N_2O: DIRECT EMISSIONS FROM AGRICULTURAL SOILS

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ABSTRACT

The OECD/IPCC/IEA phase II development of *the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)* methodology for agricultural sources of N_2O (IPCC, 1997; Mosier et al., 1998) includes methodologies for calculating both direct and indirect emissions of N_2O related to agricultural production. It takes into account anthropogenic N inputs including synthetic fertilizers, animal wastes and other organic fertilizers, biological nitrogen fixation by crops, cultivation of organic soils, and mineralization of crop residues returned to the field. Direct sources include those where N_2O is emitted directly to the atmosphere from cultivated soils and fertilized and/or grazed grassland systems. Indirect emissions result from transport of N from agricultural systems into ground and surface waters through drainage and surface runoff, or emission as ammonia or nitrogen oxides and deposition elsewhere, causing N_2O production.

Worldwide consumption of synthetic N fertilizers has increased by about 150% since 1970 to about 82 Tg N y^{-1} in 1996. Animal wastes used as fertilizer supplied an estimated additional 65 Tg N y^{-1} in 1996, compared with 37 Tg N y^{-1} in 1950. This increase in N use is now widely recognised as a major factor in the increase in N_2O emissions indicated by increases in atmospheric concentration. The evidence points to a further major increase from agricultural sources in the future, with increases in food production.

Much research published since the adoption of the present default emission factors (1.25% of N applied as synthetic and organic fertilizers, crop residues etc, and 2% of the N deposited by grazing animals) strongly suggests that seasonal weather fluctuations and management variables (e.g. the timing of irrigation), and crop type in a given region, have a large impact on fluxes. This poses the question of whether an analysis of existing data may lead to modified emission factors. This will be an important theme of the workshop discussions. The alternative to experimental determination of these factors is modelling, and the potential for the use of models in this context is reviewed. Difficulties with complex models, including the issue of the scales on which they operate, may make simplified summary models a desirable option for developing updates of emission factors.

This paper reviews the problems associated with the acquisition of activity data, quantification of uncertainties, and the achievement of completeness in source identification and calculation. It also identifies corrections that are needed to the present *IPCC Guidelines,* and examines the issue of accounting for mitigation measures. In relation to this last topic, it is concluded that careful attention needs to be given to the impact of measures taken to mitigate CO_2 or CH_4 emissions on those of N_2O. With regard to inventory quality, it is concluded that a key concept is independent, objective review to assess the effectiveness of the internal QC programme, and to reduce or eliminate any inherent bias in the inventory processes. Several types of external reviews, or audits, may be appropriate for the inventory of direct N_2O emissions from agricultural soils.

1 INTRODUCTION

1.1 Nature, magnitude and distribution of source

1.1.1 Mechanisms Responsible for Formation of N_2O

Direct emissions of nitrous oxide, N_2O, from soils result primarily from microbially driven nitrification and denitrification processes, together with non-biological chemodenitrification. Nitrification is the aerobic microbial oxidation of ammonium ions to nitrite via NH_2OH, and then to nitrate:

$$NH_4^+ \rightarrow NH_2OH \rightarrow NO_2^- \rightarrow NO_3^-$$

When oxygen is limiting, ammonium oxidisers can use NO_2^- as an alternative electron accetor and produce N_2O ("nitrifier denitrification" (Granli and Bøckman, 1994).

N_2O is also formed in the course of denitrification, the anaerobic microbial (mainly bacterial) reduction of nitrate successively to nitrite and then to the gases NO, N_2O and N_2:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Chemodenitrification involves, as its name implies, the chemical reduction of nitrite ion to N_2O by compounds such as amines present in soil organic matter, and by inorganic ions (Fe^{2+}, Cu^{2+}), particularly in subsoils (Granli and Bøckman, 1994). It is less important than nitrification or biological denitrification as a source of N_2O from agricultural soils.

Microbial production of N_2O is dependent on the presence in the soil of suitable mineral N substrates, i.e. ammonium and nitrate. Thus additions of mineral N fertilizers, and N from other sources such as animal manures, crop residues, N_2-fixing crops, and sewage sludge (from which ammonium is released by mineralisation) to agricultural soils are recognised as major drivers of N_2O emissions (Bøckman and Olfs, 1998). Additionally, there is an additional "background" source due to the mineralisation of soil organic matter (humus), and where soils have only relatively recently been brought into cultivation the accelerated decomposition of OM that may have slowly accumulated over thousands of years under natural forest or grassland vegetation will enhance this "background" source. Organic (peat) soils that have been drained and cultivated can give rise to particularly high N_2O fluxes (Kasimir-Klemedtsson et al., 1997).

1.1.2 Previous assessments of the soil source

In the IPCC (1992) assessment, the global N_2O emissions from natural soils were estimated to be in the range 3.2-7.7 Tg N y^{-1}, while the additional emission from agricultural soils was very uncertain (0.03-3.0 Tg N y^{-1}). IPCC (1995) estimated the direct contribution from agricultural soils receiving N from mineral fertilizers, manure and N_2-fixing legumes at 3.5 (1.8-5.3) Tg N y^{-1}, i.e. nearly 25% of the total global source strength of 14.7 Tg N y^{-1}. More recently, using the IPCC Phase II methodology (IPCC, 1997), the direct emissions from agricultural soils have been estimated at 2.1 (0.4-3.8) Tg N y^{-1}, with a total from agricultural systems (including emissions from animal production and indirect emissions derived from N of agricultural origin) of 6.3 Tg N y^{-1} (Mosier et al., 1998).

1.1.3 Source distribution

Worldwide consumption of synthetic N fertilizers has increased 20-fold since 1950 and by about 150% since 1970, to about 82 Tg N y^{-1} in 1996 (Mosier and Kroeze, 1999). About half of current consumption is in Asia, and much of the recent increase has occurred in this region. Animal wastes used as fertilizer supplied an estimated additional 65 Tg N y^{-1} in 1996, compared with 37 Tg N y^{-1} in 1950 (Mosier and Kroeze, 1999). This increase in N use is now widely recognized as a major factor in the increase in N_2O emissions indicated by increases in atmospheric concentration. The evidence points to a further major increase from agricultural sources in the future, in view of projections that point to a further doubling of N fertilizer use in developing countries by 2025 (Vitousek and Matson, 1993; Bouwman, 1998). Intensive use of animal manure as fertilizer is a feature of agricultural systems as diverse as intensive dairy cattle rearing in NW Europe and 1-2 ha subsistence farms in E and SE Asia, and as livestock numbers rise the tendency will be for the N input from this source to increase (Bouwman and van der Hoek, 1997).

1.2 Current state of inventory methodologies

1.2.1 Emission factor and regression approaches

In emission factor approaches emission estimates are derived by combining measurement data with geographic and statistical information on the ecosystem processes and economic activity. This can be represented as:

EQUATION 1

$$E = A \bullet E_f$$

where *E* is the emission, *A* the activity level (e.g. area of a functional unit, animal population, fertilizer use, burning of biomass) and E_f the emission factor (e.g. the emission per unit of area, animal, unit of fertilizer applied or biomass burnt). When using the emission factor approach, both the stratification scheme for delineating functional types (e.g. management systems, ecosystems, environmental provinces or entities) as a basis for scaling, and the reliability of the emission factor determine the accuracy of the flux estimates.

