6. Incorporation of N_2O and CH_4 emissions and removals due to LULUCF (WP 2.2)

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Emissions of greenhouse gases other than CO_2 in the Land Use Change and Forestry Sector come from 3 types of activities: (i) biomass burning as part of deforestation producing CH_4 and N_2O emissions, (ii) application of fertilisers to forests producing N_2O and (iii) disturbance of soils due to some types of land use change producing N_2O associated with CO_2 emissions. Emissions by biomass burning are discussed elsewhere (in the Grassland and Settlements sections of Chapter 1). Emissions of N_2O from fertilization and soil disturbance (drainage) are discussed below.

6.1 N fertilization of forests

Direct N_2O emissions from N fertilization of forests have previously not been estimated as they were assessed as small in the UK. This assessment has been re-examined but due to the incompleteness of the time series the data has not been included in the 1990-2005 CRF tables. Fertiliser containing N has not been applied to existing forests (5.A.1) in the UK since about 2000, and for 1990 – 2000 applications of 100 kg N/ha/yr were assumed to be typical. The area receiving applications of N between 1990 and 2000 are not readily available. Such data are presently being sought from the Forestry Commission and other organisations. In 2005 two forests in Scotland (Dornoch (242 ha) and Inverness (35 ha)) were experimentally fertilised with mineral N at a rate of 350 kg N/ha. Therefore a total 97 tonnes of N were applied which, using the default IPCC N_2O emission factor of 1.25%, resulted in an emission of 1.2125 tonnes N_2O-N equivalent to 1.905 tonnes N_2O, or 0.591 Gg CO_2 equivalent.

Sewage sludge has been used in Scotland in land restoration projects (5.A.2). For example in 2005 sewage sludge was used on derelict land with little or no *in situ* topsoil, where it was intended to establish new forest. Sewage sludge was also applied to harvested forest sites where it was intended to replant trees but to a much lesser extent. In 2006 the amount of sludge used for such purposes has been greatly reduced. Further investigation of similar projects in earlier years is under way. The area of restoration in 2005 is not recorded, but 48,400 t of dry sewage sludge were used. Assuming 1 t of dry sludge contains 0.03 t N, 1452 tonnes of N would have been applied. Using the default N_2O emission factor of 1.25% gives an emission of 18.15 tonnes N_2O-N equivalent to 28.52 tonnes N_2O, or 8.841.Gg CO_2 equivalent.

Together the use of fertilisers and sewage sludge on forests in 2005 is therefore estimated to have caused emission of 30.425 tonnes N_2O. Although the GWP of N_2O is 310, giving an equivalent CO_2 emission of 9.4 Gg, this is very small compared to other emissions and removals in the LULUCF Sector.

6.2 Emissions of N_2O as a result of disturbance due to land use change

In the UK drainage of some form has occurred when new forests are planted. The method recommended in the LULUCF GPG for calculating N_2O emissions due to land use change is to use the CO_2 emission due to a specific change and then use the

C:N ratio for the soils being disturbed to estimate the N lost due to the mineralisation of organic matter. The default emission factor for the N_2O pathway (1.25%) is then used to calculate the emitted flux of N_2O-N. Table 6-1 shows the emissions for the period from 1990 to 2005 adopting this approach with a C:N ratio of 15:1 for all land.

Table 6-1: Emissions of N_2O in the UK due to disturbance of soils after land use change estimated by the method of the LULUCF GPG

	Forest Land to Grassland	**Forest Land to Cropland**	**Forest Land to Settlement**	**Grassland to Cropland**	**Grassland to Settlement**	**Cropland to Settlement**	**ALL LUC**
	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O
1990	0.035	0.004	0.026	4.995	2.019	0.401	7.482
1991	0.035	0.004	0.029	5.001	2.008	0.390	7.466
1992	0.035	0.004	0.031	5.006	1.997	0.378	7.452
1993	0.034	0.004	0.035	5.012	1.986	0.368	7.439
1994	0.034	0.003	0.037	5.018	1.977	0.358	7.428
1995	0.036	0.003	0.038	5.024	1.968	0.349	7.419
1996	0.037	0.003	0.039	5.031	1.960	0.340	7.410
1997	0.034	0.003	0.044	5.037	1.953	0.332	7.403
1998	0.034	0.003	0.046	5.044	1.946	0.324	7.396
1999	0.045	0.003	0.037	5.050	1.939	0.317	7.391
2000	0.050	0.002	0.033	5.057	1.933	0.310	7.386
2001	0.054	0.002	0.031	5.064	1.928	0.303	7.382
2002	0.056	0.002	0.031	5.071	1.923	0.297	7.379
2003	0.056	0.002	0.032	5.077	1.918	0.292	7.377
2004	0.054	0.002	0.035	5.084	1.913	0.286	7.375
2005	0.056	0.002	0.035	5.090	1.909	0.281	7.373

