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The development of the EMEP/CORINAIR Guidebook with respect to the emissions of different nitrogen and carbon species from animal production

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Abstract

The reduction of emissions of air pollutants is subject of international conventions, which include reporting of emissions in accordance with guidelines or guidebooks provided. Within the Convention on the Long-range Transboundary Air Pollution, the *Atmospheric Emission Inventory Guidebook* describes the methodology. With respect to emissions from agricultural sources, in particular from animal husbandry, this guidebook at present undergoes major modifications: the calculation procedure making use of partial emission factors for the various sources of emissions (animal house, storage, manure application, etc.) is being replaced by a mass flow concept for both nitrogen and carbon species. The current state of the Guidebook, present activities to update it and future plans are described. The necessity to update both the Guidebook and the IPCC Guidelines as complementary tools to describe agricultural emissions and mass flows is emphasized.

Keywords: Emission inventories; Animal husbandry; Mass flow approach

1. Introduction

Air pollution has resulted in adverse effects, which urgently require emission reductions. However, emissions are a result of human activities, and reduction measures are likely to interfere with human needs and habits. It is therefore necessary to identify reduction potentials and evaluate them with respect to feasability, affordability and accomplishment. In any case, the initial step is the quantification of emissions in a way that allows to meet these goals. In agriculture, this stresses the need for methods, which go beyond simple calculations of the type:

$$\text{emission rate} = \text{animal number} \times \text{emission factor}$$

Air pollution is a transboundary phenomenon. It is therefore subject of international conventions. As the costly reduction of emissions may result in a distortion of markets, international regulations have to be established which provide a harmonized, transparent, comparable and consistent methodology to all partners within the respective convention.

In the UNECE Convention on the Long-range Transboundary Air Pollution (LRTAP, Geneva Convention, UNECE, 2004), the Joint EMEP/CORINAIR[3] *Atmospheric Emission Inventory Guidebook* (AEIG) (EMEP, 2003a) is

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[1] UNECE Task Force on Emission Inventories and Projections, Agriculture and Nature Panel.

[2] UNECE Working Group on Effects, Expert Group on Ammonia Abatement.

[3] EMEP: Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe; CORINAIR is the project aiming at gathering information on emissions into the air within the CORINE programme (see EMEP, 2003b).

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the collation of those procedures. It is to be used to construct emission inventories primarily of those air pollutants which fall under the regulations of this Convention, i.e. air pollutants which cause acidification, eutrophication and production of ground level ozone: sulfur dioxide (SO_2), nitrogen oxides (NO, NO_2), volatile organic compounds (methane, CH_4, as well as non-methane volatile organic compounds, NMVOC) and ammonia (NH_3). The methodologies listed are also used to determine emissions for other purposes such as the National Emission Ceilings (NEC) directive (European Parliament, 2001). The Guidebook also deals with species primarily considered to be greenhouse gases such as nitrous oxide (N_2O) and carbon dioxide (CO_2, from liming only). In this case, the AEIG takes over the relevant methodologies provided by the Intergovernmental Panel on Climate Change (IPCC) in their Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines) (IPCC, 1997, 2000), in order to avoid contradictory estimates. However, these guidelines may be "translated" into the terminology of AIEG, and they may be modified in a way that they meet the national data requirements better than the IPCC methodology.

The methodologies provided have to serve the needs of emission inventory construction as mentioned above. They also have to reflect the state of science. Therefore, both the AEIG and the IPCC Guidelines have to be updated adequately. Editing and updating of the AEIG is the responsibility of the UNECE Task Force on Emission Inventories and Projections (UNECE TFEIP, 2004). The chapter on agricultural emissions is dealt with by the Agriculture and Nature Panel of this Task Force. As NH_3 is the pollutant presently receiving most attention amongst agricultural emissions, it seems natural that the TFEIP Agriculture and Nature Panel co-operates with the UNECE Expert Group on Ammonia Abatement within the Working Group on Effects (WGE).