1.2.2 Current default emission factor for direct soil emissions

From field studies of at least 1 year's duration, Bouwman (1996) derived the following relationship for direct N_2O emissions from agricultural soils:

EQUATION 2

$$E = 1 + 0.0125 \bullet F$$

Where E is the emission rate (kg N_2O-N ha^{-1} y^{-1}), the value of 1 kg N ha^{-1} is the background emission rate and F is the fertilizer application rate (kg N ha^{-1} y^{-1}). He suggested that although this may not be adequate to estimate emissions for local conditions or specific crops it may be sufficient for global analyses. The most recent IPCC methodology (IPCC, 1997) for estimating direct N_2O emission from synthetic fertilizer applied to agricultural soils is based on Bouwman's (1996) work. It assumes the emission to be a fixed percentage, 1.25 ± 1 %, of the N applied.

The same emission factor is also applied to commercial organic fertilizers, non-commercial applications of animal waste, N in cultivated N-fixing crops (product + residue) and N in other crop residues ploughed into the soil. Also, the IPCC default approach assumes the emission to be a fixed proportion of the unvolatilised portion of the N applied. (The default values for this portion are 90% for synthetic fertilizers, 80% for organic fertilizers and animal waste, and 100% for all other categories). The default values for emissions from cultivated histosols are 5 and 10 kg N_2O-N ha^{-1} y^{-1} for temperate and tropical climates, respectively. That for N deposition by grazing animals is 2% of the unvolatilised N.

Many studies have appeared in the last few years that provide substantial additional data on direct emissions. Table 1 lists some of the results from studies over whole crop seasons (or 12- month periods of grassland management), and Figure 1 (A. R. Mosier, pers. comm.) shows the distribution of emission factors for data published since 1994 over study periods ranging from a few days to 2 years, together with earlier data from Bouwman (1996) relating to studies of ≥80 days' duration.

Smith et al. (1998a) found that the average emission factor for sites in Scotland in the early 1990s was less than the default value of 1.25% of the mineral N applied, and suggested that this might be a result of the generally lower temperatures at these sites than those covered by the review. However, results for 1997 and 1998 (seasons with higher than average summer rainfall) gave emission factors for grassland, potato and broccoli that were all greater than the default value, while those for small-grain cereal crops remained low (Table 1, Figure. 2; Dobbie et al, 1999). Data from Colorado, USA has shown comparable differences between small grain crops and maize (A.R. Mosier, pers. comm.), but a wider data comparison including data from many regions did not reveal any such overall effect (Mosier and Kroeze, 1999). Further data analysis is desirable to determine whether, within this dataset, differences between the emissions from different crops can be identified within other particular geographical or climatic zones.

TABLE 1

SOME RECENT PUBLISHED DATA ON N_2O EMISSION FACTORS FOR GRAZED AND UNGRAZED INTENSIVE GRASSLAND AND ARABLE LAND

Source of N/ Crop or land use	Country	Emission factor (%)	Reference
Mineral fertilizer			
Grassland	UK (1992-4)	0.2-1.4	Clayton et al., 1997
Grassland	UK (1997-8)	0.6-7.1	Dobbie et al., 1999
Arable (small grains)	UK (1994-7)	0.2-0.7	Smith et al., 1998a;
Arable (other crops)	UK (1996-8)	1.2-11.2	Dobbie et al., 1999
Arable (wheat)	Germany	5.0-8.8†	Flessa et al., 1995
Arable (wheat/barley/sugar beet/OS rape)	Germany	0.7-8.5	Kaiser et al., 1998
Arable (maize)	Canada	1.0-4.0	MacKenzie et al., 1998
Arable (wheat)	Mexico	1.7-3.8	Ortiz-Monasterio et al., 1996
Arable (maize)	China (NE)	2.0	Chen et al., 1997
Arable (rice)	China	0.3-1.2‡	Xu et al., 1997
Grassland	Costa Rica	6.8	Veldkamp et al., 1998
Banana	Costa Rica	1.3-2.9	Veldkamp & Keller,1997
Dung / urine (spread)			
Grassland	UK	0.1-1.4	Yamulki et al., 1998*
Grassland	Germany	0.4-1.3	Poggemann et al., 1995*
Dung / urine deposited			
During grazing			
Grassland	Netherlands	1.0-1.99	Velthof et al., 1996*
Grassland	New Zealand	0.2-1.0	Carran et al., 1995*
Grassland	UK (1996-7)	1.7-3.8	Smith et al., 1998b

*cited in Oenema et al., 1997.

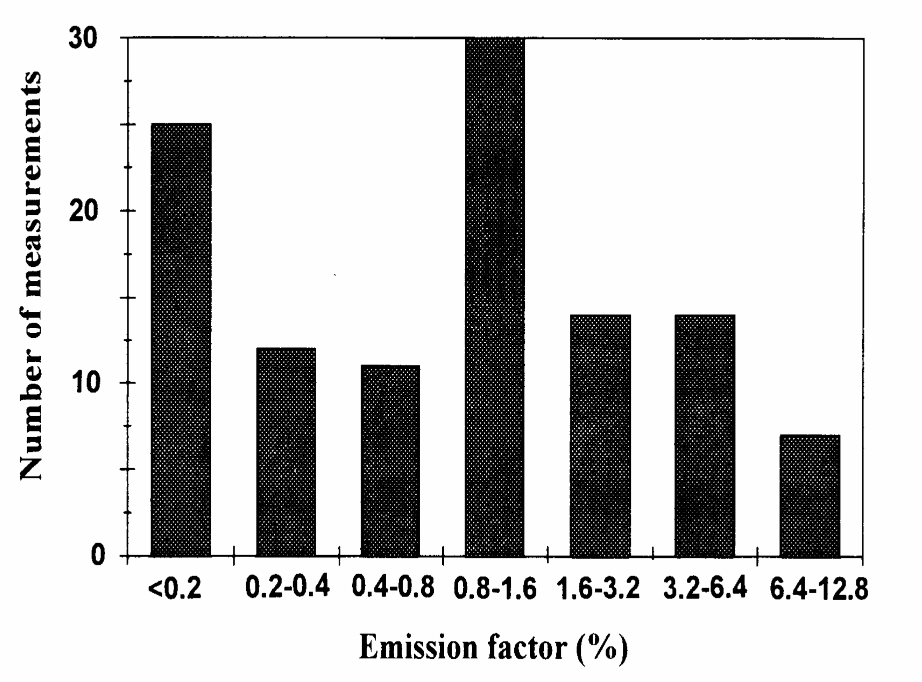
†No account taken of unknown amount of mineral N released from 10 t ha^{-1} of FYM.

‡ No account taken of unknown amount of mineral N released from 5 t ha^{-1} of pig manure.

