Review of IPCC 2006 guidelines to determine New Zealand inventory requirements from 2010

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1. Summary

- This project has focused on the impact of the changes within the IPCC *2006 Guidelines* on New Zealand's agricultural greenhouse gas inventory. The most influential changes affecting the New Zealand inventory include:-
  - Removal of adjustments of the amounts of nitrogen (N) applied as mineral and organic fertilisers for ammonia (NH_3) and NO_X volatilization.
  - Inclusion of N from below-ground crop residue as a direct source of nitrous oxide (N_2O).
  - Inclusion of N release from pasture renewal as a direct source of N_2O.
  - Inclusion of N mineralization associated with carbon (C) loss due to land-use change and management practices as a direct source of N_2O.
  - Reduction of the emission factor for N leaching or runoff (EF_5).

- Adoption of the IPCC *2006 Guidelines* resulted in the 2006, 2010 and 2020 agricultural greenhouse gas inventories being reduced compared to emissions calculated using the IPCC *Revised 1996 Guidelines*.
- The 2006 N_2O inventory was reduced by 2.0 Gg N_2O/year, from 41.1 to 39.1Gg N_2O/year which is equivalent to a reduction of 625 Gg CO_2-eq/year.
- The 2006 CH_4 inventory was reduced by 4.3 Gg CH_4/year, from 1183.5 to 1179.3 Gg CH_4/year, which is equivalent to a reduction of 90 Gg CO_2-eq/year.
- The overall reduction when adopting the *2006 Guidelines* was 715 Gg CO_2-eq/year, with this reduction increasing to 752 and 826 Gg CO_2-eq/year for the 2010 and 2020 inventories.
- Two alternative scenarios were also presented. The first was based on adopting the IPCC *2006 Guidelines* but using a lower, EF_{3PRP} for sheep. The second was also based on adopting the IPCC *2006 Guidelines* but including <u>temporary</u> land use changes in the new source F_{SOM}. Each of these had a significant effect on the total inventory.
- Adopting a sheep-specific EF_{3PRP} of 0.005 decreased the 2006 N_2O inventory based on the 1996 Guidelines by 6.8 Gg N_2O/year to 34.3 Gg N_2O/year.
- Including temporary land use changes within F_{SOM} increased the 2006 N_2O inventory based on the 1996 Guidelines by 8.6 Gg N_2O/year to 49.7 Gg N_2O/year.

- An uncertainty assessment was conducted on two influential sources of change in the guidelines: inclusion of F_{SOM} and reduction of EF_5.
- The combined uncertainty associated with F_{SOM} for the 2006 inventory was calculated to be ± 108%, which corresponded to an uncertainty range of 0.0 to 1.0 Gg N_2O/yr for this source. When temporary land use changes are included within F_{SOM}, the uncertainty range associated with this source increases to become 0.0 to 23.0 Gg N_2O/year for 2006.
- Using the uncertainty range of 0.0005 to 0.025 kg N_2O-N/kg N leached, as reported in the IPCC *2006 Guidelines*, the uncertainty range of N_2O emitted from this source in 2006 was 0.1 to 5.3 Gg N_2O/year.
- If New Zealand plans to adopt the 2006 Guidelines, more accurate activity data on land use change, specific crop areas and associated yields and pasture renewal rates are required at a minimum.
- To improve the accuracy of the inventory further, and reduce the level of uncertainty associated with the calculated emissions and the overall inventory, country-specific data and emission factors are required for EF_5, F_{CR} and F_{SOM}.
- If New Zealand plans to apply to the IPCC for a country-specific EF_{3PRP} for sheep, a more robust database is required.
- It is recommended that priority be given to the following research requirements:
    1. **Research programme focusing on better quantification of EF_5,**
    2. **Research programme focusing on better quantification of $EF_{3PRP\ SHEEP}$,**
    3. **Literature review of on-farm practices relating to pasture renewal and temporary land use changes such as supplementary feed production,**
    4. **Research programme focusing on better understanding and quantification of N transformations and subsequent N_2O emission factors for residues of lucerne, forage brassica and renewed pasture residues and from soil organic matter due to land use change.**
- The last research requirement could be aligned with the research proposed in a concurrent project, focusing on quantifying ‘background’ emissions from improved pastures (van der Weerden and de Klein, 2008).

2. Introduction

New Zealand currently uses a Tier 3 approach to determine methane (CH_4) emissions from agriculture for the main animal species, and the Intergovernmental Panel on Climate Change (IPCC) 1996 Tier 1 approach for minor species. For N_2O, New Zealand uses the Tier 1 IPCC 1996 approach with three country-specific factors/parameters. These are (i) EF_1 of 0.01, based on recommendations by Kelliher and de Klein (2006), (ii) EF_{3PRP} of 0.01, based on Carran et al. (1995), Muller et al., (1995) and de Klein et al. (2003), and (iii) $Frac_{LEACH}$ of 0.07, based on Thomas et al. (2005).

In 2006, the IPCC *Revised 1996 Guidelines* were once again and New Zealand intends to be consistent with the revised *2006 Guidelines* by 2012. Revisions include the removal of biological N fixation as a direct source of N_2O, removal of adjustments of F_{SN} and F_{AM} for volatilization, changes to the calculation of N from crop residues (which now include pasture renewal), inclusion of N mineralization associated with C loss due to land-use change and management practices and reduction of the emission factor for N leached.

For CH_4 emissions, the *2006 Guidelines* will result in minor changes to the inventory, as the Tier 1 approach is used for minor species only. Thus, the impact of adopting the 2006 guidelines is appreciably greater for N_2O compared to CH_4.

This project will adjust the existing greenhouse gas (GHG) inventory spreadsheet to include the *2006 Guidelines* and calculate New Zealand's CH_4 and N_2O inventories for 2006, 2010 and 2020. A comparison of inventory values for these years using the two methodologies will be made.

The outcomes of the project are (i) quantification of the potential effects of the changes on the inventories, including the involved uncertainties, (ii) improved understanding of the impact of adopting the *2006 Guidelines* on the CH_4 and N_2O inventory values and (iii) identification the research requirements that will fill emergent gaps in knowledge and data availability for the next commitment period.

3. Approach

This project included the following steps:

1. Review the inventory spreadsheet that is run annually by Dr Harry Clark and update the spreadsheet to match the *2006 Guidelines* and gather the required activity data and emission factor data for new sources (i.e. those not included in the 1996 guidelines). For the most part, default activity data and emissions factors were used.

The 2006 guidelines contain the following list of potentially significant changes; these were reviewed and, if applicable, implemented within the inventory spreadsheet.

i. Removal Biological N fixation as a direct source of N_2O.
ii. Disaggregation, by animal type (sheep versus cattle), of the default N_2O emission factor for animal excreta deposited by grazing (EF_{3PRP}).
iii. Removal of adjustments of the amounts of N applied as mineral and organic fertilisers for ammonia (NH_3) and NO_X volatilization.
iv. Inclusion of N from below-ground crop residue as a direct source of N_2O.
v. Inclusion of N release from pasture renewal as a direct source of N_2O.
vi. Inclusion of N mineralization associated with C loss due to land-use change and management practices as a direct source of N_2O.
vii. Inclusion of N from crop residues and mineralisation associated with C loss as a source of N leaching and thus an indirect N_2O source.
viii. Reduction of the emission factor for N leaching or runoff (EF_5).
ix. Changes to CH_4 emission factors from manure management.

2. Calculate 2006, 2010 and 2020 agricultural emissions using the *2006 Guidelines*, and compare with 2006, 2010 and 2020 emissions calculated using the *Revised 1996 Guidelines*.

3. Assessment of the uncertainties associated with the calculated agricultural emissions, especially in relation to activity data and emission factors of sources identified as having the largest influence on changes to calculated emissions due to the *2006 Guidelines*.

4. Based on the above, define the research questions that need to be addressed to ensure adequate data availability for adoption of *2006 Guidelines* from 2010 onwards.

3.1 Key changes from 1996 guidelines and their implications for NZ

Nine key changes from the *Revised 1996 Guidelines* may significantly affect the agricultural greenhouse gas inventory for New Zealand. Eight of these changes relate to the nitrous oxide inventory calculation and are found in the section "N_2O emissions from managed soils, and CO_2 emissions from lime and urea applications" (Chapter 11) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. These changes are detailed below in sections 3.1.1 to 3.1.8.

The ninth key change from the 1996 guidelines relates to the methane inventory calculation, and is found in the section "Emissions from Livestock and Manure Management" (Chapter 10) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. This change is detailed below in section 3.1.9.

3.1.1 Removal of Biological N fixation as a direct source of N_2O

Biological nitrogen fixation has been removed as a direct source of N_2O because of the lack of evidence of significant emissions arising from the fixation process itself (Rochette and Janzen, 2005). These authors concluded that the N_2O emissions induced by the growth of legume crops/forages may be estimated solely as a function of the above-ground and below-ground nitrogen inputs from crop/forage residue (the nitrogen residue from forages is only accounted for during pasture renewal).

The removal of biological N fixation as a source of N_2O will not have a major impact on New Zealand's inventory, as this applied only to N-fixing crops (peas and lentils) and not to grass/clover pasture, and was therefore not a major source in previous New Zealand N_2O inventories.

3.1.2 Disaggregation, by animal type (sheep versus cattle), of the default emission factor value for EF_{3PRP}

The default emission factor value for EF_{3PRP} has been disaggregated for different animal types based on a recent review on N_2O emissions from urine and dung depositions (de Klein, 2004). This review indicated that the emission factor for sheep is lower than that for cattle and that a value of 1% of the nitrogen deposited is more appropriate. Reasons for the lower EF_{3PRP} for the sheep include more even urine distribution (smaller and more frequent urinations), and smaller effects on soil compaction during grazing. There are no or very limited data for N_2O emission factors of other animal types, and the emission factor for poultry and swine remains at 2% of the nitrogen deposited. However, a values of 1% of the nitrogen deposited may be used for animals classified as 'other animals' which include goats, horses, mules, donkeys, reindeer and camelids, as these are likely to have nitrogen excretion rates and patterns that are more similar to sheep than to cattle.

New Zealand currently uses a country-specific emission factor of 1% based on New Zealand specific data (Carran et al.,1995, Muller et al., 1995, and de Klein et al., 2003). More recent New Zealand research (de Klein et al. 2003, 2004; Sherlock et al. 2003a,b) suggests that a more accurate country-specific emission factor for sheep would be 0.5%, while the country-specific emission factor for cattle should remain at 1%. The relative difference between cattle and sheep is consistent with the *2006 Guidelines* in that the emission factor for cattle is twice that for sheep; however the suggested country-specific emission factors for cattle and sheep depart from the IPCC default values due to New Zealand-specific data suggesting lower rates of N_2O emission from these livestock classes compared to overseas research. Animal excreta deposited on pasture are the major source of N_2O in the national inventory. Therefore, this project examined the effect of two scenarios on the inventory using different values for EF_3.

The first retained the country-specific emission factor of 1% for all animal classes, while the second disaggregated the country-specific emission factor, where the emission factor for all livestock, except sheep, remained at 1%, while the factor for sheep was 0.5%.

3.1.3 Removal of adjustments of F_{SN} and F_{ON} for volatilization

For the Tier 1 approach (as adopted by New Zealand), the amounts of applied mineral nitrogen fertilisers (F_{SN}) and of applied organic fertilisers (F_{ON}) are no longer adjusted for the amounts of NH_3 and NO_X volatilisation after application to soil. This is a change to the methodology described in the *Revised 1996 Guidelines*. The reason for this change is that field studies that have determined N_2O emission factors for applied N were not adjusted for volatilisation when they were estimated. In other words, these emission factors were determined from: fertiliser-induced N_2O-N emitted/total amount of N applied, and not from: fertiliser-induced N_2O-N emitted/(total amount of N applied – NH_3 and NO_X volatilised). As a result, adjusting the amount of N input for volatilisation before multiplying it with the emission factor would in fact underestimate total N_2O emissions.

Nitrous oxide emissions from F_{SN} and F_{ON} account for a small proportion of the total inventory, therefore the effect of removing the adjustment for volatilisation is likely to be modest.

