Review of *The uncertainty of nitrous oxide emissions from grazed grasslands: A New Zealand Case Study*

Donna Giltrap
Landcare Research

1 Background

In 2014, nitrous oxide (N_2O) emissions from agricultural soils contributed 8526.3 kt CO_2eq (11 %) towards New Zealand's total Greenhouse Gas emissions (MfE 2016). However, this category has an uncertainty of ±6326 kt CO_2eq, making it the single largest contributor to the uncertainty in the national inventory (Table A2.1.2; MfE 2016).

Kelliher et al. (2003) used a Monte Carlo simulation to calculate the 95% confidence interval for N_2O emissions from agricultural soils. The percentage error calculated in this exercise (+74% to –42%)[1] was then used to estimate the uncertainty in subsequent years, despite changes to the N_2O calculation methodology and improvements in the emission factors (EFs) used. Therefore, a re-evaluation of the uncertainty of this category is warranted.

Kelliher et al. (2016) have proposed an alternative methodology that uses an analytic approach based on Fractional Standard Errors (*FSE*s) to estimate the uncertainty in the agricultural soils N_2O emissions. A similar methodology is currently used for enteric methane (CH_4) uncertainties (Kelliher et al. 2007, 2009). However, Kelliher et al. (2016) also consider the possibility of correlations between the input variables.

2 Review comments

2.1 The Analytic Approach

The formula to calculate N_2O emissions (E_{N_2O}) was given as:

$$(1) \qquad E_{N_2O} = \left\{ \left[ad \left(\frac{1}{e}\right) p_N (1 - r_N) \right] + u \right\} \left(\frac{44}{28}\right) EF$$

The meaning of the symbols are explained on page 4 of Kelliher et al. (2016)

This formulation gives the direct N_2O emissions from animal dung and urine deposited on pasture as well as fertiliser. The fertiliser is assumed to be 100% urea. This assumption introduces a slight inaccuracy into the estimated N_2O emissions as the emission factor for urea is lower than other fertiliser types.

However, in the 2016 inventory a number of new sources have been added to the agricultural soils category. These are direct N_2O emissions as a result of adding N in the form of: organic N fertilisers (predominantly livestock manure), inputs from above- and below-ground crop residues and from forages during pasture renewal, mineralisation of cropland, soil organic

---

[1] In accordance with the IPCC Good Practice Guidelines (2006) this asymmetric range is represented by the larger of the two uncertainties, i.e. ±74%

matter loss, and cultivation of organic soils. In order to describe the entire N_2O emissions from agricultural soils category, equation (1) would need to be updated to include these additional sources.

The indirect emissions were accounted for by multiply equation (1) by a factor equal to the ratio of the total emissions to the direct emissions from the 2014 inventory (MfE 2016). The problem with this approach is that the total emissions in the 2014 inventory include sources not included in equation (1). Table 1 shows the N_2O emissions in the agricultural soil category in the 2014 inventory.

Table 1: Agricultural soils N_2O emissions in New Zealand's 2014 inventory (MfE 2016)

Source	N_2O (kt CO_2eq)	N_2O (Gg N_2O)
Direct emissions from grazing manure	5713.0	19.2
Direct emissions from fertiliser	948.1	3.18
Indirect emissions from volatilisation	918.6	3.08
Indirect emissions from leaching	503.1	1.69
Direct emissions from residues etc.	443.6	1.49
Total	8526.3	28.6

According to Table 1, the ratio of total to direct emissions is 28.6/23.9 = 1.2, or 27.1/22.4 =1.2 if only the emissions from grazing manure and fertiliser are considered. Kelliher et al. (2016) calculate a ratio of 1.5 (line 144), which is incorrect and possibly the result of neglecting to include the direct fertiliser emissions in the denominator.

Kelliher et al. (2016) neglected the uncertainty in the indirect emissions. This is only justifiable if the size of the uncertainty in the total indirect emission factor ($EF_4.\text{Frac}_{\text{GAS}} + EF_5.\text{Frac}_{\text{LEACH}}$) is small compared with the weighted mean direct emission factor. Although the uncertainties for the New Zealand indirect emission factors have not been defined, it should still be possible to perform some estimate to justify neglecting these uncertainties.

Summary

Overall, the approach is reasonable but:
- Equation (1) does not account for all emission sources now included in the agricultural soils category
- Calculation of indirect emissions is incorrect

2.2 Accounting for correlations

In the appendix the authors derive a formula for the *FSE* of the product of *N input* and *EF* based on the work of Goodman (1960). This formula allows for a potential correlation between *N input* and *EF*.

In the course of the derivation the following approximation is used (line 480):

$cov(N\ input^2, EF^2) \approx 4\mu_{N\ input}\mu_{EF}cov(N\ input, EF)$, to order $1/n$

It is not apparent how this approximation was derived and further explanation/justification should be given before this approximation is used.