Temporal variability

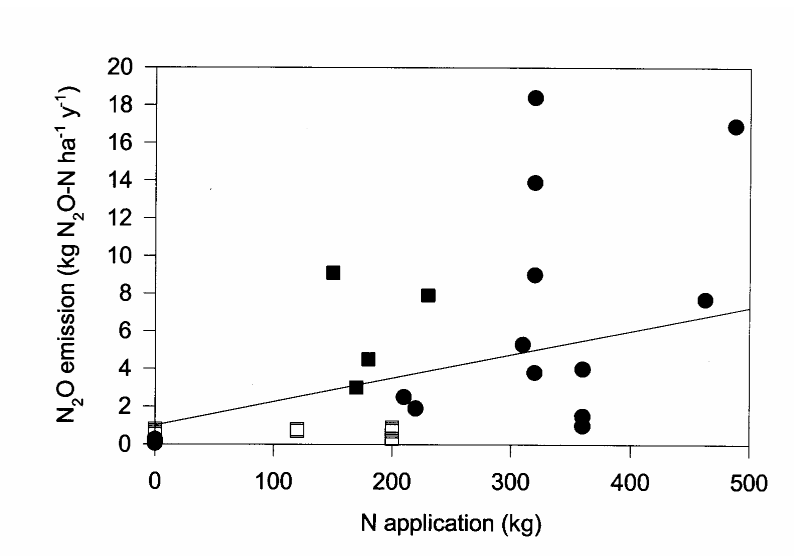
There was a 20-fold variation in annual flux at one grassland site between 1992 and 1998 reported by Dobbie et al. (1999), with the dominant factor being the rainfall around the time of fertilizer application. Flessa et al (1995) and Kaiser et al. (1998) found that a large proportion of the annual N_2O emission from arable land in Germany followed soil freezing/thawing in winter, as found in earlier work from continental climates (e.g. Goodroad and Keeney, 1984). In recent years at least, erratic winter weather has resulted in large variations in the extent to which such freeze/thaw events occur, in many countries, so this suggests that the contribution of such weather changes to emissions may vary dramatically from year to year. These observations indicate that a prolonged period of study is required in many regions before a robust annual mean flux can be obtained, even for one site, because of short-term vagaries in the weather, both in summer and winter. In hot dry environments where irrigation is applied, obviously such variations due to weather are minimised. However, variations in the system of management can be almost as important. For example, variations in time elapsed between fertilization, sowing and irrigation in a wheat system in Mexico have been shown by Ortiz-Monasterio et al. (1996) to have a large impact on N_2O.

Figure 1 Frequency distribution of N_2O emission factors (percent of fertilizer N applied) for 36 temperate studies published since 1993, together with data from Bouwman (1996) for measurement periods > 80 days and for which the emissions from fertilized plots had been corrected by subtraction of emissions from an unfertilized control (data for flooded rice not included).



Source: A.R. Mosier, pers.Comm. 1999

Figure 2 Annual N_2O emission plotted against the amount of fertilizer N applied, for crops grown in the cool temperate zone (Scotland).



Continuous line is regression line from Bouwman's (1996) analysis of emission factors published at that time. ●: grassland; ■: arable (non-cereal) crops; □: cereal crops (wheat, barley).

Source: Dobbie et al 1999

2 METHODOLOGICAL ISSUES

2.1 Selection of good practice methods

It is good practice to use country-specific data, where they are available, for activity levels and conversion factors (e.g. fertilizer consumption, crop production, harvest index), and for N_2O emission factors. A decision tree is a useful device for identification of sources and sub-sources and determination of the methodology to be applied to calculate emissions, depending on the availability of data and the importance of the source.

Where emissions are described with emission factor or regression approaches, variability can be used instead of the usual practice of averaging out the heterogeneity. This is done, for example, by presenting frequency distributions for regions or functional types, or the standard deviation for grid boxes. In many cases the point-by-point uncertainty is not known. However, even the indication of the maximum and minimum values could be more helpful than the mean alone for sensitivity and quantitative uncertainty analysis.

Where distinct and easily identified differences in structure and composition of agro-ecosystems coincide with the functions or management conditions relevant to trace-gas fluxes at the scale considered, the delineation of functionally different types or production/ management systems provides a useful basis both for measurement strategies, and development of emission factors. Appropriate selection of classes may lead to reducing the number of sites to be sampled so as to derive a reliable emission factor. Maps provide a useful basis for delineation, and in recent years remote sensing of (agro-) ecosystem characteristics has been used increasingly for classification and modelling. Such approaches use the variability of a system or landscape instead of ignoring it.

2.1.1 Process models

Reliable regional or global estimates of trace gas emissions depend on an examination of methodologies to reduce the current high uncertainty in the estimates. One potential way to do this is to develop predictive flux models. Such models have been developed for different processes and gas species on different scales.

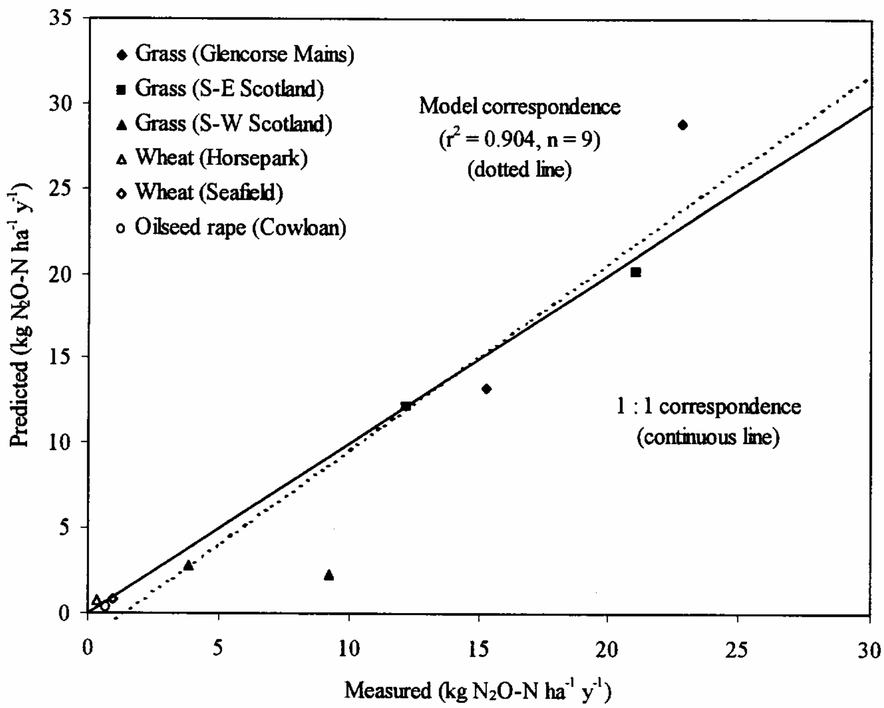
The regression relationship based on Bouwman (1996) outlined in Section 1.2.2 above is an example of a simple empirical model. Several "process-oriented" models of greater complexity have been developed over recent years, that simulate N trace gas emissions as part of more general simulations of C and N biogeochemical transformations in terrestrial ecosystems. These models include CENTURY-NGAS (Parton et al., 1994, 1996), DNDC (Li et al., 1992), ExpertN (Engel and Priesack, 1993), and NASA-CASA (Potter et al., 1997). Also, several still more detailed process-based models have been published over the last 10 years (see references in Frolking et al., 1998). Both the DNDC and ExpertN models were developed specifically for agroecosystems, and together with CENTURY-NGAS AND NASA-CASA have been used in a recent model comparisons, in which N_2O emissions from three contrasting agricultural systems were simulated and the predicted values compared with the measured ones. In most cases the simulated annual N_2O fluxes were within a factor of about 2 of the measured fluxes, although some periods of emission were considerably over- or under-estimated (Frolking et al., 1998).

