# Appendix 5
# Agriculture

## CONTENTS

# 1 Livestock

The NAEI estimates emissions of methane from farm animals resulting from enteric fermentation and the storage and spreading of animal manures and slurries. The methane emission estimates were supplied by MAFF (2000a).

## 1.1 ENTERIC EMISSIONS OF METHANE

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms. Emissions are calculated from animal population data collected in the June Agricultural Census and published in MAFF (2000b) and the appropriate emission factors. Data for earlier years are often revised so information was taken from the MAFF database. Table 1 shows the emission factors used. Apart from cattle, lambs and deer, the methane emission factors are IPCC Tier I defaults (IPCC, 1997) and do not change from year to year. The dairy cattle emission factors are estimated following the IPCC Tier 2 procedure (IPCC, 1997) and vary from year to year. For dairy cattle, the calculations are based on the population of the 'dairy breeding herd' rather than 'dairy cattle in milk' used in earlier inventories because the latter definition includes 'cows in calf but not in milk'. The emission factors for beef and other cattle were also calculated using the IPCC Tier 2 procedure (Table 3), but do not vary from year to year. The enteric emission factors for beef cattle were almost identical to the IPCC Tier I defaults so the default was used in the estimates. The base data and emission factors for 1990-1999 are given in Tables 2 and 3. The emission factor for lambs is assumed to be 40% of that for adult sheep. In using the animal population data it is assumed that the reported number of animals are alive for that whole year. The exception is the treatment of sheep where it is normal practice to slaughter lambs and other non-breeding sheep after 6 to 9 months. Hence it is assumed that breeding sheep are alive the whole year but that lambs and other non-breeding sheep are only alive 6 months of a given year. The sheep emission factors in Table 1 are reported on the basis that the animals are alive the whole year.

Table 1 Methane Emission Factors for Livestock Emissions.

| | Enteric Methane[a] kg $CH_4$/head/year | Methane from Wastes[a] kg $CH_4$/head/year |
|---|---|---|
| Dairy Breeding Herd | 115[b] | 13.0[b] |
| Beef Herd | 48 | 2.74 |
| Others>1, Dairy Heiffers | 48 | 6 |
| Others<1 | 32.8 | 2.96 |
| Pigs | 1.5 | 3 |
| Breeding Sheep | 8 | 0.19 |
| Other Sheep | 8[e] | 0.19[e] |
| Lambs < 1year | 3.2[ce] | 0.076[ce] |
| Goats | 5 | 0.12 |
| Horses | 18 | 1.4 |
| Deer (stags & hinds) | 10.4[c] | 0.26[c] |
| Deer (calves) | 5.2[c] | 0.13[c] |
| Poultry[d] | 0 | 0.078 |

a IPCC(1997)
b Emission Factor for year 1999
c Sneath *et al* (1997)
d Chickens, turkeys, geese, ducks and guinea fowl.
e Factor quoted assumes animal lives for a year. Emission calculation assumes animal lives for 6 months.

Table 2 Dairy Cattle Methane Emission Factors[1]

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Average Weight of cow (kg)[2] | 550 | 556 | 561 | 567 | 572 | 578 | 584 | 590 | 596 | 602 |
| Average Rate of Milk Production (liter/d) | 14.3 | 14.2 | 14.5 | 14.7 | 14.7 | 15.0 | 15.1 | 15.9 | 16.1 | 16.4 |
| Average Fat Content (%) | 4.01 | 4.04 | 4.06 | 4.07 | 4.05 | 4.05 | 4.08 | 4.07 | 4.07 | 4.03 |
| Enteric Emission Factor (kg $CH_4$/head/y) | 104 | 104 | 106 | 107 | 107 | 109 | 110 | 113 | 114 | 115 |
| Manure Emission Factor (kg $CH_4$/head/y) | 11.7 | 11.7 | 12.0 | 12.1 | 12.1 | 12.3 | 12.4 | 12.7 | 12.9 | 13.0 |

1 43% of animals graze on good quality pasture, rest confined
Gestation period 281 days
Digestible Energy 65%
Methane conversion rate 6%
Ash content of manure 8%
Methane Producing Capacity of Manure 0.24 $m^3$/kg VS

2 Weight assuming annual growth of 1% from 1990.

Table 3 Beef and Other Cattle Methane Emission Factors[1]

| | Beef Cattle | Other Cattle |
|---|---|---|
| Average Weight of Animal (kg) | 500 | 180 |
| Time Spent Grazing | 50% | 46% |
| GE (MJ/d) | 123.3 | 83.4 |
| Enteric Emission Factor (kg $CH_4$/head/y) | 48.5[2] | 32.8 |
| Manure Emission Factor (kg $CH_4$/head/y) | 2.74 | 2.96 |

1 Digestible Energy 65%
Ash content of manure 8%
Methane producing capacity of manure 0.24 $m^3$/kg VS

2 IPCC (1997) default (48 kg/head/y) used since calculated factor is very close to default and the difference under the Tier II method will not affect the accuracy of the emission factor at the required level of precision

## 1.2 METHANE EMISSIONS FROM ANIMAL WASTES.

Methane is produced from the decomposition of manure under anaerobic conditions. When manure is stored or treated as a liquid in a lagoon, pond or tank it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced. Hence the system of manure management used affects emission rates. Emissions of methane from animal wastes are calculated from animal population data (MAFF, 2000b) in the same way as the enteric emissions. The emission factors are listed in Table 1. Apart from cattle, lambs and deer, these are all IPCC Tier I defaults (IPCC, 1997) and do not change from year to year. The emission factors for lambs are assumed to be 40% of that for adult sheep. Emission factors for dairy cattle were calculated from the IPCC Tier 2 procedure using data shown in Tables 2 and 4 (MAFF, 2000a). For dairy cattle, the calculations are based on the population of the ‘dairy breeding herd’ rather than ‘dairy cattle in milk’ used in earlier inventories as the latter definition includes ‘cows in calf but not in milk’. The waste factors used for beef and other cattle are now calculated from the IPCC Tier 2 procedure but do not vary from year to year. Emission factors and base data for beef and other cattle are given in Table 3.

Table 4 Cattle Manure Management Systems in the UK

| Manure Handling System | Methane Conversion Factor %[a] | Fraction of manure handled using manure system % | Fraction of manure handled using manure system % |
|---|---|---|---|
| | | Dairy | Beef and Other |
| Pasture Range | 1 | 43 | 50 |
| Liquid System | 10 | 38 | 14 |
| Solid Storage | 1 | 10 | 27 |
| Daily Spread | 0.1 | 9 | 9 |

**a IPCC (1997)**

## 1.3 EMISSIONS OF NITROUS OXIDE FROM ANIMAL WASTE MANAGEMENT SYSTEMS

Animals are assumed not to give rise to nitrous oxide emissions directly, but emissions from their wastes during storage are calculated for a number of animal waste management systems

(AWMS) defined by IPCC. Emissions from the following AWMS are reported under the IPCC category, manure management.

