Review of nitrous oxide emission factors and activity data for crops

MAF Technical Paper No: 2011/25

Prepared for Ministry of Agriculture and Forestry
By Crop & Food Research (Report No. 2240)
August 2008

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ISSN 2230-2794 (online)
ISBN 978-0-478-37586-2 (online)

April 2011

Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

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Publisher

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Crop & Food Research Confidential Report No 2240

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S Thomas, T Fraser, D Curtin, H Brown & E Lawrence

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A report prepared for
Ministry of Agriculture & Fisheries

Copy 1 of 10

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Abbreviations

Nomenclature used by the IPCC (IPCC 1997 unless specified)

AG_{DM}	Above-ground residue dry matter (tonnes DM)	IPCC 2006
C_f	Combustion factor (dimensionless)	
$Crop_{BF}$	Seed yield of all pulses (kg dm/yr)	
$Crop_O$	Yield from all non-N-fixing crops (kg dm/yr)	
EF_1	Emission factor for direct soil emissions (kg N_2O-N/kg N input)	
EF_4	Indirect N_2O emissions from volatilised N (kg N_2O-N/kg NH_3 and NO_x emitted input)	
EF_5	Indirect N_2O emissions from leached or runoff N (kg N_2O-N/kg N leached/runoff)	
F_{BN}	N fixed by N-fixing crops (kg N/yr)	
F_{CR}	Amount of N entering the soil as crop residue (kg N/yr)	
$Frac_{BURN}$	Crop residue burned in fields (kg N/kg crop-N)	
$Frac_{GASF}$	Fraction of fertiliser that volatilises as NH_3 or NO_x (kg N/kg of N input)	
$Frac_{LEACH}$	Fraction of fertiliser or excreta N from leached or runoff N (kg N/kg fertiliser or excreta N)	
$Frac_{NCRBF}$	N concentration in the crop biomass (kg N/kg DM)	
$Frac_{NCR0}$	N in non-N-fixing crops (kg N/kg DM)	
$Frac_R$	Fraction of above-ground crop residues removed from the field (kg N/kg crop-N)	
N_{AG}	N content of above-ground residues (kg N/kg DM)	IPCC 2006
N_{BG}	N content of below-ground residues (kg N/kg DM)	IPCC 2006
N_{FERT}	Annual amount of synthetic fertiliser applied (kg N/yr)	
R_{BG}	Ratio of below-ground residues (AG_{DM}) to harvested yield (kg DM/ kg DM)	IPCC 2006

1 Executive summary

1.1 Introduction

Non-CO_2 greenhouse gas emissions (nitrous oxide and methane) from cropped land are accounted for in the New Zealand greenhouse gas inventory. Currently IPCC default emissions factors are used to estimate these greenhouse gas emissions (i.e. Tier 1 approach) in the absence of New Zealand specific factors. The IPCC Guidelines encourage countries to use Tier 2 approaches, using country-specific data to increase the certainty of the emissions.

1.2 Review of emission factors and activity data for cropping, stubble and savanna (tussock) burning.

The objective of this report was to review the key factors used to estimate non-CO_2 greenhouse gas emissions from cropping systems. We have reviewed EF_1 (the direct N_2O emission factor for N_2O emissions from fertiliser and crop residues), F_{CR} (crop N returns and the crop factors used to calculate F_{CR}) and $Frac_{LEACH}$ (used to calculate indirect N_2O emissions from leached N). We have reviewed sources of key activity data that are used to calculate the emissions from key crops (non-N fixing grain crops and N fixing grains and pulses, root and tuber crops, N fixing forage crops and other forage crops). We have also reviewed the calculation and activity data used to estimate emissions from stubble burning and savanna (tussock) burning. Based on our review we have made a number of recommendations to refine the direct and indirect non-CO_2 greenhouse gas emissions from cropping systems and tussock burning.

1.3 Key findings

- Currently only six crops, accounting for about 25% of the cropped area, are considered in the inventory.
- The most important crops by area are forage brassicas (about 300,000 ha) and they are not currently included in the estimates of emissions from cropping systems
- There are very few (relevant) studies of direct N_2O emissions from NZ cropping systems.
- The current estimation of the N inputs of crop residues is too simplistic. Factors for N content in residues are too high. NZ-derived values can be used to refine the estimates.
- Calculations using a modified 2006 methodology with NZ harvest index values and appropriate N concentrations suggest that emissions from crop residues may be 30% less than estimated by the current method.
- There is very little information available to estimate the N inputs from forage brassica residues.
- Indirect N_2O emissions from N that is leached from crops can be refined using process-based models. Using a single management scenario, the country-specific value for $Frac_{LEACH}$ of 7% appears to be reasonable using the Tier 1 approach currently used to estimate N_{LEACH}.
- The method to estimate emissions from stubble burning can be improved. The factor for estimating the proportion of cereals burned is too low. More appropriate values for the area of burned cereal stubble are available.
- There is no information on the proportion of crop residues that are baled or removed in NZ.

- The area of tussock burning appears to be grossly underestimated (by about 10-fold).
- NZ-derived factors used to estimate tussock biomass are probably inappropriate for a large proportion of tussock burned. The factors that are currently used have been derived from burning studies of tall tussock. Much of the burned tussock grassland is of a degraded form that may have lower biomass, or may contain woody weed species.

1.4 Recommendations

1.4.1 Key crops

More crops should be included to fully represent the range and area coverage of crops grown in NZ (see section 4).

Quantitative information is required for forage brassica production so that N_2O emissions from crop residue N and N leaching can be estimated. This is the largest area of any crop type grown in New Zealand.

1.4.2 EF_1 for synthetic and organic fertiliser applied to cropping soils

Further field studies for a range of crops are required to provide a country-specific emission factor.

1.4.3 Direct emissions from crop residues

Adoption of a more refined approach based on modification of the 2006 IPCC approach is recommended.

Use recommended factors derived for New Zealand conditions (see section 6).

More information is required for certain crops, particularly forage brassicas.

Information to estimate the proportion of crop residue that is baled or removed should be collected.

The emission factor (EF_1) of 0.01 for crop residues is appropriate based on overseas data, but it needs to be experimentally verified for NZ conditions.

1.4.4 Indirect emissions from leached N

Process-based models like the Land Use Change and Intensification (LUCI) framework model should be considered for improving the prediction of N leaching in the NZ inventory. These models are able to simulate the effects of management on leaching for a range of New Zealand crops, soils and climates.

More model simulations of N leaching are needed for a wider range of management scenarios and crop types.

New Zealand should use the EF_5 default value of 0.0075 kg N_2O-N/kg N leached/runoff as recommended in the 2006 Guidelines.

1.4.5 Emissions from stubble burning

Use NZ crop-specific data for calculating the amount of cereal stubble burned (see section 8.1).

1.4.6 Emissions from savanna (tussock) burning

Resource consent data should no longer be used to estimate annual burning areas. Historical data before burnings became permitted activities (i.e. no resource consent is now required) in regional council Plans may be the most reliable source of data to estimate the tussock area that was burned in 1990.

Further information is required to understand why the area burned reported in the Agricultural Production census data is of a magnitude greater than the estimates based on 20% of the consented area.

Until further information is available the census data should be accepted as the most accurate information for current burning practices.

Accept current IPCC default values for: fractions of live and dead biomass oxidised during burning, and CH_4, and N_2O emission ratios.

Further investigation is required to:

- confirm the areas reported in the Agricultural Production census.
- assess the proportions of tall tussock and other degraded tussock grasslands that are burned.
- assess whether the current above-ground biomass density value, proportions of live and dead biomass and N:C ratios are appropriate for the types of grassland being burned.

2 Introduction

This research was conducted as part of the MAF 'Climate Change Plan of Action' Research Programme 2007/08 contributing to the Agricultural Inventory (Project CC MAF POL_0708-61 - INVENT-04A - Review of Nitrous Oxide Emission Factors and Activity Data for Crops). The goal of the research was to review NZ's current emissions factors and activity data for cropping, legumes, stubble and savannah burning activities against current IPCC default factors.

Non-CO_2 greenhouse gas emissions (nitrous oxide [N_2O] and methane [CH_4]) from cropped land are accounted for in the New Zealand greenhouse gas inventory. Current IPCC default emissions factors are mainly used to estimate these greenhouse gas emissions (i.e. Tier 1 approaches) from cropping systems in the absence of NZ-specific factors. The IPCC Guidelines encourage countries to use Tier 2 approaches to increase the certainty of the emissions. Key factors included in the review are EF_1 (emission factor for N_2O emissions from synthetic and organic fertiliser), F_{CR} (crop N returns and the crop factors used to calculate F_{CR}) and $Frac_{LEACH}$. Key activity data include: (i) the areas of key non-fixing grains crops, N fixing grains and pulses, root and tuber crops, N fixing forage crops and other forage crops; (ii) the area of stubble burnt; (iii) the area of savanna (tussock) burned.

We have used a range of sources of published and unpublished data from New Zealand and overseas, and modelling approaches, to examine the range of activity data and factors that are used in the current national inventory.

The IPCC Good Practice Guidance and Certainty Management Guide (IPCC 2001) makes recommendations for obtaining country-specific emission factors for N_2O emissions. For cropping, these factors include emissions due to synthetic fertiliser (EF_1), biological fixation (F_{BN}), crop residue (F_{CR}) and cultivation of organic soils (F_{OS}). The IPCC Good Practice Guide (IPCC 2000) recommends that these factors need to be representative of the different environmental and management conditions for NZ. Therefore, measurements should be made in the major crop growing areas, in all seasons, for different soil types and different management conditions. The IPCC Good Practice Guidance and Uncertainty Management document (IPCC 2001) also provides further recommendations for measurement period and frequency, selection of sites, use of simulation models and key management influences.

3 Current NZ N_2O emission factors from crops

3.1 Summary of current nitrous oxide emission calculations and emission factors (IPCC 1996)

Direct N_2O and CH_4 emissions from cropping are currently calculated using Tier 1 (A and B) approaches (IPCC 1996). This means that in some cases locally derived, "country-specific" emission factors are used.

3.2 Direct soil emissions of nitrous oxide

Several sources of N_2O emissions were identified in the IPCC methodology (IPCC 1997) that are relevant to crops grown in NZ. These are the emissions related to the application of synthetic fertilisers; biological N fixation; crop residues; and the cultivation of soils with high organic content. The production of N_2O is primarily from nitrification and denitrification processes. Emissions from the cultivation of soils with high organic content are outside the scope of this review; these emissions were recently reviewed by Kelliher et al. (2003). The IPCC methodology assumes that emissions from unfertilised soils are the equivalent of background emissions, although it recognised that emissions may be greater than "natural emissions" due to mineral N release from the mineralisation of soil organic matter (IPCC 1997).

There have been recent modifications to the emission factor for synthetic fertiliser (EF_1) for NZ. The EF_1 was reduced from 1.25% to 1% in 2006 following a review of data (Kelliher & de Klein 2006). This factor is also used for NZ N_2O emissions emanating from the decomposition of crop residues (Ministry for the Environment 2008b). There is much uncertainty about how much N_2O is emitted from N that enters the soil via the biological fixation of N and from N in crop residues (IPCC 1997).

3.2.1 Direct nitrous oxide emissions from biological fixation

This calculation is aimed to account for N_2O emissions from atmospheric N_2 that has been fixed by legumes. The IPCC 1996 methodology estimates N_2O emissions from N fixed by legumes assuming that N_2O is emitted from legume fixed N in a similar way to emissions from applications of fertiliser N, or that Rhizobia in root nodules are able to produce N_2O from denitrification (IPCC 1997).

The amount of N fixed by N-fixing crops (F_{BN}) is currently estimated using a Tier 1A approach (IPCC 2000). The total N fixed by the crops is calculated from estimates of the N concentration in the dry matter ($Frac_{NCRBF}$) and the total seed or grain production of N-fixing crops ($Crop_{BF}$). Biological fixation by legumes in pastures is not included in this estimate (IPCC 1997). It is assumed that the total dry matter (residue + grain product) is twice the amount of product:

$$F_{BN} = 2 * Crop_{BF} * Frac_{NCRBF}$$ **(Equation 1)**

In the latest IPCC guidelines (IPCC 2006) this source has been removed.

3.2.2 Direct nitrous oxide emissions from crop residues

These are direct N_2O emissions arising from the decomposition of plant residues and the release of N (F_{CR}). These are calculated from crop production data. The IPCC distinguishes between the residues from N-fixing (pulses) and non-N-fixing crops (IPCC 1997). Emissions are currently calculated using a Tier 1A approach.

Annual N in the crop residue is calculated by multiplying the crop yield of non-N-fixing crops ($Crop_O$) and N-fixing crops ($Crop_{BF}$) by their respective N concentrations of the biomass ($Frac_{NCRO}$ and $Frac_{NCRBF}$). A default value of 2 is used to convert the above-ground crop yield to total above-ground biomass. An adjustment is made to account for the above-ground biomass ($Frac_R$) that is removed and burned ($Frac_{BURN}$).

$$F_{CR} = 2 * (Crop_O * Frac_{NCRO} + Crop_{BF} * Frac_{NCRBF}) * (1-Frac_R) * (1-Frac_{BURN})$$ **(Equation 2)**

3.3 Indirect nitrous oxide emission factors

Two indirect pathways of N_2O emissions are considered to contribute to agricultural emissions. These are N_2O emissions from N that is lost from soils via leaching or runoff (N_{LEACH}), and from N that is deposited as ammonia or NO_x (following volatilisation of N). Indirect emissions from leaching and runoff [$N_2O(_L)$] are calculated as a proportion ($Frac_{LEACH}$) of the total amounts of synthetic fertiliser N (N_{FERT}) and animal excreta N (N_{EX}) applied to soils and then another proportioning emission factor EF_5 is applied:

$$N_2O(_L) = (N_{FERT} + N_{EX}) * Frac_{LEACH} * EF_5$$ **(Equation 3)**

NZ uses its own specific $Frac_{LEACH}$ value (Table 1). Indirect emissions from volatilised N use the IPCC default emission factors. They are calculated by applying an emission factor (EF_4) to the sum of N_{FERT} and N_{EX} applied to the soil (Table 2).

Table 1: Values used to calculate indirect N_2O emissions in NZ.

Parameter		NZ value	Additional information
$Frac_{LEACH}$	Proportion of applied N leached or in runoff	0.07	NZ specific value. (Thomas et al. 2005)
EF_5	Indirect N_2O emissions from leaching N	0.025	(IPCC 1997)
EF_4	Indirect N_2O emissions from volatilised N	0.01	(IPCC 1997)

The IPCC 1996 calculations for leaching and runoff do not account for N inputs from crop residues, although N mineralised from crop residues will contribute to leaching (Thomas et al. 2005).

3.4 Greenhouse gas emissions from agricultural burning

Although CO_2 is emitted during burning it is assumed that there is no net emission as an equivalent amount of carbon is removed from the atmosphere during re-growth (IPCC 1997). Gases that are emitted from incomplete combustion are CH_4, N_2O, carbon monoxide (CO) and oxides of nitrogen (NO_x). These are considered to be net emissions to the atmosphere. Two types of agricultural burning are defined in the IPCC methodology: savanna burning and the field burning of crop residues (IPCC 1997).

3.4.1 Calculation of non-CO_2 emissions from savanna (tussock) burning

Greenhouse gas emissions from tussock burning (almost exclusively in the South Island) is estimated in NZ (Ministry for the Environment 2008b) and reported under the Savanna burning category. Emissions are calculated in two steps (IPCC 1997). First, the amount of carbon that is released by burning is estimated, then the emissions related to the carbon released are estimated. To estimate the N_2O and NO_x emissions the ratio of N to C for the biomass is used.

New Zealand has modified the methodology by calculating the areas burned based on a proportion of the total area consented to burn. The IPCC default methodology estimates this area based on a proportion of the total area of savanna. Expert opinion estimates that about 20% of the consented area is burned in NZ (Ministry for the Environment 2008b).

3.4.2 Calculation of non-CO_2 emissions from burning of agricultural residues

The methodology for estimating emissions from burning of agricultural residues is the similar to that used to estimate emissions from savanna burning. Crop production statistics, the ratio of residue to crop product, the dry matter content of the residue, the fraction of residue actually burned, the fraction of carbon oxidised and the carbon fraction of the residue are used to estimate the C released. The greenhouse gas emissions are calculated as a proportion of the carbon release. NZ values currently used for estimating the emissions are shown in Tables 2 and 3.

Table 2: Values used to calculate NZ emissions from burning of agricultural residues for 2006.

Crop	Residue/ Yield[1]	Dry matter fraction[1]	C fraction (% dm)[1]	N:C ratio[1]	Fraction oxidised[1]	Fraction burned in fields[2]
Wheat	1.3	0.83	0.4853	0.012	0.9	0.3
Barley	1.2	0.83	0.4567	0.015	0.9	0.3
Oats	1.3	0.92	0.4567	0.015	0.9	0.3

[1]From IPCC (1997).
[2]From Ministry of Agriculture and Forestry.

Table 3: Emission ratios for agricultural residue burning.

Compound	Emission ratio[1]
CH_4	0.005
CO	0.06
N_2O	0.007
NOx	0.121

[1]From IPCC (1997).

3.5 Summary of changes to emission factors relevant to cropping in the revised IPCC (2006)

There have been some important changes to the way non-CO_2 greenhouse gas emissions are calculated in the 2006 revised Guidelines (IPCC 2006). These are the result of issues raised from the use of the 1996 Guidelines and improvements in the understanding and quantification of direct and indirect N_2O emissions.

3.5.1 Removing direct N_2O emissions from N fixation

The 2006 Guidelines no longer include biological fixation as a direct source of N_2O. This is based on the recommendations from a comprehensive review by Rochette & Janzen (2005). They concluded that there was no evidence that biological fixation increased N_2O emissions. They recommended that emissions from N-fixing crops be estimated as a function of the N input of above- and below-ground crop residues.

We recommend that this approach is accepted in the current methodology.

3.5.2 Accounting for below-ground N inputs from crop residues

The 1996 Guidelines do not account for N inputs from below-ground crop residues, i.e. the calculation only estimated the N content of the above-ground residues (F_{CR}). In the 2006 Guidelines, the N content in both the above-ground and the below-ground residue is estimated. This means that the residue input for some crops such as forage legumes, where all the above-ground biomass is harvested, can now be accounted for.