This paper provides information about the present activities of both the UNECE TFEIP Agriculture and Nature Panel and the WGE Expert Group on Ammonia Abatement to update, amend and improve the methodologies needed to quantify the emissions in animal husbandry, in particular the necessity to develop both the AEIG and the IPCC Guidelines as complementary tools for improved inventories.

2. Driving forces

Several international protocols require emissions reporting, either as national annual totals or as gridded data with a defined resolution in space and time. In other international agreements, such as the Gothenburg Protocol (UNECE, 1999) or the National Emission Ceilings (NEC) Directive (European Parliament, 2001), parties commit themselves to emission reduction targets. High-resolution data are needed, where emission data are used to generate high-resolution maps, e.g. of critical loads exceedances. It becomes clear that in this case the resolution in space has to be of the same order of magnitude as the resolution of the maps describing effects, and that the resolution in time has to relate to the atmospheric lifetime and transport of the pollutant considered.

Unlike other sources, animal husbandry constitutes both point and area sources with low emission heights. Whereas most animal houses are likely to be point sources with a more or less continuous emission, spreading of animal wastes results in high emissions during comparatively short periods of time. The processes emitting trace gases or particles in agriculture are quite well known in principle. However, no agricultural source equals another: the number of animals kept in one unit may vary over two to three orders of magnitude; each farm has its own combination of emitting processes; each farmer has individual ideas about farm management. Thus, the updating of the emission inventories tries to account for the current understanding of the emission processes, which is then expressed in better (i.e. more precise) emission factors or functions. Amending of the methodologies aims at a completion of the inclusion both of the sources and of the methodologies to describe them. Improvement above all comprises quality assessment, i.e. a thorough description of the data and methods used (including their inadequacies) as well as the uncertainties involved.

Emission inventories are also needed to identify and quantify mitigation options. In agriculture, decisions have to be made by the farmer. Thus, the measures taken by policy makers and administration to reduce emissions have to be made plausible on the farm scale in order to be understood. This means that the tools provided for national inventories also have to be applicable at farm level to illustrate effects. Emission inventories must disaggregate emissions in such a way that the reduction measures and the mitigation potentials can be judged according to their cost effectiveness and their efficiency.

3. The mass flow approach

In contrast to most other sources, emissions in agriculture comprise a set of carbon (C) and nitrogen (N) species originating from the same source, however, under varying conditions. One source to be considered is the amount of easily degradable N compounds (total ammoniacal N, TAN) in excreta. If animals are kept in houses, emissions from this source may occur in the animal house itself or its compartments (such as a dairy parlour), during storage and during or after spreading. In each case, temperature, atmospheric exchange conditions, availability of oxygen, etc., result in different activities of microbial populations, vapour pressures and equilibria. Thus, it was felt within the Agriculture and Nature Panel that the only way to describe emissions from animal husbandry was to apply a mass flow approach, which depicts the pathways of both N and C species strictly under the aspect of mass conservation. This is illustrated below using emissions of N species as an example.

Simpler methodologies calculate overall emissions in animal husbandry using fixed *amounts* per animal or animal place such as illustrated in Fig. 1:

$$E_{\text{total}} = E_{\text{metabolic}} + E_{\text{grazing}} + E_{\text{housing}} + E_{\text{storage}} + E_{\text{spreading}} \quad (1)$$

where E is the emission (kg a^{-1}).

For a given number of animals, total emissions are calculated using the sum of the partial emission factors:

$$E_{\text{total}} = n_{\text{animal}} \cdot (EF_{\text{metabolic}} + EF_{\text{grazing}} + EF_{\text{housing}} + EF_{\text{storage}} + EF_{\text{spreading}}) \quad (2)$$

where n is the number of animals considered and EF is the emission factor (kg animal^{-1} a^{-1}).

This procedure is repeated for each gas independently.