Often, available data are too limited to satisfy the input requirements of complex models. To overcome this problem, sometimes summary models have been developed using key parameters which control the flux and which have been identified by detailed process modelling and/or by experimental observation. An approach of this type has been used recently to simulate the N_2O emission from cool temperate grassland sites in Scotland. The data of Clayton et al. (1997) and McTaggart et al. (1997) for N_2O flux, soil mineral N content, temperature and water-filled pore space (WFPS) for one site in the 1992-93 and 1993-94 seasons (in fact, one of the datasets used by Frolking et al., 1998 – see above) have been used to predict the emissions at the same site and elsewhere in 1997 and 1998. The fluxes were assumed to be capable of exceeding 10 g N_2O-N ha^{-1} d^{-1} only when the topsoil mineral N content was >10 mg kg^{-1} soil, and then flux ranges of 1-10, 10-100 or 100-1000 g N_2O-N ha^{-1} d^{-1} were predicted according to the temperature/WFPS regime at the time (Conen et al., 1999). Integration of the log-mean values over time gave generally good agreement with measured fluxes, over a wide range (Figure 3).

Mosier et al. (1998) suggested that process models should be utilised in future inventory methodology development. Consideration should be given to the question of how such models might be used, for example:

- together with non-spatially explicit subdivisions of a region in areas with similar conditions for N_2O fluxes; or
- in combination with geographical information on soils and climate (or weather) and management; or
- for the purpose of developing "mean" emission factors for the region/district/province considered.

Figure 3 Comparison of predicted and measured seasonal N_2O emissions from different arable crops and intensive grassland in Scotland.



Source : Connen et al, 1999

Arising out of the information contained in Section 1.2.2 above, it appears that although the existing default value for direct soil emissions was the "least bad" method available at the time it was adopted, there is a potential for updating it, and possibly for refining it to give regional variations according to climate, and possibly according to special aspects of management practice. The variation in flux with soil water content has been identified as a major controlling variable in grassland in regions as different as the cool temperate zone (e.g. Dobbie et al., 1999) and the humid tropics (Veldkamp et al., 1998). Up to half the annual emission from arable land can be generated by winter freeze-thaw events (Flessa et al., 1995; Kaiser et al., 1998). Ways in which the emission factor could be modified to take account of such effects should be a priority area for new synthesis work.

Current IPCC default emission factors for N_2O are given in Table 2.

The gross imbalance in experimental effort between environments in the developed countries and the developing countries needs to be addressed, particularly as the balance of N fertilizer use is progressively shifting towards the latter, and as the climates where this N is used are generally at the warmer end of the climatic range. A coordinated programme that studies emissions from the major crop/soil systems of some of the larger countries, e.g., Brazil, China, India, Indonesia, Nigeria, Pakistan, Vietnam, should be a priority.

Relevant questions relating to methodology development at this stage are:

- Are IPCC defaults adequate? Can they be (or should they be) updated, disaggregated, and/or further refined? In particular, should there not be different default values for different N inputs (e.g. animal waste, and combinations of synthetic fertilizers with crop residues or organic manures, may produce a higher percentage N_2O than synthetic fertilizers alone)?

- What are the uncertainties associated with the default emission factors? Is there any bias in the way they have been derived?

- Should countries be asked to calculate, wherever possible, emissions based on both default values and on locally derived factors, where they are clearly representative?

- What are the implications of this for uncertainties in, and compatibility among, national inventories?

- What should happen if a country uses a default emission factor, but has some information that suggests that the default may not be entirely appropriate?

- Should there be guidelines/criteria for developing "acceptable" local emission factors? (e.g. for fertilizer-derived N_2O, that emissions should be measured at a specified frequency following a fertilization application, then at specified reduced frequencies until the next application and after post-harvest cultivation, etc.) What are key considerations with respect to applicability of emission factors under different conditions?
- Is additional research needed?

In spite of the difficulties associated with making emission estimates, it is worth noting that the latest revision to the *IPCC Guidelines* (IPCC, 1997; Mosier et al., 1998) has been used to make an estimate of N_2O emissions at the *global* level, and when this estimate was used as input to a simple atmospheric box model the observed increase in atmospheric N_2O with time could be explained reasonably well (Kroeze et al., 1999).

TABLE 2

CURRENT IPCC DEFAULT METHOD FOR CALCULATING N_2O EMISSIONS FROM DIRECT SOURCES

Source	N content	Emission factor
Crop production[1] Synthetic N fertilizer	Amount of N applied - 10% NH_3 + NO_x loss	
Animal excreta used as fertilizer & other organic fertilizers	Amount of N applied - 20% NH_3 + NO_x loss	1.25%
Biological nitrogen fixation	Amount of N is 2 ● harvested crop biomass ● N content (3%) for pulses and soybeans	1.25%
Crop residues[2]	Amount of N is 2 ● harvested crop ● N content minus harvested parts (45%) minus fraction of crop residue that is burnt in field (25% in developing countries, <10% in developed countries) minus fractions used as biofuel and in construction	1.25%
Cultivation of organic soils	Area of cultivated organic soils	Temperate regions: 5 kg N_2O-N ha^{-1} y^{-1} Tropical regions: 10 kg N_2O-N ha^{-1} y^{-1}
Livestock production[3] Grazing	N in animal excreta dropped during grazing	2.0%

1 Excluding glasshouse farming.

2 Excluding root biomass.

3 Excluding direct emissions of N_2O from animals through nitrate reduction in the gut of animals.

Source: IPCC 1997.

2.2 Activity data

The major forms of economic land use activities generating emissions of N_2O and other trace gases include livestock and crop production. Livestock production is the most complex system. To estimate N_2O emissions from animal manure during and after application as a fertilizer, the following information is required: the number of animals in each category (e.g. dairy cattle), N excretion per head by animal type, and the mode and amount of manure application, together with the emission factors. For proper estimates of the ammonia and nitrogen oxides loss (see Table 2) from animal waste, it is essential to know the weather conditions during spreading (turbulence, air temperature, air humidity and rainfall), the properties of the soil to which the manure is applied, the amount of manure per unit area, and the period between application and cultivation.

Outside Europe and North America all these data are scant. Data on animal populations by category, and within a category (according to age and weight class) are almost non-existent. For many countries only the total number of animals within a category is available for a specific year. Data are not available on some animal categories, such as house pets, horses, buffalo, donkeys, camels. Estimates for regions within countries may be available, but do not always correspond to the official statistics or are outdated.