4 Review of crop activity data and data collection methodology

Yield and yield components (harvested grain, stubble, above-ground and below-ground residues) of "key crops" are used in the IPCC methods to calculate greenhouse gas emissions from cropping soils (IPCC 1997; IPCC 2000; IPCC 2006). In this section we review the key arable and vegetable crops and data that are currently used in the NZ inventory.

4.1 Key crops in New Zealand

The main arable and vegetable crops grown in NZ by area and production are shown in Table 4. The main source for these data is the Statistics New Zealand Agricultural Production Statistics. Production data sources (and their limitations) are discussed below.

Table 4: Major arable and vegetable crops grown in New Zealand, including key crops used in the current NZ inventory and suggested list for future inclusion.

Major crops	Area grown in NZ (ha)	Tonnes of crop produced annually	Key crop (NZ inventory 1990- 2006) Yes/No	Key crop recommended in 2006 IPCC Guidelines	Our new key crop recommendations (2008)
Forage brassicas	300 000[B] (*In 1990, 140 000 estimated* [C])		No		Yes
Barley	51 500[A]	335 600[A]	Yes	Yes	Yes
Grass seed	NQ	NQ	No		MDR
Wheat	40 500[A]	344 400[A]	Yes	Yes	Yes
Maize	17 000[A]	185 600[A]	Yes	Yes	Yes
Oats	5 800[A]	27 000[A]	Yes	Yes	Yes
Peas	6200 [A]	22 000 [A]	Yes	Yes	Yes
Potatoes	10 050[A] 10 850[D]	501 000	No		Yes
Lentils	50[E]	100[F]	Yes		No
Clover	NQ	NQ	No		MDR
Lucerne	NQ	NQ	No		MDR
Vegetable seed	7,330[A]		No		
Squash	7,774[A]		No		
Sweetcorn	6,210[A]		No		
Onions	4,594[A]		No		
Other outdoor vegetable (e.g. carrots, cabbage, cauliflower, lettuce)	22,356[A]		No		
Other grain and seed crops	6,982[A]		No		
Other cereal grains	2,267[A]	13,709[A]	No		
Other pulses	420[A]	847[A]	No		
Total area	519,000				

[A] = Statistics NZ's Agricultural Production Statistics, June 2007; [B] = de Ruiter et al. 2008; [C] = Gowers & Nicol 1989; [D]= Freshfacts 2007; [E]= Foundation for Arable Research expert opinion; [F]= Yield estimate based on expert opinion (Bruce McKenzie, pers comm.); NQ = Not quantified; MDR= More data required.

4.1.1 Crops included in the current inventory

Currently six crops are used to calculate emissions from cropping soils in the NZ inventory (Table 4). There are four non-N-fixing crops (wheat, barley, maize and oats) and two N-fixing crops (peas [seed and process] and lentils). There are some inconsistencies in the way the key crops are used for calculating emissions. For example, when calculating the returns of crop residues a single factor is applied to all cereal production data, whereas when calculating the amount of greenhouse gases emitted from stubble burning, cereals are separated into the key cereal crops.

4.1.2 Review of arable and vegetable crops grown in New Zealand

Based on the recent data for arable and vegetable crops in NZ, we have listed the major crops grown in NZ that could be considered as key crops from their respective land areas and production figures in Table 4. Key crops not included are forage brassicas, which have been increasing in importance. Between 1990 and 2007 the area grown has doubled according to the best available estimates.

The key crops identified in the 2007 inventory occupy about 120,000 ha. Of these crops, lentils are likely to have little effect on crop emissions as they occupy a very small area (expert opinions from FAR and Bruce McKenzie vary from 50 ha to possibly 200 ha). Other crops such as potatoes and seed crops are more significant in area and production (Table 4). When forage brassicas are excluded, the key crops represent about half of the total area of crops grown.

We suggest additional crops be included as key crops to better represent the current area of cropping in NZ. These are shown in Table 4. We have recommended that potatoes are also included as a key crop. They are the most important vegetable crop in NZ.

Seed crops also occupy a significant area. Unfortunately production data are limited and it is particularly difficult to find data for clover and grass seed.

4.1.3 Sources of activity data

We have identified two key sources of activity information: Statistics New Zealand Agricultural Production Census/survey data (APC/S); and the Foundation for Arable Research Production Database (FARPD). Both of these are discussed further below. MAF Arable & Horticultural Monitoring Reports are also available as an additional source of information, but the data are considered less pertinent to this report.

The Agricultural Production Census is currently conducted by Statistics NZ every 5 years. Since 1990 there have been three censuses (1994, 2002 and 2007) (Tables 5 and 6). Although a census was conducted in 1999, no agricultural statistics were collected.

Table 5: Agricultural Production Census and Surveys, 1990 to 2007.

Year	Census/Survey	Comment
1990	**Census**	Data collected prior to 1994 differed markedly to later data collections.
1991		
1992		Data collected before 1994 were samples taken from
1993		Statistics New Zealand's Business Directory (whether or not the businesses were registered for GST)
1994	**Census**	
1995	Survey	After 1994 the population samples for surveys and
1996	Survey	censuses changed (e.g. some only included those registered for GST) (see section 5.1.5 for details)
1997	No data collected	
1998	No data collected	
1999	Livestock and arable cropping survey	(The 1999 Census was conducted but it excluded agricultural information)
2000	No data collected	
2001	No data collected	
2002	**Census**	
2003	Survey	
2004	Survey	
2005	Survey	
2006	Survey	
2007	**Census**	

The 2007 Census involved approximately 80,000 farmers and foresters. The purpose of census data collection is to provide information for "monitoring, planning and forecasting by central and local government, business, researchers, agricultural sector organisations and the farming and rural community". More information can be found at: (http://www.stats.govt.nz/economy/primary-production/2007+Agricultural+Production+Census.htm#use).

In most other years where no census was conducted, much smaller sample surveys were carried out by Statistics NZ. However, there are years where census/survey data are not consistent, as discussed in section 4.1.5.

The Foundation for Arable Research (FAR) levy/production database (FARPD) contains production data (tonnes) by crop type on an annual basis from 1995 to 2007. These data are collected by the levy receiving organisation on behalf of FAR. Levies are collected on all grain and seed grown at the time it is sold or used on farm (e.g. fed to stock, whether whole or processed). FAR sends grain merchants/wholesalers a form to record and calculate levies due. Merchants are legally required to return the form and payment to the collection agency. Farmers are also required to pay levies when they sell grain/seed directly to other farmers. Total annual production (from the FARPD) is shown in Table 7.

Further additional information may be available directly from crop processors. However, this would require significant effort to collect and there may be associated issues of commercial sensitivity. Our view is that this information should be captured through the other sources described above. Furthermore, these data should effectively be the same as those recorded in the FAR production database.

We have obtained a copy of the latest NZ inventory spreadsheet, used for calculating emissions from agriculture. This predominately draws activity data from the APC/S.

Crop production data collected through the NZ Statistics surveys and census are reported as either tonnes of crop (fresh weight) or area of crop. Inspection of the current inventory calculation indicates that the production data have not been corrected for moisture content. Hence the total production data for each crop will overestimate the amount of crop nitrogen, as the IPCC calculations are based on the crop dry weight.

Table 6: Annual production (tonnes) by crop to 30th June year, from Statistics New Zealand Agricultural Production Census/Survey.

As: (1) no census or survey was conducted in 1997, 1998, 2000, or 2001 for these crops, (2) in 1999 a survey was conducted but data were not located, and (3) the Statistics New Zealand's website does not provide information for all crops in all years; total production for these years was filled from New Zealand Inventory Spreadsheet and is shown in *italics*. Total production, as recorded in the New Zealand Inventory Spreadsheet, differs from census/survey data provided below for barley and wheat in 2003, 2005 and 2006, and for Maize and Oats in 2004, 2005 and 2006, Seed Peas in 2004, 2005, and 2006.

	Barley	Wheat	Maize (grain)	Oats (grain)	Seed Peas	Lentils*
1990	434,856	188,047	*161,651*	*65,892*	*57,378*	*3,386*
1991	382,043	180,690	*183,388*	*78,877*	*65,064*	*3,386*
1992	318,787	191,039	*163,842*	*57,187*	*75,290*	*5,204*
1993	389,523	219,414	*133,069*	*57,625*	*63,268*	*5,018*
1994	395,476	241,853	*142,768*	*56,793*	*59,898*	*2,712*
1995	302,804	245,173	*160,797*	*57,718*	*56,448*	*923*
1996	367,181	277,014	*209,710*	*38,735*	*50,337*	*923*
1997	*411,000*	*317,379*	*193,806*	*41,217*	*50,337*	*923*
1998	*340,000*	*302,100*	*176,148*	*49,065*	*66,200*	*940*
1999	*304,000*	*320,000*	*197,000*	*42,223*	*52,200*	*0*
2000	*302,000*	*326,000*	*181,000*	*41,702*	*64,000*	*0*
2001	*365,000*	*364,000*	*177,000*	*35,398*	*37,700*	*0*
2002	440,883	301,498	148,847	34,987	29,457	*3,302*
2003	371,837	318,916	*197,182*	*29,934*	*32,200*	*2,000*
2004	226,082	255,860	234,248	30,844	31,912	*2,000*
2005	302,739	318,947	210,253	28,714	29,068	*2,000*
2006	277,020	261,798	227,054	28,478	22,506	*2,000*
2007	335,627	344,434	185,627	27,531	22,053	
Average	348,159	276,342	182,411	44,607	48,073	2,042

*Data were not available from these sources for Potatoes, Lucerne, Clover/Grass seed and Forage brassicas.

Table 7: Annual production (tonnes) by crop (for each calendar year), from the Foundation for Arable Research Production Database (FARPD).

Year	Barley	Wheat	Maize Grain	Oats	Pulses	Other Cereals	Borage Linseed	Brassica, Oil seed rape	Herbage (legume & grass)	Other crops	Total
1995	198,034	203,941	-	-	50,046	-	-	-	-	-	
1996	265,611	223,461	147,608	20,494	46,534	-	-	-	-	-	703,708
1997	307,956	232,021	169,840	18,256	41,749	-	300[#]	-	*59,213*	2,655	831,991
1998	227,452	312,837	153,802	21,817	69,074	3,401	2,732[#]	-	*53,684*	3,619	848,418
1999	203,337	268,545	173,111	18,424	50,405	5,088	1,580	299	*68,201*	-	788,991
2000	216,276	302,509	162,427	17,713	62,780	6,835	1,890	1,130	47,799	909	820,267
2001	285,756	359,940	162,186	15,796	37,261	5,621	1,831	2,496	47,059	4,175	922,120
2002	296,163	248,333	150,257	15,302	23,727	4,002	1,617	1,498	25,930	2,331	769,161
2003	303,837	250,897	188,424	14,558	31,477	4,860	1,612	3,404	64,583	8,539	872,190
2004	217,493	329,776	192,128	16,131	26,997	959	1,113	2,839	64,146	2,823	854,403
2005	200,265	275,723	159,350	13,331	29,640	9,961	1,243	1,524	75,378	2,017	768,433
2006	230,148	285,163	209,136	16,772	20,121	11,613	2,996	2,459	83,862	4,492	866,763
2007	284,800	359,841	**	19,152	27,095	11,344	1,982	3,773	35,728	3,333	747,047
Average	249,010	280,999	169,843	17,312	39,762	6,368	1,763	2,158	56,871	3,489	816,124

May include some oil seed rape.

Table 8: Differences in average annual total production between two sources of data; the NZ Agricultural production Census/survey data minus the FAR production database figures. FAR production figures are presented as a percentage of the NZ Agricultural production census/survey data. FAR's 'pulse' category has been compared with the Census/survey grouping of seed peas, as most of the pulses group consists of peas.

	Differences in estimates between the 2 data sources: Census figures minus FARDP figures (expressed in tonnes or as a % by which Census estimate is higher than FAR estimate – where comparative data are available)									
Calendar year	Barley (Tonnes)	Barley (%)	Wheat (Tonnes)	Wheat (%)	Maize (Tonnes)	Maize (%)	Oats (Tonnes)	Oats (%)	Pulses compared with seed peas (tonnes)	Pulses compared with seed peas (%)
1995	104770	35	41232	17	-	-	-	-	-	11
1996	101570	28	53553	19	62102	30	-	-	-	8
1997	103044	25	85358	27	23966	12	-	-	-	17
1998	112548	33	-10737	-4	22346	13	-	-	-	-4
1999	100663	33	51455	16	23889	12	-	-	-	3
2000	85724	28	23491	7	18573	10	-	-	-	2
2001	79244	22	4060	1	14814	8	-	-	-	1
2002	144720	33	53165	18	-1410	-1	19685	57	52.8637	19
2003	68000	18	68019	21	8758	4	-	-	-	2
2004	8589	4	-73916	-29	42120	18	14713	46	59.21903	15
2005	102474	34	43224	14	50903	24	15383	57	43.21839	-2
2006	46872	17	-23365	-9	17918	8	11706	42	68.56094	11
2007	50827	15	-15407	-4	-	-	-	33	28.12997	-23
Average % difference	-	25	-	7	-	13	-	47	-	5

4.1.4 Availability

Summarised APC/S data are available from Statistics New Zealand and some information is accessible through two key websites. The 2007 census data are available from Statistics New Zealand's website (www.stats.govt.nz/products-and-services/hot-off-the-press/agricultural-production), and historical census/survey data are available in summary tables on MAF's website (www.maf.govt.nz/statistics/horticulture). Information contained in the FARPD is reported to FAR's growers annually via newsletters. FAR provided information for this project, but access to information in the future would need to be negotiated with FAR. MAF Arable & Horticultural Monitoring Reports are published annually by MAF Policy, and can be downloaded from MAF's website (www.maf.govt.nz/mafnet/rural-nz/statistic-and-forecasts/farm-monitoring).

4.1.5 Reliability

The NZ inventory spreadsheet, used for calculating emissions from agriculture, draws activity data mainly from the APC/S. However, total production, as recorded in the New Zealand Inventory Spreadsheet, differs from APC/S data for barley and wheat in 2003, 2005 and 2006, for maize and oats in 2004, 2005 and 2006, and for seed peas in 2004, 2005 and 2006. It is unclear why these values differ.

All data collection methods are subject to some sampling errors. It is estimated that 86% of eligible businesses responded to the 2007 Agricultural Production Census, representing 87% of the total estimated value of agricultural operations. In order to estimate responses from the remaining 14% of the population, random 'hot deck' imputation is used (see census technical notes for detail). Levels of imputation per question/category are provided. Sample data collected in years other than census years (2002 and 2007) are subject to sampling and non-sampling errors as detailed on the Statistics NZ website.

The FARPD is also likely to contain some inaccuracies. These data are accounted for when levies are paid. While it is reasonably easy for farmers to side-step the system and sell farmer-to-farmer without paying the levy, Nick Pyke (CEO of FAR) predicts this would currently only account for 1–2% of all levies due. Small inaccuracies in the database may also occur due to the time period for which levies are reported, i.e. levies data are collated by the collection agency monthly, but levies are sometimes reported in the incorrect month (i.e. are a catch-up); this may affect yearly total data, but it is expected this effect would be small and moreover should not be an issue when 3-yearly average data are compared.

There were significant differences in total production between the FARPD and the APC/S data for many crops in many years (Table 8). The FARPD value for total barley production is about 25% less than the APC/S value.

Nick Pyke suggests barley is the crop where the most under-reporting of levy payments may occur, but he estimates this to be around 5%, rather than the 25% suggested by the values in Table 8. The two sources of data are more comparable for wheat, especially in recent years. For maize grain and oat grain production, the FARPD suggests APC/S overestimates production by averages of up to 13% and 47% respectively. FAR believes the census data are incorrect for these crops. Some under-reporting of levy payments for oats may occur with direct sales to racehorse stables, perhaps up to 5%, but most oat crops are processed by a small number of mills and therefore the FARPD values are likely to be reliable. APC/S figures may also be inflated by farmers incorrectly reporting green-feed oat crops as part of oat grain crop data.

FAR do not collect total production for seed peas separately from other pulse crops. However, pulse production figures are mostly from peas. When FARs 'pulse' production figures are compared with census/survey field pea production data, results are reasonably similar (Table 8).

Lentils are currently included as a separate crop in the NZ inventory spreadsheet, but no independent source of production data for lentils could be found. FAR estimates the area of lentils grown in 2007 was around 50 ha, and that this size of area is reasonably steady. It is therefore suggested lentils be removed as a key crop from the inventory calculations.

Certified ryegrass and clover production is very different to total herbage production figures as per census/survey data.

4.1.6 Changes in census and surveys since 1990

The populations used in the census and surveys of agriculture production since 1994 differ quite markedly from each other and especially from those conducted prior to 1994. Consequently it is not possible to accurately quantify the degree of change in crop production since 1990, such that one can only make broad statements about increases or decreases where the changes clearly exceed the variance in the data collected. Information relating to changes in the survey population used for each of the surveys/ censuses conducted since 1990 is detailed below:

- **Agricultural Production Census 2007 –** The 2007 Agricultural Production Census was the second census in the current agricultural statistics programme – the first was held in 2002 when the programme began. The 2007 Census involved approximately 80,000 farmers and foresters. This census updated data that are used for monitoring, planning and forecasting by central and local government, business, researchers, agricultural sector organisations, and the farming and rural communities. The Agricultural Production Census was conducted by Statistics New Zealand, and was a joint collection with the Ministry of Agriculture and Forestry.
- **Agricultural Production Census 2002** – The survey population for this census was all units that were identified on Statistics New Zealand's Business Frame or the Inland Revenue Department's (IRD) Client Register as being engaged in agricultural activity (livestock, cropping, horticulture, cropping & forestry). The Business Frame is a list of businesses in New Zealand based on firms registered for Goods and Services Tax (GST) with the Inland Revenue Department, while the Client Register consists of all businesses registered with that department. In addition, in 2002 the population was supplemented with information from 'AgriBase' (a national database maintained by AgriQuality New Zealand Ltd), previous agricultural surveys, and lists from industry sources. This composite frame was used to ensure that a comprehensive coverage of agricultural activity in New Zealand was achieved.

  The population for the Agricultural Production Census 2002 included those "lifestylers" who were identifiable on IRD's Client Register or SNZ's Business Frame as being engaged in in-scope agricultural activity. Statistics NZ has not included in the survey population "lifestylers" engaged in agricultural activity if they could not be identified on either the Client Register or the Business Frame.