3.1.4 Inclusion of N from below-ground crop residue

The equation to estimate the amount of N returned to soil as crop residues, F_{CR}, has been modified from the previous *Revised 1996 Guidelines* to account for the contribution of the below-ground nitrogen to the total input of nitrogen from crop residues, which previously was ignored in the estimate of F_{CR}. As a result, F_{CR} now represents a more accurate estimate of the amount of nitrogen input from crop residues, which makes it possible to assess the contribution of residue nitrogen arising from the growth of forage legumes such as alfalfa (known as lucerne in New Zealand), where the harvesting of virtually all the above-ground dry matter results in no significant above-ground residue.

The *2006 Guidelines* suggest that separate calculations be performed for major crop types. At a minimum, it is recommended that crops be segregated into: 1) non-N-fixing grain crops (e.g. maize, rice, wheat, barley); 2) N-fixing grains and pulses (e.g. soybeans, dry beans, chickpeas, lentils); 3) root and tuber crops (e.g. potato); 4) N-fixing forage crops (alfalfa, clover); and 5) other forages including perennial ryegrass and grass/clover pastures (see 3.1.5).

Crops currently included within the New Zealand inventory are limited to wheat, barley, oats, maize, peas and lentils. This change to the estimation of F_{CR} may result in a significant increase in the national N_2O emissions.

3.1.5 Inclusion of N release from pasture renewal

The inclusion of nitrogen from forages or pasture renewal in calculating F_{CR} is a change from the *Revised 1996 Guidelines*. Pasture renewal is defined as the complete destruction of old, low quality pastures followed by sowing improved pasture species. In New Zealand, old pastures are destroyed by herbicide application, cultivation, or both. The intensity of cultivation can range from light surface work, to full cultivation employing multiple deep passes. New pasture species can be established by either direct drilling into undisturbed soil, drilling into a prepared seedbed, or broadcast application of seed (Pottinger et al., 1993). The destruction of old species, by either cultivation or herbicide, results in stubble being returned to soil. This residue input will then be mineralised, which can lead to increased N_2O emissions (e.g. van der Weerden et al., 1999; Davies et al., 2001). Given the dominance of pastoral farming in New Zealand, this is likely to have an impact on the total N_2O inventory.

3.1.6 Inclusion of N mineralization associated with C loss due to land-use change and management practices

The inclusion of the term F_{SOM} is also a change from previous guidelines. Since organic C and N are intimately linked in soil organic matter, soil C lost through oxidation as a result of land use change or management will be accompanied by a simultaneous mineralisation of N. Where a loss of soil C occurs this mineralised N is regarded as an additional source of N available for conversion to N_2O (Smith and Conen, 2004), just as mineral N released from decomposition of crop residues, for example, becomes a source. It is worth noting that N_2O emissions due to land use change to cropping are already accounted for in the national greenhouse gas inventory; these are reported within the Land Use, Land-Use Change and Forestry (LULUCF) section of United Nations Framework Convention for Climate Change (UNFCCC) inventory report. The *2006 Guidelines* now include N_2O emissions resulting from other land use changes and management.

The default value for EF_1 for this source is 0.01. EF_1 was previously 0.0125, however this has been reduced following new analysis of available experimental data. This change does not affect other N sources for the New Zealand inventory, as 0.01 had previously been used as a country-specific value.

For New Zealand, this new source of N_2O may have a significant effect on the inventory, as land use change continually occurs, largely influenced by economic and environmental conditions. Although not abundantly clear, it appears the IPCC *2006 Guidelines* concentrate only on permanent land use change, but does not include *temporary* land use change such as pasture renewal where break crops such as forage brassicas are included in the programme. While a temporary land use change suggests carbon levels are eventually restored to the original levels, the associated N_2O emission factors during this period of change may vary, resulting in a net increase or decrease in N_2O emissions compared to the same land use where no temporary change occurs. Therefore, we initially used the area of permanent land use change only (scenario 1), and further on provided a third scenario where temporary land use change was also included in this source. As there is very little data quantifying emission factors associated with this type of temporary land use change, we have adopted the IPCC *2006 Guidelines* default approach for calculating emissions from this source. The second scenario was described above in section 3.1.2, where a country-specific EF_3 value for sheep excreta was used.

3.1.7 Inclusion of N from crop residues and mineralisation associated with C loss to N leached

The sources of N leached stated by the *Revised 1996 Guidelines* for calculating indirect N_2O emissions are restricted to N inputs from synthetic fertiliser applications and total N excreted by livestock. However, the guidelines do not include two additional N inputs to soils that may result in leaching where drainage occurs: these are N inputs from crop residues returned to soil and N mineralisation associated with land use change and management. The *2006 Guidelines* have corrected this omission, with $Frac_{LEACH}$ now having four sources: synthetic fertilisers, N excreta, crop residues and soil N mineralisation.

Nitrogen inputs from excreta are the major source of nitrate leaching in New Zealand, therefore the addition of crop residues and N mineralisation as sources of potentially leachable N is likely to have a minor effect on the indirect emissions from nitrate leaching.

3.1.8 Reduction of the emission factor for leached N

The overall value for the emission factor for leached N (EF_5) has been changed from 0.025 to 0.0075 kg N_2O-N/kg N leached/in runoff water. This emission factor incorporates three components: EF_{5g}, EF_{5r} and EF_{5e}, which are the emission factors for groundwater and surface drainage, rivers, and estuaries, respectively. Recent results indicate that the previously used emission factor for groundwater and surface drainage (0.015) was too high and should be reduced to 0.0025 kg N_2O-N/kg mineral N (mainly nitrate) leached ((Hiscock et al., 2002, 2003; Reay et al, 2004, 2005; Sawamoto et al. 2005). The emission factor for rivers has also been reduced from 0.0075 kg N_2O-N/kg N to the same value, 0.0025 kg N_2O-N/kg N in the water. This is in recognition that while still lower mean values (of the order of 0.0003 to 0.0005) have been reported by, e.g., Dong et al. (2004) and Clough et al. (2006) for relatively short river systems, there remains the possibility that higher values than those obtained by these authors apply to longer river systems. The value for estuaries remains at 0.0025 kg N_2O-N/kg N.

Indirect N_2O emissions from leached N make a significant contribution to the N_2O inventory in New Zealand. New Zealand's country-specific $Frac_{LEACH}$ value of 0.07, based on research by Thomas et al. (2005), is lower than the IPCC default value of 0.30. However, N inputs through fertiliser and animal deposits have increased since 1990 resulting in increasing N leaching estimates. The reduction in the N_2O emission factor for N leaching, as proposed in the IPCC *2006 Guidelines*, is therefore in New Zealand's advantage, as it will reduce the difference in indirect N_2O emissions from N leaching between 1990 and the first commitment period. It is important to point out that the N_2O emission factor for leached N in groundwater, surface drainage, rivers and estuaries is independent of $Frac_{LEACH}$, which represents the amount of N leached into these water bodies from soils.

3.1.9 Changes to CH_4 emission factors from manure management

Manure management methane emission factors have altered slightly for some livestock classes (e.g horses, goats), while others have been disaggregated into sub-classes. Swine and poultry are examples of the latter, where swine have been split into market and breeding, and poultry has been split into broilers and layers. Layers have been further divided into operations that manage dry and wet manure systems.

New Zealand uses the Tier 1 approach for these livestock classes, however their numbers are modest. Thus, the effect on the national methane inventory is likely to be small.

3.2 Gathering of required activity data and emission factors

Most of the required additional activity data has been obtained from sources such as expert judgement and official census data. Activity data for 2010 and 2020 has been estimated via expert judgement, extrapolation of current trends and modelled data from Dr. Harry Clark. Part of the IPCC recommended protocol for expert elicitation is to seek verification of the data supplied. For key activity data, verification of discussed or supplied data was sought by providing feedback to the expert detailing the data content. This provided an opportunity for the expert to re-examine the activity data initially provided and correct if required.

Nitrous oxide emissions from crop residues (updated formula) and pasture renewal and land use change (new sources) have been calculated following the default *2006 Guidelines* and associated default emission factors.

3.2.1 New Activity Data for 2006

To calculate the implications of the *2006 Guidelines* on the agricultural inventory, it was necessary to source additional activity data currently not included. Here we provide an overview of the source of new data used [see Appendix A for further details].

Estimating F_{CR}

The *2006 Guidelines* for estimating F_{CR} require both total area and average yield for each crop (whereas the *Revised 1996 Guidelines* only required total production).

Crops already included within the New Zealand inventory are wheat, barley, oats, maize, peas and lentils, which falls into two of the five major crop types, as outlined in the *2006 Guidelines* (Table 1). Total area and average yield for each of these crops were obtained from NZ Statistics and expert judgement (Nick Pyke, Foundation for Arable Research).

Three additional crop types are included in the *2006 Guidelines*: these are (i) root and tuber crops, (ii) N-fixing forage crops, and (iii) other forages including renewed grass/clover pastures. Suggested crops for these crop types are shown in bold in Table 1, together with the source of the total area and average yield activity data. Expert judgement for some of the forage brassicas and lucerne activity data was supplied by Dr. Derek Wilson of Crop & Food Research and Dr. Derrick Moot of Lincoln University.

The total area in grass/clover pasture is based on the LULUCF land category 'high producing grassland'. This category is defined by the Ministry for the Environment (see *Chapter 7: Land use, land-use change and forestry (LULUCF)* of *New Zealand's Greenhouse Gas Inventory 1990-2006*) as high intensity pastureland and accounted for 8.79 million hectares for 2006. The land categories are calculated via a mapping process utilising Land Cover Databases 1 and 2. According to the Ministry for the Environment (Dave Loubser, *pers. comm.*), due to the mapping process utilising a dominant cover rule, the 'high producing grassland' will also contain areas under forage brassicas and lucerne. As most forage brassica crops are grown and grazed for a 5-9 month period as a break crop within pasture renewal programmes there is no need to correct the total 'high producing grassland' area for this practice. However, the area of lucerne, estimated at 100,000 ha for 2006 (Dr. Derrick Moot, *pers. comm.*), does need to be subtracted from the total grassland area, as land is typically kept in lucerne for more than 5 years. Therefore, a corrected area of 8.69 million hectares of grass/clover pasture for 2006 is used (Table 1). It should be noted that for the calculation of F_{CR} only the percentage of grassland that is annually renewed is included, not the total area of 'grassland' (Table 1). This is further discussed within the next section.

Table 1. Existing (unbold) and additional crops (bold) included within the estimation of F_{CR} following the *2006 Guidelines*. Total and individual crop areas and average yields shown for the 2006 inventory calculation.

Major Crop Type	Crop	Crop Area		Crop Yield	
		Area (ha)	Source	Average yield (t/ha)	Source
Non-N-fixing grain crops	Wheat Barley Oats Maize	37,962 47,078 6,278 20,461	Stats NZ	7.7 5.8 4.0 7.9	Stats NZ
N-fixing grains and pulses	Peas Lentils	11,500 1,000	Stats NZ; Nick Pyke, FAR	4.7 2.0	Stats NZ; Nick Pyke, FAR; Bruce Snowdon, Heinz Watties.
Root and tuber crops	**Potato**	11,700	Fresh Facts 2006	43.0	Fresh Facts, 2006
N-fixing forage crops	**Lucerne**	100,000	Dr. Derrick Moot, Lincoln University	9.0 [A]	Purves and Wynn-Williams, 1989
Other forages (including perennial ryegrass and grass/clover pastures)	**Forage brassicas**	300,000[B]	Dr. Derek Wilson, Crop & Food.	10.0 [A]	Dr. Derek Wilson, Crop & Food.
	Grass/clover pastures (pasture renewal only)	8,686,000[B] (NB: pasture renewal = 300,000 ha/yr)	MfE (LULUCF land category data)	10.5 [A]	Roberts and Morton, 2004; Morton and Roberts, 2004.
Total area (ha)		8,921,979			

[A] Forage crop (lucerne, forage brassicas and pasture) yields presented as t DM/ha, all others presented on a Fresh Weight basis.

[B] Area of forage brassica production assumed to be part of pasture renewal programme, therefore area is included within 'grass/clover pasture' area.

There is an additional LULUCF land category for grassland, termed 'low producing grassland', which are defined in Table 7.1.4 in *Chapter 7: Land use, land-use change and forestry (LULUCF)* of *New Zealand's Greenhouse Gas Inventory 1990-2006*, as either native tussockland or areas composed of shrubby vegetation (or "scrub"). As this area does not include clover-based swards (Dave Loubser, MfE, *pers. comm.*) it was not included in the estimated area of grass/clover pastures.