In many countries it is difficult to obtain data on the amount and composition (mineral N, organic N, recalcitrant N) of animal waste for different age classes within animal categories. Therefore, these data have to be estimated from the "average" animal in a particular country or production system. Geographic data on the application rate and timing of manure application, soil conditions, and weather conditions during application are not available. In addition to spatial variability, manure application rates, and mode and timing of application, show a strong interannual variability, which is not easy to include in scaling exercises.

Data on crop production systems that are essential for estimating trace gas fluxes include fertilizer use (including animal manure and other organic inputs) and the mass of residues which is ploughed into the soil (in units of N), or the amount produced of the crop(s) whose residues are ploughed under (in units of biomass). Such data may be available for regions within countries but may not always correspond to the official statistics or may be outdated.

In summary, the economic and attribute data generally have to be inferred from aggregated country totals for the different land-use systems.

2.3 Uncertainty

Parallel to the IPCC sector-specific workshops on good practice guidance, the IPCC is completing a programme of work on emissions inventory uncertainty. This work will result in recommendations to the IPCC on approaches to assessing and managing uncertainty. During the IPCC Inventory Experts Group Meeting in Paris (October 1998), technical experts in the uncertainty programme came up with a series of questions to be answered in the sector workshops. These questions are presented in the general background paper, and are elaborated below in the context of direct N_2O emissions from agricultural soils. This working group should discuss and provide answers to these questions. These answers will contribute to the uncertainty programme's work on establishing a general methodological approach to managing uncertainties in GHG inventories. The UNFCCC Secretariat's recent report on "Methodological Issues Identified While Processing Second National Communications: Greenhouse Gas Inventories" (UNFCCC/SBSTA/1998/7) noted that all Annex I Parties who reported uncertainties with their inventory estimates characterized the uncertainty associated with N_2O emissions from agricultural soils as "high".

Table 3 lists the types of activity data required for this source category.

TABLE 3

ACTIVITY DATA REQUIRED FOR ESTIMATION OF DIRECT N_2O EMISSIONS FROM AGRICULTURAL SOILS

Type of Activity Data	Units
Commercial synthetic fertilizer consumption[1]	kg N/yr
Commercial organic fertilizer consumption[1,2]	kg N/yr
Livestock and poultry wastes that are applied to soils	kg N/yr
Crop product and residues of nitrogen-fixing crops	kg N/yr
Crop residue returned to soils	kg N/yr
Histosol area cultivated (by climatic zone)	ha/yr

[1] It is desirable to collect disaggregated data on individual crops.

[2] This value should not include animal waste nitrogen used as commercial fertilizer if the "livestock and poultry wastes that are applied to soils" data include this nitrogen.

Important questions that should be addressed by the working group on direct N_2O emissions from agricultural soils include:

- Can quantitative uncertainties be identified for the sub-sources in this source?
- Can these uncertainties be derived empirically or must expert judgement be used?
- Are qualitative uncertainty estimates more appropriate in some cases?
- Are there sub-sources for which uncertainty cannot be estimated?
- Might uncertainties change over time?

Data on mineral fertilizer production and consumption are probably more reliable than any other data needed for emission estimation. National and international fertilizer manufacturers' associations can provide good data, and are complemented by national, EU, FAO, OECD etc. statistics-gathering activities covering all major countries, providing information on consumption, exports and imports, that form part of normal economic management.

Any gaps are likely to be comparatively minor. Problems such as collection of statistics on bases other than calendar years are relatively minor as long as 12-month continuous periods can be identified, and as long as the approach is consistent and transparent, because changes in rates of consumption are fairly gradual.

The uncertainties associated with the other headings in Table 3 are evidently much greater. This poses the following additional questions:

- How might uncertainties vary if international rather than country-specific data are used for the activity data? (Note that many of the activity data are derived from other data, the individual uncertainties of which will need to be estimated.)
- What additional work is needed to quantify these uncertainties?
- Can areas of potential covariance between emissions estimates for sub-sources in this source and other sources or sub-sources be identified?
- Are there weak spots or areas of inconsistency within this source that should be emphasized (i.e., missing sub-sources, systematic errors, trend errors)?
- What documentation is necessary for the default and specific uncertainty estimates?

2.4 Completeness

The OECD/IPCC/IEA phase II development of the *IPCC Guidelines* methodology for agricultural sources of N_2O was recently described by Mosier et al. (1998), including methodologies for calculating both direct and indirect emissions of N_2O related to agricultural production. The methodology attempts to relate N_2O emissions to the agricultural nitrogen cycle and to systems into which N is transported once it leaves agricultural systems. The methodology is based on the utilization of N as a nutrient for plant growth. Anthropogenic N inputs into agricultural systems include N from synthetic fertilizers, animal wastes and other organic fertilizers, biological nitrogen fixation by crops, cultivation of organic soils, and mineralization of crop residues returned to the field. Direct sources include those where N_2O is emitted directly to the atmosphere from cultivated soils and fertilized and/or grazed grassland systems. Indirect emissions result from transport of N from agricultural systems into ground and surface waters through drainage and surface runoff, or emission as ammonia or nitrogen oxides and deposition elsewhere, causing N_2O production.

Basically, the proposed methodology is an emission factor approach. The general rules for calculating N_2O emissions for the different direct sources are listed in Table 2 above.

From the list it is clear that the methodology involves, in fact, an inventory of inputs of N in agricultural soils. It is complete, since it represents all major agricultural flows of N.

Soil sink

The “soil N_2O sink” has merited a question mark in IPCC assessments hitherto, but it is appropriate to address the issue here. There is clear evidence that in very wet soils, significant reductions of N_2O can occur in the soil before it can escape to the atmosphere, thus reducing the net emission. However, the magnitude of the uptake of N_2O already in the atmosphere is not clear, though some studies have reported small negative (i.e. sink) fluxes; these have usually been trivial compared with emissions. There is a very good reason for this, which is that the conditions required for N_2O reduction inhibit the corresponding transport of the N_2O to the microbial sites where reduction takes place. This contrasts with methane oxidation, in which the conditions promoting the oxidation also favour the transport of the substrate.

It would be desirable to attempt to put an upper limit on the size of the sink. As it may well be at least two orders of magnitude less than the source, this would make the sink <0.04 Tg N ha y^{-1}.

2.5 Other important issues

2.5.1 Linkages with other sources

Some of the databases used to derive activity data for this source will be used to derive emission estimates for other sources. Countries need to ensure that:

- consistent activity data sets are used,

- consistent conversion factors are applied to activity data, and
- the totals of activity data across sources and sub-sources are correct.