- **Agriculture Production Survey 2000 (Horticulture)** – The survey population for this survey was all identifiable farming units that indicated horticultural activity, located on the Business Frame, with coverage supplemented with information from AgriBase and available grower lists. Hence, the results from this survey are not comparable with the results from the 2002 Census or the Agricultural Production survey of 1999 as the focus was solely on horticulture.
- **Agriculture Production Survey 1999 (Livestock and arable cropping)** – This survey population was all units on AgriBase that were recorded as holding livestock and/or engaging in grain/arable cropping. The term 'livestock' includes AgriBase enterprises: beef cattle, bison, buffalo, dairy cattle, deer, emus, goats, ostriches, pigs, poultry, sheep and grazing other people's stock. The term 'grain/arable cropping' includes AgriBase enterprises: cereals, cropping and seeds. Farms with no enterprise data held on AgriBase are also included in the survey. Farms solely engaged in horticultural and forestry activities were excluded from the population.
- **Agriculture Production Census 1994 & Surveys 1995 & 1996** – The survey population was all units on Statistics New Zealand's Business Frame that were registered for GST and classified to horticulture, grain and arable cropping, livestock farming, or exotic forestry operations.
- **Prior to 1994**, the population definition for agricultural production surveys was all units on Statistics New Zealand's Business Directory (whether registered for GST or not) that were classed as horticulture, grain and arable cropping, livestock farming, or exotic forestry operations.

4.1.7 Review of changes in activity data between 1990 and present

Barley

Using the APC/S information (Table 6), we would conclude that since 1990, when around 400 000 tonnes of barley were grown, the tonnage of barley grown in New Zealand has been in a slow gradual decline with an average of 350 000 tonnes grown annually from 1990 to 2007. Yet FARPD information (Table 7) would suggest that the average amount grown over the 12 years up to 2007 has been relatively consistent and only been around 250 000 tonnes. FAR data collected soon after the organisations inception (in 1995) may be less reliable as farmers took time to adapt to the new levy system's requirements. When we compare both sets of data for 2006 and 2007 only, the differences in tonnage estimations between the different collection agencies are closer than in previous years, but the FARPD estimations are still 15% lower than the APC/S data would suggest. The Foundation for Arable Research considers that their data are more reliable, but this is difficult to confirm.

Wheat

According to APC/S figures the average tonnage of wheat grown has shown a very gradual increase from about 200 000 tonnes in 1990 to an average of 275 000 tonnes per annum over the next 17 years. The FARPD shows very similar trends with an average of 280 000 tonnes grown over the years from 1995 to 2007.

Maize

Estimates of amounts of maize grown in 1990 were around 160 000 tonnes per annum (Table 6). Average estimates show a slight increase in annual tonnage since then to around 180 000 (using APC/S figures) or to 170 000 using FARPD data.

Oats

Amounts of oats grown appear to have markedly declined since 1990 when AAPC/S data are used (Table 6). However, FARPD estimates would suggest that since 1996 the amounts produced have remained relatively static (Table 7). Comparison of the 2007 figures from each data source shows a huge variation in the actual amounts estimated as being produced, with APC/S estimates 30% higher than those of the FARPD.

Peas/pulses

Estimates of the annual tonnage of peas/pulses produced (Table 6) show about a 60% decline in the amount produced in 2007 compared with 1990. Similarly the FARPD data suggest that there is about a 45% decline in the annual tonnage of peas/pulses produced since 1995. Although the actual amounts estimated by each data source show large variation, there is the common trend of a significantly large reduction in the amounts of peas being grown.

Lentils

Estimates for lentil production are hard to come by, but from expert opinion the annual tonnage of lentils that is produced in New Zealand has markedly reduced since 1990 to near-negligible levels in 2007.

4.2 Recommendations for including crops

4.2.1 Key crops

- More crops should be included to better represent the range of crops currently grown in NZ. At present only six crops, which together account for about 25% of the actual cropped area, are considered in the inventory
- Data need to be collected for forage brassicas, in particular.
- Agricultural production data need to be corrected for moisture content in the inventory calculations.

5 Direct N_2O emissions for crops in New Zealand

5.1 Measurements of direct N_2O emissions of crops in New Zealand

There is a paucity of studies of direct nitrous oxide measurements from crops. There have been four internationally reviewed papers on studies of nitrous oxide emissions from crops: (van der Weerden et al. 2000; Choudhary et al. 2001; Choudhary et al. 2002; Thomas et al. 2008). We are aware of one study that is a peer reviewed conference paper (Thomas et al. 2004a).

In the study by van der Weerden et al. (2000), three contrasting onion production systems were compared in Canterbury over 8.5 months. These were conventionally grown onions following a clover crop, and two crops established after ploughing or rotovating an organically grown ley crop. N_2O emissions over the crop period ranged from 1.6 to 3.8 kg N/ha. The greatest emissions occurred from conventionally grown onions established after the clover crop had been ploughed in. No fertiliser N had been applied to any of the plots. The magnitude of emissions followed the order ploughed clover > rotovated ley > ploughed ley. When the previous crops were included in calculating an annual N_2O emission, the emissions from the ploughed clover treatment increased to 8.0 kg N_2O-N/ha, which was significantly greater than the other cultivated and non-cultivated treatments.

Thomas et al. (2004a) compared the effects of different N fertiliser rates (0, 225 and 450 kg N/ha t sowing) and the effects of machinery compaction on N_2O emissions over the 4 month growing period between planting and harvest from a spring-sown potato crop in Canterbury. Cumulative N_2O emissions from the fertilised ridges were not affected by the rate of fertiliser added (0.85 to 1.2 kg N/ha), but the greatest emissions (2.4 to 2.9 kg N/ha) occurred from the unfertilised furrows that were compacted by the tractor passes. Assuming that the area of compacted furrows was equivalent to uncompacted furrows, the average emissions from a paddock would have been about 1 to 1.2 kg N/ha. While fertiliser rates did not have a significant effect on emissions, there was a significant effect of soil mineral N on the N_2O emissions.

In their study conducted in the Manawatu, Choudhary et al. (2001), investigated the effect of tillage on nitrous oxide emissions. They measured emissions at low frequency (10 samplings, monthly and occasionally fortnightly) of a spring-sown maize fodder crop that was established ex-pasture and then followed by autumn-sown oats. They found that conventional (ploughed, rolled and harrowed) and no-tillage treatments did not affect N_2O emissions. Based on their very limited dataset, they estimated annual N_2O emissions were about 9 to 12 kg N/ha, mainly produced over winter when moisture contents were high. However, annual estimates of N_2O emissions based on such low measurement frequency may not be meaningful because of the large temporal variability observed for N_2O emissions.

In a second study, Choudhary et al. (2002) measured N_2O emissions from conventionally tilled maize paddocks that had been continuously cropped for 17 and 34 years. Fertiliser N was applied at a rate of 161 to 184 kg N/ha on the different paddocks. Based again on very low frequency measurements (13 samplings, monthly and occasionally fortnightly), Choudhary et al. (2002) estimated the annual emissions to be much lower (2.3 to 3.4 kg N/ha) than in the study from the ex-pasture site (2001). These values were similar to a grazed dairy pasture measured at the same time.

Nitrous oxide emissions have also been measured from a multi-graze autumn-grown cereal forage crop (triticale) following simulating grazing (Thomas et al. 2008). They found N_2O emissions were greatly enhanced when the soil was compacted through grazing and urine had been applied. The method of tillage establishment was important as was the moisture content at grazing. N_2O emissions from the crop over winter and spring (90 days) ranged from 1 to 14 kg N/ha depending on the soil compaction. Over the 90-day period the N_2O emissions ranged from 0.2 to 1.8% of the N applied depending on the soil compaction.

5.2 Emission factor (EF_1) from synthetic and organic fertiliser for crops in New Zealand

From the two studies, where frequent measurements of N_2O emissions were made from fertilised plots, emissions ranged from 0.2 to 1.8% (Thomas et al. 2008). These studies were conducted over relatively short durations in Canterbury conditions.

Findings from these studies show that the amount of mineral N that is released by soil organic matter (following cultivation) may be a much more important driver of N_2O emission than the synthetic and organic fertiliser. Crop and soil management may also have an important impact on emissions. The studies by van der Weerden et al. (1999; 2000) show the importance of N_2O emissions from incorporated crop residues when no fertiliser is applied and legumes are used as part of cropping rotations.

There are insufficient data to revise the emission factor for synthetic and organic fertiliser.

6 Direct N_2O emissions from crop residues

When residues are left on, or incorporated in to, the soil following crop harvest, nitrogen is released from the plant material. Nitrogen may also be released into the soil during crop growth from root exudation, sloughing and senescence of roots. Mineralisation of organic nitrogen in residues provides a source for N_2O.

The IPCC accounts for the direct N_2O emissions arising from the decomposition of plant residues and the release of N (FCR), using crop production data. The calculation distinguishes between the residues from N-fixing (pulses) and non-N-fixing crops (IPCC 1997). Emissions are currently calculated using a Tier 1A approach.

Annual N in the crop residue is calculated by multiplying the crop yield of non-N-fixing crops ($Crop_O$) and N-fixing crops ($Crop_{BF}$) by their respective N concentrations ($Frac_{NCRO}$ and $Frac_{NCRBF}$). A default value of 2 is used to convert the crop yield to total above-ground biomass. An adjustment is made to account for the above-ground biomass ($Frac_R$) that is removed and burned ($Frac_{BURN}$). The factors currently used for the NZ inventory are shown in Table 9.

$$F_{CR} = 2 * (Crop_O * Frac_{NCRO} + Crop_{BF} * Frac_{NCRBF}) * (1-Frac_R) * (1-Frac_{BURN}) \quad \textbf{(Equation 4)}$$

Table 9: Values used to calculate direct N_2O emissions from crop residues in NZ from MfE spreadsheet calculations.

Parameter	Fraction of:	NZ value	Additional information
$Frac_{BURN}$	Crop residue burned in fields	0.5[1]	MAF (expert opinion). Default value 0.25 (kg N/kg crop-N)
$Frac_{BURNL}$	Legume crop residue burned in fields	0	MAF (expert opinion)
$Frac_{NCRBF}$	N in N-fixing crops	0.03	(IPCC 1997)
$Frac_{NCR0}$	N in non-N-fixing crops	0.015	(IPCC 1997)
$Frac_R$	Crop residue removed from the field as crop	0.45	(IPCC 1997)

[1]This is the value used in the current National Inventory spreadsheet, although MAF expert opinion is also recorded as 0.3.

6.1 Suggested methodology for refining crop residue calculations

The 1996 Guidelines enable emissions to be estimated as a function of crop yield. While this approach is easy to implement, it is underpinned by simplifying assumptions that may result in significant error in N_2O emission estimates. Crops are divided into just two broad categories (non-N-fixing and N-fixing crops) but this “coarse” sub-division ignores the large differences that exist between crops within each of these categories. The use of a default value of 2 to convert crop yield to above-ground biomass assumes that all crops have a harvest index of 0.5. Harvest index values have been experimentally determined for major crops grown in New Zealand and therefore use of these NZ-specific values is preferable to acceptance of the IPCC default. Similarly, use of local data to estimate N concentrations in crop residues should be a better alternative to the use of IPCC prescribed values for N-fixing and non-N-fixing crops. Below-ground residues are not explicitly considered in the 1996 method.

In effect, the 1996 guidelines make use of only part of the available NZ data (i.e., yields only). The 2006 IPCC guidelines provide equations to estimate above- and below-ground residues for individual crops based on measured yields. While the 2006 approach is an improvement on the 1996 methodology, the suggested equations may not be appropriate to NZ, as they are derived from overseas rather than local data. In section 6.2 we describe a modification of the 2006 method to enable above- and below-ground residues to be estimated for key crops from locally-determined harvest index data. The factors used to estimate N inputs from residues using the IPCC 1996 and 2006 methodology are listed in Appendix 7.

A literature review was conducted covering both New Zealand and international literature. The following framework was used as a guideline for the literature search.

The amount of N returned to the soil in crop residuals is dependent on a number of factors, as demonstrated in Figure 1.

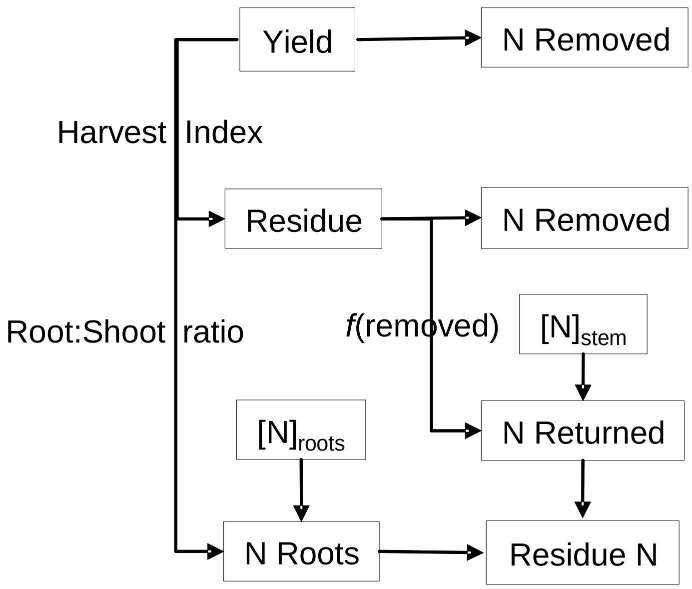

Figure 1: Schematic representation of factors required for calculating N returns to the soil from crop residues.

The literature review was therefore mainly structured under the following headings:

Crop yield. The mean yield of key crops determined from published statistics and model runs for a range of soil/environment combinations (Table 10).

Harvest index. The fraction of the crop that is harvested for the primary purpose of growing the crop (e.g. grain). The harvest index is therefore required in order to calculate how much plant biomass may be returned to the soil (Appendix 1).

$[N]_{residue}$. The N content of the plant residue (Appendices 2 and 3).

f(removal). In most instances only a portion of the total residue is returned to the soil (incorporated by various means or left on the soil surface). The remainder may be baled, grazed or burned (Appendix 4).

Root:Shoot ratio. The amount of N returned by roots is dependent upon the total biomass of roots which can be calculated by using known root: shoot ratios (Appendices 5 and 6).

$[N]_{roots}$. The N concentration of the roots. There is a dearth of information on N content of roots, as this area of study has received little attention (Appendix 3).

Table 10: Mean yields for key crops grown in New Zealand.

Key crops	Yields (t/ha)	Reference
Barley	6.8-10.2	AgNZ/ Stats NZ/ FAR info
Wheat		
(Sapphire wheat)	5.6	FAR Cereals Update No 113
(Milling wheat)	7.4-10.6	AgNZ/ Stats NZ/ FAR info
(Feed wheat - spring)	7.4-8.0	AgNZ/ Stats NZ/ FAR info
(Feed wheat - autumn)	8.4-11.8	AgNZ/ Stats NZ/ FAR info
Maize (grain)	11.5	AgNZ/ Stats NZ/ FAR info
Maize (silage)	16-20	AgNZ/ Stats NZ/ FAR info
Oats	4.5-6.5	AgNZ/ Stats NZ/ FAR info
Peas	6.0-7.6	AgNZ/ Stats NZ/ FAR info
Lentils	2.0	Statistics NZ; (McKenzie 1989)
Potatoes	40-50	AgNZ/ Stats NZ/ FAR info
Clover seed	0.6	Crop & Food Research, unpublished
Lucerne	15-20	(Brown & Moot 2004)
Grass seed	1.5	Crop & Food Research, unpublished
	1.8-2.5	AgNZ/ Stats NZ/ FAR info
Forage brassicas	Up to 20	(de Ruiter et al. 2008)
Kale seed	1.3	Crop & Food Research, unpublished
Rape seed	1.9	Crop & Food Research, unpublished

Table 11: Summary of crop information for calculating residue nitrogen from published and unpublished sources.

Key crops	Production (t/ha)	Harvest index	Root:shoot ratio	Above-ground residue N (%)	Below-ground residue N (%)
Barley	6.8-10.2	0.46-0.0.56	0.08-0.6	0.4-1.5	0.15-0.34
Wheat	5.6- 11.8	0.37- 0.60	0.09-0.22	0.2-1.1	0.15-0.19
Maize (grain)	11.5	0.5	(Not available)	0.5-0.8	0.15
Maize (silage)	16-20	0.48-0.52 (but 0.95 is harvested)	(Not available)	0.1	0.20
Oats	4.5-6.5	0.41-0.53	0.11-0.42	0.6	0.20-0.29
Peas	6.0-7.6	0.5	(Not available)	1.5	0.08-0.20
Lentils	2.0	0.40	(Not available)	0.9-1.4	0.20
Potatoes	40-50	[1]About 90% of plant dry matter is harvested as tubers; negligible roots = 15% residue.	(Not available)	2.0	0.10
Clover seed	0.6	0.08	(Not available)	2.2	(Not available)
Lucerne	15-20	(Not available)	0.7	4.3	(Not available)
Grass seed	1.8-2.5	0.17	0.7-2.5	0.7-1.5	0.4
Forage brassicas	Up to 20	[2]About 85% of above-ground plant dry matter is harvested	Not available	2.5-3.5	1.5

[1] R.J. Martin, [2]A Fletcher (pers. comm.).

Table 12: Summary of recommended factors used to estimate N inputs from crop residues using a modified IPCC 2006 methodology for NZ conditions.

Key crops	Production (t/ha)	Harvest index	Root:shoot ratio	Above-ground residue N (%)	Below-ground residue N (%)	Factor for residue DM content
Barley	6.8-10.2	0.5	0.1	0.7	1.4#	0.86[1]
Wheat	5.6- 11.8	0.5	0.1	0.6	0.9#	0.86[1]
Maize (grain)	11.5	0.5	0.1	0.7	0.7#	0.86[1]
Maize (silage)	16-20	0.5§	0.1	0.7	0.7#	0.86[1]
Oats	4.5-6.5	0.45	0.1	0.7	0.8#	0.86[1]
Peas	6.0-7.6	0.5 (variable)	0.1	0.8	1.4	0.21[2] 0.14[3]
Lentils	2.0	0.4	*	*	*	*
Potatoes	40-50	0.85	0.1	0.9	*	0.2
Clover seed	0.6	0.08	*	2.2	2	
Lucerne	15-20	*	*	*	*	*
Grass seed	1.8-2.5	0.17	§	0.7	*	*
Forage brassicas	Up to 20	[85% is grazed off]	§	3	*	*

= limited data, accept IPCC 2006 default values.
[1] Standard grain dry weight factor - R.J. Martin (pers. comm.).
[2] Fresh peas (Edelenbos et al. 2001).
[3] Standard grain dry weight factor – R.J. Martin (pers. comm.).
[4]R.J.Martin (pers, comm.).
*more information required.
§ however, 95% of above-ground biomass removed.