However, if one considers the mass flow to follow a leaky pipe system such as in Fig. 2, it becomes clear that the approach has to be different in principle. If the pipes release N in the form of NH_3 and also nitrous oxide (N_2O), nitric oxide (NO) and dinitrogen (N_2) from the same source of TAN, the losses E_i from each step i in the lower half of the drawing have to be described as:

$$E_i = F_i \cdot (EF_{i,NH_3} + EF_{i,NO} + EF_{i,N_2O} + EF_{i,N_2}) = F_i \cdot \sum EF_i \quad (3)$$

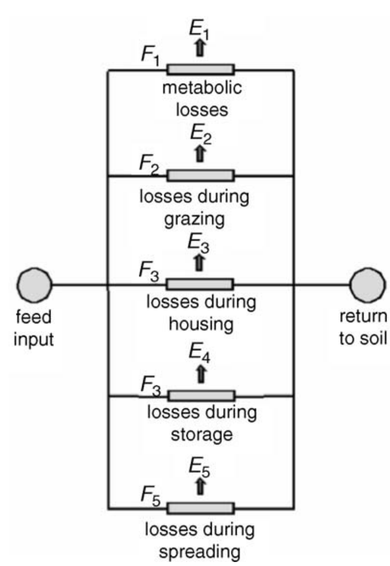


Fig. 1. Leaky pipe illustrating losses from animal excreta due to metabolic processes, during grazing, housing, storage and spreading according to the approach using "classical" partial emission factors for parallel flows. F denotes fluxes and E denotes emissions.

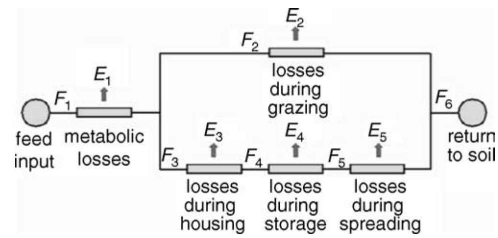


Fig. 2. Leaky pipe illustrating losses from animal excreta due to metabolic processes, during grazing, housing, storage and spreading according to the mass flow approach and consecutive losses in the housing to spreading line. F denotes fluxes and E denotes emissions.

resulting in a flux of matter to the next step F_{i+1} which is related to F_i according to:

$$F_{i+1} = F_i - E_i = F_i \cdot (1 - \sum EF_i) \quad (4)$$

As a rule, emissions of N species in animal husbandry are a function of:

- the amount of N excreted, which itself is at least a function of the respective (quantity and composition of) animal feed and performance (e.g. milk yield, live weight gain, egg production rate);
- the composition of the excreta, in particular the portion of N which may be readily converted to ammonia (TAN) and the distribution of N fractions between faeces and urine;
- the amount of N excreted during grazing, which is a function of the duration of grazing and of animal behaviour, temperature, etc.;
- the amount of N excreted during housing (including excretions on various hard standings such as the dairy parlour), differentiated according to the various building types;
- the amount of N imported into the system with bedding materials;
- the transformations of N pools into one another (TAN into organic N: immobilization; organic N into TAN: mineralization);
- the amount of N transferred to the various storage facilities, differentiated according to the storage type and duration of storage, the temperature of the store, etc.;
- the amount of N (or TAN) left before spreading, the method used to spread, the temperature and other meteorological parameters at the time of spreading, infiltration properties of the soil, density and height of plants, and the time between spreading and incorporation.

Slurry and manure treatment (bio-gas production, slurry separation, manure composting, etc.) may change the properties of the emission source decisively. External sources (the use of additives, etc.) may contribute to the mass flow.

The overall treatment of this mass flow is quite complicated. A system of leaky pipes, which may be consecutive or switched in parallel, still serves as model. If it is integrated in the agricultural mass flow system, a pattern as illustrated in Figs. 3 and 4 results.