The sum of all crops now included in the inventory calculation total 8.92 million hectares for 2006 (Table 1). While significant areas of other crops exist in New Zealand (for example, squash and sweetcorn), these crops do not have default factors for estimating N inputs from their residues, as outlined in Chapter 11 of the *2006 Guidelines*. Nevertheless, the 8.92 million hectares of crops included here already account for 97% of the total agricultural area containing annual and perennial crops and improved grasslands, which is estimated to be 9.21 million hectares in 2006 (from LULUCF land category data). Therefore, it can be safely concluded that the majority of New Zealand's agricultural production has been accounted for in this project.

The *2006 Guidelines* outline a default approach for estimating the nitrogen inputs from these crop residues, with values provided for dry matter content, fraction of above ground biomass as residue, ratio of below ground residues to above ground residues, and the N content of both above and below ground residue components. Crop & Food Research are leading a MAF-funded project to determine if the default values are appropriate for New Zealand. Furthermore, their study will also assess the appropriateness of using 0.01 for EF_1. As the outcome of their project will not be available before end June, we have used the default values here.

Estimating N inputs from crop residues relating to pasture renewal

As discussed above, inclusion of N from grass/clover pastures for F_{CR} only applies to the percentage of grassland that is annually renewed. Pasture renewal is defined as the complete destruction of old pasture (sprayed or cultivated), which is then replaced with improved species (see section 3.1.5). This differs from "pasture renovation", defined as where it is neither desirable nor necessary to kill the entire existing sward (Baker et al., 1996). Stubble returns to the soil will be negligible under a renovation programme unless there are a significant percentage of weeds present. The IPCC *2006 Guidelines* focus on pasture renewal, which is more significant in terms of stubble residue inputs. While Agricultural Statistics now include data on the total land area cultivated and direct drilled, this cannot be used to quantify the area of pasture renewal, as it is a fraction of the total area cultivated or drilled. Therefore, the area renewed each year was estimated from expert judgement. Recently, the Pasture Renewal Charitable Trust (PRCT) was formed by several agricultural industries, including seed and agrichemical suppliers and FAR. Murray Willocks (*pers. comm.*), chairman of PRCT, estimates a pasture area of 300,000 ha was renewed in 2006, based on local perennial and hybrid ryegrass seed sales. This does not include the sowing of temporary annual grasses. Using a total grass/clover pasture area of 8.69 million hectares, this represents a 3.5% per annum pasture renewal rate.

The rate of N mineralisation of the stubble may vary according to the method used for pasture removal, which includes cultivation, herbicide, or both. New Zealand-specific data is not available for quantifying the effect of these contrasting practices; therefore the IPCC default calculation has been adopted.

The default emission factor for pasture renewal is the same as that for other F_{CR} components i.e. 0.01. It should be noted that the pasture renewal component of F_{CR} only accounts for additional N to soils from grass/clover stubble residue. Any additional N mineralisation of organic matter and subsequent N_2O emissions following soil cultivation and seedbed preparation would be accounted for under the new F_{SOM} category. However, F_{SOM} accounts for permanent land use changes rather than temporary land use changes: pasture renewal is regarded as a temporary change. This is further discussed below.

Estimating F_{SOM}

Land use and land management activities can have a large influence on the C pool of mineral soils, particularly when converting from grassland or forestry to cropping. Such changes can result in 20-40% of the original soil C stocks being lost over 20 or more years (*IPCC 2006 Guidelines*). Soil carbon stocks can change with management or disturbance of the net balance between C inputs and C losses from soil. Management activities such as the addition of organic amendments, practices that enhance plant production and the removal of biomass all influence soil C stocks. Decomposition of soil organic carbon results in N mineralisation, which provides a source of N, F_{SOM}, available for nitrification and denitrification.

F_{SOM} was calculated following the default *2006 Guidelines*. This requires an estimation of (i) the annual average loss of soil C, (ii) the soil C:N ratio of the landuse prior to conversion, and (iii) the area of land use change and/or management.

The annual average loss of soil C was estimated following *Good Practice Guidelines*. New Zealand uses a country-specific reference soil C stock value of 83 t C/ha for the 0-30 cm depth (Ministry for the Environment, 2008). Data already exists within the LULUCF section of the inventory that can be utilised for estimating net soil C changes, which are calculated based on a 20 year inventory period, after which steady state conditions are assumed – this is in accordance with the IPCC *Good Practice Guidelines* for LULUCF. The Ministry for the Environment have used 1990 as a 'baseline' to account for land use change and its associated net soil C changes.

Nitrous oxide emissions due to forestry or grassland conversion to cropping have previously been captured within the LULUCF section: this N_2O source is now added to the agricultural section to ensure the implications of the 2006 guidelines are fully documented. An additional agricultural land use change now accounted for as a source of N mineralisation and N_2O emission is the conversion of cropping land to forestry, as this results in a net soil C loss. It is worth noting that land use change to grassland will result in net C uptake, leading to the sequestering of inorganic N (immobilisation). The IPCC *2006 Guidelines* do not account for this process "because of the different dynamics of soil organic matter (SOM) decomposition and formation, and also because reduced tillage in some circumstances can increase both SOM and N_2O emissions" (page 11.15, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*).

A default value of 15 was used for the C:N ratio of soil organic matter (top 30 cm) for land converting to cropland or forestry: the LULUCF section also relies on this default value. New Zealand-specific C:N ratio data is limited, with most measurements made in the top 7.5 or 10cm depth. Sparling and Schipper (2004) examined trends in soil properties across a range of land use categories. They found that the C:N ratio, measured in the top 10cm, was 11.8 and 11.3 under dry stock and dairy pastures, respectively, increasing to 15.5 for exotic forestry. The value for arable cropping and mixed cropping was 17.5 and 12.0, respectively. The large difference in these values is likely due to the former land use containing many allophonic soil sites, while the latter were sampled primarily from sedimentary, low C sites. Because the sites are independent of each other, with soil order having some influence on the data, we have chosen to use the IPCC default factors.

Where there is no change in land use (for example, grassland remaining grassland, or cropland remaining cropland), soil carbon stocks remain constant due to steady state condition, thus is consistent with the *2006 Guidelines*.

The third parameter that is required for calculating F_{SOM} is the land use change area. This is currently calculated by the Ministry for the Environment where the LCDB (Land Classification Data Base) classes are mapped to Land Use Changes (LUC). The change between the LCDB2 and LCDB1 (2002 and 1997) was divided by 5 to give an annual figure, which is then extrapolated back for year's pre 1997 and post 2002. For permanent land use changes such as grassland converted to forestry or long term cropping, this approach appears sufficient considering that the areas of land use change equates to approximately 0.2% of the land area remaining under their initial uses i.e. no change. Appendix A details the areas of land use change for each category. Here we provide two examples: conversion of grassland to plantation forestry, at an estimated rate of 18,197 ha per year, and grassland to annual cropping, at an estimated rate of 24 ha per year (these areas are sourced from the LULUCF dataset, Ministry for the Environment, 2008).

It is stated in *Chapter 5: Cropland* of the *2006 Guidelines* that areas are considered as having gone through a land use changes if they remain in the conversion category for 20 years. However, the guidelines text also points out that "other periods reflecting national circumstances" need to be considered. This appears to be the only reference in the IPCC *2006 Guidelines* to the required duration for a conversion to be considered as a land use change: it can be found in a section discussing the choice of biomass activity data (section 5.3.1.3). A later section (5.3.3.2) refers to the choice of initial soil carbon stock for calculating soil C loss. It is this section that relates to the methodology for calculating N mineralisation following decomposition of soil organic matter, however there is no mention of required duration that the land should remain in the converted state. New Zealand has several examples where temporary land use change is practiced. On many farms pasture is converted to forage or cereal/maize silage crops for short periods (6 months – 2 years), which are subsequently returned back to pasture, often part of a pasture renewal programme. Although not abundantly clear, it would appear that this type of temporary land use change is not included within the IPCC definition of N_2O emissions due to "N mineralisation from loss in soil organic C in mineral soils through land use change or management practices" (page 11.15, *Chapter 11: N_2O emissions from Managed Soils, 2006 Guidelines*). We have made the assumption that this type of temporary land use change is not included in the IPCC definition of land use change, and thus have used the areas utilised within the LULUCF section. However, in section 5, we will present a third scenario based on the *2006 Guidelines*. We will recalculate the inventory with the assumption that temporary land use changes are included within F_{SOM}: this is presented to illustrate the potential effect of including temporary land use changes on the inventory.

The default emission factor used for this new source is EF_1 (0.01). As there is little New Zealand research data available quantifying N_2O emission due to land use change, the default EF has been employed here.

Disaggregating swine and poultry manure management systems

The proportion of market and breeding swine was based on Statistics New Zealand's Agricultural production census. From this data it was calculated that breeding swine typically make up 12.5% of the total swine population. Market swine have an EF of 13 kg CH_4/head/year while the EF for breeding swine is 23 kg CH_4/head/year, therefore the weighted average EF becomes 14.25 kg CH_4/head/year .

Poultry numbers are separated into layers and broilers for most years by statistics New Zealand. There is no official data on the type of manure management system for layers. It was assumed that 'wet' meant the manure was sufficiently wet that anaerobic conditions were produced. Expert judgement was sought from Natalie Crystal of the Poultry Industry Association (PIANZ). She considers that the "vast majority" would be managed dry on the basis that there would be no point in adding water as that would only make management harder; however there would be some intrinsic wetness, especially for caged birds where manure falls through cage floor. Thus, a value of 97.5% was chosen to represent the dry management of manure, where the associated EF is 0.03 kg CH_4/head/year. The 2.5% of layers managed on wet manure systems have an associated EF of 1.4 kg CH_4/head/year. This results in a weighted average EF of 0.064 kg CH_4/head/year for layers. It should be noted that because of the large difference in *2006 Guidelines* EF values for dry and wet management systems (0.03 and 1.4%, respectively), a small change in the percentage with wet management can have a significant effect on the total CH_4 emissions from poultry manure.

3.2.2 Estimating data for 2010 and 2020

Livestock numbers and excreta production

Estimation of livestock numbers and excreta for cattle, sheep, deer and goats came from Dr. Harry Clark, as part of his predictions for MAF project AG-INVENT-01. Livestock numbers for poultry, swine, horses and goats were estimated based on algorithms utilised by the Ministry for the Environment. These algorithms should be treated with caution, as the extrapolation out to 2020 is based on a 5 year trend. For instance, broiler poultry has a population of 22,247,000 in 2006 more than doubles by 2020 to 47,653,000. One needs to consider the uncertainty associated with these extrapolations. For swine, it was assumed that the percentage of breeding swine remained at 12.5% of the total swine population for 2006, 2010 and 2020.

Pasture and Crop areas and yields

Crop area and yields values for 2010 and 2020 were based on expert judgement, utilising the same experts that provided information outlined in Table 1. Predicted pasture area was sourced from LULCF data, while DM production was assumed to remain constant over time.

Future pasture renewal rates are considered to remain unchanged up to 2020 (Dr. David Stevens, AgResearch, *pers. comm.*), suggesting a renewal rate of 3.5% of pasture area, or ~300,000 ha per year. This prediction of a constant rate is due to several factors influencing renewal rates, such as future fuel and fertiliser pricing, future returns from dairy and red meat and better pasture utilisation. An alternative prediction by Murray

Willocks, chairman of PRCT, suggests pasture renewal area may increase from ~300,000 ha in 2006 to ~390,000 and ~480,000 ha in 2010 and 2020, respectively. As pasture renewal currently influences N inputs from residues only, a simple comparison showed that the two different predictions had a minor effect on the total inventory for 2010 and 2020 (data not presented). Therefore, for this project we have adopted the more conservative estimate suggested by Dr. Stevens.

Land Use Change and Management

The rate of land use change to cropping or forestry over time was considered to be constant, as this is the assumption used by the Ministry for the Environment. As mentioned in Section 3.2.1 the associated soil C changes are calculated for a 20 year inventory period, after which it is assumed soil C stocks have reached steady state conditions. As 1990 is effectively a 'baseline' for these calculations, by 2010 and 2020 (20 and 30 years following 1990, respectively) the calculated national rate of soil C change will presumably be constant due to the associated constant rate of land use change. Appendix A details the calculated soil C changes for 2006, 2010 and 2020.