The 1990 emission rate for all land use change from Table 6-1 is equivalent to an emission of 2319 Gg CO_2 (using a GWP of 310), which is similar to the net uptake of CO_2 equivalents by all other activities in the UK LULUCF Sector. It is therefore of considerable importance that the methodology used is scientifically sound. On further investigation this does not appear to be the case. The LULUCF GPG methodology relies on estimating gross nitrogen loss from a gross carbon loss and a C:N ratio, but several factors suggest that this approach does not lead to reliable values. There are few measurements of C:N ratios for different land use and for different environmental conditions, making it difficult to generalise values for a whole country. More importantly, understanding of the mechanisms that cause C:N ratios to vary with different land management is weak, particularly in relation to how changes in the C:N ratio of different pools in the soil affect the gross C:N ratio. For example Pineiro *et al.* (2006) show that it is possible to obtain gross N-mineralisation changes of opposite sign depending on whether changes in whole-soil or individual pool C:N ratios are considered in a model of the effect of grazing on soil. It would therefore seem prudent to await an alternative approach to estimating N_2O emissions due to land use change before including any data in the inventory. Research is being undertaken to measure change in stocks of soil carbon and nitrogen due to ploughing of an upland grassland (Work Package 2.6), which should contribute to greater understanding in this area.

6.3 Emissions of N_2O from disturbance of soils by afforestation

The methodology used to estimate CO_2 removals and emissions due to the establishment of forests is described in the Forest Land section of Chapter 1. Included in these estimates are emissions relating to the loss of carbon (as CO_2) as a result of disturbance of the pre-existing soil. The pattern of immediate and delayed emissions is taken to be that measured at a peatland site but the amplitude of the loss is reduced for afforestation in other locations. It could therefore be assumed that nitrogen in the soil will be lost with the carbon in proportion to the C:N ratio as suggested by the LULUCF GPG for other types of land use change that cause carbon mineralization. Area afforestation rates in the UK have been disaggregated into those for planting of conifers on organic and non-organic soils and for broadleaves (which normally occurs on mineral soils). We investigated this approach for calculating nitrogen loss by assuming that organic soils (conifer planting) had a C:N ratio of 30:1 but non-organic soils used for planting had a C:N ratio of 15:1. The N_2O emission factor was taken to be the default value of 1.25%. Emissions of N_2O estimates by this approach are presented in Table 6-2. All forests planted since 1921 are included in this approach but no explicit account of the degree of drainage in these forests is included. The fluxes measured by Hargreaves *et al*. (2003), which are the basis for the method of estimating CO_2 emissions due to planting, were ~ 4 tC/ha/yr initially and estimated to fall to ~0.3 tC/ha/yr in the long term. Assuming a C:N ratio of 30:1 for peat the resulting N_2O emissions would be of the same order of magnitude as those suggested as Tier 1 Defaults in the LULUCF GPG. These emission rates are not as large as those found for Grassland conversion but the criticisms of using gross C:N ratios to obtain N loss also apply. A further consideration of methods will therefore be needed before data can be included in the inventory.

Table 6-2: Emissions of N_2O due to afforestation since 1921 in the UK using an adaptation of the LULUCF GPG approach for general land use change.

	Conifer organic	**Conifer mineral**	**Broadleaf (mineral)**
	Gg N_2O	Gg N_2O	Gg N_2O
1990	0.154	0.885	0.097
1991	0.147	0.849	0.117
1992	0.139	0.812	0.135
1993	0.131	0.776	0.155
1994	0.123	0.737	0.183
1995	0.116	0.704	0.211
1996	0.111	0.678	0.230
1997	0.106	0.654	0.244
1998	0.101	0.633	0.260
1999	0.097	0.614	0.274
2000	0.093	0.597	0.288
2001	0.090	0.579	0.311
2002	0.085	0.559	0.327
2003	0.082	0.540	0.328
2004	0.078	0.523	0.326
2005	0.075	0.506	0.325

6.4 References

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