Flushing Anaerobic Lagoons. These are assumed not to be in use in the UK.
Liquid systems
Solid storage and dry lot (including farm-yard manure)
Other systems ( including poultry litter, stables)

According to IPCC(1997) guidelines, the following AWMS are reported in the Agricultural Soils category

All applied animal manures and slurries
Pasture range and paddock

Emissions from the combustion of poultry litter for electricity generation are reported under power stations.

The IPCC (1997) method for calculating emissions of $N_2O$ from animal waste management systems can be expressed as:

$$N_2O_{(AWMS)} = 44/28 \cdot \sum N_{(T)} \cdot Nex_{(T)} \cdot AWMS_{(T)} \cdot EF_{(AWMS)}$$

where

$N_2O_{(AWMS)}$ = $N_2O$ emissions from animal waste management systems (kg $N_2O$/yr)
$N_{(T)}$ = Number of animals of type T
$Nex_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)
$AWMS_{(T)}$ = Fraction of Nex that is managed in one of the different waste management systems of type T
$EF_{(AWMS)}$ = $N_2O$ emission factor for an AWMS (kg $N_2O$-N/kg of Nex in AWMS)

The summation takes place over all animal types and the AWMS of interest. Animal population data is taken from MAFF Statistics (MAFF, 2000b). Table 5 shows emission factors for nitrogen excretion per head for domestic livestock in the UK (Nex). These are based on a balance by Smith (1998). The UK methodology assumes that 20% of the total N emitted by livestock volatilises as $NO_x$ and $NH_3$ and therefore does not contribute to $N_2O$ emissions from AWMS. This is because in the absence of a more detailed split of $NH_3$ losses at the different stages of the manure handling process it has been assumed that $NH_3$ loss occurs prior to major $N_2O$ losses. Hence the Nex factors used in the AWMS estimates and those reported in Tables 5 and 6 exclude the fraction of N volatilising. Hence they are 20% less than if they were reported on the same basis as the ‘total’ Nex factors reported in the IPCC Guidelines. The estimates of total N excreted reported in the Common Reporting Format are not corrected in this way and report total N excreted from livestock.

Nex factors for dairy cattle take account of the assumed growth in the average cow weight by 1% per annum and are shown in Table 6. The conversion of excreted N into $N_2O$ emissions is determined by the type of waste management system used. The distribution of waste management systems for each animal type ($AWMS_{(T)}$) is given in Table 7. Table 8 gives the $N_2O$ emission factor for each animal waste management system ($EF_{(AWMS)}$). These are expressed as the emission of $N_2O$-N per mass of excreted N processed by the waste management system.

Emissions from grazing animals (pasture range and paddock) and daily spread are calculated in the same way as the other AWMS. However, emissions from land spreading of waste that has previously been stored in liquid systems, other systems, solid storage and dry lot are treated differently. These are discussed in Section 2.6 on Organic Fertilizer.

Table 5 Nitrogen Excretion Factors for Animals in the UK[1]

| Animal Type | Emission Factor kg N/animal/yr[2] |
|---|---|
| Dairy cows | 93.8[3] |
| Other cattle > 2yr | 60 |
| Other cattle 1-2 yr | 47 |
| Other cattle >1 | 11.8 |
| Pigs < 20kg | 3 |
| Other Pigs 20-50 kg | 7.1 |
| Fattening & Other Pigs > 50 kg | 10.7 |
| Breeding pigs > 50 kg | 14.3 |
| Breeding Sheep | 9.2 |
| Other Sheep <1 | 9.2[5] |
| Lambs | 3.36[5] |
| Goats | 6.4 |
| Broilers | 0.495 |
| Broiler Breeders | 0.899 |
| Layers | 0.589 |
| Ducks, | 0.984 |
| Turkeys | 1.052 |
| Growing Pullets | 0.106 |
| Other Poultry | 0.49 |
| Horses | 32 |
| Deer: Stags[4] | 17.5 |
| Deer: Hinds[4] | 11.7 |
| Deer: Calves[4] | 8.64 |

1 Smith(1998)
2 Nex factors exclude 20% N volatilising as $NO_x$ and $NH_3$
3 Estimate for year 1999
4 Sneath *et al*, (1997)
5 Factor quoted assumes animal lives for a year. Emission calculation assumes animal lives for 6 months.

Table 6 Nitrogen Excretion Factors for Dairy Cattle[1]

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| Emission Factor kg N/animal/yr | 84.8 | 85.8 | 86.8 | 87.7 | 88.7 | 89.8 | 90.8 | 91.8 | 92.9 | 93.8 |

1 Nex factors exclude 20% N volatilising as $NO_x$ and $NH_3$

Table 7 Distribution of Animal Waste Management Systems used for Different Animal types[c]

| Animal Type | Liquid System | Daily Spread | Solid Storage and dry lot[a] | Pasture range and paddock | Other [b] | Fuel |
|---|---|---|---|---|---|---|
| Dairy cows | 38 | 9 | 10 | 43 | 0 | |
| Other cattle | 14 | 9 | 27 | 50 | 0 | |
| Fattening & Other Pigs > 50 kg, (1990-97)[e] | 59 | 14 | 27 | 0 | 0 | |
| Breeding sows (1990-97)[e] | 41 | 10 | 19 | 30 | 0 | |
| Weaner Pigs (1990-97)[e] | 53 | 13 | 24 | 10 | 0 | |
| Finishing Pigs (1990-97)[e] | 59 | 14 | 27 | 0 | 0 | |
| Sheep | 0 | 0 | 2 | 98 | 0 | |
| Goats | 0 | 0 | 0 | 96 | 4 | |
| Broilers, Pullets(1970-91)[f] | | | | 1 | 99 | 0 |
| Broilers, Pullets (1992-96)[f] | | | | 1 | 64 | 35 |
| Layers (1970-91)[f] | | | | 10 | 90 | 0 |
| Layers (1992-96)[f] | | | | 10 | 89 | 1 |
| Ducks, Geese & Guinea Fowl[f] | | | | 50 | 50 | 0 |
| Turkeys[f] | | | | 8 | 92 | 0 |
| Horses | | | | 96 | 4 | 0 |
| Deer: Stags[d] | | | | 100 | 0 | |
| Deer: Hinds & Calves[d] | | | | 75 | 25 | |

a Farmyard Manure
b Poultry Litter, Stables
c ADAS (1995a)
d Sneath *et al* (1997)
e Agricultural Economics Unit Exeter University (1996)
f Tucker (1997)

Table 8 Nitrous Oxide Emission Factors for Animal Waste Handling Systems[a]

| Waste Handling System | Emission Factor kg $N_2O$-N per kg N excreted |
|---|---|
| Liquid System | 0.001 |
| Daily Spread[b] | 0 |
| Solid Storage and Dry Lot | 0.02 |
| Pasture, Range and Paddock[b] | 0.02 |
| Fuel | - |
| Other | 0.005 |

a IPCC(1997)
b Reported under Agricultural Soils

# 2 Agricultural Soils

Direct emissions of nitrous oxide from agricultural soils are estimated using the IPCC recommended methodology (IPCC, 1997) but incorporating some UK specific parameters. The IPCC method involves estimating contributions from:

(i) The use of inorganic fertilizer
(ii) Biological fixation of nitrogen by crops
(iii) Ploughing in crop residues
(iv) Cultivation of histosols (organic soils)
(v) Spreading animal wastes on land
(vi) Manures dropped by animals grazing in the field

In addition to these, the following indirect emission sources are estimated:

(vii) Emission of $N_2O$ from atmospheric deposition of agricultural $NO_x$ and $NH_3$.
(viii) Emission of $N_2O$ from leaching of agricultural nitrate and runoff.