A more robust approach to estimating soil carbon changes, among other variables, is currently in progress. This project, Land Use and Carbon Analysis System (LUCAS), will support and underpin New Zealand climate change policy development through to 2012 and beyond.

3.3 Uncertainty Assessment

Previously calculated uncertainties associated with the N_2O inventory when based on the *Revised 1996 Guidelines*, as submitted by New Zealand to the IPCC, are shown in Table 2.

Table 2. Uncertainties in N_2O emissions from agricultural soils for 1990, 2002 and 2006 estimated using Monte Carlo simulations (1990, 2002) and the 95 per cent confidence interval (2006) (source: Ministry for the Environment, 2008).

Year	N_2O emissions from agricultural soils (Gg/annum)	95 % CI min	95% CI max
1990	32.4	18.8	56.4
2002	39.6	23.0	68.9
2006	41.1	23.8	71.5

An uncertainty analysis on the estimated total N_2O inventory based on the *2006 Guidelines* is likely to result in a similar uncertainty. We have decided that there would be more value in conducting an uncertainty analysis on two of the key changes included within the *2006 Guidelines*. These are:

- inclusion of N mineralisation associated with C loss due to land use change and management, F_{SOM}.
- reduction of emissions factor for leached N, EF_5.

3.3.1 Inclusion of F_{SOM}

Calculated N_2O emissions are the product of activity data and an associated emission factor. The new source, F_{SOM}, has been included to account for N_2O emissions associated with N mineralised from loss in soil organic C in mineral soils through land use change or management practices. Under the *Revised 1996 Guidelines*, N_2O emissions associated with land use change to cropping were included within the LULUCF section of the national inventory. The *2006 Guidelines* suggest N_2O emissions from all land use change be included, and is now contained within the section *N_2O emission from managed soils*.

Activity data is used to calculate F_{SOM}, which is a function of the average annual **loss of soil carbon** for each land use type, the **C:N ratio** of the soil organic matter, and the **area of each land use and/or management** type. For mineral soils this is based on a default depth of 30cm. The calculation used by New Zealand for its LULUCF reporting follows Tier 1 and 2 approaches, where default values obtained from the *Revised 1996 Guidelines* have been used, with C losses from differing land uses being calculated.

Loss of soil organic C

The average annual loss of soil C is based on a Tier 2 approach where different rates are calculated for the various land use change scenarios (see Appendix A). This C loss can be presented on a per hectare basis (to 30cm depth) by altering the calculation, revealing that the value used for soil C loss associated with a land use change from highly productive pasture to annual cropping is 40 t C/ha. The pre-conversion C stock for New Zealand pastures, based predominantly on 600-700 hill country sheep pasture sites, has been measured as being 105 t C/ha for the top 30cm (Tate et al., 2003: cited by the Ministry for the Environment, 2008). The loss of 40 t C/ha when converting grassland to annual cropping represents the total loss over a 20 year period, and is equivalent to 38% of the soil C being lost from pasture soils. This value of 40 t C/ha was derived by following IPCC default methodology, where it was assumed conventional cultivation is employed when converting pastures to cropping (Table 3.3.4, IPCC *Good Practice Guidelines* for LULUCF).

The country-specific soil C stock value of 105 t C/ha for "pasture soil" agrees with New Zealand values reported elsewhere. Sparling and Schipper (2004) have shown that, on average, dryland pasture and dairy pasture contain 51 and 67 t C/ha, respectively, in the top 10cm. This was based on 142 and 127 sites, respectively. Converting these values to the top 30cm, it can be assumed that the typical A horizon has a depth of 18.5 cm (Edmeades and Roberts, 2002), and that the C content below this is negligible. From this, it is estimated that the soil C content for the top 30cm is 94 and 124 t C/ha: the value of 105 t C/ha lies midway between these values. Soil order also has a large influence on the pre-conversion (and post-conversion) soil C stock. For Pallic and Brown soils, the total C content for pastures in the top 18.5cm (typical A horizon depth) was estimated to be 50-90 t C/ha, while for Allophanic and Pumice soils the values were higher, at 100-175 t C/ha (Edmeades and Roberts, 2002).

Total C content of cropping farms was reported to be, on average, approximately 40 t C/ha for the top 10cm (Sparling and Schipper, 2004). Converting this value to a depth of 30cm is more prone to error than for pasture, as the topsoil is mixed down the profile to the depth of cultivation, which can vary from 15 to 25 cm. These depths suggest the average soil C content in cropping soil could lie somewhere between 60 to 100 t C/ha in the top 30cm.

New Zealand data on measured soil C losses due to land use change is scarce. Preliminary results from the Millennium Tillage Trial (MTT), sited in Canterbury on a Pallic soil, suggest that approximately 13 t C has been lost from the top ~25cm over a seven year period following conversion from improved pasture to cropping (Dr. Mike Beare, *pers, comm.*). Data from this trial suggest the initial soil C stock for the improved pasture was approximately 85 t C/ha to a depth of 25cm, thus around 15% of the soil C was lost over seven years, regardless of the tillage method (intensive tillage, minimum tillage and no tillage). However, the tillage method did influence the rate of loss, where intensive tillage resulted in approximately 10% of the soil C being lost by the end of the first year compared to 1.5% of the C in the first year for no tillage. It can also be assumed that losses will continue beyond the seventh year following conversion, albeit at a reduced rate, as decomposition of organic matter is typically more rapid soon after conversion to cropping.

The uncertainty associated with soil C loss is likely to be very large, due to the factors outlined above (soil orders, tillage method) plus other factors not considered here (e.g. organic matter quality, climatic conditions at the time of conversion). With an appreciation of the large uncertainties associated with these losses, we propose an uncertainty range of ± 70%. This encompasses the C losses estimated over a seven year period when converting from improved pasture to cropping, as suggested by the MTT preliminary results. It should be restated that inventory calculations are based on net C changes occurring over a 20 inventory period.

It is noteworthy that while the MTT research suggests form of tillage does not influence C loss over an 8 year period, it may still have a direct influence on the N_2O emissions, depending on the land use. For example, when compared to conventional cultivation, no tillage may lead to increased emissions due to an increased N pool in the surface layers and enhanced anaerobic conditions (Smith et al., 2001), or may decrease emissions due to less risk of soils being pugged by livestock grazing on drilled forage crops (Thomas et al., 2008). According to the latest Agricultural Statistics (June 2007), sourced from the Ministry of Agriculture and Forestry, the total land area cultivated was 477,867 ha while the area direct drilled was 282,373 ha, representing 37% of the total area re-sown.

C:N ratio

New Zealand uses the default value of 15 for the C:N ratio for all land use change scenarios. The New Zealand data presented earlier (Sparling and Schipper, 2004) suggests dairy pasture has a C:N ratio of 11.3, while mixed cropping paddocks have a similar C.N ratio of 12.0. These data may not be representative of land use change, as the sites were independent of each other, thus do not represent temporal changes. Indeed, conversion of pasture to annual cropping is likely to result in the C:N declining due to decomposition of soil organic matter. Thus, as New Zealand data may be limited, we have accepted the IPCC default value of 15. The default C:N ratio of 15 for forestland and grassland will also have an associated uncertainty; a default uncertainty range (95% confidence interval) of 10 to 30 is provided by the *2006 Guidelines*, which is equivalent to an uncertainty range of 50-200%. Topsoil C:N ratios are very rarely less than 10 (Sparling and Schipper, 2004). The upper limit represents a carbon to nitrogen ratio double that of the average. Sparling and Schipper (2004) reported that the average C:N ratio for indigenous forests was 16.2. The C:N ratio of soils under this land use will be greater than that of improved forestry and agricultural soils due to the absence of anthropogenic N inputs, apart from presumably low rates of N deposition. Therefore, it was felt that 30 represented an upper limit that was unrealistic. Hence a more realistic upper limit of 20 is suggested for New Zealand forestry and grassland soils. This is akin to an uncertainty range of $\pm$ 33%.

Area of land use change and/or management

The total area of land use change and management is considered to be 27,087 ha per annum (LULUCF data). This represents several types of conversions, dominated by grassland converting to plantation forestry and perennial crops, and plantation forestry converting to perennial crops (see Appendix A). This area is calculated from the LCDB1 and LCDB2 data, which has an associated uncertainty of $\pm$ 6% (Ministry for the Environment, 2008). Because this value is based on the difference in land classes between the years 1997 and 2002, there will be additional temporal error associated with this data. Economic conditions have a large influence on land conversion. For example, recent record payouts for milk solids has resulted in an expansion in the dairy industry, with many hectares of plantation forestry being converted to improved pastures for dairy production. The original LULUCF data had the conversion of highly productive grassland to plantation forestry representing 67% of the total converted land area. Today, the net conversion rate would be in the opposite direction for these two particular land uses. Consequently, we have adopted an uncertainty error of ± 75% for the total land use change data.

Combining uncertainties in Activity Data

When there is more than one uncertainty, these need to be combined (Uncertainties, Chapter 3, *IPCC 2006 Guidelines for National Greenhouse Gas Inventories*). It can be assumed that the activity data (rate of C loss, C:N ratio of soil and area of land use change) are independent of each other. Therefore, on this basis, when using the multiplication approach to combining uncertainties representing a 95% confidence interval (page 3.28, Chapter 3, *IPCC 2006 Guidelines for National Greenhouse Gas Inventories*), the combined uncertainty associated with the activity data is ± 108%.

EF_1

While the uncertainty analysis is focused on the activity data for this new source, it seems appropriate to also examine the rationale for the emission factor EF_1 for F_{SOM} and its associated uncertainty. The emission factor used for this additional source of N is the same as that used for direct emissions resulting from fertiliser and manure applications to land. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* state on page 11.15 that the "ammonium and nitrate resulting from soil organic matter mineralisation is of equal value as a substrate for the microorganisms producing N_2O by nitrification and denitrification, no matter whether the mineral N source is soil organic matter loss from land-use or management change, decomposition of crop residues, synthetic fertilisers or organic amendments".

The *2006 Guidelines* default EF_1 value is now 0.01: previously this had been 0.0125, however following new analysis of a larger experimental dataset, this has been reduced to 0.01, and is now the same as the New Zealand specific values for EF_1 and EF_{3PRP}. As a source of N that is subject to nitrification and denitrification, it makes sense that these two values are the same. While the probability density function (PDF) for EF_1 will be a skewed, log-normal distribution, the value for EF_1 (0.01) is termed the "mean" of the PDF.

The default uncertainty range around EF_1 is 0.003 to 0.03 (Table 11.1, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*). The 95% confidence lower limit is 30% of the mean of the PDF, 0.01 kg N_2O-N/kg N addition to soil. The corresponding upper limit is 0.03 N_2O-N/kg N additions to soil, which is 300% of the mean of PDF and equivalent to 3% of the maximum possible value of 1 kg N_2O-N/kg N addition to soil. This is quite a large difference compared to the mean, and when looking at the full range (0.003 to 0.03) this represents a factor of 10.

3.3.2 Reduction of EF_5

The overall value for the emissions factor associated with leached N is denoted EF_5. The *2006 Guidelines* state (Chapter 11, page 24) the default value for EF_5 has been changed downwards from 0.025 to 0.0075 kg N_2O-N/kg N leached/in runoff water. The recommended default value is thus only 30% of the former value. The three (additive) components of EF_5 are denoted

- EF_{5g} for groundwater and surface drainage,
- EF_{5r} for rivers and
- EF_{5e} for estuaries.

The former and recommended default values are shown in Table 3. The new recommendations mean the same default value should be used for each of the three components of EF_5 (= 0.0025 kg N_2O-N/kg N leached/in runoff water).

Table 3: Recommended default values for EF_5 reported in the *Revised 1996 Guidelines* and the *2006 Guidelines*.

Water body	**Revised 1996 Guidelines**	**2006 Guidelines**
EF5g (groundwater and surface drainage)	0.015	0.0025
EF5r (rivers)	0.0075	0.0025
EF5e (estuaries)	0.0025	0.0025
EF5 total	**0.025**	**0.0075**

The recommendations were based on expert judgement. This included consideration of data from field studies published in peer-reviewed scientific journals. Recent results from these studies were interpreted to have “indicated” (quoting from Chapter 11, page 24) the former value of EF_{5g} was “too high”, so it “should be reduced”. The recommended default values are intended to be the most likely values. Until recent results were obtained, the same applied to the former recommended default values.

