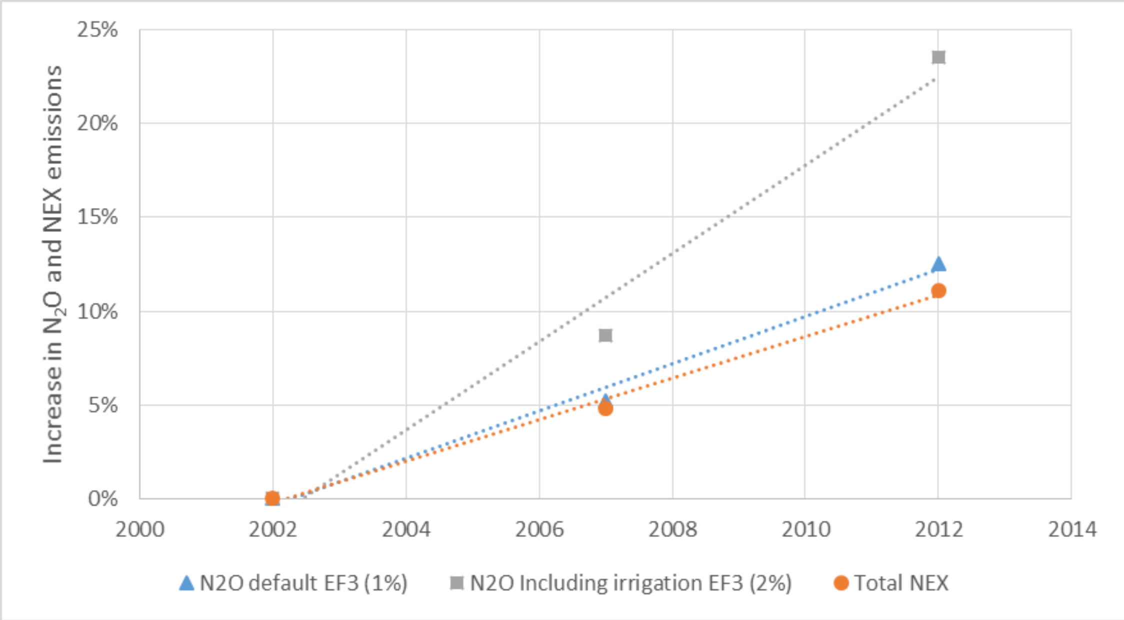

Figure 9. Increase in total N_2O emissions from Canterbury and Otago between 2002 and 2012 when the default EF_3 for urine (1%) is applied across all land (triangles) and when EF_3 is doubled for irrigated land (squares) and total NEX (circles) for Canterbury and Otago.