Descriptions of the methods used follow.

## 2.1 INORGANIC FERTILISER

Emissions from the application of inorganic fertilizer are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(SN)} = 44/28 \cdot N_{(FERT)} \cdot (1-Frac_{(GASF)}) \cdot EF_1$$

where

$N_2O_{(SN)}$ = Emission of $N_2O$ from synthetic fertiliser application (kg $N_2O$/yr)
$N_{(FERT)}$ = Total use of synthetic fertiliser (kg N/yr)
$Frac_{(GASF)}$ = Fraction of synthetic fertiliser emitted as $NO_x + NH_3$
= 0.1 kg $NH_3$-N+$NO_x$-N / kg synthetic N applied
$EF_1$ = Emission Factor for direct soil emissions
= 0.0125 kg $N_2O$-N/kg N input

Annual consumption of synthetic fertilizer is estimated based on crop areas (MAFF, 2000b) and fertilizer application rates (BSFP, 2000).

## 2.2 BIOLOGICAL FIXATION OF NITROGEN BY CROPS

Emissions of nitrous oxide from the biological fixation of nitrogen by crops are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(BF)} = 44/28 \cdot 2 \cdot Crop_{(BF)} \cdot Frac_{(NCRBF)} \cdot EF_1$$

where

$N_2O_{(BF)}$ = Emission of $N_2O$ from biological fixation (kg $N_2O$/yr)
$Crop_{(BF)}$ = Production of legumes (kg dry mass/year)
$Frac_{(NCRBF)}$ = Fraction of nitrogen in N fixing crop
= 0.03 kg N/ kg dry mass
$EF_1$ = Emission Factor for direct soil emissions
= 0.0125 kg $N_2O$-N/kg N input

The factor of 2 converts the edible portion of the crop reported in agricultural statistics to the total biomass. The fraction of dry mass for the crops considered is given in Table 9

Table 9 Dry Mass Content and Residue Fraction of UK Crops

| Crop Type | Fraction dry Mass[b] | Residue/ Crop |
|---|---|---|
| Broad Beans, Green Peas | 0.08 | 1.1 |
| Field Bean[d], Peas(harvest dry) | 0.86 | 1.1 |
| Rye, Mixed corn, triticale | 0.855[a] | 1.6 |
| Wheat, Oats | 0.855[a] | 1.3 |
| Barley | 0.855[a] | 1.2 |
| Oil Seed Rape, Linseed | 0.91[a] | 1.2 |
| Maize | 0.50 | 1 |
| Hops[c] | 0.20 | 1.2 |
| Potatoes | 0.20 | 0.4 |
| Roots, Onions | 0.07 | 1.2 |
| Brassicas | 0.06 | 1.2 |
| Sugar Beet | 0.1 | 0.2 |
| Other | 0.05 | 1.2 |
| Phaseolus beans | 0.08 | 1.2 |

a MAFF(2000b)
b Burton (1982), Nix (1997) or MAFF estimates
c Hops dry mass from Brewers Licensed Retail Association(1998)
d Field beans dry mass from PGRE (1998)

The data for residue/crop is taken from IPCC (1997) defaults in the Agricultural Soils section, or derived from Table 4.17 of the Field Burning of Agricultural Residues section. Crop production data is taken from MAFF (2000b,2000d). The total nitrous oxide emission reported also includes a contribution from improved grass calculated using a fixation rate of 4 kg N/ha/yr (Lord, 1997).

## 2.3 CROP RESIDUES

Emissions of nitrous oxide from the ploughing in of crop residues are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(CR)} = 44/28 . 2 .(Crop_O . Frac_{(NCRO)} .+ Crop_{(BF)} . Frac_{(NCRBF(}) (1-Frac_R) . (1-Frac_B) . EF_1$$

where

$N_2O_{(CR)}$ = Emission of $N_2O$ from crop residues (kg $N_2O$/yr)
$Crop_O$ = Production of non-N fixing crops (kg dm/yr)
$Frac_{(NCRO)}$ = Fraction of nitrogen in non-N fixing crops
= 0.015 kg N/ kg dm
$Frac_R$ = Fraction of crop that is remove from field as crop
$Frac_B$ = Fraction of crop residue that is burnt rather than left on field
$EF_1$ = Emission Factor for direct soil emissions
= 0.0125 kg $N_2O$-N/kg N input
$Crop_{(BF)}$ = Production of legumes (kg dry mass/year)
$Frac_{(NCRBF)}$ = Fraction of nitrogen in N fixing crop
= 0.03 kg N/ kg dry mass

Production data of crops is taken from MAFF(2000b, 2000d). The dry mass fraction of crops and fraction of crop removed from the field are given in Table 9. Field burning has largely ceased in the UK since 1993. For years prior to 1993, field burning data was taken from the annual MAFF Straw Disposal Survey. (MAFF, 1995)

## 2.4 HISTOSOLS

Emissions from histosols were estimated using the IPCC(1997) default factor of 5 kg $N_2O$-N/ha/yr. The area of cultivated histosols is assumed to be equal to that of eutric organic soils in the UK and is based on a FAO soil map figure supplied by SSLRC.

## 2.5 GRAZING ANIMALS

Emissions from manure deposited by grazing animals are classified under agricultural soils by IPCC. The method of estimation is the same as that for AWMS in Section 1.3 but applying factors for pasture range and paddock.