The overall mass flow in agriculture depicted in Fig. 3 considers inputs from external sources, in particular as mineral fertilizers and N fixation. N can remain in the plant soil system and can be directly released as NH_3, N_2O, NO and N_2 from fertilizers, soils and plants. Crops produced can serve as animal feed. If so, they are inputs into the animal subsystem. In the animal subsystem, direct metabolic emissions will occur, in particular of CH_4 from enteric fermentation. N and C excreted are then stored and eventually spread. These flows and the respective emissions are dealt with in the manure management subsystem. After spreading these manures, their contents are returned to the soil/plant subsystem, where they will result in further direct and indirect emissions, the latter originating from run-off and leached as well as from deposited reactive N species.

Fig. 4 gives details on the flows considered in the manure management subsystem naming the various processes which contribute to fluxes as well as the locations where they happen, in particular, yards (waiting yards, exercise yards,

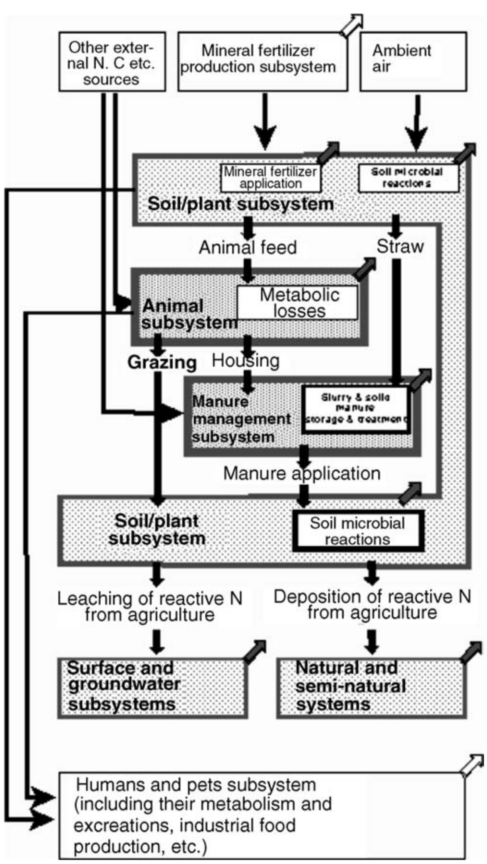


Fig. 3. Overall mass flows through the agricultural subsystems considered in the EMEP/CORINAIR Guidebook Chapter 10 (Agriculture). *Overview*—narrow arrows: mass flow between external sources and sinks and the agricultural subsystems; wide black arrows: fluxes between agricultural subsystems; wide gray arrows: emissions to the atmosphere included; wide white arrows: emissions to the atmosphere not included (Dämmgen et al., 2003).

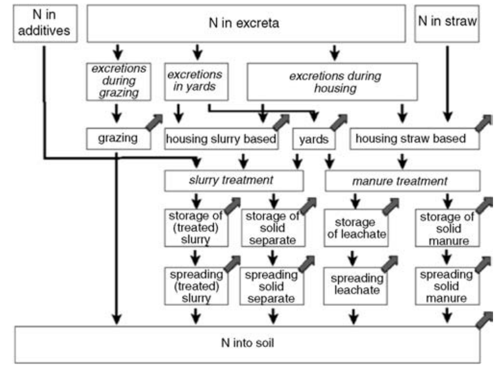
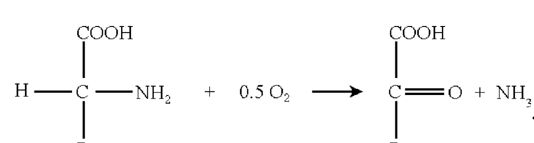


Fig. 4. Details of the mass flows considered in the EMEP/CORINAIR Guidebook Chapter 10 for description of the manure management subsystem (Dämmgen et al., 2003).

dairy parlour) have been identified as important sources of NH_3 emissions, which have to be treated separately. In straw-based systems, N in straw has to be included. Slurry and manure treatments are important measures to reduce emissions. Immobilization and mineralization processes have to be considered. Their influence on the emissions of gases other than the one primarily considered has to be judged. The four rectangles symbolizing storage comprise the various ‘‘parallel pipes’’ for the respective housing types involved (slurry and straw-based tied systems or cubicle houses, deep litter systems, etc.) as well as the fact that straw-based systems may produce leachate, which has to be stored separately. Both slurry and solid manures are spread using various methods and incorporation times. This is reflected in the mass flow approach.