Recommended default values should be considered highly probable unless compelling, country-specific data reveals a different and thus more appropriate value. The choice of default values can be justified on the bases of expert judgement and statistics.

A compelling reason to accept EF_5 = 0.0075 kg N_2O-N/kg N leached (revised IPCC *2006 Guidelines* default value of EF_5 = 0.75% ≈ 1%) as the most likely value is that it would then effectively equal New Zealand specific values for EF_3 and EF_1 (the direct N_2O emissions factor for fertiliser N applied to soils). That is, for New Zealand, adopting the new IPCC default value of EF_5 means $EF_5 \approx EF_3 = EF_1$. The New Zealand specific values of EF_3 and EF_1 are based on evidence (field trial data) rather than expert judgement in the absence of country specific data (EF_5). For dairy cattle urine, 17 field measurement trials conducted by NzOnet researchers (de Klein et al., 2003) in different seasons yielded a geometric average value of EF_3 that was 0.90% ≈ 1% (Kelliher et al., 2005). For dairy cattle urine applied to a poorly drained soil in the Waikato region, 7 field measurement trials conducted in different seasons yielded arithmetic and geometric average values of EF_3 that were 0.6 and 0.3%, respectively (Luo et al., 2008). An international data set of 1008 measurements for agricultural soils yielded an arithmetic average value of EF_1 = 1% according to Laegreid and Aastveit, (2002). For nitrogen fertiliser, 7 seasonal field measurement trials conducted in New Zealand yielded a geometric average value of EF_1 that was 0.80% ≈ 1% (Kelliher and de Klein, 2006). These data included 4 seasonally-averaged values that have been more recently reported by Luo et al. (2008).

With respect to uncertainty associated with the recommended default value of EF_5, the (possible) range of values has also been determined by expert judgement (Table 11.3, *Chapter 11: N_2O emissions from soils, Volume 4, 2006 Guidelines*). The lower limit is 0.0005 kg N_2O-N/kg N leached/in runoff water. This is analogous to a minimum value based on a sample of measurements. The lower limit barely exceeds zero and thus set close to the (EF_5 frequency) distribution's "left wall". Occurrence of the lower limit should be considered highly improbable, thus it seems unlikely this limit should be reduced in future.

The upper limit is 0.025 kg N_2O-N/kg N leached/in runoff water, which happens to be the former default value. The upper limit cannot exceed 100%, and indeed was set to only 2.5% of the maximum, possible value. This means the upper limit is far from the distribution's "right wall", so it's possible for this value to be increased in future. Nevertheless, this upper limit is extremely different to the EF_5 value of 0.0075 kg N_2O-N/kg N leached/in runoff water. Occurrence of the upper limit should also be considered highly improbable. Therefore, 0.0005 and 0.025 kg N_2O-N/kg N leached are regarded as the 95% confidence limits for EF_5.

4. Comparison of agricultural emissions for 2006, 2010 and 2020

4.1 Influence of 2006 Guidelines on calculated emissions.

4.1.1 Nitrous Oxide

In this section we look at the influence of the IPCC *2006 Guidelines* on the calculated N_2O inventory, examining the effect of three different scenarios. These scenarios were presented in Section 3.1, and can be summarised as follows:

Scenario 1: Implementation of 2006 Guidelines (where EF_3 = 1% for all animal types and F_{SOM} excludes temporary land use change).

Scenario 2: Alternative EF_{3PRP} (0.5%) for sheep, with inventory calculation otherwise based on 2006 Guidelines.

Scenario 3: Alternative F_{SOM} where temporary land use change is included, with inventory calculation otherwise based on 2006 Guidelines.

The first scenario is based on the 2006 Guidelines, apart from country-specific emission factors. The second scenario disaggregates the country-specific emission factor, where the emission factor for all livestock, except sheep, remains at 1%, while the factor for sheep was 0.5%. The third scenario incorporates the area of temporary land use change (e.g. forage brassica cropping, pasture renewal) into F_{SOM}.

Scenario 1: Implementation of 2006 Guidelines (where EF_3 = 1% for all animal types and F_{SOM} excludes temporary land use change).

The effects of the new *2006 Guidelines* on individual source estimates of N_2O emissions are presented for years 2006, 2010 and 2020 (Tables 4, 5 and 6, respectively). The percent change from the *Revised 1996 Guidelines* for each source is also presented. These results are for scenario 1 for EF_3 and F_{SOM} i.e. EF_3 equals 1% for all animal types and F_{SOM} is based on the permanent land use change area.

The relative change to the calculated inventory for each year is also illustrated in Figure 1. Also shown is the effect of Scenarios 2 and 3: these are described later in this section.

Table 4. Influence of individual changes in Guidelines on 2006 N_2O inventory.

Change included within 2006 GL	**Source affected**	**Effect on inventory (Gg N_2O/yr)**	**Percentage change**
Removal Biological N fixation as a direct source of N_2O	N-fixing crops	-0.05	-100%
Disaggregation, by animal type (sheep versus cattle), of the default emission factor value for EF_{3PRP}	Animal production (retained national EF_{3PRP})	nil	nil
Removal of adjustments of F_{SN} and F_{AM} for volatilization	Synthetic fertiliser (F_{SN}) and Animal waste (F_{AW})	+0.68	+13%
Inclusion of N from below-ground crop residue	Crop residue (F_{CR})	+0.57	+344%
Inclusion of N release from pasture renewal			
Inclusion of N mineralization associated with C loss due to land-use change and management practices	F_{SOM}: New source for agricultural inventory	+0.47	NA
Inclusion of N from crop residues and mineralisation associated with C loss to N leached	Indirect emissions from leaching	+0.21	+4%
Reduction of the emission factor for N leached		-3.89	-70%
Net Effect on N_2O inventory from managed soils		**-2.02 (=625 CO_2e)**	**-5%**

Table 5. Influence of individual changes in Guidelines on 2010 N_2O inventory.

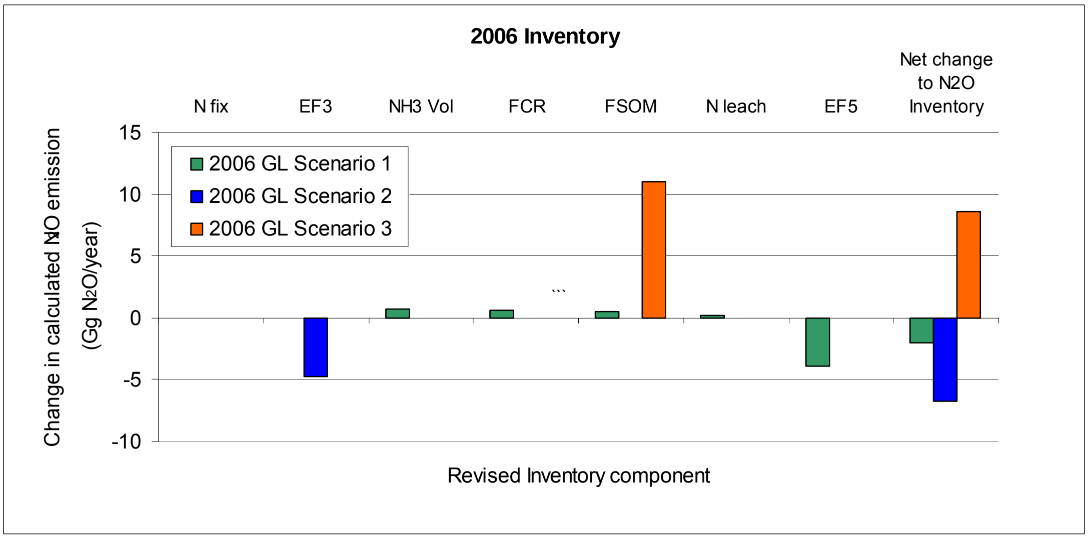
Change included within 2006 GL	**Source affected**	**Effect on inventory (Gg N_2O/yr)**	**Percentage change**
Removal Biological N fixation as a direct source of N_2O	N-fixing crops	-0.05	-100%
Disaggregation, by animal type (sheep versus cattle), of the default emission factor value for EF_{3PRP}	Animal production (retained national EF_{3PRP})	nil	nil
Removal of adjustments of F_{SN} and F_{AM} for volatilization	Synthetic fertiliser (F_{SN}) and Animal waste (F_{AW})	+0.81	+13%
Inclusion of N from below-ground crop residue	Crop residue (F_{CR})	+0.55	+252%

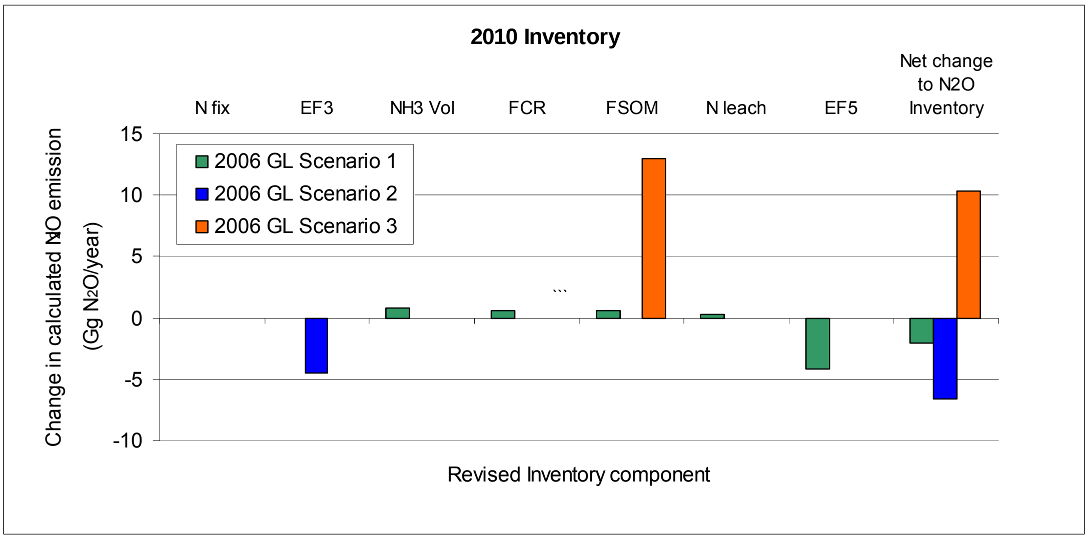
Inclusion of N release from pasture renewal			
Inclusion of N mineralization associated with C loss due to land-use change and management practices	F_{SOM}: New source for agricultural inventory	+0.55	NA
Inclusion of N from crop residues and mineralisation associated with C loss to N leached	Indirect emissions from leaching	+0.23	+4%
Reduction of the emission factor for N leached		-4.18	-70%
Net Effect on N_2O inventory from managed soils		**-2.10 (=652 CO_2e)**	**-5%**

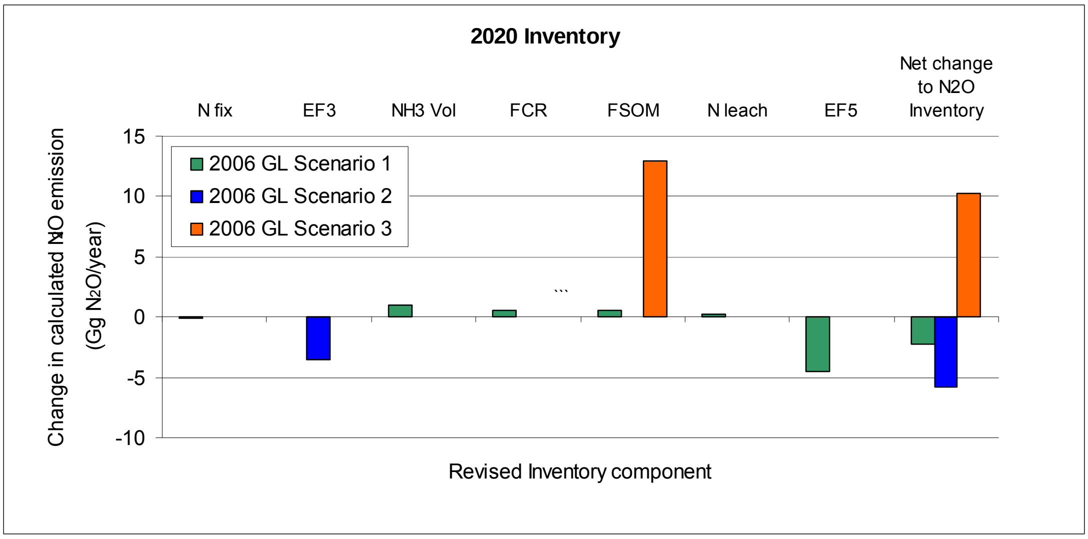
Table 6. Influence of individual changes in Guidelines on 2020 N_2O inventory.