6.2 Estimation of above-ground residue dry matter $AG_{DM(T)}$[1] (Mg/ha)

The 2006 IPCC Guidelines provide linear regression equations to estimate $AG_{DM(T)}$ from yield of harvested dry matter yield ($Crop_T$). However, the coefficients of determination (R_2) for the relationship between $AG_{DM(T)}$ and ($Crop_T$) are often not very high (e.g. 0.45 for oats). For wheat the slope value ranges from 1.29 for spring wheat to 1.61 for winter wheat. The IPCC's suggested regression equations are presumably based on data obtained under a range of climatic conditions and for genotypes that are not grown in New Zealand. The applicability of these equations to New Zealand conditions needs to be ascertained.

An alternative approach is to estimate $AG_{DM(T)}$ from the harvest index (HI). The HI is calculated as $Crop_T/(Crop_T + AG_{DM(T)})$. Although the HI may be affected by environmental conditions and can differ between cultivars (Donald & Hamblin 1976), it tends to remain within a relatively narrow range, particularly when the climatic range is restricted. Therefore, using a mean HI value, it should be possible to get reliable national estimates of dry matter allocation to above-ground residue for several crops. Research over many years has provided reliable information of the harvest indices of many of the key crops under New Zealand conditions, particularly small grains and maize. Published information and expert knowledge suggests that an appropriate HI value for wheat, barley, and maize is 0.5, with oats being somewhat lower at 0.45.

A comparison of amounts of $AG_{DM(T)}$ estimated from IPCC equation versus the harvest index method are shown in Table 13 for crops yielding 5 and 10 Mg/ha of grain. For barley and maize, both approaches give similar estimates of $AG_{DM(T)}$. For wheat the IPCC estimate is considerably higher than the HI estimate, with the reverse being the case for oats. The HI method probably yields more reliable $AG_{DM(T)}$ estimates since it is based on locally-measured dry matter allocation data and, therefore, we recommend that this method be adopted for small grains and maize. In the case of maize silage crops, where essentially the entire above-ground biomass is harvested and removed, $AG_{DM(T)}$ may be assumed to be about 5% of the harvested dry matter (Dr Andrew Fletcher, pers. comm.).

The available information for calculating residue N using the modified IPCC 2006 method is summarised in Table 11. Based on the available crop residue information we recommend the factors for NZ crops in Table 12.

[1] We have followed the IPCC 2006 IPCC 2006: 2006 IPCC guidelines for national greenhouse gas inventories, prepared by the National Greenhouse Gas Inventories Programme. Japan, IGES, http://www.ipcc-nggip.iges.or.jp/. nomenclature in this section.

Table 13: Estimates of $AG_{DM(T)}$ (Mg/ha) obtained from the IPCC regression equation versus $AG_{DM(T)}$ estimated from harvest index values in Table 12 for crops yielding 5 and 10 Mg/ha of grain.

Crop	Grain yield 5 Mg/ha		Grain yield 10 Mg/ha	
	IPCC	HI[2]	IPCC	HI
Wheat[1]	8.5	5.0	16.5	10.0
Barley	5.5	5.0	10.4	10.0
Oats	5.4	6.1	10.0	12.2
Maize	5.8	5.0	10.9	10.0

[1]The slope and intercept values used in the IPCC estimate were 1.61 and 0.40, respectively (i.e., suggested values for winter wheat).
[2]Estimated as (1/HI-1)*grain yield. A HI of 0.5 was used for wheat, barley and maize and 0.45 for oats.

The HI of peas can be more variable than that of cereals. Based on expert knowledge, we have taken 0.5 as a realistic mean HI. The IPCC estimate of $AG_{DM(T)}$ for peas (based on generic slope and intercept values for beans and pulses of 1.13 and 0.85, respectively) is somewhat higher than $AG_{DM(T)}$ estimated assuming a HI of 0.5. For a pea crop yielding 5 Mg/ha, the IPCC value of $AG_{DM(T)}$ is 6.5 compared with 5.0 mg/ha for the HI-based estimate. While the difference in the two estimates is not very large, we recommend that the HI approach be adopted as it is based on local knowledge.

The IPCC regression to estimate lentil $AG_{DM(T)}$ is the same as that used for peas (generic equation for beans and pulses). Expert opinion suggests that an appropriate HI for lentils grown in New Zealand is 0.4 (Dr Bruce MacKenzie, pers. comm.). Lentil $AG_{DM(T)}$ calculated from the IPCC and HI methods is similar (4.2 and 4.0 Mg/ha at a typical yield of 3 t/ha).

The IPCC 2006 Guidelines include a generic equation for tubers, but the reliability of its $AG_{DM(T)}$ prediction is open to question, given that the R^2 value is only 0.18. Therefore, we recommend that $AG_{DM(T)}$ of NZ-grown potatoes be estimated based on local knowledge rather than from IPCC's suggested equation. The best estimate of the proportion of crop dry matter in leaves and stems at harvest is ~15% (Dr R.J. Martin, pers. comm.). For an average potato crop yielding 45 Mg/ha (~9 Mg/ha of dry matter; assuming tuber dry matter content of 20%), estimated $AG_{DM(T)}$ is about 1.5 Mg/ha, increasing to 2.5 Mg/ha for a high yielding crop (70 Mg/ha).

6.3 Estimation of ratio of below-ground residues to above-ground residues (R_{BG-BIO})

There is a dearth of information on below-ground partitioning of dry matter in crops because of the difficulty involved in quantitatively extracting plant roots. The 2006 IPCC guideline suggests that below-ground crop residues be estimated as a proportion of above-ground biomass. For cereals, the suggested ratio of below-ground residue to above-ground biomass ranges from 0.23 for spring wheat to 0.28 for winter wheat. It has been shown that the ratio of roots to shoots can vary depending on the conditions in which the crop is grown. Wheat crops grown under water-limited conditions can allocate a relatively high proportion of dry matter below-ground. For example, Campbell & de Jong (2001) estimated that the root:straw ratio of spring wheat grown in the semiarid Canadian prairies was in the 0.36-0.58 range (roots measured in the 0 to 120 cm depth at anthesis). From a compilation of studies in Europe and North America, Williams (2006) showed that the root:shoot ratio in small grains tends to decline as shoot biomass increases. Root mass (y) was linearly related to shoot dry matter (x) by the equation:

$y = 0.064\ x + 0.34$ ($R^2 = 0.84$) **(Equation 5)**

where root and shoot mass are in Mg/ha of dry matter. Roots were measured at about anthesis, when root mass is at its maximum, and shoot biomass was measured at maturity.

For crops producing 5, 10, and 20 Mg/ha of above-ground biomass, the root mass is estimated from this equation to be 0.66, 0.98, and 1.62 t/ha, respectively. The ratio of below-ground residues to above-ground biomass ($R_{BG\text{-}BIO}$) decreases as above-ground dry matter increases (0.13 at 5 Mg/ha; 0.08 at 20 Mg/ha). These values are considerably lower than IPCC's suggested values, which are perhaps more appropriate to crops grown in water-limited environments than to high-yielding cereal crops in New Zealand. For a wheat crop producing average yield of 8.5 Mg/ha, $R_{BG\text{-}BIO}$ is estimated from the above equation to be 0.084, assuming a harvest index of 0.5. Calculations using unpublished data from Francis (Dr G.S. Francis, pers. comm.) for barley and wheat grown at Lincoln (Canterbury) gave average $R_{BG\text{-}BIO}$ values of 0.08 for barley and 0.12 for wheat.

For peas, an $R_{BG\text{-}BIO}$ of 0.09 was estimated for unpublished data of Francis (Dr G.S. Francis, pers. comm.). Expert opinion suggests that the $R_{BG\text{-}BIO}$ for potatoes is unlikely to exceed 0.10 (R.J. Martin, pers. comm.).

There is an urgent need to determine $R_{BG\text{-}BIO}$ for key crops under New Zealand conditions. In the meantime, we suggest that a value of 0.1 be used for small grains, maize, peas, and potatoes.

6.4 N content of above-ground residues (N_{AG})

The IPCC default N_{AG} value for wheat is 0.6%. Wheat straw N content can vary depending on N supply. Measurements at five sites in Canterbury during the 2001-02 season showed that straw from unfertilised control plots contained an average of 0.4% N compared with 0.7% in N fertilised plots (D. Curtin, unpublished data). There was a positive relationship between straw N and grain N. When data for one site with severe take-all (*Gaeumannomyces graminis* var. *tritici*) infection was excluded, straw N (y) increased linearly as grain N (x) increased:

$y = 0.71\ x - 0.65$ ($R^2 = 0.75$; n = 12)

It may be possible to get realistic estimates of straw N from grain protein content, although further work is needed to determine if the relationship between grain and straw N is consistent over different environments and growing seasons. In the meantime, use of the default value (0.6% N) is justified.

Nitrogen content of barley straw appears to vary considerably, from about 0.4% to 1.5% (Appendix 2). With limited available data, we cannot estimate a realistic mean value for NZ-grown barley. The IPCC default values for wheat, oats and maize appear to be realistic, based on the scant available data. The IPCC value for pulses (0.8% N) also accords well with the few available data for NZ-grown peas (< 1% N) and lentils (~0.7%) (Dr Bruce MacKenzie, pers. comm.).

Martin (1995) measured N in potatoes (Russet Burbank) fertilised with N at rates of 0 to 300 kg/ha (trial was located in Canterbury). Total N in plant tops peaked at about 70 days after planting, and then declined rapidly to reach low levels (estimated < 1% N) by the time the tops died down. The IPCC default value for potato residues (1.9% N) is relatively high but, with few data available, we do not know if it is appropriate to NZ-grown crops.

6.5 N content of below-ground residues (N_{BG})

As New Zealand data for N in below-ground residues are lacking, the IPCC default values should be accepted.

6.6 Estimates of N_2O emissions from crop residues following a refined approach

We have estimated N_2O emissions using the modified 2006 IPPC methodology, using an extended range for key crops (Appendix 8).

Using this approach we estimate that N_2O emissions are 30 % less than the emissions calculated in the 2007 NZ inventory. This is a change of about 12,500 tonnes of CO_2-e.

6.7 Emission factor (EF_i) for crop residues

Novoa & Tejeda (2006) reviewed recently published (post-1995) studies of N_2O emissions from crop residues. They compiled a database that included a total of 46 studies carried out under a range of climatic conditions. A wide range of plant residue types and residue application rates were represented. Linear regression of N_2O emitted on N applied in residues gave an emission factor of 1.06%. However, only about 60% of the variation in emissions was accounted for by residue N. They concluded that the emission factor is a variable coefficient that depends on environmental conditions and management variables. A regression that included rainfall and temperature substantially improved prediction of N_2O emissions (83% of variability explained).

The emission factor for plant residues clearly needs to be determined under appropriate environmental conditions. Until an experimentally determined factor is available for NZ conditions, use of the default value of 1% is recommended for all crop residues.

6.8 Recommendations for estimating N inputs from crop residues

- Adoption of a more refined approach based on modification of the 2006 IPCC approach is recommended, including calculating residues from key crops independently and using more realistic residue N contents.
- Use recommended factors derived for New Zealand conditions.
- More information is required for certain crops, particularly forage brassicas.
- The emission factor (EF_1) of 0.01 for crop residues is appropriate based on overseas data, but it needs to be experimentally verified for NZ conditions.

6.8.1 Recommended steps for calculating N inputs from crop residues

Step 1: Calculate annual crop production dry matter data (Crop):

We recommend that the use of Agricultural Production Statistics for the key crops, although there is some indication from FAR industry data that there may be inaccuracies in reporting.

Where yield data are not reported, average yield data (tonnes/ha) should be used for crops that are only reported on a per hectare basis (e.g. fresh peas and potatoes) (Table 12).

Agricultural production data need to be converted to dry matter basis (Table 12).

Step 2: Calculate above-ground residues (AG_{DM}) using harvest index data for NZ crops.

AG_{DM} = (Crop/Harvest Index) – Crop

Step 3: Account for residue burning

Discussion of burning of crop residues is discussed in section 9.1.

AG_{DM} needs to be corrected for the residue burning of cereal straw. This can be estimated for wheat and barley from survey information from Canterbury and Southland using the proportion of cereal areas that are burned (Table 14). Alternatively, the recent Agricultural Production Statistics census might be used but this does not differentiate between crops.

Table 14: Recommended values for estimating the amount of residue burned for wheat, barley and oat crops.

Crop	Area burned as a proportion of total production area	Proportion of residue burned in a field (C_f)	Estimated "fraction of crop residue burned" (Area burned * cf)
Wheat	Canterbury = 0.7 Southland = 0.6	0.7	Canterbury = 0.49 Southland = 0.42
Barley	Canterbury = 0.5 Southland = 0.3	0.7	Canterbury = 0.35 Southland = 0.21
Oats	As barley	0.7	

A combustion factor (Cf) needs to be applied to the estimated burned residue. We recommend that a value of 0.7 is applied.

AG_{DM} = ((Crop/Harvest Index) – Crop) * $Frac_{BURN}$ * Cf

Step 4: Account for residue removed for feed and bedding.

We recommend that this is ignored until data are available.

Step 5: Calculate the amount of above-ground N residue

Apply crop specific nitrogen content factors (N_{AG}, Table 12) to the above-ground residue dry matter.

$AG_{DM} * N_{AG}$

Step 6: Calculate the amount of below-ground N residue

Apply a factor to estimate the amount of biomass below-ground BG_{DM}) from an estimate of the ratio (R_{BG}) of the below-ground dry matter (BG_{DM}) to the total crop biomass for each crop (AG_{DM} + Crop). We have recommended that this value is about 0.1. Since there is so little residue for some of the root vegetable crops this might be ignored (e.g. potatoes and onions).

The N in the below-ground residue is calculated by applying an N concentration value (N_{BG}).

$(AG_{DM} + Crop) * R_{BG} * N_{BG}$

Step 7: Calculate the N_2O emission from crop residues:

Apply the EF_1 value (0.01 kg N_2O-N/kg N) to the sum of the above-ground and below-ground N (i.e. sum of steps 5 and 6).

The recommended calculation using crop production data from the 2007 inventory spreadsheet is given in Appendix 8.

7 Indirect emissions from N leached from crops

Currently, indirect N_2O emissions from N that is leached and in runoff, and N that is redeposited following volatilisation, are accounted for at a national level based on the amount of N fertiliser and the amount of N excreted by animals. There is no differentiation between leaching and runoff from pastoral systems or from crops. There are improved modelling tools available to better estimate leaching amounts from different farm systems, including arable and vegetable crops.

A proportion of N applied to land ($Frac_{LEACH}$) is assumed to leach (N_{LEACH}). In New Zealand a value of 7% is used, whereas the IPCC default value is 30% (IPCC 1997). The NZ default value was reduced from a previous country specific value of 15%, based on the findings from a modelling exercise using OVERSEER® for different farm system types (Thomas et al. 2002; Thomas et al. 2005). It was concluded from those studies that the NZ $Frac_{LEACH}$ default value of 15% was too high for N leaching from sheep and beef and dairy systems on a national basis and that the value should be reduced to 7%. However, it was also concluded that high N leaching estimates from OVERSEER for arable and vegetable cropping were not reliable. The N leaching estimates tended to be greater from these crops than those reported from NZ studies and those predicted by the IPCC method using the 15% default figure.

In this report, we have re-examined N leaching from arable and vegetable cropping systems using a new model (LUCI) calibrated for New Zealand cropping that is able to predict leaching from cropping sequences on an annual basis.

7.1 Background for calculating N leaching using LUCI

N leaching from a crop is a function of the N content of soil water and the volume of water that drains out of the soil profile. Both drainage and mineral N content vary substantially due to variation in the contributing factors (Figure 2).

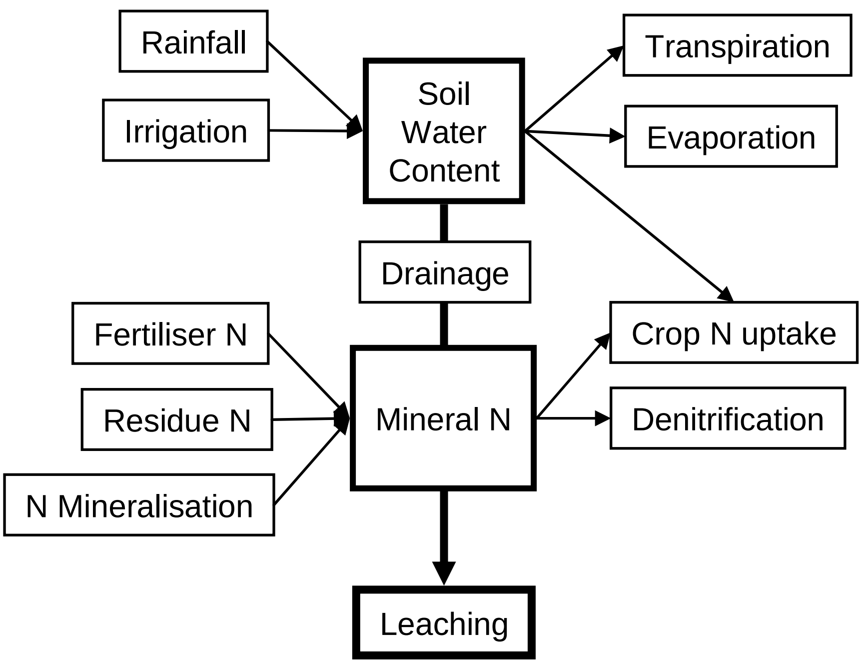

Figure 2: Schematic representation of the factors that influence nitrogen leaching from crops.

Each of the contributing factors can vary greatly from one field to another, even if both fields are growing the same crop. Thus it is essential to account for variation in these factors and how this influences N leaching to calculate a sensible N leaching inventory.

7.1.1 Drainage

Drainage occurs when there is excess water in the soil profile above the soil's capacity to hold water, so it drains through the soil. It is dependent on a number of factors that influence the soil water balance. Some of these factors change daily and must be considered at this level of detail to give sensible predictions of drainage.