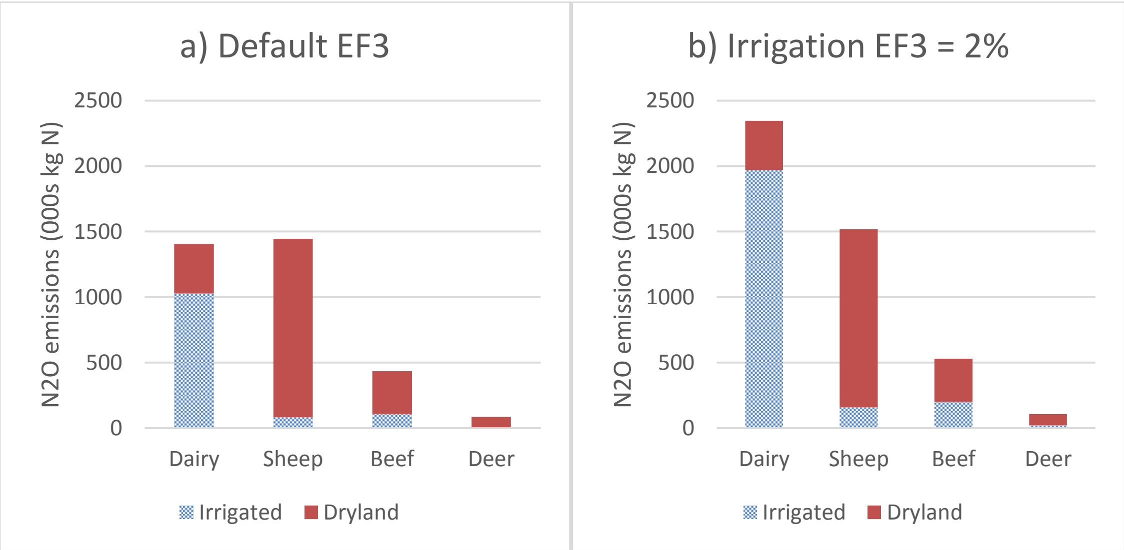

Figure 10. Effects of increasing EF_3 on N_2O emissions from a) 1% (default New Zealand value) to b) 2% for irrigated land use in Canterbury and Otago (Scenarios 1 and 2). Estimated using NEX data calculated from 2012 Census.

As field and modelling suggested the dryland EF_3 values are lower than the New Zealand EF_3 default value we next assessed how emissions might be affected when soil-specific emission factors were applied. We based the dryland emissions on the low frequency irrigation treatments for freely drained and poorly drained soils (EF_3 of 0.2 and 2.7% for freely and poorly drained soils, respectively) and the higher irrigated factors based on the high frequency irrigation treatment from the SLMACC field trials (EF_3 of 0.4 and 3.4% of the freely and poorly drained soils, respectively) (Table 7 and Section 2.2.1). The inclusion of the higher emission factors for irrigation increased emissions by 9 to 14% between 2002 and 2012 (Figure 11).

Note these emissions are much lower than those estimated in Figure 10. This is largely due to the measured freely draining soil emission factors being 2.5 to 5 times lower than the default EF_3 value.

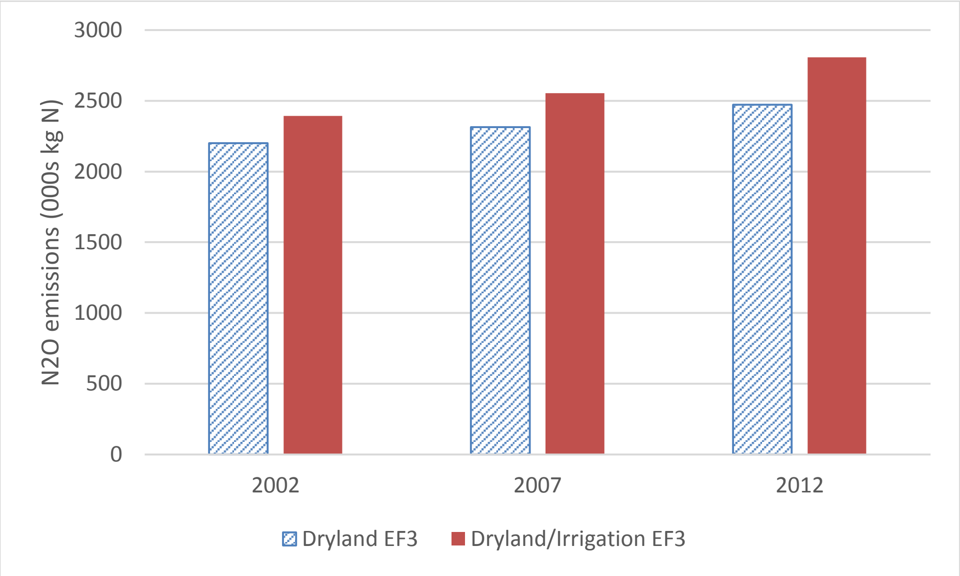

Figure 11. Effect of inclusion of freely and poorly drained EF_3s on dryland (blue bars) and with an irrigation EF_3 applied (red bars) for Canterbury and Otago (Scenarios 3 and 4).

Greatest emissions were predicted from dairying after the increased EF_3 values were included (Figure 12). The emissions from the poorly drained soils were always much larger than freely drained soils due to the large difference in emission factors.