## 2.6 ORGANIC FERTILIZERS

Emissions from animal manures and slurries used as organic fertilizers are classified under agricultural soils by IPCC. The procedure involves estimating the amount of nitrogen applied to the land and applying IPCC emission factors. For daily spreading of waste, the emission is given by:

$$N_2O_{(DS)} = 44/28 \, . \, \sum N_T \, . \, Nex_{(T)} \, . \, AWMS_{(T)} \, . \, EF_1$$

where

$N_2O_{(DS)}$ = $N_2O$ emissions from daily spreading of wastes (kg $N_2O$/yr)
$N_T$ = Number of animals of type T
$Nex_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)
$AWMS_{(T)}$ = Fraction of Nex that is daily spread
$EF_1$ = Emission Factor for direct soil emissions
= 0.0125 kg $N_2O$-N/kg N input

For the application of previously stored wastes to land, a correction is applied to account for previous $N_2O$ losses during storage.

$$N_2O_{(FAW)} = 44/28 \,.\, \sum (N_T \,.\, Nex_{(T)} \,.\, AWMS_{(T)} - N_{(AWMS)}) \,.\, EF_1$$

where

$N_2O_{(FAW)}$ = $N_2O$ emission from organic fertiliser application
$N_{(AWMS)}$ = $N_2O$ emissions from animal waste management systems as nitrogen (kg $N_2O$-N/yr)
$N_T$ = Number of animals of type T
$Nex_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)
$AWMS_{(T)}$ = Fraction of Nex that is managed in one of the different waste management systems of type T

The summation is for all animal types and for liquid system, solid storage and other systems where wastes are stored.

## 2.7 ATMOSPHERIC DEPOSITION OF $NO_x$ AND $NH_3$

Indirect emissions of $N_2O$ from the atmospheric deposition of ammonia and $NO_x$ are estimated according to the IPCC (1997) methodology but with corrections to avoid double counting N. The sources of ammonia and $NO_x$ considered, are synthetic fertiliser application and animal wastes applied as fertiliser.

The contribution from synthetic fertilisers is given by:

$$N_2O_{(DSN)} = 44/28 \,.\, (N_{(FERT)} - N_{(SN)}) \,.\, Frac_{(GASF)} \,.\, EF_4$$

where

$N_2O_{(DSN)}$ = Atmospheric deposition emission of $N_2O$ arising from synthetic fertiliser application (kg $N_2O$)
$N_{(FERT)}$ = Total mass of nitrogen applied as synthetic fertiliser (kg N)
$N_{(SN)}$ = Direct emission of $N_2O_{(SN)}$ as nitrogen (kg $N_2O$-N)
$Frac_{(GASF)}$ = Fraction of total synthetic fertiliser nitrogen that is emitted as $NO_x$ + $NH_3$
= 0.1 kg N/ kg N
$EF_4$ = N deposition emission factor
= 0.01 kg $N_2O$-N/kg $NH_3$-N and $NO_x$-N emitted

The estimate includes a correction to avoid double counting $N_2O$ emitted from synthetic fertiliser use.

The indirect contribution from waste management systems is given by

$$N_2O_{(DWS)} = 44/28. \,(N_{(EX)}/(1-Frac_{(GASM)}) - N_{(F)}) \,.\, Frac_{(GASM)} \,.\, EF_4$$

where

$N_2O_{(DWS)}$ = Atmospheric deposition emission of $N_2O$ arising from animal wastes(kg $N_2O$)
$N_{(EX)}$ = Total N excreted by animals
$Frac_{(GASM)}$ = Fraction of livestock nitrogen excretion that volatilises as $NH_3$ and $NO_x$
= 0.2 kg N/kg N
$N_{(F)}$ = Total N content of wastes used as fuel (kg N)

The equation corrects for the N content of wastes used as fuel but no longer for the N lost in the direct emission of $N_2O$ from animal wastes as previously. The nitrogen excretion data in Table 5 already excludes volatilisation losses and hence a correction is included for this.

## 2.8 LEACHING AND RUNOFF

Indirect emissions of $N_2O$ from leaching and runoff are estimated according the IPCC methodology but with corrections to avoid double counting N. The sources of nitrogen considered, are synthetic fertiliser application and animal wastes applied as fertiliser.

The contribution from synthetic fertilisers is given by:

$$N_2O_{(LSN)} = 44/28 \cdot (N_{(FERT)} \cdot (1-Frac_{(GASF)}) - N_{(SN)}) \cdot Frac_{(LEACH)} \cdot EF_5$$

where

$N_2O_{(LSN)}$ = Leaching and runoff emission of $N_2O$ arising from synthetic fertiliser application (kg $N_2O$)
$N_{(FERT)}$ = Total mass of nitrogen applied as synthetic fertiliser (kg N)
$N_{(SN)}$ = Direct emission of $N_2O_{(SN)}$ as nitrogen (kg $N_2O$-N)
$Frac_{(GASF)}$ = fraction of total synthetic fertiliser nitrogen that is emitted as $NO_x + NH_3$
= 0.1 kg N/ kg N
$Frac_{(LEACH)}$ = Fraction of nitrogen input to soils that is lost through leaching and runoff
= 0.3 kg N/ kg fertiliser or manure N
$EF_5$ = Nitrogen leaching/runoff factor
= 0.025 kg $N_2O$-N /kg N leaching/runoff

The estimate includes a correction to avoid double counting $N_2O$ emitted from synthetic fertiliser use.

The indirect contribution from waste management systems is given by

$$N_2O_{(LWS)} = 44/28. (N_{(EX)} - N_{(F)} - N_{(WS)}) \cdot Frac_{(LEACH)} \cdot EF_5$$

where

$N_2O_{(LWS)}$ = Leaching and runoff emission of $N_2O$ from animal wastes

(kg $N_2O$)
$N_{(EX)}$ = Total N excreted by animals (kg N)
$N_{(F)}$ = Total N content of wastes used as fuel (kg N)
$N_{(AWMS)}$ = Total N content of $N_2O$ emissions from waste management systems including daily spread and pasture range and paddock (kg $N_2O$-N)

The equation corrects both for the N lost in the direct emission of $N_2O$ from animal wastes and the N content of wastes used as fuel.

# 3 Field Burning.

The NAEI estimates emissions from field burning under the category agricultural incineration. The estimates are derived from emission factors calculated according to IPCC(1997) and from USEPA (1997) shown in Table 10

Table 10 Emission Factors for Field Burning (kg/t)

| | $CH_4$ | CO | $NO_x$ | $N_2O$ | NMVOC |
|---|---|---|---|---|---|
| Barley | 3.05[a] | 63.9[a] | 2.18[a] | 0.060[a] | 7.5[b] |
| Other | 3.24[a] | 67.9[a] | 2.32[a] | 0.064[a] | 9[b] |

a IPCC(1997)
b USEPA(1997)

The estimates of the masses of residue burnt of barley, oats, wheat and linseed are based on crop production data (MAFF, 2000d) and data on the fraction of crop residues burnt (MAFF, 1997; ADAS(1995b)). Field burning ceased in 1993 in England and Wales. Burning in Scotland and Northern Ireland is considered negligible as is grouse moor burning, so no estimates are reported from 1993 onwards. The carbon dioxide emissions are not estimated because these are part of the annual carbon cycle.

