A FRAMEWORK TO ESTIMATE NITROUS OXIDE EMISSIONS AT REGIONAL AND NATIONAL SCALE

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Abstract
The current method for calculating direct nitrous oxide (N_2O) emissions from agricultural soils in the National Inventory uses a constant emission factor (EF) multiplied by the nitrogen (N) input from fertiliser and animal excreta. However, N_2O emissions are actually the result of complex soil microbial processes, and soil properties, climate conditions and management practices can also influence emission levels. The National Inventory method is therefore limited in its ability to account for regional differences in N_2O emissions resulting from differences in soil, climate and management practices.

An alternative approach to estimate emissions is the use of the process-based DeNitrification DeComposition (DNDC) model. This model has been modified by taking account of New Zealand soils, climate, and grazed pasture management (NZ-DNDC), and used to estimate anthropogenic N_2O emissions in the Manawatu-Wanganui region. However, the model takes a long time to run when simulating a large number of points as it simulates many soil properties at daily time steps, and it is not easily integrated into GIS software. Further model simplification is therefore necessary to upscale NZ-DNDC to regional and national scales.

Here, we propose a framework whereby multi-year NZ-DNDC simulations are used to generate EFs (with uncertainties) over the range of soils, climates and farm systems and management practices occurring in New Zealand. The soil types are based on the New Zealand Soil Classification (NZSC) and climate zones determined from LENZ level 2 data (Leathwick et al. 2002). The framework will initially be based on 'average' farm management practices of dairy, intensive sheep and beef, hill-country sheep and beef, and deer farms, but will have the provision to accommodate other farm types, new management practices and mitigation strategies (e.g. the use of nitrification inhibitors, stand-off paddocks). This framework will be used to estimate the impacts of land use, grazing regime, land-management practices and mitigation strategies on N_2O emission in a fast and efficient way, enabling stakeholders to explore future scenarios for land management.

Introduction
Nitrous oxide from agricultural soils is a major source of greenhouse gas emissions in New Zealand accounting for 15.2% of total greenhouse gas emissions (Ministry for the Environment, 2010). New Zealand currently uses country-specific emission factors to calculate direct nitrous oxide emissions from animal excreta and fertiliser application to agricultural soils. However, N_2O emissions are actually the result of complex soil microbial processes, and soil properties, climate conditions, and management practices can also influence emission levels. The National Inventory method is therefore limited in its ability to account for regional differences in N_2O emissions resulting from differences in soil, climate and management practices.

DNDC (DeNitrification DeComposition) is a process-based model developed in the USA to calculate greenhouse gas emissions from agricultural soils (Li et al. 1992a, b). The model has since been adapted and applied in many different farm systems and countries (Giltrap et al. 2010a). In New Zealand, a modified version of the model (NZ-DNDC) has been used to model N_2O emissions from dairy-grazed farms (Saggar et al. 2004), and N_2O and CH_4 fluxes from a sheep grazed farm (Saggar et al. 2007). There has also been some work on modelling the effects of nitrification inhibitors on N_2O emissions (Giltrap et al. 2010b).

The DNDC model can also be run at regional to national scales. Previous regional scale studies using DNDC include net N_2O emissions, NO_3^- leaching and NH_3 volatilisation from agriculture in the UK (Brown et al. 2002), N_2O and NO from European forests (Kesik et al. 2005), N_2O emissions from agriculture in the USA (Li et al. 1996), and greenhouse gas emissions from rice production in China and India (Li et al. 2004; Pathak et al. 2005). Giltrap et al. (2008) used the NZ-DNDC model to simulate agricultural N_2O emissions in the Manawatu-Wanganui region of New Zealand.

There are some disadvantages to using the NZ-DNDC model at regional to national scale. First, it can take a long time to run a regional simulation when there are a large number of polygons, farm types and climate years to be considered. This makes it cumbersome for performing multiple scenario analyses. Second, the DNDC source code is proprietary and the standard user interface is not easily integrated into other software (e.g. GIS applications). For these reasons, we propose to use the NZ-DNDC model to generate look-up tables of emission factors that take soil, climate and management factors into consideration.

Proposed Methodology

To run DNDC in Regional Mode, the region is broken down into spatial units or zones with homogeneous soil and climate properties within each zone. “Farm Types” are defined as sets of common management practices (e.g. crop or stock type, grazing times and stocking rates, fertilizer timing and application) and within each zone the number of hectares in each defined “Farm Type” is specified. For each zone, maximum and minimum values for SOC, clay content, pH and bulk density are specified. The model uses these ranges to estimate the uncertainties in a particular output (e.g. N_2O emissions) by running two simulations using the extreme values of the most sensitive factors for that output (Li et al. 2006). Our proposed methodology is to use the regional mode of NZ-DNDC to generate look-up tables of N_2O emission factors for combinations of soil type, climate class and farm type. The soil-climate combinations will have the ranges of soil properties (min and max) required for the uncertainty assessment.

Figure 1 shows this schematically. Since we are generating emission factor look-up tables, the EF can be multiplied by the nitrogen inputs to estimate N_2O emissions. Spatially explicit nitrogen inputs can be generated from land-use maps.