Soil water holding capacity. This is dependent on the texture of the soil (sand, silt clay) and the depth to stones. It represents the soil's capacity to absorb added water before drainage begins. It varies from <50 mm on very shallow soils to >250 mm on deep silt soils and can change substantially over short distances.

Rainfall and irrigation. On any given day rainfall varies substantially from site to site and irrigation varies substantially from field to field. The likelihood of a given rainfall or irrigation event causing drainage depends on the water holding capacity of the soil and how far the soil has been depleted below its maximum by evaporation and crop transpiration.

Evaporation and transpiration are dependent on weather conditions that determine the potential for water to evaporate (temperature, humidity, wind speed, solar radiation), and vary substantially by site and season. Evaporation is also dependent on the frequency of rainfall events and how wet the soil surface is subsequently. Transpiration depends on the size of a crop's canopy and the depth to which the crop's roots can extract water. Evapotranspiration varies from <0.5 mm/day to >6 mm/day depending on the crop type and soil and weather conditions.

In summary, the annual drainage from a key crop will be dependent on the water status of the soil left from the previous crop, when and where the crop was sown and how it is managed throughout a year. These factors all vary substantially, making it difficult to construct meaningful generalisations of the magnitude and timing of drainage events.

7.1.2 Mineral N

The amount of soil mineral N is a balance of the amount of N that is removed by crop uptake and denitrification and the amount that is added from fertiliser and mineralisation of crop residue (stem, leaf and root material) and soil organic matter.

Crop uptake. The amount of N that a crop takes up is dependent on the potential yield of the crop, and the overall nitrogen content of that crop. Irrigation is one of the key factors influencing the productivity of a crop, with an unirrigated crop in a dry environment extracting <100 kg N/ha/y and a well-irrigated crop extracting up to 400 kg N/ha/y. Crop type also has an important bearing on the response of crops to irrigation and its potential yield and N content.

Fertiliser N. This varies substantially and can be zero under some scenarios and > 300 kg/ha for others.

Residue N. This also varies substantially dependent on the crop type (N content of residual) and the treatment of that residual (burned, baled, grazed, incorporated).

Organic matter mineralisation. This may vary from < 50 kg N/ha for paddocks that have been under intensive cultivation for a prolonged period to > 200 kg N/ha for soils that have been cultivated out of long-term pasture. The type of cultivation (ploughing vs direct drilling) also has a substantial influence on the amount of soil organic N mineralised.

The mineral N in the soil below a particular crop type will vary hugely depending on the soil status inherited from the previous crop and the management of that particular crop.

From the brief outline of the N leaching process above it is clear that any measurement of N leaching from a crop will be specific to the soil the measurement was conducted on, the previous history and current management of the paddock and the specific weather encountered during the period of measurement. The situation is further complicated for annual crops that do not grow for a full year so it is also necessary to consider the crops that are grown prior to and following the key crop of interest. Thus, it would be incorrect to use measurements of N leaching to calculate the inventory for a key crop because the conditions under which the measurements were conducted could differ substantially from what would be representative conditions. It is not practical to collect enough measurements to give representative values because the measurements are labour-intensive and would need to be conducted under hundreds of soil/climate/management combinations to give a representative range.

Fortunately, simulation models have been developed that predict all of the detailed processes that contribute to leaching on a daily basis. One example is the LUCI framework model, which is able to predict the water use and N uptake of any crop as well as the water and N balance of the soil. This model has been tested and is capable of predicting individual components of the crop-soil system, and its predictions of N leaching have been validated against actual measurements. Such models are a practical method to estimate N leaching from a range of climate/soil/management combinations.

7.1.3 What is the best procedure to give robust estimates of N leaching inventory?

To obtain meaningful generalisations of the amount of N leached from key crops, estimations from an appropriate range of the following factors must be considered.

Location variation: Rainfall and potential evapotranspiration will vary from place to place so the range of regions where a crop is grown must be considered to give a representative range of potential drainage.

Soil variation: This is a major factor controlling drainage and a range of soil types (light, medium and heavy) must be considered to give a representative range of potential drainage.

Management variation: For each given location/soil combination, a range of standardised management protocols must be determined, including previous, current and following crops. The development of standardised management protocols will require the collection of information on crop rotations, timing of key crop events (planting, harvest, irrigation and fertilisation) and the amounts of irrigation and fertiliser generally applied. These would then need to be grouped into a number of representative protocols to give a range of leaching potentials.

Seasonal variation: For each location/soil/management combination, actual leaching will vary from year to year depending on climate variability. The response of the crop-soil system to changes in the magnitude and timing of rainfall is non-linear so it is not appropriate to use long-term mean weather data. Thus, to get representative estimates of N leaching it is necessary to run each location/soil/management combination over a number of years (>20) and take the average of these values.

It is then necessary to weight the annual mean leaching from each location/soil/management combination in accordance with the proportion of the total production that particular scenario represents to gain a robust estimate of N leaching for each key crop.

7.1.4 Methodology

Based on the large number of factors influencing N leaching from different cropping systems, soils and environments, we have had to make large generalisations to examine differences in N leaching for different key crops, regions and soils.

The approach we have used is to create a single management protocol for each crop/location combination. A description of the key information about each management protocol is presented in Appendix 9. We assume these protocols do not vary from one soil type to another, which may not be appropriate but is the best we could do in the absence of better information. These simulations have been run over a 30 year period to give a mean value of N leaching for the assumed management of each key crop in each location/soil type scenario.

The subsequent estimates are useful to demonstrate the range of N leaching in absolute amounts (kg/ha) and as a % of fertiliser applied for comparison with the IPCC calculations.

7.2 N leaching results

Our simulations clearly show that N leaching is greatly dependent on crop, soils, and region (Tables 15–17). The 30 year average for N leached ranged from 0 for squash grown on a heavy soil in the Hawke's Bay to 96 kg/ha for a maize crop grown on a light soil in Northland (Table 18). As a percentage of fertiliser applied N leaching ranged from 0 to 54% (Table 18). Soil type had a large effect on the amount of N leached, ranging from 4% from heavy soils to 26% from light soils (Table 16). There was also substantial variation between regions with low values (5–7%) in dry East coast locations and higher values (up to 26%) in higher rainfall areas like Southland (Table 17).

The substantial amount of variation shows it will be necessary to use appropriate weighting factors for soil and location to produce robust estimates of N leaching. These results also show that in most cases the % of fertiliser leached is much less than the default IPCC leaching fraction of 30%.

Actual leaching amounts will depend greatly on the range of management and cropping rotations practiced. The selected management protocol is our best approximation representing standard cropping rotations and management.

These values are from only one management protocol so do not represent a range of management practices that would be expected. For example, the amount leached from a winter potato crop in the Auckland region might be larger than the summer management conditions we have simulated.

Actual management practices would also vary between soil type and location but our standardised management practices do not capture this. Soil organic N was taken as the value measured in a single pit that was dug to describe the soil type. This value will be dependent on the management history of the field that the pit was dug in and may not represent the actual organic N on soils that are typically cropped. Organic N has a large effect on the amount of N that enters the soil from mineralisation.

Taking average values of leaching from these results does not give appropriate values to represent specific crop, location or soil situations, because these results are from a single management protocol and are not weighted for the relative importance of each situation. However, the values generated represent the potential N leaching from probable management scenarios and are useful to demonstrate the variation in N leaching from one situation to another.

Table 15: Simulated N leached from key crops. Data are un-weighted statistics estimated by running a detailed process based crop-soil model (LUCI). For each crop a standard management practice was repeated for 30 years (1972–2002) in key production regions and on three different soil types.

Crop	Fertiliser N kg/ha	N leached (kg/ha/year)			% leached
		Median	Min	Max	
Wheat	187.5	28.7	0.0	202.7	15%
Barley	138.0	30.6	0.0	167.2	22%
Maize	173.3	26.1	0.0	204.6	15%
Sweetcorn	100.0	7.3	0.0	100.7	7%
Potato	200.0	8.7	0.0	140.3	4%
Onion	138.8	11.1	0.0	70.4	8%
Squash	150.0	2.8	0.0	24.7	2%
Clover	0.0	22.8	0.0	138.1	-
Ryegrass	120.0	21.1	0.0	155.8	18%

Table 16: N leached from differing soil types. Data are un-weighted statistics estimated by running a detailed process based crop-soil model (LUCI). For each soil a standard management practice was repeated for 30 years (1972–2002) in for key crops in key production regions.

Soil	Fertiliser N kg/ha	N leached (kg/ha/year)			% leached
		Median	Min	Max	
Light	158.5	37.7	0.0	204.6	26%
Medium	158.5	13.1	0.0	88.2	9%
Heavy	158.5	5.3	0.0	52.6	4%

Table 17: N leached from different regions. Data are un-weighted statistics estimated by running a detailed process based crop-soil model (LUCI). For each soil a standard management practice was repeated for 30 years (1972–2002) in for key crops in key production regions.

Region	Fertiliser N kg/ha	N leached (kg/ha/year) Median	Min	Max	% leached
Bay of Plenty	180.0	41.6	0.0	157.6	23%
Canterbury	171.7	9.2	0.0	155.8	7%
Gisborne	143.3	6.7	0.0	46.1	5%
Hawke's Bay	160.7	6.6	0.0	79.4	5%
Northland	158.3	16.8	0.0	132.5	10%
Southland	160.0	39.8	6.3	101.7	26%
Waikato	158.3	14.2	0.4	88.2	9%

Table 18: N leached from key crops. Data are 30 year means of N leaching estimated using a detailed process based crop-soil model (LUCI). For each crop a standard management practice was repeated for 30 years (1972–2002) in key production regions and on three different soil types.

Crop	Region	Soil	Fertiliser N kg/ha	N leached (kg/ha/year) Median	Min	Max	% leach
Wheat	Canterbury	Heavy	180.0	3.0	0.0	20.5	2%
		Medium	180.0	2.2	0.0	21.0	1%
		Light	180.0	14.8	2.8	34.7	8%
	Hawke's Bay	Heavy	240.0	2.0	0.1	5.0	1%
		Medium	240.0	3.1	0.0	7.6	1%
		Light	240.0	11.3	0.8	26.1	5%
	Southland	Heavy	180.0	13.7	6.3	18.2	8%
		Medium	180.0	31.3	12.8	45.4	17%
		Light	180.0	59.8	31.7	86.4	33%
Barley	Canterbury	Heavy	140.0	0.7	0.0	10.0	0%
		Medium	140.0	0.2	0.0	8.3	0%
		Light	140.0	9.8	1.5	23.4	7%
	Hawke's Bay	Heavy	140.0	6.2	0.3	17.6	4%
		Medium	140.0	8.5	0.2	31.2	6%
		Light	140.0	31.5	5.4	79.4	23%
	Southland	Heavy	140.0	21.3	10.4	36.1	15%
		Medium	140.0	44.7	23.3	74.9	32%
		Light	140.0	68.2	45.0	101.7	49%
Maize	Bay of Plenty	Heavy	180.0	6.5	0.0	27.8	4%
		Medium	180.0	33.7	4.3	80.4	19%
		Light	180.0	84.6	29.3	157.6	47%
	Gisborne	Heavy	180.0	5.2	0.0	13.8	3%
		Medium	180.0	10.9	0.2	42.1	6%
		Light	180.0	14.8	0.0	46.1	8%

Crop	Region	Soil	Fertiliser N kg/ha	N leached (kg/ha/year) Median	Min	Max	% leach
	Hawke's Bay	Heavy	180.0	1.5	0.0	7.3	1%
		Medium	180.0	1.9	0.0	9.5	1%
		Light	180.0	11.1	1.0	31.3	6%
	Northland	Heavy	180.0	5.9	0.3	12.7	3%
		Medium	180.0	5.2	1.0	8.8	3%
		Light	180.0	96.4	20.8	132.5	54%
	Waikato	Heavy	180.0	5.1	0.4	14.5	3%
		Medium	180.0	35.1	6.9	88.2	20%
		Light	180.0	9.9	1.8	21.5	5%
Sweetcorn	Canterbury	Heavy	100.0	2.5	0.0	21.5	2%
		Medium	100.0	3.6	0.0	21.5	4%
		Light	100.0	28.3	1.5	100.7	28%
	Gisborne	Heavy	100.0	3.3	0.0	9.8	3%
		Medium	100.0	7.6	0.0	35.5	8%
		Light	100.0	9.1	0.0	44.0	9%
	Hawke's Bay	Heavy	100.0	1.3	0.0	5.3	1%
		Medium	100.0	1.7	0.0	9.4	2%
		Light	100.0	8.0	1.0	21.8	8%
Potato	Canterbury	Heavy	340.0	2.3	0.0	25.5	1%
		Medium	340.0	2.6	0.0	25.5	1%
		Light	340.0	17.5	0.0	140.3	5%
	Hawke's Bay	Heavy	180.0	1.8	0.0	7.2	1%
		Medium	180.0	1.5	0.0	11.2	1%
		Light	180.0	6.6	1.2	22.9	4%
	Northland	Heavy	160.0	2.6	0.0	8.5	2%
		Medium	160.0	2.9	0.3	5.8	2%
		Light	160.0	8.2	0.6	17.3	5%
	Waikato	Heavy	180.0	4.8	0.7	12.9	3%
		Medium	180.0	13.0	1.2	55.7	8%
		Light	180.0	6.8	1.0	17.2	4%
Onion	Canterbury	Heavy	150.0	0.5	0.0	7.4	0%
		Medium	150.0	1.0	0.0	12.0	1%
		Light	150.0	13.6	0.0	62.5	9%
	Hawke's Bay	Heavy	135.0	4.1	0.0	12.9	3%
		Medium	135.0	7.8	0.0	26.4	6%
		Light	135.0	22.3	0.9	52.4	17%
	Northland	Heavy	135.0	6.5	1.8	16.5	5%
		Medium	135.0	5.6	2.1	9.9	4%
		Light	135.0	18.4	5.8	23.6	14%
	Waikato	Heavy	135.0	6.9	1.4	14.8	5%
		Medium	135.0	31.5	5.6	70.4	23%
		Light	135.0	14.5	5.0	25.8	11%

Crop	Region	Soil	Fertiliser N kg/ha	N leached (kg/ha/year) Median	Min	Max	% leach
Squash	Gisborne	Heavy	150.0	1.7	0.0	7.7	1%
		Medium	150.0	4.1	0.0	24.7	3%
		Light	150.0	3.8	0.0	21.1	3%
	Hawke's Bay	Heavy	150.0	0.0	0.0	7.3	0%
		Medium	150.0	1.5	0.0	11.9	1%
		Light	150.0	5.8	0.6	19.2	4%
Clover	Canterbury	Heavy	0.0	10.2	0.0	51.7	
		Medium	0.0	8.0	0.0	62.6	
		Light	0.0	50.3	2.5	138.1	
Ryegrass	Canterbury	Heavy	120.0	8.7	0.0	49.0	7%
		Medium	120.0	6.7	0.0	56.2	6%
		Light	120.0	48.1	2.2	155.8	40%

7.3 Discussion of N leaching results and IPCC calculated leaching

Using the LUCI model, the amounts of N leaching for a range of different key crops can be simulated under different management regimes, taking account of climate and soil differences. Using a modelling approach, changes in management practices can be incorporated and new values of N leaching can be simulated.

Based on our simulations, there was no relationship between the N leaching calculated using the IPCC (7% of N fertiliser applied) and the values simulated for the different crops on the three different soil types. This is not surprising due to the large effect that soil type and climate (region) has on leaching. Furthermore, the IPCC method ignores the contribution of mineralised soil organic matter and crop residues to leaching, which is very important in arable systems in NZ (Haynes 1999). A NZ study (Haynes 1999) showed that only 5% of the applied fertiliser remained in the soil at harvest, while 25% had been incorporated into soil organic matter. Deficiencies in the IPCC method for calculating N leaching for cropping and other farming systems in New Zealand are discussed by Thomas et al. (2004b).

We used the Statistics New Zealand Agricultural Production regional data to estimate $Frac_{LEACH}$ for key crops by using regional production statistics to weight our leaching estimates for each region (Table 19). Our weighting using regional data and the modelled regional leaching estimates account for between 68 and 94% of the total cropping area (Table 19). The weighting is based on an average leaching value from the three different soil types. There is no information on the proportion of crops grown on different soil types.

Table 19: Estimates of N leaching and the fraction of N leached for key crops. Leaching estimates are weighted using regional cropping area statistics from the 2007 Agricultural Production Census. Pre-weighted data are 30 year means of N leaching estimated using a detailed process based crop-soil model (LUCI). For each crop a standard management practice was repeated for 30 years (1972–2002) in key production regions. Weighted estimates are based on average leaching predictions from three different soil types.

Crop	Total crop area (ha)	Weighted estimate of leaching fraction (%)	% of total crop area contributing to weighting
Barley	40,500	5	80
Wheat	51,500	4	94
Maize	17,000	12	89
Potatoes	10,450	3	68
Onions	4,590	11	92
Total area	124,000		
Average of weighted value		6	85

However, our estimates are based on simulations from a few of the key crops (Table 19) accounting for about one-quarter of the area cropped (including the large area of forage brassicas; see Table 4). A key limitation to this approach is that we have only considered one management to represent all crops. Running the simulations with a range of management scenarios will provide additional certainty about these estimates. We have also made some generalisations to categorise the soils in each region, and we do not know what proportion of individual crops is grown on the different soil types. In the future we will be able to estimate N leaching from forage brassica crops as a new brassica sub-model is being incorporated into the LUCI model.

7.4 Recommendations for calculating N leaching

7.4.1 $Frac_{LEACH}$

- Based on the simple weighting exercise (Table 19) it would appear that the country-specific value for $Frac_{LEACH}$ of 7% is reasonable when using the Tier 1 approach to estimating N_{LEACH}.
- We recommend that process based models like the LUCI model be considered for improving the prediction of N leaching in the NZ inventory in future. These models are able to simulate the effects of changes in management on leaching, and the effects of changing cropping patterns across New Zealand using appropriate soil and climate data.
- Model simulations of N leaching are needed for a wider range of management scenarios and crop types.

7.4.2 EF_5

This emission factor has very large uncertainty, and is based on very few studies worldwide (Thomas et al. 2002). Based on a number of reviews and field studies, including some recently conducted in New Zealand, the current default value is probably too high (Nevison 2000; Clough et al. 2007).