For example, crop production data may be used to estimate non-CO_2 emissions from agricultural residue burning, N_2O emissions from agricultural soils, non-CO_2 emissions from biofuel combustion, and CH_4 emissions and carbon sequestration from waste management. In this case, not only should the source of crop production data be the same for all four sources, but also the residue to crop mass ratios and other conversion factors (dry matter fractions, carbon and nitrogen fractions) used to estimate emissions from the latter four sources must be consistent.[1]

Also, the crop residue production that is implied by the crop production statistics for each crop should be consistent with the assumptions used to estimate the amounts of residue that are burned, ploughed under, used as fuel, treated as waste, and the amounts that are used in other applications that might not be included in the inventory (e.g. as fodder and construction material). Another example is animal waste data, which in addition to being used in the agricultural soil calculations, are used to estimate CH_4 emissions from manure management and may be used to estimate non-CO_2 emissions from biofuel combustion. In countries that utilise animal wastes in a variety of applications (e.g. as fertilizer, fodder, construction material, and biofuel), the sum of the parts should not be greater than the whole. The working group should review and document these linkages among sector and subsector activity data so that QA/QC guidance can be developed for this source.

2.5.2 Corrections to Revised 1996 *IPCC Guidelines*

The Agriculture chapter of the *IPCC Guidelines* includes methodologies to estimate CH_4 emissions from enteric fermentation; CH_4 and N_2O emissions from manure management; CH_4 emissions from rice cultivation; CH_4, CO, N_2O, and NO_x emissions from savanna burning and from agricultural residue burning; and N_2O emissions from agricultural soils. Activity data and emission factors overlap between source categories; however, there are some inconsistencies in the default values and use of these variables across and within sub-sections of the *IPCC Guidelines.* The following is a preliminary list of inconsistencies across sub-sections.

Nitrogen Fractions

Table 4.19 default parameter for the fraction of nitrogen in N-fixing crops ($FRAC_{NCRBF}$) in Agricultural Soils sub-section (p. 4.94) is inconsistent with the default values for soya beans in agriculture residue burning section.

Residue to crop product mass ratios

The Residue Burning sub-section contains crop-specific values (Table 4-17), while the “Residue crop application” part and the “Biological N fixation” part of the Agricultural Soils sub-section assume a ratio of 1 for all crops. Also, the procedures for estimating crop residue mass vary between the Residue Burning and the Agricultural Soils sub-sections. (Note: The table of conversion factors in the Residue Burning subsections contains errors [i.e., dry matter fractions from Strehler and Stutzle], and should be corrected.)

Manure Management System Usage

Table 4-21, p. 4.101, in Agricultural Soils sub-section is inconsistent with Table B-3 in Appendix B in Manure Management sub-section. Both are based on Safely et al., 1992. Table B-3 is the most updated and should replace Table 4-21.

Daily Spread

The Reference manual uses the term “daily spread” to mean two different processes. “Daily spread” is used in the context of Safley et al.’s (1992) work (i.e., to mean a waste management technique), as well as to encompass all forms of application of wastes to soils (daily spreading, spraying after storage, etc.). Both usages of the term appear in the Agricultural Soils sub-section. The latter use of the term should probably be dropped from the Guidelines to avoid confusion, and another term be devised for this process.

Dry Weights

It is not clear if the dry weight conversions are oven dry or air dry. This should be clarified and conversions should be consistent across sources.

Within the Agricultural Soils sub-section itself, there are some errors, inconsistencies, and areas for improvement. Table 4 highlights a preliminary list of errors and offers corrected formulas as well as recommendations for further improvements. The text should also be revised to incorporate any changes.

[1] At present, some of the default values in the Guidelines are not consistent across source categories.

2.5.3 Accounting for mitigation measures

At the third Conference of the Parties to the UNFCCC in December 1997, Annex I Parties agreed to legally binding emission reduction commitments which are specified in Annex B of the Kyoto Protocol. Article 7 of the Protocol requires decisions on the use of inventories to demonstrate compliance with commitments be made by the Conference of the Parties serving as the Meeting of the Parties at its first session (COP/MOP1), and Article 5 requires the COP/MOP1 to make decisions on national systems for inventories, including decisions on revisions to the IPCC inventory methods based on work of the IPCC. Now that there are binding national commitments under the Kyoto Protocol to the UNFCCC, the IPCC should consider the ability of the IPCC inventory methods to accurately account for mitigation measures. COP/MOP1 may be in place by 2001 or 2002; therefore, the IPCC should reach conclusions on this issue by 2001.

The current IPCC method for estimating direct N_2O emissions from agricultural soils may not capture all of the emission impacts of possible national mitigation measures, depending upon how the method is implemented. Implementation depends, in part, upon the clarity and detail of the methodology description in the *IPCC Guidelines*.

The current IPCC method for estimating N_2O emissions from this source utilises three types of primary activity data:

- Additions of nitrogen to soils from fertilizer application (synthetic and organic, including animal wastes), cultivation of nitrogen-fixing crops, and incorporation of crop residues;
- Mineralisation of soil organic matter (humus) through cultivation of histosols, and
- Additions of nitrogen to soils from grazing animals.

Mitigation activities that directly reduce the magnitude of these activities (e.g., reduced national consumption of fertilizers, reduced national populations of grazing animals) will be reflected in national inventories because the underlying primary activity data will reflect these changes. However, mitigation measures that affect a) the conversion factors that are applied to the primary activity data, or b) the emission factors that are applied to the final activity data, may not be reflected in national inventories unless the inventory calculations incorporate these changes accurately. This may be particularly problematic if mitigation measures are implemented to reduce a different GHG source than N_2O from agricultural soils, and the effects on sources that are not being targeted directly are not evaluated or monitored. For example, if livestock feed practices are altered to improve livestock productivity (and reduce associated CH_4 emissions from digestion), and this results in a change in nitrogen excretion per head, new nitrogen excretion rates will need to be developed and used in the inventory calculations. Another example is soil and crop management practices to increase soil carbon stocks, such as use of no-till rather than tillage systems or use of “organic” rather than conventional cropping systems (e.g. Drinkwater et al., 1998). If these management practices also result in altering the fraction of applied nitrogen that is emitted as N_2O, and the emission factor is not revised, this additional benefit will not be captured in the national inventory.

This working group should consider examples of other mitigation measures whose emission impacts might not be completely captured, and develop recommendations for improvements to the Guidelines to address this potential shortcoming. There are two primary issues to consider:

- Guidance to users for the selection of appropriate stratification schemes for emission estimates, based on the scale of the exercise and the available spatial data, and the development of site-specific emission factors, and
- A discussion of the possible impacts of mitigation measures across sources.

3 REPORTING AND DOCUMENTATION

The UNFCCC Secretariat’s recent report on “Methodological Issues Identified While Processing Second National Communications: Greenhouse Gas Inventories” (UNFCCC/SBSTA/1998/7) noted that while most countries reported N_2O emissions from agricultural soils, the thoroughness of reporting was highly variable among countries.