# 4 Quality Assurance

The livestock activity data used for constructing the inventory is supplied annually by MAFF Economics and Statistics Group, who have specific QA procedures they adhere to from the June census. Activity data on mineral fertiliser are calculated using application rates from MAFF's Annual British Survey of Fertiliser Practice (see reference list) multiplied by crop areas in MAFF's Survey of Farming Incomes (June Census). Data from the June Census, in the form of *.PDF files, can be downloaded from the MAFF website (www.maff.gov.uk) and incorporated into inventory spreadsheets without the need for manual data entry and “double entry”. Annual comparisons of the emission factors and co-efficient used are made by contractors compiling the inventory on behalf of MAFF and by MAFF personally. Any changes are documented in the spreadsheet and in the accompanying chapter of the National Inventory Report. Hardcopies of the submitted inventories, plus associated Emails, copies of activity data, are filed in Government secure files adhering to Government rules on document management.

MAFF contractors who work on compiling the agricultural inventory, IGER, operate strict internal quality assurance systems with a management team for each project overseen by an experienced scientist with expertise in the topic area. A Laboratory Notebook scheme provides quality control through all phases of the research and these are archived in secure facilities at the end of the project. All experiments are approved by a consultant statistician at each of the planning, data analysis and interpretation and synthesis stages. A range of internal checks exist to ensure that projects run to schedule, and internal and external (viz. Visiting Group procedures etc.) reviews ensure the quality of the outputs.

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# Appendix 6
# Land Use Change and Forestry

## CONTENTS

# 1 Introduction[1]

The estimates for Land Use Change and Forestry are from work carried out by the Centre for Ecology & Hydrology (Cannell et al 1999, Milne and Brown 1999). The data is reported under IPCC categories 5A (Changes in Forests and Other Woody Biomass, 5C ($CO_2$ Emissions from Soils) and 5E (Other). No data is included for Categories 5B (Forest and Grassland Conversion ) or 5C (Abandonment of Managed Lands) as these are considered to be negligible, or not occurring, in the UK.

# 2 Changes in Forests and Other Woody Biomass Stocks (5A)

The estimates are based on data for the areas of forest plantation published by the UK Forestry Commission and the Northern Ireland Department of Agriculture. The carbon uptake is calculated by a carbon accounting model (Dewar and Cannell 1992, Cannell and Dewar 1995, Milne et al 1998) as the net change in pools of carbon in standing trees, litter, soil in broadleaf forests and products. All commercial forest is assumed to be restocked. It should be noted that for consistency with previous reports those parts of the net uptake by litter, soils and products are included in the data reported in this category. The values of these removals are also provided in footnotes to the Tables to allow comparison with data from countries which report only changes in woody biomass and include soils etc. elsewhere and with data provided in the Common Reporting Format.

The carbon accounting model of Dewar and Cannell (1992) calculated the mass of carbon in trees, litter, soil and wood products from harvested material in new even-aged plantations which were clearfelled and then replanted at the time of Maximum Area Increment (MAI). Two types of input data and two parameter sets were required for the model (Cannell and Dewar, 1995). The input data are a) areas of new forest planted in each year in the past and b) the stemwood growth rate and harvesting pattern. Parameter values were required to estimate i) stemwood, foliage, branch and root masses from the stemwood volume and ii) the decomposition rates of litter, soil carbon and wood products.

For the estimates described here we used the combined area of new private and state planting from 1921 to 1996 for England, Scotland, Wales and Northern Ireland sub-divided into conifers and broadleaves (Milne et al 1998). Restocking was dealt with in the model through the second and subsequent rotations for the 'new' areas and hence areas restocked each year did not need to be considered separately.

The carbon flow model uses Forestry Commission Yield Tables (Edwards and Christie, 1981) to describe forest growth. It was assumed that all new conifer plantations have the same growth

[1] The land use change and forestry chapter was provided by R Milne, Centre for Ecology & Hydrology, Bush Estate, Penicuik, EH26 OQB

characteristics as Sitka spruce (*Picea sitchensis* (Bong.) Carr.) under an intermediate thinning management. Milne et al. (1998) have shown that mean Yield Class for Sitka spruce varied across Great Britain from 10 to 16 $m^3$ $ha^{-1}$ $a^{-1}$ but with no obvious geographical pattern and that this variation had a less than 10% effect on estimated carbon uptake. The Inventory data has therefore been estimated by assuming all conifers in Great Britain followed the growth pattern of Yield Class 12 $m^3$ $ha^{-1}$ $a^{-1}$, but in Northern Ireland Yield Class 14 $m^3$ $ha^{-1}$ $a^{-1}$ , Sitka spruce. Milne at al. (1998) also showed little effect of different assumptions on broadleaf species. Hence it was assumed here, that broadleaf forests had the characteristics of beech (*Fagus sylvatica* L.) of Yield Class 6 $m^3$ $ha^{-1}$ $a^{-1}$ .

Increases in stemwood volume were based on standard Yield Tables, as in Dewar and Cannell (1992) and Cannell and Dewar (1995), and the mass of carbon in a forest was calculated from this volume by multiplying by wood density, stem to branch and root mass ratios and the fraction of carbon in wood (0.5 assumed). The values used for these parameters for conifers and broadleaves are given in Table 1.

Table 1: Main parameters for forest carbon flow model for species used to estimates carbon uptake by planting of forests of Sitka spruce (P. sitchensis)and beech (F. sylvatica) in United Kingdom (data from Dewar & Cannell, 1992).

| | ***P. sitchensis*** | ***P. sitchensis*** | ***F. sylvatica*** |
|---|---|---|---|
| | **YC12** | **YC14** | **YC6** |
| **Rotation (years)** | 59 | 57 | 92 |
| **Initial spacing (m)** | 2 | 2 | 1.2 |
| **Year of first thinning** | 25 | 23 | 30 |
| **Stemwood density (t $m^{-3}$)** | 0.36 | 0.35 | 0.55 |
| **Max. carbon in foliage (t $ha^{-1}$)** | 5.4 | 6.3 | 1.8 |
| **Max. carbon in fine roots (t $ha^{-1}$)** | 2.7 | 2.7 | 2.7 |
| **Fraction of wood in branches** | 0.09 | 0.09 | 0.18 |
| **Fraction of wood in woody roots** | 0.19 | 0.19 | 0.16 |
| **Max. foliage litterfall (t $ha^{-1}$ $a^{-1}$)** | 1.1 | 1.3 | 2 |
| **Max. fine root litter loss (t $ha^{-1}$ $a^{-1}$)** | 2.7 | 2.7 | 2.7 |
| **Foliage decay rate ($a^{-1}$)** | 1 | 1 | 3 |
| **Wood decay rate ($a^{-1}$)** | 0.06 | 0.06 | 0.04 |
| **Fine root decay rate ($a^{-1}$)** | 1.5 | 1.5 | 1.5 |
| **Soil organic carbon decay rate ($a^{-1}$)** | 0.03 | 0.03 | 0.03 |
| **Fraction of litter lost to soil organic matter** | 0.5 | 0.5 | 0.5 |

The parameters controlling the transfer of carbon into the litter pools and its subsequent decay are given in Table 1. Litter transfer rate from foliage and fine roots increased to a maximum at canopy closure. A fraction of the litter was assumed to decay each year, half of which added to the soil organic matter pool which then decayed at a slower rate. The decay of litter and soil matter was assumed to be controlled only by tree species and Yield Class and unaffected by other factors which varied with location. Additional litter was generated at times of thinning and felling.