The authors estimate the correlation between N input and EF using data from field and laboratory experiments involving 6 New Zealand soils. From this they derived an estimate of 0.40 ± 0.37 for the correlation coefficient. However, in the field and laboratory experiments it was actually the concentration of the N inputs that was correlated to the EF. In the national inventory an increase in the N input in a given year may not be the result of higher concentrations of N applications (for example, an increase in animal numbers might result in a higher number of urine patches rather than higher N concentrations within each patch). In addition, part of the concentration effect may already be captured by the different EF values used for sheep and cattle urine.

If the correlation is neglected, the equation for FSE[$N\ input.EF$] becomes:

$$FSE[N\ input.EF] = (FSE[N\ input]^2 FSE[EF]^2 + FSE[N\ input]^2 + FSE[EF]^2)^{0.5}$$

Summary

- There is some evidence of correlation between EF and N concentration
- Inclusion of correlation effects not recommended as inventory uses total N input not N concentration

2.3 Monte Carlo Comparison

A Monte Carlo simulation was performed to compare with the analytic method. For the EF the same weighted mean value (0.0062) was used but with a log-normal distribution on EF measurements from 185 trials. It is not clear whether the data plotted in Figure 1 used a single N source (e.g. cattle urine) or a mixture of sources. In either case it is not correct to assume that the distribution of the weighted mean EF will be the same as the distribution of site scale EFs. A national (weighted) mean EF based on large numbers of field trials should have less variability than the individual trials. This was recognised in the analytic method, which used standard errors rather than standard deviations. To be a fair comparison with the analytic method the Monte Carlo simulation should use the distribution of the weighted mean EF.

2.4 Overall comments

The analytic method shows some promise, although it needs to be updated to account for the new sources now included in the agricultural soils category (and the indirect emissions need correcting). It has the advantage of being similar to the method used to calculate enteric CH_4 emissions. However, as it uses a weighted mean EF, the inventory would need to recalculate the EF value and FSE[EF] each year to account for the different relative weightings of each N source over time. One disadvantage of the analytic method is that it does not give any information about any asymmetry in the emission uncertainty, although this is not reported using Approach 1 uncertainty calculations.

The organisation of this paper does not make it easy to compare the uncertainty ranges produced by the different methodologies (current method, analytic method, analytic method with correlations, updated Monte Carlo simulation). A table comparing these results would be very useful.

2.5 Minor corrections

- Line 111: The quantity (*ad*) should have units MJ.y^{-1} not $\text{MJ.animal}^{-1}\text{.y}^{-1}$
- Table 1: The column heading should be *EF* not Fractional *EF* as this matches the terminology used in the rest of the MS
- Line 466: In the first equation should be $\text{FSE}[\text{N input}] = \left(\frac{\text{x}^2\text{FSE}[\text{x}]^2+\text{u}^2\text{FSE}[\text{u}]^2}{(\text{x}+\text{u})^2}\right)^{0.5}$
- Line 466: $FSE[EF]$=0.27 (Table 2)
- Line 468: $\text{FSE}\left[\text{E}_{\text{N}_2\text{O}}\right] = 0.277$

3 Recommendations

- The analytic method could be considered for the national inventory estimate of N_2O emissions from agricultural soils. However, the following corrections would be needed:
    - Modify equation (1) to include all the new N sources now included in the agricultural soils category
    - Correct the calculation of indirect emissions
    - Confirm that the uncertainties in the indirect emissions can be neglected
- That the correlation between *N input* and *EF* not be included. The correlation found was actually between N concentration and EF, and the inventory does not have concentration data
- That the Monte Carlo simulation be rerun using the distribution of the weighted mean EF rather than the distribution of individual EF measurements to see how the precision compares to the analytic method.

4 References

Goodman LA 1960. On the exact variance of products. Journal of the American Statistical Association 55: 708–713.

Kelliher FM, Clark H, Smith MH, Lassey KR, Sedcole R 2009. Reducing uncertainty of the enteric methane emissions inventory. Report prepared for MAF by AgResearch.

Kelliher FM, Henderson HV, Cox NR 2016. Estimating the uncertainty of New Zealand's agricultural soils nitrous oxide emissions inventory. Unpublished MS,

Kelliher FM, Ledgard SF, Clark H, Walcraft AS, Buchan M, Sherlock RR 2003. Revised nitrous oxide emissions from New Zealand agricultural soils: 1990–2001. Report prepared for the Ministry of Agriculture and Forestry.

Kelliher FM, Cox N, van der Weerden TJ, de Klein CAM, Luo J, Cameron KC, Di HJ, Giltrap D, Rys G 2014. Statistical analysis of nitrous oxide emission factors from pastoral agriculture field trials conducted in New Zealand. Environmental Pollution 186: 63–66.

Ministry for the Environment (MfE) 2016. New Zealand's Greenhouse Gas Inventory 1990–2014. Wellington, Ministry for the Environment.