TABLE 4

CORRECTIONS TO SECTION 4.5 (IPCC GUIDELINES) GREENHOUSE GAS EMISSIONS FROM AGRICULTURAL SOILS

Reference[a]	Current Approach	Corrected Approach	Recommended Improvements
Pg 4.92, Equation 1	$F_{CR} = 2 \bullet [Crop_0 \bullet Frac_{NCR0} + Crop_{BF} \bullet Frac_{NCRBF}] \bullet (1\text{-}Frac_R) \bullet (1\text{-}Frac_{BURN})$	$F_{CR} = [Crop_0 \bullet Res_0/Prod_0 \bullet Frac_{DM} \bullet Frac_{NCR0}] + [Crop_{BF} \bullet Res_{BF}/Prod_0 \bullet Frac_{DM} \bullet Frac_{NCRBF}] \bullet (1\text{-}Frac_{BURN})$	Subtract fraction used in construction, fraction used as biofuel, and fraction used as fodder: $(1\text{-}Frac_{BURN}\text{-}Frac_{BIOFUEL}\text{-}Frac_{CNST}\text{- }Frac_{FOD})$
Pg 4.92, Equation 1	$N_2O_{DIRECT} = [(F_{SN} + F_{AW} + F_{BN} + F_{CR}) \bullet EF_1] + F_{OS} \bullet EF_2$		Include organic fertilizers other than crop residues and animal wastes. State the default volatilization fraction for these fertilizers.
Pg 4.92, Equation 1	$F_{BN} = 2 \bullet Crop_{BF} \bullet Frac_{NCRBF}$	$F_{BN} = (Crop_R + Crop_{BF}) \bullet Frac_{NCRBF}$ where $Crop_R$ is the crop residue specific to the crop.	Based on Table 4-17, the factor of 2 is much too low for pulses & soybeans. Current equation does not apply to fodder crops such as alfalfa.
Pg 4.92, Equation 1	$F_{AW} = (Nex \bullet (1\text{-}(Frac_{FUEL} + Frac_{GRAZ} + Frac_{GASM})$		Acknowledge that some countries use some of their animal waste as animal feed or for construction: $F_{AW} = (Nex \bullet (1\text{-}(Frac_{FUEL} + Frac_{GRAZ} + Frac_{CNST} + Frac_{AF} + Frac_{GASM})$
Pg 4.94, Table 4.19	$Frac_R$ default value = 0.45 kg N/kg crop-N	$Frac_R$ default value = 0.5 kg N/kg crop-N because text assumes aboveground residue/crop mass ratio equals 1. Also, definition of FracR on page 4.93 should be corrected to "fraction of aboveground crop biomass (residue + product) that is removed from the field as crop.	Change name to $Frac_{Prod}$ because the variable's definition is the amount of total aboveground biomass that is removed as *product*. However, this variable is not needed if the equation for F_{CR} is corrected as shown in top row above.
Pg 4.96	The N_2O emission is expressed as gN/kg of nitrogen in Appendix A, Table A-1	The N_2O emission is expressed as a percent (e.g., $gN_2O\text{-}N/10^2gN$) in Appendix A, Table A-1	
Pg 4.104, Table 4-22	Footnote c on Solid storage and drylot (To be reported under "Agricultural Soils" under direct soil emissions from agricultural fields after spreading)	Replace footnote c on Solid storage and drylot with footnote b (To be reported under "Manure Management")	
Pg 4.106, Equation 3	$N_{LEACH} = [N_{FERT} + N_{EX}] \bullet Frac_{LEACH}$		Include nitrogen from organic fertilizers other than crop residues and animal wastes.

[a]All page references from Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

Note: These corrections should be made in Workbook as well.

3.1 Current IPCC reporting guidelines[2]

The *IPCC Guidelines* are used to guide countries in the preparation and submission of inventories of annual greenhouse gas emissions and sinks to the UNFCCC Secretariat. The Guidelines establish:

Standard tables, definitions, units, and time intervals for reporting all types of emissions to ensure consistency of reporting across countries;

The necessary documentation to enable comparison of national inventories, including worksheets, major assumptions, methodological descriptions, and enough data to allow a third party to reconstruct the inventory from national activity data and assumptions, and an uncertainty assessment.

Nitrous oxide emissions from agricultural soils are reported under the IPCC category 4D, within the Agriculture sector. At present, the Reporting Instructions do not disaggregate this category into sub-sources, e.g., direct emissions from agricultural soils, direct emissions from grazing animals, indirect emissions from agricultural soils and livestock wastes. As distinct (but related) components, these three sub-sources could each be listed as a separate category under agricultural soils.

Estimates of N_2O emissions from agricultural soils are reported in Vol 1 IPCC Table 4: Sectoral Report for Agriculture, which calls for estimates for each agricultural source of CO_2, CH_4, N_2O, and precursor gases (NO_x, CO, NMVOC) except agricultural soil sources of CO_2 (which are reported in Vol 1 IPCC Table 5: Sectoral Report for Land-Use Change and Forestry). Currently, the table does not have a separate entry for each of the sub-sources within the N_2O from agricultural soils source. Because this source is composed of three distinct sub-sources that are based on partially, but not completely, overlapping activity data and emission factors, reporting by sub-source rather than by source total would be more meaningful and transparent to third party reviewers. The working group should determine what level of disaggregation (to the three sub-sources, or further) would be optimal in terms of transparency.

Estimates of N_2O emissions from agricultural soils are also reported in aggregate in IPCC Tables 7A (Summary Report), 7B (Short Summary Report), and 8A (Overview Table). The working group should determine what level of disaggregation is appropriate in these tables too. And given the recommended level of disaggregation, the working group should also evaluate the use of "PART", "ALL", "NE", and IE, and "OE" in the Table 8A and the adequacy of the Disaggregation Key (IPCC Table 8B).

In addition to the lack of transparency in the reporting tables, there is also a lack of clear guidance on reporting of how estimates were calculated. Issues to consider in order to address this shortcoming include:

- Reporting of the estimation methodology, including algorithms and equations used and assumptions made;
- Reporting of the source and nature of activity data and emissions factors, including analysis of trends;
- Reporting of how emission estimates may have changed from previous inventories, and
- Reporting on QA/QC procedures.

3.2 Confidential business information

The activity data and conversion factors needed to estimate direct N_2O emissions from agricultural soils are all likely to be publicly available. No issues associated with data confidentiality are expected to arise in reporting emission estimates from this source.

[2] Note from authors: This section reflects the state of IPCC reporting guidance in early 1999, when this paper was written. Since then, revised reporting tables for national greenhouse gas inventories have been drafted and agreed to by the Conference of the Parties (see http://www.unfccc.int/resource/docs/cop5/07.pdf). These revised reporting tables, which are referred to as the "Common Reporting Format", address many of the issues discussed in this section.

4 INVENTORY QUALITY

4.1 Introduction

Inventory quality assurance and quality control (QA/QC) is a process integral to the development of a credible inventory. A well-developed and well-implemented quality assurance programme fosters confidence in the final inventory results regardless of the purpose and goal of the inventory. A successful quality assurance programme requires internal quality control procedures and an unbiased, external review and audit. The internal QC activities are designed to ensure accuracy, documentation, and transparency. The external review process is designed to minimize errors that occur in the preparation of emission inventories, and reduce or eliminate potential inherent bias. Figure 4 outlines the flow of information and processes followed at each step.