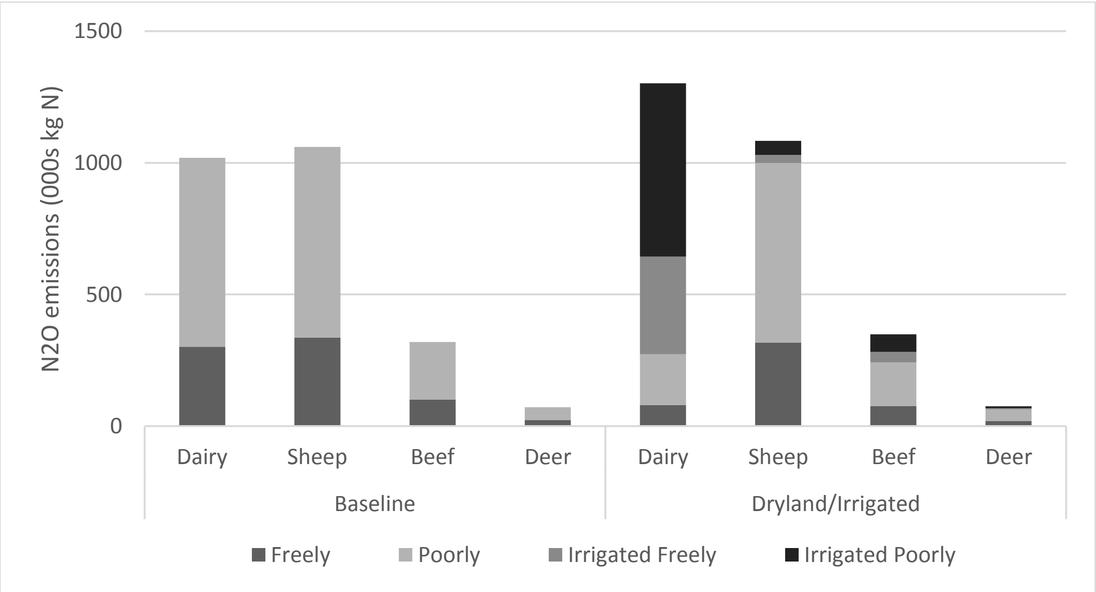

Figure 12. Effect of inclusion of different soil type based EF_3s (freely and poorly drained) on N_2O emissions from different pastoral land uses. Baseline does not include an increased EF_3 for soil type. NEX data used for emission calculations is estimated using 2012 animal numbers (Scenarios 3 and 4).

Figure 13 shows the results from using the range of modelled EF_3 values from APSIM. We assumed the dryland EF_3 values were 0.4 and 1.3% for the freely and poorly drained soils (Scenario 5, Table 7). Using average annual or monthly EF_3 outputs from APSIM the effect of irrigation ranged from 6 to 9% between 2002 and 2012 (Scenarios 6 and 7). Using the maximum EF_3 values, N_2O emissions by up to 28 to 43%; this gives the upper range predicted by the APSIM modelling.

Monthly values are similar to the annual average values as they were based on monthly average EF_3 values (Scenario 8 and Figure 1).