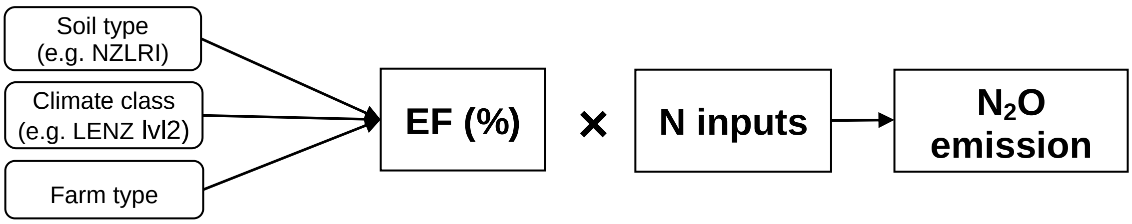

Figure 1: Schematic diagram of the proposed methodology.

Soil type

The New Zealand Land Resource Inventory (NZLRI) contains the soil information that can be used to run NZ-DNDC in regional mode (refer to Giltrap et al. (2008) for an example). For the soil types to include in the look-up tables we will use the New Zealand Soil Classification (NZSC) sub-groups. The ranges of SOC, clay content, bulk density and pH values in each soil sub-group will be used to estimate the uncertainties of the EF estimates of each soil type.

Climate class

The Land Environments of New Zealand (LENZ) database divides New Zealand into ecologically similar regions on the basis of climate, landform and soil (Leathwick et al. 2002). The climate classes used in the look-up tables will be based on level 2 LENZ data. Table 1 shows the climate classes being considered. Some of the level 2 categories have been combined as they were considered climatically similar (differing mainly in soil types). Climate classes unsuitable for agriculture (e.g. alpine regions) were excluded.

Table 1: Climate classes for look-up table based on LENZ level 2

Climate Class (Look-up table)	LENZ level 2
A	A1, A2, A3, A6, G1, G4
B	A4, A5, A7
C	B1, B2, B3, B4, B5, H1, H3, I3, J1
D	B6, B7, B8, B9, I4, J3
E	C1, C2, C3, I1, I2, J4
F	D1, D2
G	D3, D4, G2, G5, G6, I5, I6
I	E1, E2, E3, E4, K2
J	F1, F2, F3, F7
K	F4, F5, F6, G3, H2, H4
L	L1, L2, L3, L4, L5
M	M1, M2, M3, M4
N	J2, K4, K5, N1, N2, N3
O	K3, N4, N5, N6, N7, N8
P	Q1, Q2, Q3
Q	Q4
Z (Unsuitable)	all others

NZ-DNDC requires daily temperature, precipitation and solar radiation data for each climate region. Giltrap et al. (2008) found that simply changing from 2003 to 2004 weather data while keeping all other factors constant resulted in a change in estimated N_2O emissions of almost 20%. Therefore we will use 20 years of weather data to generate long-term average EF values and to estimate inter-annual variability in N_2O emissions.

Farm type

The NZ-DNDC farm type specifies management practices, such as animal types, stocking rates, timing, and amount of fertiliser applications and whether set stocking or rotational grazing is practiced. For the Manawatu-Wanganui simulation, Giltrap et al. (2008) specified 4 grazing farm types (dairy, intensive sheep and beef, hill country sheep and beef, and deer) and 7 cropping types (barley, cereals, fruit trees, maize, potatoes, leguminous and non-leguminous hay, rapeseed, and vegetables). In this study the focus will primarily be on grazed systems with dairy, sheep and beef, and deer farming systems. We will also differentiate dairy farms with and without irrigation.

Discussion and Conclusion

The framework uses a unique combination of soil and climate units, consistent with the spatial information available at national scale. The selection of soil sub-groups and climate areas resulted in combination of 1413 zones of combined soil-climate zones. We will therefore run NZ-DNDC for these 1413 zones and the farm types defined in the methodology. Future work will involve testing the homogeneity of these soil-climate zones, to estimate the uncertainty surrounding the upscaling process. Since the assumption in this framework is that the emission factor is independent of the nitrogen input, we also intend to evaluate the sensitivity of EF to nitrogen inputs by varying stocking rates and fertiliser applications.

At a national level, there may still be a need to define some new regional farm types to account for different management practices in different regions. For scenario analysis it would also be useful to define some farm types where different mitigation strategies are employed (e.g. nitrification inhibitors, restricted grazing).

Compared with other upscaling methods in the literature, our approach is similar to Brown et al. (2002), who used the DNDC model to simulate N_2O emissions from agriculture and generated EFs to enable comparison with the IPCC methodology. Britz and Leip (2009) took a slightly different approach to model N_2O emissions in Europe. They ran Monte Carlo DNDC simulations over different combinations of crop type, environmental conditions and fertiliser application (about 90 000 simulations). Regression analysis was then performed on the results using 14 different explanatory variables to find regression equations ("meta-models") to approximate the DNDC predictions. However, this method requires input data that are not easily obtainable at a national level in New Zealand, and the EFs are not explicitly defined in their regression model. The EF look-up tables in our case have the advantage that they can be compared with the current New Zealand national inventory method.

This proposed framework will enable the estimation of the impacts of land use, grazing regime, land-management practices, and mitigation strategies on N_2O emissions in a fast and efficient way, enabling stakeholders to explore future scenarios for land management. The framework also has the potential to be extended to cover other farm types, other greenhouse gases, and other environmental issues such as nitrate leaching.

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