- We recommend that New Zealand uses the default value of 0.0075 kg N_2O-N/kg N leached/runoff as per the 2006 Guidelines.

8 Direct emissions from stubble and savanna burning

8.1 Stubble burning

8.1.1 Calculation of the amount of stubble residue burned

New Zealand emissions from burning of agricultural residues are estimated in accordance with the revised 1996 IPCC guidelines (IPCC 1996). The amount of crop residues burned is calculated as a proportion of the dry matter of the crops that are burned. The amount of carbon released is estimated from the carbon content of the residues (C fraction), the amount of N released is estimated from the nitrogen to carbon ratio of the residues burned. An oxidation factor is assumed to account for the incomplete combustion. The emissions of CH_4, CO, N_2O and NO_x are calculated using the carbon released and an emissions ratio. Nitrous oxide and NO_x emissions calculations are based on the nitrogen to carbon ratio. IPCC good practice guidance (IPCC 2000) suggests that an estimate of 10 per cent of residue burned may be appropriate for developed countries but also notes that the IPCC defaults "are very speculative and should be used with caution".

The factors currently used to calculate emissions from stubble burning are recorded in Tables 20 and 21:

Table 20: Values used to calculate NZ emissions from burning of agricultural residues for 2006.

Crop	Residue/yield[1]	Dry matter fraction[1]	C fraction (% dm)[1]	N:C ratio[1]	Fraction oxidised[1]	Fraction burned in fields[2]
Wheat	1.3	0.83	0.4853	0.012	0.9	0.3
Barley	1.2	0.83	0.4567	0.015	0.9	0.3
Oats	1.3	0.92	0.4567	0.015	0.9	0.3

[1]From IPCC (1997).
[2]From Ministry of Agriculture and Forestry.

Table 21: Emission ratios for agricultural residue burning.

Compound	Emission ratio[1]
CH_4	0.005
CO	0.06
N_2O	0.007
NOx	0.121

[1]From IPCC (1997).

From 1990 to 2003 it is estimated that 50% of stubble was burned. For the years 2004 to 2006, MAF experts assessed this to have decreased to 30% (Sonia Petrie, pers. comm.). These values were developed from opinions of MAF officials working with the arable production sector. It is unclear, however, what definition of stubble these experts used and which crops were included in these estimations.

We consider that burning of crop residues should only be considered applicable to three crops – barley, wheat and oats – as other crop residues are not usually burned.

Using Statistics New Zealand 2007 Census information, the total area of wheat plus barley plus oats grown equalled 97,791 hectares and estimates from the same Census showed that the area burned was 59,498 hectares. These data therefore suggest that approximately 61% of these crops' residues are burned after harvest.

These results are in close agreement with the results of a Cropping Sequences survey (Lawrence et al. 2007) where estimates showed that 70% of Canterbury wheat growers burn their crops and 60% of Southland wheat growers burned their wheat crop residues.

There is, however, some variation in burning practice between the three crops (barley, wheat and oats), largely due to variation in potential markets for these crop residues. Barley and oat straws are more palatable and digestible for animals, so there is a tendency for more of these crop residues to be baled and used for other purposes such as animal feeding than wheat. The recent significant increases in dairy production on a national scale, for example, have resulted in a concomitant increase in market demand for barley straw – as it is used as a high fibre feed supplement for dairy cows. Results from the Cropping Sequences survey (Lawrence et al. 2007) concur with this trend – around 50% of farmers surveyed in Canterbury who grew barley burned their barley crop residues. An even lower proportion (around 30%) of barley growers in Southland burned their crop residues, which may in part be due to this increased demand by dairy farmers. Similarly, oats residues are sought after in the horse industry. However, we have no reported information on the amount of cereal crop residues that are baled.

8.1.2 Reliability of stubble burning activity data

Crop yield data for crops whose residues are burned have been discussed in Section 6.1, Table 10.

The current calculation in the National Inventory Spreadsheet includes other key crops that do not have their residues burned. For example, residues from the key N-fixing crop (peas) are not burned in NZ, yet a burning factor of 0.3 is applied to all crops including peas.

Given that in general only three crops have residues that are burned on occasion, it would be advisable to limit the calculation of emissions burning to crops that are burned rather than using an average factor for all crops.

Moreover, where crop residues are burned, the extent of the burn will be affected by environmental conditions. If cool, wet conditions follow harvest then a good burn will not be achieved because the residues are too wet. The method of burning employed is also an important consideration (e.g. some farmers prefer to burn in the swaths, which results in striping in the field with burned swaths and unburned stubble in between; other farmers opt for total cover burning after spreading the residue). Estimates of losses of N to the atmosphere during burning are in the order of 30–90% depending upon the extent of the combustion (Raison & McGarity 1979; Biederbeck et al. 1980). This represents a loss of 10–25 kg N/ha for a straw crop of 5 t/ha.

To take into account the variation in environmental conditions and the method of burning we suggest that where crop residues are burned, a 70% average figure for the extent of burn is used (i.e. assuming that 30% of residues will be largely unaffected by the burning process).

8.1.3 Recommendations for refining calculation of emissions from stubble burning

Use crop residue calculations for barley, wheat and oats described in Section 6, including the dry matter fractions we have recommended (Table 12).

Use values in Table 14 to calculate the amount of cereal stubble burned.

8.2 Savanna (tussock) burning

Current estimates from the 2005 inventory are that about 1 Gg of CO_2-e are emitted as N_2O (0.15 Gg CO_2-e) and CH_4 0.83 (Gg CO_2-e) from controlled burning tussock land.

Greenhouse gas emissions from tussock burning in the South Island is estimated in NZ (Ministry for the Environment 2008b) and reported under the Savanna burning category. Emissions are calculated following the 1996 IPCC methodology in two steps (IPCC 1997). First, the amount of carbon that is released by burning is estimated (Equations 6–9), then the emissions related to the carbon released are estimated. To estimate the N_2O and NO_x emissions the ratio of N to C for the biomass is used. Emissions are then converted on a molecular mass basis.

Calculation of the biomass burned and carbon released:

Biomass burned (t dm) = area of tussock burned annually * above-ground biomass density (t dm/ha) * fraction actually burned – **(Equation 6)**

C released from live biomass (t C) = biomass burned (t dm) * fraction that is live * fraction oxidised * C content of live biomass (t C/t dm) – **(Equation 7)**

C released from dead biomass (t C) = biomass burned (t dm) * fraction that is dead * fraction oxidised * C content of dead biomass (t C/t dm) – **(Equation 8)**

Total C released (t C) = C released from live material (t C) + C released from dead material t C/t dm) – **(Equation 9)**

Calculation of the emission form the biomass burned:

CH_4 emissions = Total C released * emission ratio * 16/12

N_2O emissions = Total C released * N/C ratio * emission ratio * 44/28

Only N_2O and CH_4 are currently included in the NZ inventory calculation. These are the only gases described in the methodology included in the Agricultural section of the IPCC Good Practice Guidance and Uncertainty Management guide (IPCC 2000). The values currently used in the NZ inventory are shown in Table 22.

Table 22: Values used to calculate emissions from savannah burning for 2006.

Description	Factor	Source
Tussock above-ground biomass density (t dm/ha)	28	(Payton & Pearce 2001)
Biomass fraction burned	0.32	(Payton & Pearce 2001)
C content of live biomass (t C)	0.45	(IPCC 1997)
C content dead biomass (t C)	0.4	(IPCC 1997)
Fraction of live material	0.361	(Payton & Pearce 2001)
Fraction of dead material	0.639	(Payton & Pearce 2001)
Fraction live material oxidised	0.8	(IPCC 1997)
Fraction dead material oxidised	1	(IPCC 1997)
CH_4 emission ratio	0.004	(IPCC 1997)
N_2O emission ratio	0.007	(IPCC 1997)
N/C ratio	0.006	(IPCC 1997)

8.2.1 Calculation of the area of tussock burned.

New Zealand has modified the IPCC methodology by estimating the area of tussock burned annually from Regional Council resource consent data (Ministry for the Environment 2008b). Regional Councils are responsible for the impacts on land, water and air from burning. Resource consents were issued by South Island Regional Councils (Canterbury, Otago and Southland) for tussock burning and the applications included the proposed area of burn. The area of actual burn may have differed from the area granted in the resource consents. For example, weather conditions may have prevented burning in the year that the consent was granted.

MfE currently assumes 20% of the area that has been given a resource consent is actually burned. This is based on a single expert opinion from Southland Regional Council (S. Petrie, pers. comm.). There do not appear to be any other estimates of this proportion for the other main regions (Canterbury and Otago). In 2006, MfE estimated that the total consented area was 11,309 ha, and assumed that only 2,262 ha (20% of the consented area) was burned.

8.2.2 Reliability of Regional Council consent data for tussock burning

Consent activity data since about 2004 do not provide an accurate measure of how much tussock burning is planned as most tussock burning is now a permitted activity (i.e. no resource consent is required) under Canterbury and Otago Regional Council rules. However, we would expect consent data in 1990 to reflect the areas that were planned to be burned.

Environment Canterbury (ECan) allows burning as a permitted activity as long as certain criteria are met in the Land and Vegetation Management Regional Plan (Part IV). If these conditions are met it does require the landowner to inform ECan of the planned burning, provide a map of the burn area, and approximate date of burning. The Plan became operable in 2005. The area of burn from these plans submitted by the farmers is not currently analysed by ECan.

The resource consent data reported for each year reflect the area of burning that was applied for in that year. In some cases an area will not be burnt due to unsuitable weather conditions. Similarly, where burning is a permitted activity and burn plans need to be lodged, these burns may not occur due to unsuitable weather. Recent compliance checks by ECan staff have also found that some burns have not been notified to ECan.

Based on a small sample from a flyover survey in 2007 six un-notified burns were observed. This indicated that less than half of the burns had plans submitted in 2007 for the survey area in the Southern Canterbury region (F. Willox, pers. comm.). The area of burns in the submitted plans for the Southern Canterbury region was only about 100 ha. The proportion of burns that are advised to ECan is expected to improve in the future as ECan is widely publicising the requirements for permitted burns.

In Otago, burning is a permitted activity when the "Code of Practice for the management of Vegetation Burning in the Otago High Country" is followed. The code was developed with the Otago Regional Council. Compliance checks should provide some information about the areas burned although this information does not appear to be readily available and is unlikely to provide accurate area data. We were advised by staff at Otago Regional Council that better information about the areas burned may come from district councils and other agencies responsible for issuing fire permits. Southland Regional Council still requires land use consents for burning.

There are a number of other agencies that are responsible for managing burning, and at least four of these (including regional councils) are responsible for issuing consents or permits. District Councils are the fire control authority for most rural land. Their prime concerns are that the fire is properly contained. If the risk of fire is low they do not necessarily require permits for all fires at all times.

In the Central Otago District, high country tussock can be burned without a permit in the open fire season, but permits are required in restricted season usually from about mid-September. Large areas of tussock are burnt at the end of August and the beginning of September when no fire permits are required. As a result there is no quantitative information on the area or locations of these fires, unless there are accidental or uncontrolled burns.

The Department of Conservation (DOC) is the fire authority for land in the conservation estate and surrounding land within a 1 km margin. A permit is required for burning within 1 km of DOC managed land.

On pastoral lease land the Commissioner of Crown Lands is required by the Crown Pastoral Lands Act to issue consents for vegetation fires. He is required to balance inherent values (such as indigenous plants and animals, natural ecosystems, landscapes, cultural, historical or scientific) with the farming values.

8.2.3 Reliability of tussock burning area data

The consent data used to estimate land areas burned in 1990 may be the most reliable available. The total consented area reported in 1990 was 35,391 ha. At that time Otago and Canterbury Regional Councils would have required resource consents. However, not all consented areas will have been burned due to weather conditions, and consent data do not include accidental burns, burning that was not properly controlled, or burning that occurred illegally.

The 2007 Agricultural Production Census was the first census that asked for tussock burning areas. This was directly in response to the need for more accurate information for the NZ inventory. Three questions were asked to estimate the area of stubble burning, tussock burning (including oversown tussock) and other vegetation burning.

According to the NZ agricultural production census, 23,383 ha was burned between July 2006 and June 2007. This is ten times the area of tussock estimated in the 2005 inventory. Most was burned in Otago (15,869 ha) and Canterbury (5,083 ha). These data are contrary to the trend of declining burning described in the Greenhouse Gas Inventory reports as recently as 2008 that said that tussock burning has been steadily decreasing over the past 50 years (Ministry for the Environment 2008a). A further 13,184 ha was recorded in the "other standing vegetation" category, 75% of which occurred in the South Island, mostly in Otago and Canterbury. Furthermore, we do not know whether these areas are likely to be under-reported by farmers. The census does not distinguish between controlled burns for agricultural management and uncontrolled burns.

Our assessment of the data available from consents and the census, and discussions with Regional Council and District Council staff, leads us to believe that the area of tussock burning has been greatly under-reported in the national inventory in the past. A method to improve the accuracy of the data might be to aerially survey burned high country grassland area in October or use satellite remote sensing techniques.

8.2.4 Calculations of tussock biomass burned

The actual amount of biomass that is burned is calculated by firstly estimating the above-ground dry matter biomass for the area of tussock land that is burned and estimating the fraction of this biomass that is burned.

New Zealand uses an above-ground biomass estimate of 28 t dry matter/ha (Ministry for the Environment 2008b). This value is based on measurements of live and dead vegetation in tall tussock grassland (C*hionochloa* spp.) at two Otago sites: Deep Stream near Dunedin (27 t/ha) and Mount Benger near Roxborough (29 t/ha) (Payton & Pearce 2001) and a more recent report (Payton & Pearce 2008).

There have been a number of other studies (reviewed by O'Connor et al. (1999)) that have reported above-ground biomass for tall tussocks. The above-ground biomass varies greatly between the different sites from about 17 t/ha to 66 t/ha.

Based on the tall tussock dry matter values reported in these studies, the average dead above-ground biomass (about 28 t/ha) is more than twice the live above-ground biomass (about 12 t/ha), while the mean and median above-ground biomass is about 40 t DM/ha, which is greater than the current factor used in the NZ inventory.

O'Connor et al. (1999) reported dry matter values from other tussock and hill country grasses (Table 23). In general, aboveground biomass and nutrients decrease as the tussock grasslands become more degraded from tall tussocks through mixed tussock. As might be expected, short tussock and "short weedy grassland" were much lower in DM than the tall tussocks. Reasons for these differences in tussock grassland include the climate and differences in the past management of the sites, (e.g. burning and grazing).

One of the key issues for improving the estimate of tussock biomass burned is to have an understanding of the proportions of the areas of different types of tussock or grassland that are burnt. It is assumed that most is controlled burning of tall tussock grasslands.

The estimated proportion of the above-ground biomass that is actually burned is 32%. This is based on results from the study by Payton & Pearce (2001). The IPCC default value is much higher (85–100%) for much drier savanna grasslands (IPCC 1997).

The New Zealand value is solely based on the burning results reported for the Deep Stream site. This was burned in spring, which would be in accordance with controlled burning rules (Payton & Pearce 2008). In that study, large plots (1 ha) at two sites were used to simulate real world conditions for early and late-season fires, and damp versus dry burns.

Approximately 36% of the above-ground biomass was lost in a spring burn at Mount Benger compared with 75% in a spring burn at Deep Stream (Payton & Pearce 2008). Summer burns designed to simulate wildfires at Mount Benger consumed about 63% of the above-ground biomass, whereas about 75% was lost at Deep Stream (Payton & Pearce 2008).

Biomass burning occurred when the sites were dry and was least when they were damp. The biggest differences in fuel characteristics between the spring and summer burns were the moisture content of the tussock bases and upper soil layers (Payton & Pearce 2001).

Table 23: Tall tussock live and dead above-ground biomass, total above-ground biomass and fractions of live and dead biomass.

Site	Live DM (kg/ha)	Dead DM (kg/ha)	Live + Dead (kg DM/ha)	% Live	% Dead
Craigeburn[1]	7900	47100	55000	14%	86%
Craigeburn[1]	8900	33400	42300	21%	79%
Craigeburn[1]	14400	40600	55000	26%	74%
Hakatere Basin[1]	4500	12200	16700	27%	73%
Hakatere Basin[1]	10300	30600	40900	25%	75%
Tekapo[1]	11400	18800	30200	38%	62%
Old Man range[1]	16900	25100	42000	40%	60%
Old Man range[1]	16500	16500	33000	50%	50%
Old Man range[1]	21300	44800	66100	32%	68%
Deep Stream[2]	10901	15961	26862	41%	59%
Mt Benger[2]	9161	19891	29052	32%	68%
Mean	12015	27723	39738	31%	69%
Median	10901	25100	40900	32%	68%

Source: [1]O'Connor et al (1999); [2]Payton & Pearce (2001).

Table 24: Other tussock/hill country grassland live and dead above-ground biomass, total above-ground biomass and fractions of live and dead biomass (from O'Connor et al. 1999).

Site	Live (kg DM/ha)	Dead (kg DM/ha)	Live+dead (kg DM/ha)	% Live	% Dead
Mixed tussock grassland:					
Hakatere Basin	6400	9800	16200	40%	60%
Short tussock grassland:					
Tekapo	4600	5200	9800	47%	53%
Weedy short grassland:					
Craigieburn	3400	1600	5000	68%	32%
Hakatere Basin	800	1000	1800	44%	56%
Tekapo	1800	1400	3200	56%	44%
Average weedy short grassland:	2000	1333	3333	56%	44%

8.2.5 Reliability of tussock biomass estimates

The calculations are based on two studies of tall tussock grassland (C*hionochloa* spp.) at two Otago sites. The data are appropriate for these sites and are likely to be appropriate for other similar tall tussock grasslands.

However, there are a range of grasslands that may have different amounts and species of tussocks. These may have quite different total, live and dead biomass (see Table 24). We have not been able to find any data on the proportion of different grasslands compositions that are burned. It is probable that the area of tall tussock that is burned is reducing, but there may be large areas of degraded tussock that are being burned. The factors derived from the tall tussock (biomass density, and proportion of live and dead biomass) are very different to degraded tussock grassland (Tables 23 and 24).

Anecdotally, in southern areas of Canterbury there is less tussock burning and more "scrub" burning prior to establishment of pastures (F. Willox, pers. comm.).