Change included within 2006 GL	**Source affected**	**Effect on inventory (Gg N_2O/yr)**	**Percentage change**
Removal Biological N fixation as a direct source of N_2O	N-fixing crops	-0.05	-100%
Disaggregation, by animal type (sheep versus cattle), of the default emission factor value for EF_{3PRP}	Animal production (retained national EF_{3PRP})	nil	nil
Removal of adjustments of F_{SN} and F_{AM} for volatilization	Synthetic fertiliser (F_{SN}) and Animal waste (F_{AW})	+1.01	+13%
Inclusion of N from below-ground crop residue	Crop residue (F_{CR})	+0.57	+242%
Inclusion of N release from pasture renewal			
Inclusion of N mineralization associated with C loss due to land-use change and management practices	F_{SOM}: New source for agricultural inventory	+0.55	NA
Inclusion of N from crop residues and mineralisation associated with C loss to N leached	Indirect emissions from leaching	+0.24	+4%
Reduction of the emission factor for N leached		-4.52	-70%
Net Effect on N_2O inventory from managed soils		**-2.22 (=688 CO_2e)**	**-5%**

Figure 1: Influence of 2006 Guidelines on change in calculated N_2O inventory for 2006, 2010 and 2020.







The most influential change on the total N_2O inventory is the reduction of EF_5 from 0.025 to 0.0075, which reduces the national inventory by 3.89 Gg N_2O/year in 2006 and 4.52 Gg N_2O/year in 2020 (Table 6). For each of these years, this reduction represents a 70% decrease in the emission from leached N.

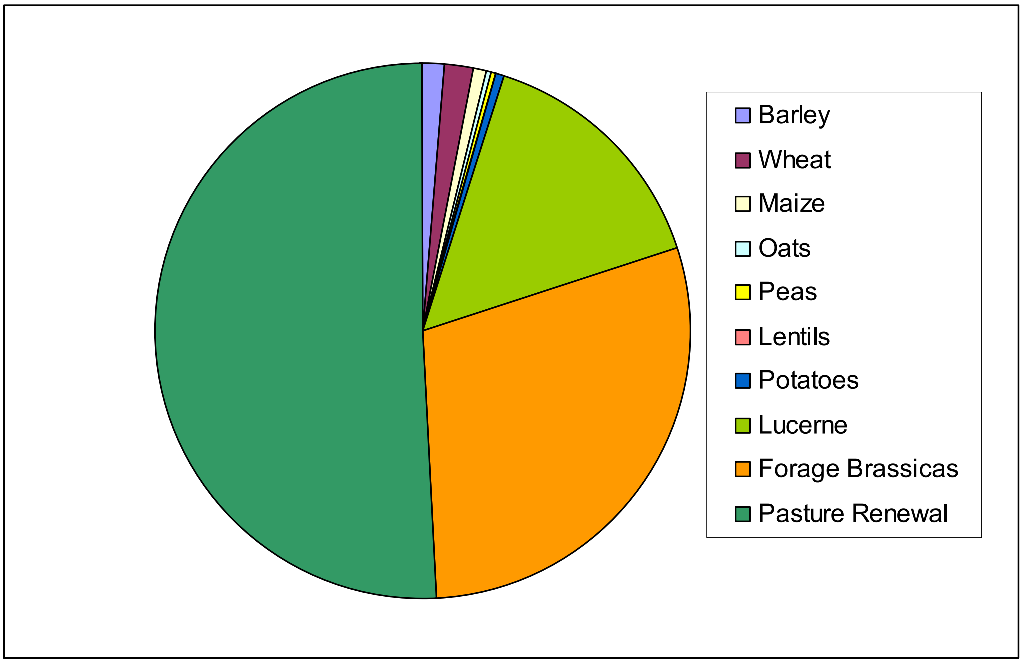
The individual effect of the removal of the adjustment for ammonia volatilisation from F_{SN} and F_{AM}, is an increase in the N_2O inventory by 0.68 Gg N_2O/yr in 2006. This increases to 1.01 Gg N_2O/yr in 2020 due to the predicted higher N inputs due to increased fertiliser use relative to other N inputs. This guideline change effectively increases reported inventory emissions from this source by 13% for all years calculated.

The individual effect of the revised calculation for the contribution of crop residues, F_{CR}, also increased the N_2O inventory. This revision now accounts for below ground residue N inputs, as well as including additional crops such as potatoes, forage brassicas, lucerne and renewed pasture. The estimated increases in calculated emissions are projected to rise by 0.55-0.57 Gg N_2O/year, representing an increase of between 240 to 344% for this source, depending on the inventory year (Tables 4, 5 and 6).

Figure 2 illustrates the contribution of the various crop types to the increase in estimated emissions from crop residues in 2006. The *Revised 1996 Guidelines* crops currently include barley, wheat, maize grain, oats, peas and lentils. The *2006 Guidelines* includes residues from other crops and the estimated effects of pasture renewal. As Figure 2 shows, there are large contributions from lucerne, forage brassicas and pasture renewal, with the latter contributing 50% to the total N_2O emission from crop residues; this is based on the assumption that 3.5% of pasture is renewed annually. For 2010 and 2020 the N_2O contribution from pasture renewal declines slightly to 49% and 47%, due to the constant rate of pasture renewal over time (this is regarded as a conservative prediction), predicted decrease in the area under grass/clover pastures (based on LULUCF predictions) and a predicted increase in lucerne area.

Inclusion of N mineralisation due to land use change, a source of N_2O not accounted for in the *Revised 1996 Guidelines*, saw the inventory increase by 0.47 Gg N_2O/year in 2006, increasing to 0.55 Gg N_2O/year for both 2010 and 2020 (Table 4-6). The identical values calculated for 2010 and 2020 are due to the Ministry for the Environment using 1990 as a 'baseline' when calculating the area of land use change (i.e. calculations are based on the assumption that land use change began in 1990), which subsequently affects the rate of soil C change. In accordance with the IPCC *Good Practice Guidelines* for LULUCF a 20 year inventory period is used in these calculations with steady state conditions being resumed following this period. The rate of land use change is assumed to be constant over time, therefore after 20 years (i.e. in both 2010 and 2020) the rate of soil C change will also be constant. Consequently, by following the IPCC *2006 Guidelines* for calculating emissions from F_{SOM}, the calculated N mineralisation rates and N_2O emissions due to soil C loss will also be constant in 2010 and 2020, as both these projected years occur more than 20 years after the 'baseline' of 1990.

Figure 2: Contribution of 'crop' types to N_2O emissions from "Crop Residues" in 2006 following *2006 Guidelines*.



We have assumed in Scenario 1 that the estimated contribution of N due to land use change and management accounts for permanent land use change only, and does not account for potential emissions during a temporary land use change. As the *2006 Guidelines* account for N_2O emissions due to land use change within the section *N_2O emission from managed soils*, it will be important to avoid double-counting, as emissions due to land conversion to cropping are currently accounted for within the LULUCF section of the inventory.

The inclusion of N from crop residues and N mineralisation to N leaching sees subsequent N_2O emissions from this source in the inventory increasing by 0.2 Gg N_2O/year.

Removal of biological fixation as a source of N_2O had a minor effect on the inventory, as New Zealand accounts for emission via biological fixation from peas and lentils only, in accordance with the IPCC *Revised 1996 Guidelines*.

The net calculated effect of changes to the N_2O inventory methodology is a decrease of 2.02 Gg N_2O/yr for 2006. This represents a decrease of 625 Gg CO_2equivalents/yr

(CO_2-eq/yr) (Table 4). The decrease is slightly more for later years: 2.10 and 2.22 Gg N_2O/yr for 2010 and 2020, equivalent to 652 and 688 CO_2-eq/yr, respectively. The decrease in the inventory compared to that calculated based on the *1996 Guidelines* is principally due to the influence of the downwardly revised EF_5 being approximately double the combined effect of the other 2006 Guideline changes on the inventory.

The effect of the *2006 Guidelines* on the national inventory for years 2006, 2010 and 2020 are presented as Scenario 1 in Table 7. If New Zealand remains with the *Revised 1996 Guidelines*, the national inventory is estimated to increase by 6.5 Gg over this 14 year period, from 41.1 to 47.6 Gg N_2O/year. Whereas, if New Zealand adopts the *2006 Guidelines*, the national N_2O inventory for 2006 will decrease to 39.1 Gg N_2O/year (2006 GL Scenario 1, Table 7). The increase over the 14 year period will be the slightly less, estimated at 6.3 Gg, lifting the inventory to 45.4 Gg N_2O/year by 2020.

Table 7: Nitrous oxide emissions from soils (Gg N_2O/year), calculated for 2006, 2010 and 2020 following the *Revised 1996 Guidelines* and the *2006 Guidelines* (Scenarios 1, 2 and 3[A]).

Inventory Year	IPCC guidelines and scenarios used for calculating emissions				Difference between Revised 1996 GL and 2006 GL Scenarios		
	Revised 1996 GL	2006 GL Scenario 1	2006 GL Scenario 2	2006 GL Scenario 3	1996 GL and 2006 GL Scen.1	1996 GL and 2006 GL Scen.2	1996 GL and 2006 GL Scen.3
2006	41.1	39.1	34.3	49.7	-2.0	-6.8	+8.6
2010	44.1	42.0	37.6	54.5	-2.1	-6.6	+10.4
2020	47.6	45.4	41.8	57.8	-2.2	-5.8	+10.2
Difference between 2006 and 2020	6.5	6.3	7.5	8.1			

[A] Scenario 1 refers to the adoption of the 2006 Guidelines, Scenario 2 refers to the adoption of the 2006 Guidelines with an alternative EF_{3PRP} for sheep (0.005), and Scenario 3 refers to the adoption of the 2006 Guidelines with an alternative F_{SOM} where temporary land use change is included. For Scenarios 2 and 3, apart from the noted changes, all other calculations are identical to those used for Scenario 1.

Scenario 2: Alternative EF_{3PRP} (0.5%) for sheep, with inventory calculation otherwise based on 2006 Guidelines.

Currently New Zealand uses a national EF_{3PRP} value of 0.01, as opposed to adopting the IPCC default value of 0.02. There is some evidence from small plot trials conducted across New Zealand that suggest EF_{3PRP} for sheep should be half that of cattle, with a value of 0.005 (de Klein et al. 2003, 2004; Sherlock et al. 2003a,b). Scenario 2 is based on the adoption of this alternative EF_{3PRP} for sheep, which results in lowering emissions from excreta returns to soils, and consequently lowering the calculated N_2O inventory further to 34.3 Gg N_2O/year for 2006 ("2006 GL Scenario 2", Table 7). However, it is important to note that, based on the *2006 Guidelines*, the increase in the national N_2O inventory from 2006 to 2020 will be the slightly **less** (at 6.3 Gg N_2O) compared to that based on the *Revised 1996 Guidelines* (6.5 Gg N_2O), whereas, if adopting the "2006 GL Scenario 2", the increase from 2006 to 2020 is **greater** (7.5 Gg N_2O) when compared to that calculated using the *Revised 1996 Guidelines* (Table 7).

Scenario 3: Alternative F_{SOM} where temporary land use change is included, with inventory calculation otherwise based on 2006 Guidelines.

In Scenario 1 we assumed that the area of temporary land use change such as forage brassica production either for supplementary feed and/or as a break crop during pasture renewal programmes was not included as 'land use change' when calculating F_{SOM}. However, since the 2006 Guidelines are not abundantly clear whether or not N release due to temporary land use change should be included within F_{SOM}, here we include these areas and present them as Scenario 3. Note, these calculations were done using scenario 1 for EF_3 i.e. EF_3 = 1% for all animal types.