As in Cannell and Dewar (1995) it was assumed that conifer forests increased the amount of organic carbon in litter but did not increase the net amount of carbon in soil due to gains from the new forest being balanced by loss due to the disturbance at planting. Broadleaved forests were assumed to increase the net amount of carbon in litter and soil. Harvested material from thinning and felling, which is made into wood products, was assumed to decay over a period equal to the rotation of the forest, conifer or broadleaf as appropriate, since products from broadleaves (e.g. furniture) will decay more slowly than those from conifers (e.g. paper, building timber). A detailed description of all the assumptions in the model was given by Dewar and Cannell (1992) and Cannell and Dewar (1995).

# 3 $CO_2$ Emissions and Removals from Soils (5D)

Three processes are reported in this category: changes in soil stocks due to land use change, change in soil stocks due specifically to the change in land use from arable in Set Aside schemes and emissions due to the application of lime and dolomite.

## 3.1 LAND USE CHANGE

The basic method for assessing changes in soil carbon due to land use change is to use a matrix of change from surveys of land linked to a dynamic model of gain or loss of carbon. In the latest version of the method matrices from the Monitoring Landscape Change (MLC) data from 1947 & 1980 and the DETR/ITE Countryside Surveys (CS) of 1984 & 1990 are used. Land use in the UK can be placed into 4 broad groups – (Semi) Natural, Farming, Woodland and Urban – and hence the more detailed categories for the two surveys were combined as shown in Table 3a for MLC and 3b for CS. In both cases only unimproved grassland is included in the Natural category. For the CS the different types of grass are shown in Table 4.

A database of soil carbon density for the UK has been constructed (Milne and Brown 1995, Cruickshank *et al.* 1998) from information provided by the Soil Survey and Land Research Centre, the Macaulay Land Use Research Institute and Queen's University Belfast on soil type, land cover and carbon content of soil cores. These densities include carbon to a depth of 1 m or to bedrock whichever is the shallower, for mineral and peaty/mineral soils. Deep peats in the North of Scotland are identified separately and depths to 5 m are included but these play a minor role in relation to land use change. MLURI reviewed and revised downwards the values of soil carbon density for some peaty soils types in Scotland for this 1999 Inventory. Table 2 shows average values of soils carbon density for different land covers in the four devolved areas of the UK. The data of Table 2 shows no strong evidence of a major difference in the soil carbon density of tilled cropland or actively managed grass hence the inclusion of both uses within the Farm category.

Table 2 Average soil carbon density (t C $ha^{-1}$) for different land cover in the UK

| Land cover | England | Scotland | Wales | N. Ireland |
|---|---|---|---|---|
| **Forest** | 217 | 580 | 228 | 563 |
| **Arable** | 153 | 156 | 93 | 151 |
| **Pasture** | 170 | 192 | 200 | 178 |
| **Other** | 33 | 141 | 43 | 102 |

Table 3a: Grouping of MLC land cover types for soil carbon change modelling.

| FARM | NATURAL | WOODLAND | URBAN |
|---|---|---|---|
| Crops | Upland heath | Broadleaved wood | Built up |
| Market garden | Upland smooth grass | Conifer wood | Urban open |
| Improved grassland | Upland coarse grass | Mixed wood | Transport |
| Rough pasture | Blanket bog | | Mineral workings |
| | Bracken | | Derelict |
| | Lowland rough grass | | |
| | Lowland heather | | |
| | Neglected grassland | | |
| | Marsh | | |

Table 3b: Grouping of CS land cover types for soil carbon change modelling. For Managed grass (I) signifies “Improved”, usually by ploughing and seeding, (U) signifies “Unimproved” by such means.

| FARM | NATURAL | WOODLAND | URBAN |
|---|---|---|---|
| Tilled land | Rough grass/marsh | Broadleaved/mixed | Communications |
| Managed grass(I) | Managed grass (U) | Coniferous | Built up |
| | Dense bracken | | Inland bare (Hard areas) |
| | Moorland grass | | |
| | Dense heath | | |
| | Open heath | | |

Table 4: Different types of CS land cover included in the “Improved” and “Unimproved” groups for soil carbon modelling.

| Managed grass (I) | Managed grass (U) |
|---|---|
| Recreational | Non-agricultural improved |
| Recently sown | Calcareous |
| Pure rye | Upland |
| Well managed | |
| Weedy swards | |

Table 5: Area and change data sources for different periods in estimation of changes in soil carbon. (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al*. (1993).

| **Year or Period** | **Area data** | **Change matrix or data** |
|---|---|---|
| 1930 | Land use Survey (1) | |
| 1930 – 1947 | *Interpolated* | MLC 1947->MLC1980 |
| 1947 | MLC (2) | |
| 1947-1980 | *Interpolated* | MLC 1947->MLC1980 |
| 1980 | MLC (2) | |
| 1980-1984 | *Interpolated* | *Interpolated* |
| 1984 | CS1984 (3) | |
| 1984-1990 | *Interpolated* | CS1984->CS1990 |
| 1990 | CS1990 (3) | |
| 1990-2010 | *Extrapolated from 84->90* | CS1984->CS1990 |

Area data exist for the period 1930 to 1990 and those from 1984 to 1990 are used to extrapolate forward for the years 1991 to 1998. Land use change matrices for the periods 1947 to 1980 and 1984 to 1990 are used. See Table 5 for the sources of information for land use and matrices of change.

The core equation describing changes in soil carbon with time for any land use transition is

$$C_t = C_f - (C_f - C_0)e^{-kt}$$

$C_t$ is carbon density at time t
$C_0$ is carbon density initially
$C_f$ carbon density after change to new land use
k is time constant of change

If the inventory year is 1990 and $A_T$ is area in a particular land use transition in year T considered from 1930 onwards then total carbon lost or gained from 1930 to 1990 ($X_{1990}$) and from 1930 to 1989 ($X_{1989}$) is given by

$$X_{1990} = \sum_{T=1930}^{t=1990} A_T (C_0 - C_f)(1 - e^{-k(1990-T)})$$

$$X_{1989} = \sum_{T=1930}^{T=1989} A_T (C_0 - C_f)(1 - e^{-k(1989-T)})$$

Hence flux of carbon in 1990 is given by difference:

$$F_{1990} = X_{1990} - X_{1989}$$

The land use transitions considered are each of those between the (Semi) Natural, Farm, Woodland and Urban categories. Scotland, England and Wales are treated separately. Northern Ireland does not yet have a matrix of land use change and changes in soil carbon are calculated by a method based on that recommended by the IPCC (1997b, c). The area data for Great Britain are shown in Table 6. The data from the CS has had a small adjustment applied to account for one of the detailed land types (Non-cropped arable) actually bridging the main Natural and Farm categories.