Figure 4 Inventory QA/QC Process

Data Collection Agencies

Internal QC:	Activity data and calculations
Documentation:	Activity data provided to the government agency, and results of internal QC

⇩

Inventory Agency

Review/QA:	Activity Data, emission factors, and calculations
Internal QC:	Compilation of national inventory from activity data, conversion factors, and emission factors
Documentation:	Results of compilation and results of QA/QC
Reporting:	Official submission to UNFCCC

⇩

External Review

External Review:	External audit, stakeholders, peer & public review of inventory results, external verification against other data etc.
Documentation:	Results of external review

⇩

UNFCCC Secretariat

External Review:	Requires standard format and transparency – ensure consistency with other inventories and external data

4.2 Internal inventory QA/QC systems

4.2.1 Data collection agency activities

Activity Data QC

The personnel that collect data are responsible for reviewing the data collection methods, checking the data to ensure they were collected and aggregated correctly, and cross-checking the data with previous years to ensure the data are reasonable. The basis for the estimates, whether statistical surveys or "desk estimates," must be reviewed and described as part of the QC effort. The various data sets that are required for the direct N_2O emissions from agricultural soils would be collected by different agencies and/or organizations:

Commercial Fertilizer Consumption Data

Commercial fertilizers include both synthetic and organic fertilizers. Annual synthetic fertilizer consumption data are generally available in-country; if not, statistics on fertilizer production, consumption and trade are available on the internet from the International Fertilizer Industry Association (which gives data on the various fertilizer types), as well as the reports on fertilizer use by crops compiled by FAO (FAO/IFA/IFDC, 1994, and later editions). This information may become important if emission factors for individual crops/crop groups are developed in the future. Annual commercial organic fertilizer consumption data may or may not be available; if available, these data, and the synthetic fertilizer data, would typically be collected by a country's ministry of agriculture or a fertilizer trade organization.

Livestock and Poultry Wastes that are Applied to Soils

These data will be obtained from the N_2O from manure management inventory. The personnel that obtain these data for the soil calculations are responsible for determining that the values used do not include wastes that are deposited by grazing animals and wastes that are used for other purposes (such as for biofuel or feed).

Crop Product and Residues of Nitrogen-Fixing Crops, and Crop Residue Returned to Soils

These data will be derived from annual crop production statistics. These statistics are generally collected by a country's ministry of agriculture or similar organization; if not, FAO statistics may be used.

Histosol Area Cultivated (By Climatic Zone)

These data may be difficult for many countries to obtain. While geo-referenced databases of soil types are generally available from the ministry of agriculture or similar organization, information on which areas are cultivated may not be readily available. In some cases, an academic research study may have compiled these data at a national or regional level.

Wastes from Grazing Animals

These data will be obtained from the N_2O from manure management inventory.

Activity Data Documentation

Documentation is a crucial component of the review process because it enables reviewers to identify mistakes and suggest improvements. The following information should be included in the documentation:

- A detailed description of the methods used to collect the activity data, and
- A discussion of potential areas of bias in the data, including a discussion of whether any of the data may be misrepresentative of the country.

4.2.2 Inventory agency activities

Inventory Agency Review (QA) of Activity Data

Before accepting the activity data, the inventory agency should assess the activity data. This review involves close cooperation with the personnel responsible for collecting, compiling, and analyzing the data. The assessment should include a review of the detailed methods used to collect the data, including a review of any surveys and interviews performed to collect the data. In addition, the assessment should include a comparison of the activity data with historical data and with similar data used for other sources in the inventory, and an evaluation of the potential for bias and areas for improvement.

Inventory Agency QC on Compiling National Emissions

In addition to a thorough quality assessment of data discussed above, the inventory agency should ensure that the processes of aggregating and converting activity data to develop the national inventory undergoes quality control. This should include, among other things:

- Cross-referencing the crop product and crop conversion factors with values used to estimate emissions from other sources;
- Ensuring that all bottom-up activity estimates are complete and that there has been no double counting of activity levels among sources, and
- Comparing with national trends to look for anomalies.

In addition, the emission factors should also undergo review. QC procedures include reviewing the values available (default or otherwise) and documenting the rationale for selecting specific values.

Inventory Agency Documentation on Compiling National Emissions

Documentation is a crucial component of the review process because it enables reviewers to identify mistakes and suggest improvements. If default emission factors are not used, a detailed description of the equations and/or approach used to derive emission factors is needed. The input parameters must be defined and the process by which they are obtained must be described. The frequency of data collection and estimation, and results of determinations of accuracy and precision, must be elaborated. In addition, a standardized reporting form is recommended to provide transparent information on the steps taken to calculate the emission factors and derive the activity data. Each step should contain the numbers used in each calculation, including the source of any data collected.

4.3 External inventory QA/QC systems

External QA activities include a planned system of review and audit procedures conducted by personnel not actively involved in the inventory development process. The key concept is independent, objective review to assess the effectiveness of the internal QC programme, the quality of the inventory, and to reduce or eliminate any inherent bias in the inventory processes. Several types of external reviews, or audits, may be appropriate for the inventory of direct N_2O emissions from agricultural soils.

Third party audit by an accredited organisation, expert, independent third party

An audit of the documentation and calculations ensures that each number is traceable to its origin.

Expert (peer) review

Although a detailed peer review would be appropriate when a procedure for determining N_2O emissions is first adopted or revised; it would not be needed on an annual basis. Such a review is designed to ensure that the methodology is rigorous, accurate, and that the data and assumptions reflect the best available information.

Stakeholder review

Review by industrial organizations and government can provide a forum for review of the methods used.

Public review

Some countries make their entire inventory available for public review and comment. This process may result in a range of comments and issues broader than those from other review processes.

5 CONCLUSIONS

Direct emissions of N_2O from agricultural soils have increased substantially over the last few decades, in parallel with increasing use of N fertilizers. Current emissions, which have been estimated by the IPCC Phase II methodology to be about 2.1 Tg N y^{-1}, are likely to increase still more in future, as inputs of N to agriculture continue to rise.

The present IPCC default emission factor for N_2O of 1.25±1.0 percent of the N applied must necessarily stand for the time being, but there is considerable scope for more data analysis to see whether significant differences between crop types and/or between regions and climatic zones are now discernible. In some variable environments, several years of study will be needed to derive robust mean emission values. The soil sink for N_2O is unlikely to exceed 1 percent of the soil emission source

In compiling national GHG inventories, it is good practice to use country-specific data, where available, for the activity data and N_2O emission factors. It is also desirable, if the data are available, to report frequency distributions for emission factors, rather than just to average out the heterogeneity. There is a potential for reducing the present high uncertainty in emission estimates through the development of predictive flux models.

In the course of calculating N_2O emissions at the country level, there is a need to ensure consistency in activity data sets, crop conversion factors and the like. Also, a number of corrections are required to the methodologies contained in the *IPCC Guidelines*, to remove inconsistencies. Disaggregation of agricultural soil emissions into component sub-sources would improve the transparency of the information.

Improvements to methods for estimating emissions may also be needed to determine the impacts of possible mitigation measures, both those aimed directly at N_2O reduction but also soil management measures designed to increase soil carbon.

To satisfy quality assurance and quality control requirements, there needs to be detailed documentation of the methods used to compile activity data and the approach used to derive emission factors, coupled with independent review and audit procedures.

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