The area under temporary conversion in 2006 is likely to be around 300,000 ha (based on expert judgement). We will use this area to represent pasture being converted to short term forage brassicas, maize silage and cereal silage or resown into new pasture. Land use changes due to pasture renewal (old pasture → forage brassicas or similar → renewed pasture) will not be detected by the mapping process used due to the relatively brief period these pastures are under cropping and also because the Land Cover Databases 1 and 2 applies a dominant cover rule mapping process. Crops such as forage brassicas will be difficult to distinguish from pasture under this process. In discussion with the Ministry for the Environment (Sonia Petrie and Chris Cameron) it would appear the new LUCAS project will not distinguish these types of land use changes and management (pasture renewal, forage brassica production) from permanent pasture.

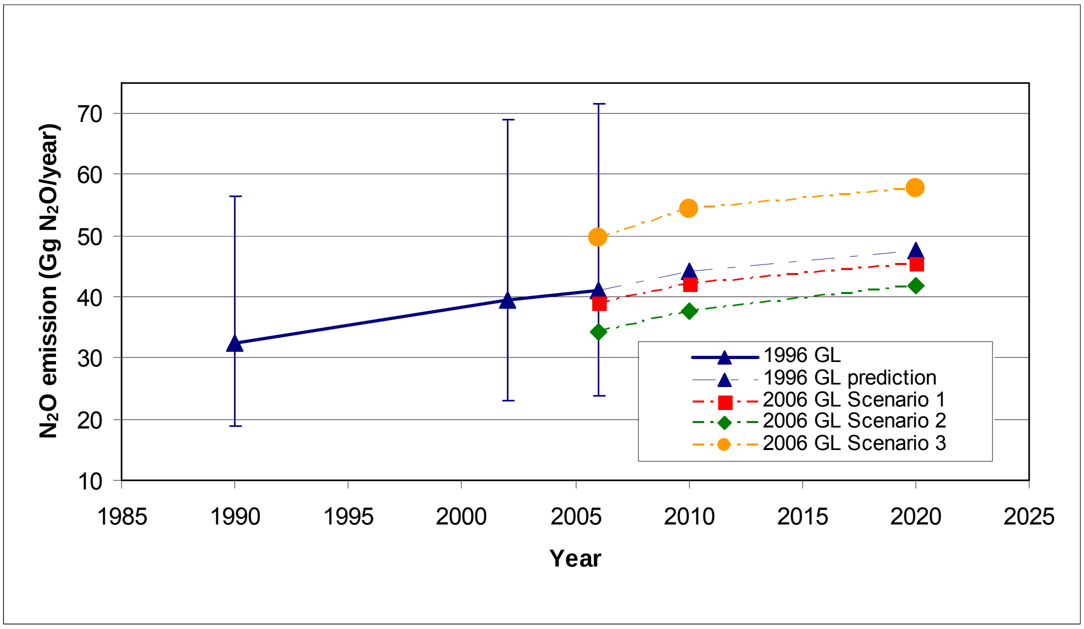
The effect of using 300,000 ha/year as the land use change area is very significant. The additional contribution to the inventory increases from 0.47 Gg N_2O/year to 11.05 Gg N_2O/year in the 2006 inventory. Temporary land use change has a larger effect on the 2010 and 2020 inventories, increasing the calculated emissions from 0.55 Gg N_2O/year to 13.00 Gg N_2O/year. The effect of this change on the national inventory for years 2006, 2010 and 2020 is presented in Table 7 as "2006 GL Scenario 3". Instead of a decrease in the N_2O inventory compared to that calculated using the 1996 Guidelines, there is now a predicted increase of 8.6 Gg N_2O/year for the 2006 inventory, equivalent to an additional 2666 Gg CO_2-eq/year. The increase in the national N_2O inventory from 2006 to 2020 is also greater (at 8.1 Gg N_2O) compared to that based on the *Revised 1996 Guidelines* (6.5 Gg N_2O) and also when compared to Scenarios 1 and 2 using the *2006 Guidelines* (Table 7).

It is clear that the inclusion of the temporary land use change due to forage and cereal/maize silage production within the inventory methodology, presented as Scenario 3, can have a significant effect on the calculated N_2O inventory.

There appears to be a lack of information on the effect of temporary land use changes on N_2O emissions. Soil disturbance due to the establishment of crops via direct drilling or conventional cultivation will influence N_2O emissions. Limited New Zealand data suggest N_2O emissions will be stimulated following conversion of pasture to cropping via cultivation. While van der Weerden et al. (1999) observed an increase in N_2O emissions following the conversion of pasture to cropping, this was in the absence of grazing animals. Thomas et al. (2008) showed that N_2O emissions from soils compacted by simulated animal hooves under wet conditions can be significantly greater when forage crops are established using conventional cultivation techniques compared to no tillage techniques. The effect of destroying old pastures, establishing new pasture or crops, grazing management, and subsequent regrassing on N cycling and N_2O emissions all need to be better quantified. While cultivation may lead to increased N_2O emissions due to decomposition and mineralisation of organic matter, it is also possible that N_2O emissions are reduced in the months following regrassing when compared to pastures that have not been renewed, or were renewed using no tillage techniques. This may occur if a portion of the N input (via, for example, excreta or fertiliser) is immobilised by the re-accumulation of soil C under the newly established pasture. Such a situation would be regarded as being at 'steady state' when national inventories are calculated. Quantification of emissions and associated emission factors under these farming practices will be required to determine if N_2O emissions from this potential source need to be included within the inventory methodology. One possible way of including this source is to use a Tier 2 approach, treating this land use change separately from that considered as a permanent land use change, using country-specific emission data.

The results from the calculations based on the *Revised 1996 Guidelines* and *2006 Guidelines* Scenarios 1-3 are illustrated in Figure 3, where values for 1990 (baseline) and 2002 are included to show trends over time. Uncertainties associated with the reported inventories for 1990, 2002 and 2006 (Table 2) are also illustrated.

Figure 3. N_2O emissions from soils (Gg N_2O/year), calculated using the *Revised 1996 Guidelines* (▲), *2006 Guidelines Scenario 1* (■), *2006 Guidelines Scenario 2* (◆) and *2006 Guidelines Scenario 3* (●). Values for 1990, 2002 and 2006 using the *Revised 1996 Guidelines*, with the associated 95% confidence intervals, are taken from *New Zealand's Greenhouse Gas Inventory 1990-2006* (Ministry for the Environment, 2008).



4.1.2 Methane

The revision of the emission factors associated with management of manure from swine, poultry, horses and goats in the *2006 Guidelines* have resulted in relatively small changes to the methane inventory. Methane emissions from manure management have been reduced by 12 to 14% (Table 8). This reduction is principally due to two revisions: (i) a decrease in the EF value for market swine manure management, where it is assumed that market swine represent 87.5% of the national swine population, and (ii) a decrease in the EF for poultry manure. Based on the *Revised 1996 Guidelines*, the total CH_4 inventory is 1183.5, 1238.44 and 1299.0 Gg CH_4/year for 2006, 2010 and 2020. Because enteric fermentation is the major source of CH_4 from agriculture, the net effect of the *2006 Guidelines* on the total CH_4 inventory is minor, at 0.5% or less (Table 8).

4.1.3 Net effect on N_2O and CH_4 emissions

As the *2006 Guidelines* influence both N_2O and CH_4 emissions, the net effect is presented as CO_2 equivalents (CO_2-eq) in Table 9. The net effect of the new guidelines is a decrease of 715 Gg CO_2-eq for 2006 compared to using the *Revised 1996 Guidelines*. The net effect decreases further over time, to a difference in the inventories of 752 and 826 Gg CO_2-eq by 2010 and 2020, respectively. This is equivalent to a decrease of about 2% for all three calculated years.

Table 8: Influence of 2006 Guideline changes to CH_4 emission factors from manure management for 2006, 2010 and 2020 inventories.

Inventory year	Effect on inventory (Gg CH_4/yr)	Percentage change to emissions from manure mgt	Net effect on agricultural CH_4 emissions
2006	-4.27 (=90 CO_2-eq)	-12%	-0.4%
2010	-4.79 (=101 CO_2-eq)	-12%	-0.4%
2020	-6.72 (=141 CO_2-eq)	-14%	-0.5%

Table 9: Net effect of using *2006 Guidelines* (scenario 1 for N_2O) instead of *Revised 1006 Guidelines* on greenhouse gas inventory from New Zealand agriculture for 2006, 2010 and 2020.

Year	**Inventory**	Effect on inventory (Gg N_2O or CH_4/yr)	Percentage change from *Revised 1996 Guidelines*
2006	Net Effect on N_2O inventory from managed soils	-2.02 (=625 CO_2-eq)	-4.9%
	Net Effect on CH_4 inventory	-4.27 (=90 CO_2-eq)	-0.4%
	Net effect on agricultural GHG inventory (Gg CO_2-eq/year)	**-715**	**-1.9%**
2010	Net Effect on N_2O inventory from managed soils	-2.10 (=652 CO_2-eq)	-4.8%
	Net Effect on CH_4 inventory	-4.79 (=101 CO_2-eq)	-0.4%
	Net effect on agricultural GHG inventory (Gg CO_2-eq/year)	**-752**	**-1.9%**
2020	Net Effect on N_2O inventory from managed soils	-2.21 (=685 CO_2-eq)	-4.6%
	Net Effect on CH_4 inventory	-6.72 (=141 CO_2-eq)	-0.5%
	Net effect on agricultural GHG inventory (Gg CO_2-eq/year)	**-826**	**-2.0%**

It is clear that the new guidelines have a greater influence on the N_2O inventory than on the CH_4 inventory. The calculated reduction in the N_2O inventory following the *2006 Guidelines* represents 83-87% of the total calculated decrease in the inventory for the three reported years.

4.2 Application of uncertainty assessment on calculated emissions

Because the *2006 Guidelines* have a greater influence on the N_2O inventory (Table 9), we have focused our uncertainty analysis on this particular gas. Furthermore, rather than examining the uncertainty in the whole N_2O inventory, we have instead concentrated on the uncertainty associated with two influential sources of change in the guidelines: inclusion of F_{SOM} and reduction in EF_5. The degree of their influence over the N_2O emissions inventory was presented in Tables 4 to 6 (section 4.1.1).

4.2.1 Uncertainty associated with F_{SOM}

As described in Section 3.1.1, the value for F_{SOM} is the product of three separate activity data (rate of C loss due to changes in land use and management, soil C:N ratio, and area of land use change and management). The combined uncertainty associated with F_{SOM} has been calculated as ± 108% (Section 3.3.1). Here we apply this combined uncertainty associated with the 2006 F_{SOM} source based on Scenario 1 (permanent land use change area only). The contribution from this new source is calculated to be 0.47 Gg N_2O/year in 2006, while the uncertainty range is estimated to be 0.00 to 0.98 Gg N_2O/year.

However, applying the same uncertainty to F_{SOM} based on Scenario 3, where temporary land use change in included, the uncertainty range associated with the calculated contribution of 11.05 Gg N_2O/year for 2006 is 0.00 to 22.98 Gg N_2O/year. Nitrous oxide emissions from this source represent 1.2% of the national N_2O inventory when based on Scenario 1, increasing to 22% when based on Scenario 3.

It is important to point out that while this may represent a large uncertainty in a given year, the error associated with the trend over time may be smaller. It is also important to consider that as more confidence is associated with the activity data used, the uncertainty range is likely to reduce.

4.2.2 Uncertainty associated with EF_5

Based on the 2006 Guidelines, N_2O emissions from leached N are estimated to be 1.67 Gg N_2O/year in the 2006 inventory. Using the default uncertainty associated with this emission factor (as discussed in section 3.3.2) the 95% confidence range associated with this mean is 0.11 to 5.34 Gg N_2O/year. Emissions from this source (indirect emissions associated with leached N) are calculated as being 4% of the national N_2O inventory for 2006.

5. Future Research

New Zealand may wish to adopt the *2006 Guidelines* for future inventory submissions. To make a defendable case to IPCC, New Zealand should collect additional activity data and establish emission factors for key activities to improve the robustness of its inventory, if based on the *2006 Guidelines*.

There are three key knowledge gaps that require further research. These are

(i) the activity data and associated N_2O emission factor for the newly introduced source F_{SOM},

(ii) the activity data and associated N_2O emission factor for the revised source F_{CR}.

(iii) the N_2O emission factor EF_5.