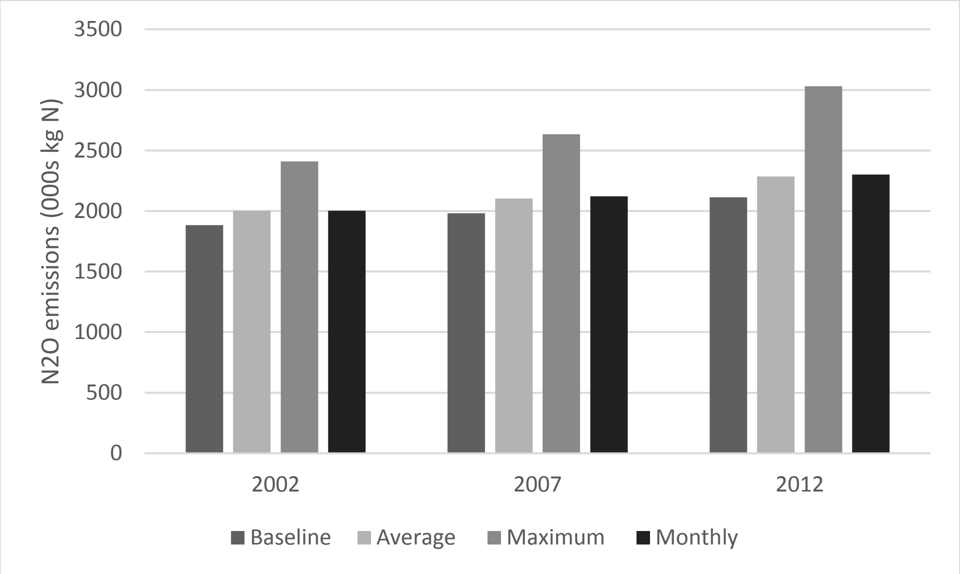

Figure 13. Results from four different scenarios run with EF_3 data from APSIM modelling of effects of irrigation on N_2O emissions from freely and poorly drained soils from Canterbury and Otago (Scenarios 5 to 8).

3.1.5 Effect on inferred EF_3

Results of included increased emission factors on the inferred EF_3 are given in Table 7 andTable 8. Applying an increased EF_3 (urine only) based on field trial and modelled results increased the inferred EF_3 for Canterbury and Otago by 7 to 31%.

The effect on the inferred EF_3 for New Zealand is much less. When we doubled EF_3 to 2% for irrigated land this increased the inferred EF_3 by 3%, from 0.76 to 0.78% (Table 8). We did not compare the change in the national inferred EF_3 with any other scenarios as we used different dryland EF_3 values for Canterbury and Otago (Table 7).

Our simple scenario comparisons demonstrate that national N_2O emissions would increase if there was a larger emission factor due to irrigation. However, this is likely to be small based on the increase observed with inferred emissions factor. Our ability to reasonably quantify an appropriate EF_3 is greatly limited by the variability in measured of inferred EF_3 from a small number of studies.

3.2 Summary of findings from the modelling exercise

- Canterbury and Otago currently contribute about one-quarter of New Zealand’s N_2O emissions; this contribution has been increasing since 2002.
- Increasing the emission factor for irrigation based on modelled and measured information will increase N_2O emissions.
- The impact on total New Zealand emissions is likely to be small based on comparison of inferred EF_3. Doubling the default EF_3 value for irrigated pastoral land in Canterbury and Otago increased the inferred emission factor for the whole of New Zealand by 3% (from 0.76 to 0.78%).
- Irrigated dairying had the greatest emissions from a land use due to their relatively large NEX inputs.
- Selection of appropriate EF_3 values for irrigation is challenging. Emissions estimated using EF_3 values from the SLMACC field trials or modelling were lower than the New Zealand default EF_3 value. This is largely due to low emission factors for freely drained soils that are likely to dominate Canterbury and Otago irrigation. EF_3 (urine) used in some scenarios was greater than the value used for dung.

4 DISCUSSION AND RECOMMENDATIONS

4.1 Emission factor

We have reviewed the effect on the EF_3 of urine only. There is a lack of information on the effects of irrigation on either EF_3 for dung or EF_1 for fertiliser or manures. Our review found that even within those limited studies with urine amended soils that the manner of irrigation might influence whether there is an effect or not. Irrigation management is likely to have a large effect on emissions. Overall, modelling and field trials indicate that where soils were maintained wet (frequently irrigated back to field capacity) emissions would be enhanced, and through less frequent irrigation and retaining greater soil moisture deficit these emissions can be reduced (Thomas et al. 2016b).

Per hectare, N_2O emissions from irrigated land will be greater than non-irrigated land, even if the EF_3 is not modified. This is due to increased NEX inputs from the greater feed consumed due to increased production (per ha). This is particularly the case for Canterbury and Otago where the rapid expansion in more intensive dairying has been enabled through irrigation. As the inventory applies emission factors to the total amount of N inputs at a national level, per ha emissions are currently not important. However, if in the future disaggregation of emissions based on land use, or soil based criteria at different spatial (e.g. regional) or time scales then this would become important.