8.2.6 Calculation of the amount of carbon released from tussock burning

The amount of carbon released by burning of savanna grasslands is currently estimated separately for carbon released from live vegetation and dead vegetation. The IPCC default assumes that there is more carbon in live material (45% of the dry matter) than in dead material (40% of the dry matter).

Carbon contents of above-ground biomass of tall tussock (mainly *Chiolochloa rigida*) at Deep Stream and Mount Benger was about 46–47% of live and dead dry matter (Payton & Pearce 2008).

The fractions that are currently used to estimate carbon from live and dead biomass are 0.36 and 0.64, respectively, based on the tall tussock burning studies by Payton & Pearce (2001). These values are similar to the values (0.32 and 0.68) that we calculated when including the dry matter data from review by O'Connor et al. (1999). However, more degraded tussock grasslands (Table 24) tended to have higher proportions of live vegetation than dead.

We have already discussed the effect of the timing of burning can have on the fraction of above-ground biomass that is actually burned (see Section 9.2.4). This clearly affects the amount of dry matter and carbon released. Best practice is to burn in the spring period. This practice is most likely to be complied with, and this is encouraged by the Regional and District Councils.

The amount of the carbon in the above-ground biomass that is oxidised is also partitioned into live and dead components. The factors that NZ uses are the IPCC defaults (0.8 and 1, respectively).

8.2.7 Greenhouse gas emissions from biomass burned.

There are some NZ data for the N:C ratio of live and dead tussock grassland biomass. The IPCC factor (0.006) is currently used for both live and dead biomass in the NZ inventory. This is similar to the value that Payton & Pearce (2008) reported for tall tussock grassland, but is lower than those reported by O'Connor et al. (1999).

Table 25: Nitrogen contents and N:C ratios in live and dead aboveground biomass (from data reported by O'Connor et al. (1999) and Payton & Pearce (2008).

	N contents (kg/ha)			N:C ratios		
Site	Live	Dead	Live + Dead	Live	Dead	Live+ Dead
Tall tussock grassland:						
Craigieburn	75	153	228	0.019	0.011	0.013
Hakatere Basin	61	115	176	0.013	0.009	0.010
Tekapo	63	62	125	0.012	0.008	0.010
Deep Stream	76	90	167	0.014	0.011	0.006
Mt Benger	66	86	151	0.014	0.009	0.005
Average of tall tussock grassland	*79*	*101*	*169*	*0.015*	*0.010*	*0.009*
Short tussock grassland:						
Tekapo	38	31	69	0.017	0.012	0.014
Mixed tussock grassland:						
Hakatere	52	59	111	0.016	0.012	0.014
Weedy short grassland:						
Craigieburn	30	8	38	0.018	0.010	0.015
Hakatere	7	4	11	0.018	0.008	0.012
Tekapo	15	10	25	0.017	0.014	0.016
Average of weedy short grassland	17	7	25	0.017	0.011	0.014

Live aboveground biomass has higher N:C ratios than the litter (Table 25). The tall tussock grasslands contain much more N in the above-ground biomass than the more degraded grassland. The mean difference between the tall tussocks and the weedy short grassland was 152 kg N/ha (O'Connor et al. 1999). Hence, the N:C ratio is higher in the more ecologically degraded grasslands (mixed and short tussock) that are much less productive than the tall tussock grasslands (Table 25).

In the study by Payton & Pearce (2008) nitrogen losses were proportional to tall tussock biomass losses, indicating that fire temperatures were high enough to volatilise nitrogen. One of the key recommendations made by Payton & Pearce (2008) was that tall tussock burning is only carried out in late winter or early spring. This reduces the amount of biomass and nutrient losses, and increases the likelihood of tall-tussock survival.

8.2.8 Tussock burning emission factors

The IPCC estimates the uncertainty about the N_2O and CH_4 emission factors for Savanna of about ± 20% (IPCC 2000) based on field and laboratory measurements in America and Africa. The efficiency of the emission factor for CH_4 depends on the combustion efficiency. More CH_4 is produced for fires that have low combustion efficiency. The N_2O emission factor increases linearly with CO_2 emission and depends on the N content of the vegetation. We are not aware of any NZ measurements of these emission factors in the field or laboratory.

The IPCC 2006 guidelines for Tier 1 methodologies provide a more generic approach for emissions from burning than the 1996 Guidelines.

8.2.9 Recommendations

Resource consent data should no longer be used to estimate annual burning areas. Although historical data before burning became permitted activity in regional council plans may be the most reliable source of data to estimate the tussock area that was burned.

Further information is required to understand why the area burned reported in the Agricultural Production census data is a magnitude greater than the estimates being currently used based on 20% of the consented area.

Until further information is available accept the census data as being the most accurate information for current burning practices.

Further investigation is required to:

- confirm the areas reported in the Agricultural Production census
- assess whether remote sensing can improve the uncertainty of area burned;
- assess the proportions of tall tussock and other degraded tussock grasslands that are burned;
- assess the appropriateness of the current above-ground biomass density value, proportion of biomass actually burned, proportions of live and dead biomass and N:C ratios for the types of grassland being burned.

Accept IPCC default values for fractions of live and dead biomass oxidised during burning, and CH_4, and N_2O emission ratios.

Consider using the IPCC 2006 Tier 1 methodology and default values (Chapter 2, IPCC 2006) until more quantitative burning data are available.

9 Summary of recommendations for improving uncertainty in NZ inventory calculations

9.1 Key crops

The key crops we recommend should be reported and for which data are available are: barley, wheat, maize, oats, peas and potatoes. More information is required for forage crops (brassicas, cereals and lucerne), and clover and grass seed crops. Lentils, which are currently reported, are a minor crop and we recommend that this does not need to be reported.

9.2 Calculation of N inputs from crop residues

We recommend a refined method based on the IPCC 2006 methodology but using crop harvest index to estimate the residue described in Section 6.8.1 and Table 26.

9.3 Calculation of emissions from stubble burning

We recommend changing the fraction of cereal crops that are burned in the field from the current values used. New values are described in Section 8.1.2 and Table 26.

9.4 Calculation of emissions from tussock (savanna) burning

Based on the 2007 Agricultural Production census, the area of tussock burnt is grossly under-reported. We recommend that this new census information is used.

There is a dearth of information about the biomass that is burned. Further investigation is needed to assess the appropriateness of the NZ-specific values derived from two tall tussock burning trials to all tussock grassland that is burned. Recommended values are shown in Table 26.

Table 26: Recommendations for factors to calculate greenhouse gas emissions from cropping, stubble burning and tussock (savanna) burning based on the MfE NZ inventory spreadsheet 2008.

A. Calculation of crop residue N

See Table 12 and Appendix 8

B. Parameter values for agricultural emissions of nitrous oxide

Parameter	Description...	Current value	Recommendations	Recommended values	Comments
$Frac_{BURN}$	Fraction of Crop residue burned in fields	0.5	Use new values for cereal crops in Table 14	0.3 to 0.7	Survey data available for different regions for wheat and barley
$Frac_{BURNL}$	Legume crop residue burned in fields	0	Use current value	0	Legume residues are not burned
$Frac_{LEACH}$	Nitrogen input to soils that is lost through leaching and run-off	0.07	Use model for leaching estimates under range of crop management conditions. For well managed crops current value is appropriate	0.07	See section 7
$Frac_{NCRBF}$	Nitrogen concentration in N-fixing crops	0.03	Use modified IPCC 2006 calculation. Use NZ values for individual crops in Table 12	-	Value is too high for residues. See section 6.
$Frac_{NCR0}$	Nitrogen concentration in non-N-fixing crops	0.015	Use modified IPCC 2006 calculation. Use NZ values for individual crops in Table 12	-	Value is too high for residues. See section 6.
$Frac_{R}$	Crop residue removed from the field as crop	0.45	Use harvest Index values in Table 11	-	See section 6.

C. Emission factor for agricultural emissions of nitrous oxide from crops

Emission factor	Emission factor for ...	Current value	Recommendations	Recommended values	Comments
EF^{1}	Direct emissions from N input to soil	0.01	Accept current value		Lack of NZ data

D. Savanna burning			Recommendations	Recommended values	Comments
Factor	Description	Current value			
savdensity		28	More information is required on the amount and type of tussock vegetation burned. Accept this value in meantime.		Large range in tussock biomass reported depending on tussock grassland composition. See Section 8 From (Payton & Pearce 2001)
fracburned		0.32			From Payton & Pearce (2001)
Ch4ratio	CH_4 emission ratio	0.004			IPCC 1996 default value
coratio	CO emission ratio	0.06			IPCC 1996 default value
n2oratio	N_2O emission ratio	0.007			IPCC 1996 default value
noxratio	NO_x emission ratio	0.121			IPCC 1996 default value
ncratio	N/C ratio	0.006			IPCC 1996 default value
FracLive	fraction of live material	0.36	More information is required. Accept this value in meantime.		From Payton & Pearce (2001)
FracDead	fraction of dead material	0.64	More information is required. Accept this value in meantime.		From Payton & Pearce (2001)
FracLiveOxid	fraction live material oxidised	0.8			IPCC 1996 default value
FracDeadOxid	fraction dead material oxidised	1			IPCC 1996 default value
Clive	C content of live biomass (living)	0.45			IPCC 1996 default value
Cdead	C content dead biomass	0.4			IPCC 1996 default value

E.Field burning

Factor	Description	Current value	Recommendations	Recommended values	Comments
Barley					
rcrbarley	Residue to crop ratio	1.2	Use modified IPCC 2006 method for calculation residues.	N/A	Use NZ Harvest Index values in Table 12
dmfbarley	Dry matter fraction	0.83	Use new value.	0.86	NZ standard dry matter conversion factor for grains
fbfbarley	Fraction burned in fields	0.3	Use new values for each crop/region	Canterbury 0.35 Southland 0.21	
fracoxidbarley	Fraction oxidised	0.9	Use IPCC 1996 default		

cfrbarley	Carbon fraction of residue	0.4567	Use IPCC 1996 default		
nitratiobarley	Nitrogen-ratio	0.015	Use IPCC 2006 value	0.007	IPCC 2006 value appropriate
Wheat					
rcrwheat	Residue to crop ratio	1.3	Use modified IPCC 2006 method for calculation residues	N/A	Use NZ Harvest Index values in Table 12
dmfwheat	Dry matter fraction	0.83	Use new value	0.86	NZ standard dry matter conversion factor for grains
fbfwheat	Fraction burned in fields	0.3	Use new values for each crop/region	Canterbury 0.49 Southland 0.42	See Table 14
fracoxidwheat	Fraction oxidised	0.9	Use IPCC 1996 default		
cfrwheat	Carbon fraction of residue	0.4853	Use IPCC 1996 default		
nitratiowheat	Nitrogen-ratio	0.012	Use IPCC 2006 value	0.006	IPCC 2006 value appropriate
Oats					
rcroats	Residue to crop ratio	1.3	Use modified IPCC 2006 method for calculation residues	N/A	Use NZ Harvest Index values in Table 12
dmfoats	Dry matter fraction	0.92	Use new value	0.86	NZ standard dry matter conversion factor for grains
fbfoats	Fraction burned in fields	0.3	Use new values for each crop/region	Canterbury 0.49 Southland 0.42	See Table 14
fracoxidoats	Fraction oxidised	0.9	Use IPCC 1996 default		
cfroats	Carbon fraction of residue	0.4567	Use IPCC 1996 default		
nitratiooats	Nitrogen-ratio	0.015	Use IPCC 2006 value	0.007	IPCC 2006 value appropriate
Emissions ratio to C or N					
ERCH4	CH_4	0.005	Use IPCC 1996 default		
ERCO	CO	0.06	Use IPCC 1996 default		
ERN2O	N_2O	0.007	Use IPCC 1996 default		
ERNOX	NO_x	0.121	Use IPCC 1996 default		

10 Acknowledgements

Sonia Petrie (MfE) for providing latest versions of NZ National Inventory spreadsheet and for information about inventory calculations; Nick Pyke (FAR) for providing arable activity data; Ian Payton (Landcare) and Grant Pearce (Scion) for information about tussock burning and Geoff Hicks (DOC) for allowing access to an unpublished tussock burning report. Fiona Willox and Lucy Bowker (Environment Canterbury) and Gary Morgan (Environment Southland) for information about regional Council burning consents; David Rose, Statistics NZ; and Glyn Francis (AgResearch), Bruce McKenzie and Derrick Moot (Lincoln University), Andrew Fletcher, Dick Martin, John McCallum and John de Ruiter (Crop & Food Research) and Peter Clifford for crop production and stubble burning advice.

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Appendix 1 Average yields and harvest index of current key crops grown in New Zealand

Key crops	Yields (t/ha)	Reference	Harvest Index	*Reference*
Barley			0.46-0.48	(Gallagher et al. 1983); NZ
			0.565	(Bolinder et al. 1997); Canada – Ottawa
			0.53	FAR Cereals Update No 113
	6.8-10.2	AgNZ/ Stats NZ/ FAR info		
			0.53	(Bolinder et al. 2007); Canada
Wheat			0.37	(Bolinder et al. 1997); Canada – Quebec
			0.49	(Bolinder et al. 1997); Canada – Ottawa
(Sapphire wheat)	5.6	FAR Cereals Update No 113	0.54-0.60	FAR Cereals Update No 113
(Milling wheat)	7.4-10.6	AgNZ/ Stats NZ/ FAR info		
(Feed wheat - spring)	7.4-8.0	AgNZ/ Stats NZ/ FAR info		
(Feed wheat - autumn)	8.4-11.8	AgNZ/ Stats NZ/ FAR info		
			0.40	(Bolinder et al. 2007); Canada
Maize (grain)	11.5	AgNZ/ Stats NZ/ FAR info	0.5	(Underwood 1985); NZ Also (Pearson & Glassey 2008); NZ
Maize (silage)	16-20	AgNZ/ Stats NZ/ FAR info	0.48-0.52 but 0.95 is harvested	Dr A. Fletcher, pers comm; NZ
Oats			0.408	(Bolinder et al. 1997); Canada – Ottawa
			0.43-0.47	FAR Cereals Update No 113
	4.5-6.5	AgNZ/ Stats NZ/ FAR info		
			0.53	(Bolinder et al. 2007)
Peas			0.50 avg (variable)	(Wilson et al. 1989); NZ
			0.49-0.63	(Martin & Jamieson 1996); NZ
	6.0-7.6	AgNZ/ Stats NZ/ FAR info		
Lentils	2.0	Statistics NZ; (McKenzie 1989)	0.40	(McKenzie et al. 1989):NZ
Potatoes	40-50 46	AgNZ/ Stats NZ/ FAR info Fresh Facts 2007	*About 90% of plant dry matter is harvested as tubers; negligible roots = 15% residue.	Dr RJ Martin, pers comm.; NZ
Clover seed	0.6	Crop & Food Research, unpublished	0.08	Dr RJ Martin, pers comm.; NZ
Lucerne	15-20	(Brown & Moot 2004)	Not available	
Grass seed	1.8-2.5	AgNZ/ Stats NZ/ FAR info	0.17	Dr RJ Martin, pers comm.; NZ
Forage brassicas	Up to 20	(de Ruiter et al. 2008)	*About 85% of above-ground plant dry matter is harvested	Dr J de Ruiter, pers comm.; NZ

Appendix 2 Concentration of nitrogen [N] in the plant residue (NZ references only)

Key crops	Amount of N in residue (%)	Country	Reference (for N content)
Barley	0.46	NZ	(Fraser & Francis 1996)
	1.5	NZ	(Kumar & Goh 2003)
Wheat	0.69	NZ	(Fraser & Francis 1996)
	0.60	NZ	(Kumar & Goh 2003)
Maize	0.8 (grain)	NZ	(Pearson & Glassey 2008)
	1.1 (silage)	NZ	(Pearson & Glassey 2008)
	0.94 (silage)	NZ	Fraser & Curtin, unpublished
Oats	0.59	NZ	(Fraser & Francis 1996)
	1.7	NZ	(Kumar & Goh 2003)
Peas	0.65-0.88	NZ	Francis, unpublished
	1.5	NZ	(Kumar & Goh 2003)
	<1.0 avg estimate	NZ	Bruce McKenzie, pers. comm.
Lentils	0.85-1.5	NZ	(Ayaz et al. 2004)
Potatoes	NQ	-	-
Clover seed	2.2	NZ	(Kumar & Goh 2003)
Lucerne	1.92	-	(Brown & Moot 2004)
Grass seed	0.7	NZ	(Kumar & Goh 2003)
Forage brassicas	2.5-3.5	NZ	(de Ruiter et al. 2008)
Kale	Leaf: 2.5-3.5		
	Stem:1.5-2.0		(de Ruiter et al. 2008)
Swedes	Leaf: 2.5-3.5		
	Bulb:1.5-2.5		(de Ruiter et al. 2008)
Turnips	Leaf: 2.5-3.5		
	Bulb:1.5-2.5		(de Ruiter et al. 2008)
Rape	Leaf: 3.0		
Leafy turnip	Leaf: 2.5		(de Ruiter et al. 2008)

Note: Expert opinion (by Dr J de Ruiter) estimates that Forage brassicas (currently estimated to be grown on 300 000 ha in NZ) can be divided into 5 main categories and their respective proportions grown (by area across New Zealand) are approximately:

Kale	55%
Swedes	15%
Turnips	15%
Rape	10%
Leafy turnip	5%

Biofuel = proportion of brassica seed used in future may rise. Current areas unknown. Kale varieties vary markedly – giant crops and short crops – utilisation varies.