High quality activity data for both F_{SOM} and F_{CR} are critical to ensure inventories are accurate with a relatively narrow uncertainty range. For many of the calculations within this project, IPCC default values provided in the *2006 Guidelines* were used. The calculations also relied on the default EF_5 value of 0.0075.

Below we outline the required activity data and research for a Tier 1 and Tier 2 approach to the 2006 Guidelines. We also outline future research requirements to determine the significance of specific management practices and to establish appropriate emission factors for such practices.

5.1 Tier 1 approach.

At a minimum, the activity data collected the annual agricultural production survey (APS) will need to be expanded to include the following:

Crop Residues

- Potatoes: total area (ha) and average annual yield (t/ha)
- Lucerne: total area (ha) and average annual dry matter production (t DM/ha)
- Forage Brassicas: total area (ha) and average annual dry matter production (t DM/ha)
- Pasture Renewal: total area renewed (ha)

Soil Organic Matter

Improved accuracy of permanent land use change areas for all agricultural land use categories:

- Total area converting from Cropping to Forestry
- Total area converting from Grassland to Forestry
- Total area converting from Forestry to Cropping
- Total area converting from Grassland to Cropping
- Total area converting from Forestry to Grassland
- Total area converting from Cropping to Grassland

The LUCAS project will help provide better quality data, although this may be limited to changes coming out of or going into forestry. Thus it may not assist with the Grassland-Cropping and Cropping-Grassland land use changes.

However, if New Zealand does intend to adopt the *2006 Guidelines*, we suggest country-specific data and emission factors need to be determined for significant sources of N_2O (as outlined in section 5.2 below).

5.2 Tier 2 approach

New Zealand will produce a more accurate inventory with a smaller associated uncertainty if quality country-specific activity data and emission factors are applied. It is important to consider the major effects to the inventory due to changes in the guidelines. In addition to the activity data required for a Tier 1 default approach, we recommend the following information is quantified, through literature reviews and research programmes:

Crop Residues

- method of pasture renewal (including establishment techniques) and an understanding of the associated N_2O emissions
- type of pasture renewal programme (grass-grass vs grass-supplementary feed-grass)
- soil N inputs due to crop and pasture residue returns (residue:harvestable yield, dry matter content of residue, above and below ground partitioning and N content) (Note: much of this may have been reported within MAF project AG-INVENT-04 "*Review of Nitrous Oxide Emission Factors and Activity Data for Crops*").

- rate of N mineralisation of residue returns for different crop types, particularly lucerne, forage brassicas and renewed pasture,
- quantification of EF_1 for residues from lucerne, forage brassicas and renewed pasture.

Soil Organic Matter

- rate of C loss with land use change for key land use sub-categories, as influenced by tillage (based on limited New Zealand data, the IPCC default approach would appear to over-estimate C loss),
- soil C:N ratios for different land use classes,
- an understanding of how land use change influences N_2O emissions, both for <u>long-term</u> and <u>temporary</u> land use changes,
- rate of N mineralisation of organic matter,
- quantification of EF_1 for N mineralisation of organic matter.

$EF_{3PRP\ SHEEP}$

- better quantification of EF_{3PRP} for sheep, improving the quality of the existing data set.

EF_5

- better quantification and associated understanding of the processes relating to EF_5.

While the annual APS can be used to collect a proportion of the activity data, it should be noted that there will need to be an assessment of the uncertainty associated with this data: this will require formal quantification. In some cases, activity data needs to be sourced from industry groups. An example of this is the area of pasture renewal: a potential source of data is seed suppliers. This is also an example of where market sensitive information may hamper access to the data. A clear understanding is required as to how this information would be used to ensure national inventories are calculated using the highest quality activity data. Where possible, cross-checking of activity data should be conducted, to ensure consistency and robustness in the supplied data.

Research will be required to better understand the processes leading to N_2O emissions from activities such as temporary and permanent land use change, crop and pasture residue returns, and associated N mineralisation. One only needs to consider that the revised method for calculating emissions from crop residues has 50% of the calculated

N input coming from pasture renewal. Furthermore, if temporary land use changes are included within the definition of F_{SOM}, then this can have a significant impact on the calculated N_2O inventory, as presented in this report. Research is required to determine if the N_2O emission factor changes for temporary land use changes such as forage cropping, as it is possible emissions from subsequent animal excreta and N fertiliser application are reduced due to partial immobilisation.

New Zealand currently uses a country-specific emission factor for EF_{3PRP}. Recent research suggests New Zealand could argue for a lower EF_3 value for sheep excreta. The present dataset justifying such an argument may be considered as limited, therefore there would be value in improving the quality and robustness of this data if government plans to apply to the IPCC for a country-specific value.

If government plans to adopt the downwardly revised value for EF_5, more detailed experimentation is required to quantify this for New Zealand water bodies. The initial work by Clough et al. (2006) suggests a value much less than the revised IPCC value: more research is required in this area.

As there is some commonality in the research requirements relating to N inputs from crop residues and soil organic matter, we suggest research in these two key areas is combined.

The research requirements can therefore be separated into four distinct projects, all of which have equal importance. In terms of timing, the findings of project 3 will help determine the design of project 4:

1. **Research programme focusing on better quantification of EF_5,**

2. **Research programme focusing on better quantification of EF_{3PRP} for sheep excreta,**

3. **Literature review of on-farm practices relating to pasture renewal and temporary land use changes such as supplementary feed production, and**

4. **Research programme focusing on better understanding and quantification of N transformations and subsequent N_2O emission factors for residues of lucerne, forage brassica and renewed pasture residues and from soil organic matter due to land use change.**

This last proposed research programme could be aligned with the proposed research programme for quantifying ‘background’ emissions from improved pastures, as recommended in the MAF-funded project AG-INVENT-03A (van der Weerden and de Klein, 2008). ‘Background’ emissions are considered to be enhanced emissions from improved pastures, after accounting for N inputs such as animal excreta, manure application, N fertiliser application and N deposition. They may come from the mineralisation of pasture litter returns and/or from mineralisation of soil organic matter. Therefore, the proposed measurements of N transformations and N_2O emissions from native soils and improved pastures are similar to those proposed here.

A better understanding of underlying processes is critical for providing a defensible N_2O inventory. An added advantage of this knowledge is the potential for identifying mitigation technologies.

6. Conclusions

If New Zealand plans to adopt the 2006 Guidelines, more accurate activity data on land use change, specific crop areas and associated yields and pasture renewal rates are required at a minimum. To improve the accuracy of the inventory further, and reduce the level of uncertainty associated with the calculated emissions and the overall inventory, country-specific data and emission factors are required for EF_5, F_{CR} and F_{SOM}. If New Zealand plans to apply to the IPCC for a country-specific EF_{3PRP} for sheep, a more robust database is required.

It is recommended that a priority be given to the following research requirements:

1. **Research programme focusing on better quantification of EF_5,**
2. **Research programme focusing on better quantification of $EF_{3PRP\ SHEEP}$,**
3. **Literature review of on-farm practices relating to pasture renewal and temporary land use changes such as supplementary feed production,**
4. **Research programme focusing on better understanding and quantification of N transformations and subsequent N_2O emission factors for residues of lucerne, forage brassica and renewed pasture residues and from soil organic matter due to land use change.**

The last research requirement could be align with the research proposed in a concurrent project, focusing on quantifying ‘background’ emissions from improved pastures.

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8. Appendix A

Calculation of the New Zealand Greenhouse Gas Inventory for 2006, 2010 and 2020 following the IPCC *2006 Guidelines* required the following additional activity data for F_{CR} and F_{SOM}.

1. F_{CR}

Table A1: Total area and average yield for each crop included in inventory[A].

Crop type	2006		2010		2020	
	Area (ha)	Average Yield (t/ha)	Area (ha)	Average Yield (t/ha)	Area (ha)	Average Yield (t/ha)
Wheat	37,962	7.7	44,990	8.6	49,080	8.6
Barley	47,078	5.8	59,180	7.4	64,560	7.8
Oats	6,278	4.0	6,490	5.1	7,080	6.8
Maize grain	20,461	7.9	17,700	9.6	17,700	9.6
Peas	11,500	4.7	10,000	5.6	8,500	6.5
Lentils	1,000	2.0	1,000	2.0	1,000	2.0
Potatoes	11,700	43.0	11,700	43.0	11,700	43.0
Lucerne	100,000	9.0 [B]	112,000	9.0 [B]	150,000	9.0 [B]
Forage brassicas[C]	300,000[C]	10.0 [B]	300,000[C]	10.0 [B]	300,000[C]	10.0 [B]
Improved Grass/clover pasture[C]	8,686,000[C]	10.5 [B]	8,594,462[C]	10.5 [B]	8,357,618[C]	10.5 [B]
Total Area	**8,921,979**		**8,857,522**		**8,667,238**	

[A] Sources of information: Statistics NZ (2006), Nick Pyke, FAR; Bruce Snowdon, Heinz Watties; Derek Wilson, Crop & Food Research; Derrick Moot, Lincoln University; Purves and Wynn-Williams, 1989; Fletcher et al.,1999; extrapolation of LULUCF trends, MfE.

[B] Forage crop (lucerne, forage brassicas and pasture) yields presented as t DM/ha, all others presented on a Fresh Weight basis.

[C] Area of forage brassica production assumed to be part of pasture renewal programme, therefore area is included within 'Improved grass/clover pasture' area.

2. F_{SOM}

Table A2: Area of land use change and management, net change in soil C per year (assuming a 20 year inventory period), and resulting annual N mineralisation (to 30cm depth): data shown only where areas are greater than 0 hectares (values are identical for 2006, 2010 and 2020)[A]. Initial C:N ratio is assumed to be 15 for cropping, forestry and grassland soils (data adapted from LULUCF spreadsheet, sourced from Ministry for the Environment, 2008).

Land use Change category		**Area (ha)**	**Change in soil C (t C/ha/yr)**	**N mineralised (t N/ha/yr)**
LUC to Forestry				
Cropping to Forestry	Annual to plantation	1	0.88 [A]	0 [A]
	Perennial to plantation	3	0.56 [A]	0 [A]
Grassland to Forestry	Highly productive to plantation	18,197	-1.10	0.07
	Highly productive to natural	56	-1.10	0.07
	Low productive to plantation	7922	-0.58	0.04
	Low productive to natural	1	-0.58	0.04
LUC to Cropping				
Forestry to Cropping	Plantation to perennial	42	-0.56	0.04
	Natural to annual	1	-0.89	0.06
Grassland to Cropping	Highly productive to annual	24	-1.98	0.13
	Highly productive to perennial	839	-1.66	0.11
LUC to Grassland				
Forestry to Grassland	Plantation to high productive	26	1.10 [A]	0 [A]
	Plantation to low productive	250	0.58 [A]	0 [A]
	Natural to highly productive	186	1.10 [A]	0 [A]
	Natural to low productive	560	0.58 [A]	0 [A]

[A] Positive value for net C loss equates to a C sink, suggesting no N mineralisation. N_2O sink activity due to N immobilisation of N is not accounted for in the IPCC inventory calculations.

3. F_{SOM}

Table A3: Net soil C change for specific land use change sub-categories for 2006, 2010 and 2020. Soil C changes are based on a 20 year inventory period, accounting for land use changes since 1990. Steady state conditions are reached after 20 years (data extrapolated from LULUCF spreadsheet, sourced from Ministry for the Environment, 2008).

Land use Change category		**Net soil C change (Gg C/year)**		
		2006	**2010**	**2020**
LUC to Forestry				
Cropping to Forestry	Annual to plantation	0.020	0.024	0.024
	Perennial to plantation	0.029	0.034	0.034
Grassland to Forestry	Highly productive to plantation	-340.725	-400.853	-400.853
	Highly productive to natural	-1.053	-1.239	-1.239
	Low productive to plantation	-78.248	-92.057	-92.057
	Low productive to natural	-0.009	-0.011	-0.011
LUC to Cropping				
Forestry to Cropping	Plantation to perennial	-0.402	-0.473	-0.473
	Natural to annual	-0.010	-0.012	-0.012
Grassland to Cropping	Highly productive to annual	-0.803	-0.944	-0.944
	Highly productive to perennial	-23.674	-27.852	-27.852
LUC to Grassland				
Forestry to Grassland	Plantation to high productive	0.495	0.583	0.583
	Plantation to low productive	2.468	2.904	2.904
	Natural to highly productive	3.475	4.088	4.088
	Natural to low productive	5.532	6.508	6.508