We have shown that irrigation of pasture in Canterbury and Otago makes an important contribution to national N_2O emissions. More than a quarter of reported New Zealand emissions come from these two regions and this proportion has been increasing. Our analysis shows that irrigated dairying is the most important single contributor of these emissions at a regional level. Growth of dairying has led to the increase in contribution from Canterbury and Otago since at least 2000.

Our review and analysis has highlighted the potential over-estimation of emissions from freely drained soils in Canterbury and Otago. Measurements from field plot trials and modelling suggest that the EF_3 for dryland and irrigated freely drained soils (<0.5%) are half the current New Zealand default EF_3 (1%). Conversely, predicted and measured emission factors from irrigated poorly drained soils (a single field site) were much larger than the freely drained soils, and larger than New Zealand's EF_3 value. However, previous meta-analysis from more than 40 non-irrigated field studies doesn't support this observation. Hence before considering disaggregating land by irrigation and/or soil drainage class a better understanding of the drivers of these differences in findings is required.

We have considered whether a modified or new EF_3 for irrigation should be recommended. Although, there is evidence that irrigated soils are going to emit more N_2O and recognising this in the inventory should enable more accurate quantification of emissions, our recommendation is that **there is <u>currently</u> insufficient justification or supporting information for modifying or applying a new EF_3 value for irrigation for the following reasons:**

- The value(s) would be highly uncertain based on limited data.
- The increase in inferred EF_3 appears to be small if irrigation is accounted for, and based on current land use.
- Evidence of effects of irrigation on emissions is highly variable. This variability is likely to be affected by both soil type and the type of irrigation management. Studies on similar

soils under similar climate regimes have reported strong or no response. More information is required to understand and quantify this variability.

- Emissions from freely drained soils, the major irrigated soil type, appear to be much smaller than the New Zealand EF_3 value. This needs further investigation and needs to be addressed for dryland as well as irrigated soils.
- There are limited or no data for irrigation derived emission factors from dung and fertiliser.
- There is a lack of international data to support any revision of EF_3 from irrigated pasture. Most key information is from the few New Zealand studies.

This uncertainty in the value for EF_3 for irrigated land can be addressed in the future through some targeted field studies supported by modelling. Modelling approaches have been used overseas to derive emission factors for fertiliser under different environmental conditions.

If more information becomes available to confidently derive irrigation-based emission factors then the simplest approach based on our current inventory methodology would be to use an inferred emission factor, i.e. increase the emission factor based on higher relative emissions from irrigation. This is a similar approach to that used for EF_1 for fertiliser that combines urea and other N fertiliser sources into a single EF_1 value.

The inferred emission factor will increase if more relatively more land is converted from dryland. Projections are that irrigation could increase by 50% by 2025 (NZIER 2010).

4.2 Activity data

Key activity data that would need to be derived are proportions of NEX produced from irrigated and dryland land uses. Estimates of NEX are currently used in the inventory at the national scale and are based on animal numbers from Statistics NZ surveys and census. It can be determined by animal classes at regional scales as we used in our analysis.

In our model we achieved this by apportioning NEX on the basis of difference in pasture production due to irrigation and by the proportion of land use that was irrigated. Based on the limited data available we assumed pasture production (per ha) would be doubled due to irrigation (Section 2.4.2). If this method of estimation was adopted then this assumption should be further checked and tested using other datasets (this may need new targeted experiments) and modelling.

The best available data source to determine the relative area of a land use that is irrigated is from the Statistics NZ census and MAF survey data. This is available from Statistics NZ at the Regional scale. Unfortunately, this is collected less frequently and there is no census information between 1990 and 2002. It does not appear to be collected in the annual surveys. There is a 1985 MAF survey that has been reported that could be used to help interpolate increase in area irrigated since 1990 (Figure 2; Lincoln Environmental (2000)). While information on different types of irrigation systems (e.g. flood, spray and microsprinkler) is collected, there is a lack of information to link irrigation type to N_2O emissions. More useful information would be how irrigation is managed (i.e. establishing relationships between irrigation management and soil water contents), but it is unclear how this might be achieved.