Table 6a:Area of land in England for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al*. (1993).

| | | **Area(ha)** | | | |
|---|---|---|---|---|---|
| ***Source*** | Year | **Farm** | **Natural** | **Urban** | **Woodland** |
| ***lus (1)*** | ***1930*** | 9,542,340 | 1,543,000 | 1,034,858 | 843,800 |
| ***mlc (2)*** | ***1947*** | 9,242,777 | 1,639,511 | 823,665 | 865,370 |
| ***mlc (2)*** | ***1980*** | 9,013,401 | 1,307,178 | 1,301,965 | 948,779 |
| ***cis (3)*** | ***1984*** | 8,670,815 | 1,908,436 | 1,249,383 | 1,303,455 |
| ***cis (3)*** | ***1990*** | 8,336,428 | 2,120,609 | 1,323,084 | 1,353,399 |

Table 6b: Area of land in Wales for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al*. (1993).

| | | **Area(ha)** | | | |
|---|---|---|---|---|---|
| ***Source*** | Year | **Farm** | **Natural** | **Urban** | **Woodland** |
| ***lus (1)*** | ***1930*** | 1,094,187 | 771,520 | 77,298 | 120,439 |
| ***mlc (2)*** | ***1947*** | 1,061,571 | 701,347 | 71,422 | 160,077 |
| ***mlc (2)*** | ***1980*** | 1,148,150 | 521,131 | 121,459 | 203,677 |
| ***cis (3)*** | ***1984*** | 1,155,174 | 585,248 | 176,112 | 221,521 |
| ***cis (3)*** | ***1990*** | 1,132,768 | 593,918 | 188,628 | 222,953 |

Table 6c: Area of land in Scotland for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

| | | **Area(ha)** | | | |
|---|---|---|---|---|---|
| ***Source*** | Year | **Farm** | **Natural** | **Urban** | **Woodland** |
| ***lus (1)*** | ***1930*** | 1,861,215 | 5,265,673 | 146,906 | 443,187 |
| ***mlc (2)*** | ***1947*** | 2,037,860 | 5,209,630 | 260,313 | 447,753 |
| ***mlc (2)*** | ***1980*** | 2,100,125 | 4,667,711 | 297,076 | 890,644 |
| ***cis (3)*** | ***1984*** | 2,109,333 | 4,940,892 | 287,471 | 1,019,931 |
| ***cis (3)*** | ***1990*** | 2,059,553 | 4,935,184 | 294,291 | 1,068,543 |

In the model, the change is required in equilibrium carbon density from the initial to the final land use during a transition. Here, these are calculated for each land use category as averages for Scotland, England and Wales. In order to account for variation in carbon density and Land Use Change in different soil types these averages are weighted by the area of soil groups used by IPCC (1997c). They define five groups, which are represented in Great Britain, on the basis of their carbon content and activity namely; aquic, high activity clay, low activity clay, sandy and organic. In Great Britain few clay soils truly fall into the 'high activity' class so the *total clay content* is used to divide these soils into 'high' and 'low' groups. For Great Britain all soil types not falling into these five types an 'undefined' groups is used. Mean soil carbon density change are calculated as.

$$\overline{C}_{ijc} = \frac{\sum_{s=1}^{6}(C_{sijc}L_{sijc})}{\sum_{s=1}^{6}L_{sijc}}$$

which is the weighted mean, for each country, of change in equilibrium soil carbon when land use changes and
i = initial land use (Natural, Farm, Woods, Urban)
j = new land use (Natural, Farm, Woods, Urban)
c = country (Scotland, England & Wales)
s = soil group (High clay, low clay, aquic, organic, sandy, undefined)
$C_{sijc}$ is change in equilibrium soil carbon for a specific land use transition within a soil group region in a specific country
$L_{sijc}$ is area change (1984 to 1990) for a specific land use transition within a soil group region in a specific country.

The rate of loss or gain of carbon is dependent on the type of land use transition (Table 8). For transitions where carbon is lost e.g. transition from Natural to Farm land, a 'fast' rate is applied whilst a transition which gains carbon occurs much more slowly. This 'slow' rate had in the 1998, and earlier, GHG Inventories been set such that 99% of the change occurred in 100 years throughout GB as had been observed at Rothamsted (Howard *et al.* 1994). However, it was observed that due to the high carbon densities in Scottish soils that the uptake rates of carbon in that country were unreasonably large when land moved to the Natural class from the Farm class. For the 1998 Inventory the rate of uptake was therefore reduced until the uptake of soil carbon in such transitions was less than the order of net primary productivity for cold temperate grasslands (about 300 g $m^{-2}$ $a^{-1}$). Thus a rate of soil carbon accumulation in Scotland which took the equivalent of 800 years to reach 99% of the new values was used. Here, for the 1999 Inventory, a different approach to taking account of the uncertainty in such rates of transition was adopted. A literature search for information on measured rates of changes of soil carbon due to land use was carried out and, in combination with expert judgement, ranges of possible times for completion of different transitions were selected. These are shown in Table 7.

Table 7: Range of times for soil carbon to reach 99% of a new value after a change in land use in England (E), Scotland (S) and Wales (W).

| | **Low (years)** | **High (years)** |
|---|---|---|
| **Carbon loss ("fast") E, S, W.** | 50 | 150 |
| **Carbon gain ("slow") E, W.** | 100 | 300 |
| **Carbon gain("slow") S.** | 300 | 750 |

Table 8: Rates of change of soil carbon for land use change transitions. ("Fast" & "Slow" refer to 99% of change occurring in times shown in Table 7.

| | | **1984** | | | |
|---|---|---|---|---|---|
| | | **Farm** | **Natural** | **Urban** | **Woods** |
| **1990** | **Farm** | | *fast* | *slow* | *fast* |
| | **Natural** | *slow* | | *slow* | *fast* |
| | **Urban** | *fast* | *fast* | | *fast* |
| | **Woods** | *slow* | *slow* | *slow* | |

The model of change was then run 500 times with the time constant for change in soil carbon being selected separately using a Monte Carlo approach for England, Scotland and Wales from within the ranges of Table 7. The mean carbon flux for each region resulting from this imposed random variation was then reported as the estimate for the Inventory. An adjustment was made to these calculations for each country to remove increases in soil carbon due to afforestation, as the value for this was considered to be better estimated by the C-Flow model used for the Changes in Forests and Other Woody Biomass Stocks (5A) category.