Appendix 3 N concentration in various plant components and nitrous oxide emissions (*where quantified*)

Key crops	N concentration (gN/kg)			Reference/ Country	Total N_2O-**N** emitted (kg ha^{-1})
	Product/ grain	Above-ground residue	Roots/ below-ground		
Barley	26	6	10	(Janzen et al. 2003); Canada	
	15			(Kelstrup et al. 1996); NZ	
		4.6		(Fraser & Francis 1996); NZ	
		15		(Wagner-Riddle & Thurtell 1998; Kumar & Goh 2003)	
	16.9	4.30		(Beare et al. 2002); AI Irr	
	14.5	3.42		(Beare et al. 2002); SI Irr	
	22.9	7.30		(Beare et al. 2002); AI NIrr	
	21.3	6.03		(Beare et al. 2002); SI NIrr	
		6.80		(Curtin et al. 2008): NZ	
		5-15		Crop & Food Research, MTT trial - unpublished	
				(Harrison et al. 2002)	0.251-0.673
Wheat	19	7	10	(Janzen et al. 2003); Canada	
		6.9		(Fraser & Francis 1996);NZ	
		4.8		(Aulakh & Doran 2002); USA	2.0
		6		(Baggs et al. 2003); UK	0.367-3.456
		6		(Kumar & Goh 2003)	
		2.1		(Andersson et al. 2005); cv Sport (in soln)	
		2.2	5.5	(Andersson et al. 2005); cv WL (in soln)	
			4.9	(Wagner-Riddle & Thurtell 1998)	
	32-36			(Lenssen et al. 2007); USA	1.16
		5.0		(Curtin et al. 2008); NZ	
		3.4 – 11.2		Curtin, 5 sites, unpublished	
				(Vinther et al. 2002)	2.6
Maize (grain)	15	5	7	(Janzen et al. 2003); Canada	
		8		(Pearson & Glassey 2008), April 2008; NZ	
	15.7			(Khalil et al. 2002); Tropics	0.314
				(Wagner-Riddle & Thurtell 1998)	0.52-1.67
		6.7		(Curtin et al. 2001); NZ	
Maize (silage)		11		(Pearson & Glassey 2008); NZ	
		9.4		Fraser & Curtin, 2003, unpublished; NZ.	
Oats	18	6	10	(Janzen et al. 2003); Canada	
				(Baggs et al. 2000); UK	0.100
		5.9		(Fraser & Francis 1996); NZ	

Appendix 3 (continued) N concentration in various plant components and nitrous oxide emissions (*where quantified*)

Key crops	N concentration (gN/kg)			Reference/ Country	Total N_2O-**N** emitted ($kg\ ha^{-1}$)
	Product/ grain	Above-ground residue	Roots/ below-ground		
Peas	40			(Kelstrup et al. 1996); NZ	
		15		(Harrison et al. 2002); UK	0.365- 0.839
	29			(Ayaz et al. 2004); NZ (1998/99 expt)	
	31.7			(Ayaz et al. 2004); NZ (1999/2000 expt)	
	49.3			(Lenssen et al. 2007); USA	
Lentils	44	10	10	(Janzen et al. 2003); Canada	
	39			(Kelstrup et al. 1996); NZ	
	30.4	8.5	-	(Ayaz et al. 2004) NZ (1998/99 expt)	
	34.5	14.3		(Ayaz et al. 2004) NZ (1999/2000 expt)	
	50.5			(Lenssen et al. 2007); USA	
Potatoes	15	20	10	(Janzen et al. 2003); Canada	
Clover				(Baggs et al. 2000); UK	0.05
		22		(Kumar & Goh 2003); NZ	
			20.7	(Strachan 1994); NZ	
Lucerne				(Wagner-Riddle & Thurtell 1998)	3.79
		43.3		(Lenssen et al. 2007)	13.0
Grass seed	30	15	13	(Janzen et al. 2003); Canada	
Forage brassicas	40	8	10	(Janzen et al. 2003); Canada	
				(Baggs et al. 2000); UK	0.182 (forage peas)

Appendix 4 Percentage of residue remaining after harvest that is returned to the soil

Key crops	Estimated Average Percentage of the Above-ground Residues Returned to Soil when…			
	Residues incorporated	**Residues baled and removed**	**Residues burned**	**Residues Grazed**
Barley	100	20	30	n/a
Wheat	100	20	30	n/a
Maize (grain)	100	n/a	n/a	n/a
Maize (silage)	5	n/a	n/a	n/a
Oats	100	20	30	n/a
Peas	100	10	n/a	n/a
Lentils	100	n/a	n/a	n/a
Potatoes	10	n/a	n/a	n/a
Clover seed	100	n/a	n/a	10
Lucerne	100	10	n/a	n/a
Grass seed	100	10	n/a	20
Forage brassicas	15	n/a	n/a	n/a

n/a = Not applicable (as not usual management practice for the given crop).

Appendix 5 Relative dry matter allocation in above and below-ground plant components

Key crops	Relative DM allocation			Reference/ Country
	Product/ grain	Above-ground residue	Roots/ below-ground	
Barley	0.38 0.37	0.47 0.29	0.15 0.34	(Janzen et al. 2003); Canada (Bolinder et al. 1997); Canada
Wheat	0.34 0.23 0.40 0.32	0.51 0.66 0.41 0.55	0.15 0.11 0.19 0.13	(Janzen et al. 2003); Canada Francis, unpub 3; NZ (Bolinder et al. 1997); Canada – Ottawa (Bolinder et al. 1997); Canada – Quebec
Maize (grain)	0.47	0.38	0.15	(Janzen et al. 2003); Canada
Maize (silage)	0.72	0.08	0.20	(Janzen et al. 2003); Canada
Oats	0.33 0.29	0.47 0.43	0.20 0.29	(Janzen et al. 2003); Canada (Bolinder et al. 1997); Canada
Peas	0.29 0.40	0.51 0.52	0.20 0.08	(Janzen et al. 2003); Canada Francis, unpub 2; NZ
Lentils	0.28	0.52	0.20	(Janzen et al. 2003); Canada
Potatoes	0.68	0.23	0.10	(Janzen et al. 2003); Canada
Clover seed	-	-	-	
Lucerne	-	-	-	
Grass seed	0.12 (forage for seed)	0.48	0.4	(Janzen et al. 2003); Canada
Forage brassicas	0.26 (mustard seed)	0.6	0.15	(Janzen et al. 2003); Canada

Appendix 6 Shoot:root ratio for the main range of crops grown in New Zealand

Key crops	Shoot:Root Ratio	Reference
Barley	11.5	Francis, unpub 4; NZ
	13.9	Francis, unpub 5; NZ
	10-12.5	(Kwabiah et al. 2005); Canada – Newfoundland
	1.7-2.3	(Bolinder et al. 1997)(0-30cm); Canada – Ottawa
	3.8	(Paustian et al. 1990); Sweden – unfert'd
	5.9	(Paustian et al. 1990); Sweden – fert'd
	7.0	(Welbank et al. 1974)– unfert'd
	11.0	(Welbank et al. 1974)– fert'd
	9.4-12.5	(Xu & Juma 1992); Western Canada
	4.8-8.1	(Rutherford & Juma 1989); Canada
Wheat	6.8	Francis, unpub 1; NZ
	9	Francis, unpub 4; NZ
	10	Francis, unpub 5; NZ
	4.9	(Bolinder et al. 1997)(0-30cm); Canada – Ottawa
	7.0	(Bolinder et al. 1997)(0-30cm); Canada – Quebec
	1.6	(Buyanovsky & Wagner 1987); USA
	6.8-10.8	(Welbank et al. 1974); Gregory et al 1978; UK
(Spring)	4.5-7.1	(Campbell & de Jong 2001); Canada – Saskatchewan
Maize (grain)	-	-
Maize (silage)	-	-
Oats	8.1-8.8	(Kwabiah et al. 2005); Canada
	2.4-2.7	(Bolinder et al. 1997)(0-30cm); Canada – Ottawa
	4.4	(Welbank et al. 1974)– unfert'd; UK
	7.7	(Welbank et al. 1974)– fert'd; UK
Peas	-	-
Lentils	-	-
Potatoes	-	-
Clover seed	-	-
Lucerne	1.4	(Bolinder et al. 2002); Canada
Grass seed	0.4-1.5	(Bolinder et al. 2002); Canada
Forage brassicas	Not available	

A literature review by Bolinder (2007) put forward the following averages for Canadian crops:
Mean S:R ratios for annual crops were highest for small grain cereals (7.4) followed by corn (5.6) and soybeans (5.2) and lowest for forages (1.6). Legumes were about 2.2 and grass species 1.3 on average.

Appendix 7 Summary of factors used to estimate N inputs from crop residues for the IPCC 1996 methodology and IPCC 2006 methodology

	Chapter 4: IPCC 1996, 2000			Chapter 11: IPCC 2006			
Key crop	Residue/ Crop Product Ratio (IPCC Chpt 4)	Dry matter fraction (Chpt 4)	Nitrogen fraction	Dry matter fraction of harvested product*	N content of above-ground residues (N_{AG})*	Ratio of below-ground residues to above-ground biomass* (R_{BG-BIO})	N content of below-ground residues* (N_{BG})
Barley	1.2	0.82-0.88	0.0043	0.89	0.007	0.22(+/-33%)	0.014
Wheat	1.3	0.82-0.88	0.0028	0.89	0.006	0.24(+/-32%)	0.009
Maize (grain)	1.0	0.70-0.86	0.0081	0.87	0.006	0.22(+/-26%)	0.007
Maize (silage)	-	-	-	-	-	-	-
Oats	1.3	0.92	0.0070	0.89	0.007	0.25(+/- 20%)	0.008
Peas	1.5	0.87	0.0142	-	-	-	-
Lentils	-	-	-	-	;	-	-
Potatoes	0.4	-	0.0110	0.22	0.019	0.2(+/-50%)	0.014
Clover	-	-	-	-	-	-	-
Lucerne	-	-	-	0.90	0.027	0.40(+/-50%)	0.019
Grass seed	-	-	-	-	-	-	-
Forage brassicas	-	-	-	-	-	-	-

Appendix 8 Calculation for estimating crop residue N and N_2O emissions using recommended method

	Wheat	Barley	Oats	Other cereal grains	Maize grain	Field / seed peas	Other pulses	Peas (fresh & process)	Potatoes	Onions	Total
Step 1. Calculate annual crop production dry matter data (Crop):											
Average yield t/ha FW								**7**	**45**	**40**	
Total product/grain harvested (tonnes) = area (ha) * average yield (t/ha)	344434	335627	27531	13709	185627	22053	847	47537	452250	183760	
fraction dry weight (DRY)	**0.86**	**0.86**	**0.86**	**0.86**	**0.86**	**0.86**	**0.86**	**0.21**	**0.2**	**0.12**	
Total production DW (tonnes)	303102	288639	23677	11790	159639	18966	728	9983	90450	22051	
Step 2. Calculate above ground residues (AGDM) using harvest index.											
Harvest Index	**0.5**	**0.5**	**0.45**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.85**	**0.9**	
Above ground residue dry matter [AG_{DM}, tonnes] = (CropT/HI)-CropT											
AG_{DM} tonnes (North Island)	10646	27,808	601	225	154,499	2,643	0	2,033	8,697	2,069	
AG_{DM} tonnes (South Island)	292456	260,831	28,337	11,564	5,140	16,322	727	7,950	7,265	381	
Step 3. Account for residue burning											
Fraction of areas burned (FracBurnt)											
Canterbury & Otago	**0.7**	**0.5**									
Southland	**0.7**	**0.3**									
Straw burned (tonnes): AGDM = (CropT/HI)-CropT* FracBurnt											
Canterbury & Otago (tonnes)	195945	120237									
Southland	0	5486									
Combustion factor	**0.7**	**0.7**									
Total straw burned	137161	88006									
AG_{DM} tonnes (Total NZ, adj for burning) (AGDM-Straw burned)	126752	200633	28938	11790	159639	18965	727	9983	15962	2450	
Step 4. Account for residue removed for feed and bedding.											
FracRemove	0	0	0	0	0	0	0	0	0	0	
Step 5. Calculate the amount of above ground N residue											
N_{AG}	**0.006**	**0.007**	**0.007**	**0.007**	**0.006**	**0.008**	**0.008**	**0.008**	**0.009**	**0.01**	
Step 6. Calculate the amount of below ground N residue											
R_{BG}	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0**	**0**	
BG_{DM} tonnes = (AGDM + total Yield) * RatioBG	60620	57728	6431	2358	31928	3793	145	1997	0	0	
N_{BG}	**0.009**	**0.014**	**0.008**	**0.008**	**0.007**	**0.014**	**0.014**	**0.014**	**0.009**	**0.01**	
Step 7. Calculation of N_2O emission											
Residue N tonnes	1306	2213	254	101	1181	205	8	108	144	25	
Emission Factor (EF_1)	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	
N_2O Emission Gg N	0.013	0.022	0.003	0.001	0.012	0.002	0.000	0.001	0.001	0.000	0.055

Notes: Above-ground residue dry matter was estimated from 2007 crop production statistics.

Appendix 9 Description of key weather, soil and management practices assumed for estimations of N leaching

Canterbury				
Weather station	Lincoln			
Irrigation	Deficit irrigation (40 mm applied at a trigger deficit of 60 mm)			
Soil type	Name	Physical description	Organic Nitrogen (t/ha)	Database number
Light	Lismore	Shallow silt loam with stones at 25 cm depth	5	
Medium	Templeton	Silt loam with stones at 80 cm depth	8.3	
Heavy	Temuka	Clay loam	8.2	SB10110
Initial conditions	Cultivated from pasture, 90 kg mineral N/ha in soil			
Crops	Sowing date	kg/ha N applied (date applied)	Finish date*	Following crop
Wheat	20-Apr	60(8-Oct), 60(23-Oct), 60(20-Nov)	Jan-Feb	Fallow
Barley	20-Sep	60(8-Oct), 60(23-Oct)	Feb	Autumn wheat
Potato	15-Oct	100(15-Oct), 80(15-Dec), 80(15-Jan), 80(15-Feb)	Mar	Autumn wheat
Sweat corn	15-Oct	50(15-Oct), 50(8-Dec)	Mar	Autumn wheat
Onion	15-Oct	50(15-Dec), 50(15-Jan), 50(15-Feb)	Mar	Autumn wheat
Ryegrass	15-Mar	60(5-Sep), 60(20-Sep)	Jan	Fallow
Clover	20-Mar	Nil	Jan	Pasture

Hawke's Bay				
Weather station	Hastings			
Irrigation	Deficit irrigation (40 mm applied at a trigger deficit of 60 mm)			
Soil type	Name	Physical description	Organic Nitrogen (t/ha)	Database number
Light	Takapau	Sandy loam	12.5	SB09819
Medium	Tyford	Silt loam	7.6	SB09760
Heavy	Hastings	Silt clay loam	6	SB09788
Initial conditions	Cultivated from pasture, 90 kg mineral N/ha in soil			
Crops	Sowing date	kg/ha N applied (date applied)	Finish date*	Following crop
Wheat	20-Apr	60(8-Oct), 60(23-Oct), 60(20-Nov)	Jan-Feb	Fallow
Sqush	26-Oct	50(26-Oct), 100(15-Dec)	Apr	Autumn wheat
Potato	25-Oct	80(15-Oct), 50(15-Dec), 50(15-Feb)	Mar	Autumn wheat
Sweat corn	15-Oct	50(15-Oct), 50(8-Dec)	Apr	Autumn wheat
Onion	15-Jul	45(15-Oct), 45(15-Nov), 45(15-Dec)	Feb	Autumn wheat
Barley	20-Sep	60(8-Oct), 80(23-Oct)	Feb	Autumn wheat

Maize	15-Oct	100(15-Oct), 80(8-Dec)	May	Autumn wheat

Southland

Weather station	Gore			
Irrigation	Nil			
Soil type	Name	Physical description	Organic Nitrogen	Database number
Light	Dryden	Shallow sandy loam	7.6	SB09722
Medium	Invermay	Silty clay loam	10.7	SB09727
Heavy	Owaka	Silt loam	8.1	SB10163
Initial conditions	Cultivated from pasture, 90 kg mineral N/ha in soil			
Crops	Sowing date	kg/ha N applied (date applied)	Finish date*	Following crop
Wheat	20-Apr	60(8-Oct), 60(23-Oct), 60(20-Nov)	Jan-Feb	Fallow
Barley	20-Sep	60(8-Oct), 80(23-Oct)	Feb	Autumn wheat

Gisborne

Weather station	Gisborne			
Irrigation	Nil			
Soil type	Name	Physical description	Organic Nitrogen	Database number
Light	Kopuawhara	Sandy loam	12	SB10147
Medium	Taiteatea loam	Loamy sand	8	SB10179
Heavy	Ormond hill	Clay loam	6.8	SB10152
Initial conditions	Cultivated from pasture, 90 kg mineral N/ha in soil			
Crops	Sowing date	kg/ha N applied (date applied)	Finish date*	Following crop
Maize	15-Oct	100(15-Oct), 80(8-Dec)	May	Autumn wheat
Sweat corn	15-Oct	50(15-Oct), 50(8-Dec)	Apr	Autumn wheat
Squash	11-Oct	50(26-Oct), 100(15-Dec)	Apr	Autumn wheat

Bay of Plenty

Weather station	Te Puke			
Irrigation	Nil			
Soil type	Name	Physical description	Organic Nitrogen	Database number
Light	Papamoa	Loamy sand	4.3	SB09796
Medium	Opotiki	Sandy loam	9.1	SB09860
Heavy	Paerata	Silt loam	8.8	SB09849

Initial conditions	Cultivated from pasture, 90 kg mineral N/ha in soil			
Crops	Sowing date	kg/ha N applied (date applied)	Finish date*	Following crop
Maize	15-Oct	60(15-Oct), 80(8-Dec)	Apr	Autumn wheat

Northland

Weather station	Kaikohe			
Irrigation	Nil			
Soil type	Name	Physical description	Organic Nitrogen	Database number
Light	Te Kopuru	Sand	4.3	SB09534
Medium	Kerikeri	Silt loam	7.2	SB10056
Heavy	Otaha	Silty clay loam	7.9	SB10059
Maize	15-Oct	60(15-Oct), 80(8-Dec)	Apr	Annual ryegrass
Potato	25-Oct	80(15-Oct), 50(15-Dec), 50(15-Feb)	Mar	Autumn wheat
Onion	15-Jul	45(15-Oct), 45(15-Nov), 45(15-Dec)	Feb	Autumn wheat

Waikato

Weather station	Ruakura			
Irrigation	Nil			
Soil type	Name	Physical description	Organic Nitrogen	Database number
Light	Waihou	Gritty silt loam	6	SB10113
Medium	Horotiu	Silt loam	8	SB09944
Heavy	Patumahoe	Clay loam	7	SB09804
Initial conditions	Cultivated from pasture, 90 kg mineral N/ha in soil			
Crops	Sowing date	kg/ha N applied (date applied)	Finish date*	Following crop
Potato	25-Oct	80(15-Oct), 50(15-Dec), 50(15-Feb)	Mar	Autumn wheat
Onion	15-Jul	45(15-Oct), 45(15-Nov), 45(15-Dec)	Feb	Autumn wheat
Maize	15-Oct	60(15-Oct), 80(8-Dec)	Apr	Autumn wheat