We have already highlighted the potential influence of soil type on EF_3. If future analysis suggests there is a benefit in disaggregating emissions by soil type then disaggregating by irrigation and soil type should be considered, as we have done in our scenarios.

Irrigation information has not been associated to soil type except by the work reported by Carrick et al. (2013). However, if this approach was used it would require correction by ground truthing (Pairman et al. 2011). It should be possible use the GIS methods to merge soil database and remote sensed data to do this (Landcare Research have this information and capability). It is unclear whether this approach could be used to gather information back to 1990.

If irrigation is included in the inventory then we recommend the following activity data sources are used:

- Current approaches for estimating NEX, which could be reported regionally.
- Statistics NZ agricultural production census information and MAF survey information to provided irrigated area information.
- As most irrigation is practiced in Canterbury and Otago (about 80%), then to account for the effect of irrigation on total New Zealand emissions we recommend that NEX is proportioned between dryland and irrigated land for these two regions. We recommended this approach if there is no other regional disaggregation in the inventory.
- Consideration of disaggregating by soil type and irrigation/dryland. This is only likely to be useful if our current inventory approach and understanding of soil type effects on emissions changes.

In addition, the pasture responses to irrigation need to be thoroughly assessed to correct NEX inputs.

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APPENDIX 1. ANNUAL EXCRETAL-NITROGEN (NEX) FOR DIFFERENT ANIMAL TYPES CALCULATED FOR 2002, 2007 AND 2012 BY REGION BASED ON AGRICULTURAL PRODUCTION CENSUS DATA.

	Total nitrogen excreta (NEX) (Gg N)											
	Sheep			Dairy cattle			Beef cattle			Deer		
	2002	2007	2012	2002	2007	2012	2002	2007	2012	2002	2007	2012
Northland	8.9	9.0	8.0	44.2	39.8	43.2	34.5	37.2	29.2	0.5	0.2	0.2
Auckland	6.3	4.9	3.7	16.2	12.3	13.2	12.7	11.8	9.0	0.6	0.4	0.4
Waikato	44.4	45.0	32.2	191.0	189.0	214.0	49.1	50.8	38.9	4.0	3.4	2.4
BOP	7.1	6.5	5.9	37.3	34.9	37.8	9.9	9.0	7.2	1.9	1.6	1.3
Gisborne	28.8	30.9	28.1	1.2	0.7	1.7	22.8	21.6	20.6	1.0	0.8	0.5
Hawkes Bay	64.9	61.3	59.2	8.6	8.3	9.8	40.9	32.9	36.2	4.1	2.6	2.1
Taranaki	12.0	11.1	7.9	72.2	67.2	73.4	9.4	10.3	8.0	0.2	0.1	0.1
Manawatu-Wanganui	112.5	114.1	101.8	46.1	44.6	54.5	53.5	51.1	44.5	3.8	3.1	2.2
Wellington	31.1	30.8	30.2	12.1	10.8	12.5	13.3	11.7	10.8	0.7	0.5	0.4
Marlborough	13.5	9.8	9.9	3.3	2.7	3.5	5.3	4.9	4.6	0.6	0.4	0.2
Tasman	6.1	5.9	5.0	7.9	7.7	8.7	3.6	3.9	3.1	0.9	0.6	0.5
Nelson	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.0	0.0	0.0
West Coast	1.6	0.9	1.1	14.6	18.2	21.0	2.9	2.3	2.2	1.2	1.2	1.0
Canterbury	132.9	121.2	97.0	61.4	85.8	138.0	37.2	43.9	36.2	12.5	11.6	8.7
Southland	102.0	95.7	79.0	43.1	52.1	82.4	15.0	15.6	13.2	10.8	9.0	7.1
Otago	104.9	102.0	96.9	23.3	24.9	38.2	19.7	21.9	22.3	5.7	5.5	4.5

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