## 3.2 SET ASIDE

The estimation of changes in soil carbon calculated by the matrix method for all transitions does not fully include the effects of the policy of Set Aside from production of arable areas. This is the case because although the schemes were introduced in 1988 there was a slow rate of acceptance by farmers and it was not until after 1990 that significant areas are recorded in the Annual Farm Census. In this post-1990 period the matrix method uses an extrapolation of the CS field data from 1984 to 1990 therefore a separate estimate of the effect of Set Aside on soil carbon for these later years has been made. Data reported in inventories prior to 1997 were based on the observation from the Annual Farm Census that Set Aside was continuing to increase in total area. However from more recent Census data it would seem that the total area has now passed its maximum and is beginning to fall. This reflects the fact that the Schemes will be phased out, to be replaced with others with different objectives. The data reported here therefore take into account not only the effect of soil carbon increasing in areas where land is not used for arable purposes but the subsequent loss of the extra accumulated carbon from the soil when land is returned to arable use.

Set Aside areas are taken from the Annual Farm Census for Scotland and England & Wales separately. Scottish soils coming out of arable use are assumed to be able to take up 300 t/ha but that this happens at a rate which would only allow 99% of that change to occur in 500 years. For English & Welsh soils it is assumed that the change in equilibrium soil carbon density would be 60 t/ha and that 99% of this change would occur in 200 years. These times fall in the middle of the ranges used in the main calculation for the effect of land use change causing an increase in soil carbon. The new areas of land in Set Aside are calculated from the increases in area up to the maximum total recorded area (in 1995 throughout GB). The emission of carbon from these areas are calculated for years up until 1999 when it is assumed that all land will have returned to arable. To compensate for the reducing area, two assumptions were made: a) the area lost in each year from 1995 onwards was assumed to have been in Set Aside for 3 years and b) the carbon gained in these 3 years would be lost at a rate which would cause 99% of the change to occur in 20 years. The 3 year assumption is made as there is no clear indication of how long any area does remain in Set Aside. This value is not unreasonable but may be low given that some Set Aside could have existed from 1988. Prior to the 1998 Inventory it was assumed that all Set Aside was simply abandoned but between 30 and 50% is actually managed by cutting etc. Such areas will not be very different from other rotational pasture situations which we have already shown to have similar soil carbon to arable areas. Hence such areas have been excluded from estimates of the effect of Set Aside reported here.

*Thus for the estimates reported here the assumptions are: Set Aside area rises to a maximum in 1995 then falls away to zero by 1999, uptake occurs slowly in Scotland and 50% of areas in the Agricultural Census are in rotational form of management are excluded. Northern Ireland has negligible change in soil carbon due to Set Aside*

## 3.3 EMISSIONS OF $CO_2$ FROM SOIL DUE TO LIMING

Emissions of carbon dioxide from the application of limestone, chalk and dolomite to agricultural soils were estimated. Data on the use of limestone, chalk and dolomite for agricultural purposes is reported in BGS (2001). It is assumed that all the carbon contained in the lime is released in the year of use. For limestone and chalk , a factor of 120 t C/kt is used, and for dolomite application, 130 t C/kt. These factors are based on the stoichiometry of the reaction and assume pure limestone and dolomite.

# 4 Other sources and sinks (5E)

These are:
Sources
Drainage of deep peat
Drainage of lowland wetlands
Peat extraction

and sink

- Changes in crop biomass

The activity data and carbon fluxes are based on data from (Bradley 1997, Cannell *et al*. 1993, Cruickshank et al. 1997, Hargreaves and Fowler 1997) for sources and from (Adger and Subak 1995) for the sink.

## 4.1 CHANGES IN CROP BIOMASS

This value was originally derived by Adger & Subak (1995) using Agricultural Census and other data up to 1992. From the 1998 Inventory onwards more recent data from the Agricultural Census were considered but did not support any change to the existing estimate. This rate is therefore reported for all years from 1990 to 1999.

## 4.2 PEAT EXTRACTION

Trends in peat extraction in Scotland and England over period 1990 to 1999 are included. In Northern Ireland no new data on use of peat for horticultural use was available and a recent survey of extraction for fuel use suggested that there is no significant trend for this purpose. The contribution of emissions due to peat extraction are therefore incorporated as constant from 1990 to 1999. Peat extraction is negligible in Wales.

## 4.3 LOWLAND (FEN) PEAT DRAINAGE

The trend in emissions due to changing areas of drainage is based on the work of Bradley (1997).

## 4.4 UPLAND (FORESTRY) PEAT DRAINAGE

The area of forestry on peat is unlikely to have changed due to present policy. Emissions from planted areas tend to exist for considerable periods due to the large stock of carbon that is available for decomposition and hence the emissions included under this heading are reported as constant from 1990 to 1999.

The sources are summarised in Tables 9 and 10 and also detailed in footnotes to Inventory Table 5E.

Table 9 Summary of Emission Factor Data for Deep Peat Drainage and Lowland Wetland Drainage

| | Emission Factor $g\ C/m^2/y$ |
|---|---|
| Deep Peat Drainage | 200 |
| Lowland Wetland Drainage | 297 |

Table 10 Summary of Emission Factor Data for Peat Extraction (GB Great Britain, NI Northern Ireland)

| | Emission | Factor |
|---|---|---|
| | kg C $m^{-3}$ | Gg C/Gg |
| GB Horticultural Peat | 55.7 | - |
| GB Fuel Peat | 55.7 | - |
| NI Horticultural Peat | 44.1 | - |
| NI Fuel Peat | - | 0.3 |

# 5 Quality Assurance Methods and Standards

CEH has put in place high quality assurance standards, and selects subcontractors from professional organisations who meet those standards. The general standards are:
- The use of professionally qualified staff.
- The application of rigorous quality control procedures.
- The use of modern equipment.
- The use of validated methods.
- The quality control and curation of databases.
- The establishment of management procedures to ensure compliance.
- The particular quality control measures relevant to this report are as follows.

*Databases*
The databases used to calculate carbon sources and sinks are all quality controlled at source by the responsible organisation, e.g. CEH for land use, SSLRC and MLURI for soils and FC for forestry statistics.

*Models*
All modelling is done by trained staff, who now have many years' experience of simulating changes in soil and biomass carbon. The output of models is checked against quality assured data. Predictions of future sources and sinks are bench marked against predictions made by other researchers in Europe through a COST E21, other research meetings and the scientific literature.

*Output*
The integrity of results, the quality of the reports, the relationship to contracted deliverables and the punctuality of reporting, are all subject to management vetting and tracking within CEH, through the Heads of Sections, Directors of Sites and the Finance Administration. Additionally, all staff are required to publish as much non-confidential scientific information in the peer reviewed scientific literature, with the prior approval of the customer and customer acknowledgement.

*Field measurements of sources and sinks*
All fieldwork, sampling and data handling is done by experienced and trained staff to defined protocols agreed to meet the objectives of the work. The procedures for flux measurement are fully documented and instruments are calibrated directly with primary standards.

*Chemical analysis*
All chemical analyses are done at CEH, Merlewood and are supported by full quality assurance and control procedures under BS 5750. The integrity of results is checked by conducting bi-monthly inter-laboratory comparisons (Aquachecks and the International Soil Exchange Scheme).

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