In the AEIG, the mass flow approach is the detailed methodology (equivalent to Tier 2 in the IPCC Guidelines) and does not make use of default values. As can be expected, detailed calculations deviate from default assumptions. This is exemplified in Fig. 5 for N excreted from a dairy cow (columns A and C). It also shows that actual NH_3 emissions may be much larger than standard IPCC values, if conventional housing, storage and spreading systems are used (compare columns B and D). In addition, it illustrates that NH_3 emissions, which were reduced during housing and manure storage, will result in increased emissions from spreading. The simpler methodology would suggest the same emissions at this stage. The mass flow also quantifies the amount of N returned to the soil.

In faeces, NH_3 is primarily released from the decay of amino acids. Thus, whenever NH_3 is formed, the simultaneous formation of volatile fatty acids (non-methane volatile organic compounds, NMVOC) is likely to happen, e.g.



amino acid α-keto acid

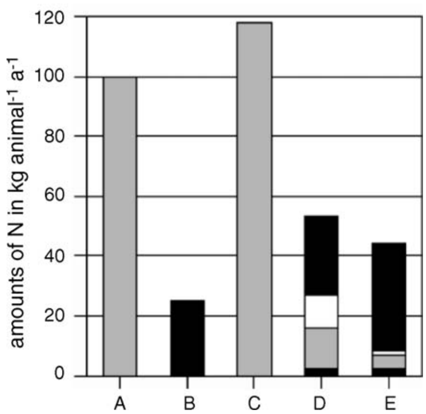


Fig. 5. Nitrogen excretion and emissions of dairy cows. Column A: excretion of the IPCC default dairy cow in Western Europe. Column B: IPCC default NH_3-N emissions from this cow. Column C: Excretion of a dairy cow producing 8000 kg a^{-1} milk according to a detailed calculation. Stacked column D: NH_3-N emission of this cow from milking (black, bottom), housing (slurry, cubicle house, gray), storage (open tank, no crust, white) and spreading (broadcast on arable land; black, top). Stacked column E: NH_3-N emission of the same cow with emission reductions in housing and storage; emissions from milking (stacked columns as for D), housing (slurry, tied), storage (tank with solid cover) and spreading (broad cast on arable land without incorporation) (columns D and E calculated using the mass flow approach for NH_3; N_2O and N_2 losses are not significant).

The degradation of organic material under anaerobic conditions both inside the rumen and in waste by bacteria produces methane (CH_4). Management or feeding practices, which influence the formation of NH_3, are likely to affect CH_4 and N_2O emissions as well. It therefore makes sense to combine the estimations of NH_3 emissions with the consideration of *all* those gases formed from the particular source, which are formed simultaneously in *one* calculation procedure. In a stepwise approach, the AEIG aims at a description of all emissions at least in animal husbandry according to this mass flow approach.

4. The *Atmospheric Emission Inventory Guidebook*

4.1. The present state of the agriculture sector in the Guidebook

The agriculture sector (sector 10 of the AEIG) is subdivided into chapters dealing with emissions from the plant soil system and from animal husbandry. Each chapter deals with topics of general importance and provides background information. It also normally contains descriptions of simpler and detailed methodologies, gives default or exemplary emission factors and discusses open questions and uncertainties. A comprehensive list of references illustrates the state of knowledge, which was incorporated into the chapter. Most chapters of the Guidebook have been updated during the past 2 years. The availability and the degree of detail of the various methods dealing with emissions from animal production are illustrated in Tables 1 and 2.

The AEIG and the respective IPCC methodologies differentiate between direct and indirect emissions. Due to historic reasons, the AEIG deals with the emitter ‘‘dairy cow’’ in five different chapters:

- direct emission of NH_3 and N_2O from excreta dropped by grazing animals in Chapter 10 01;
- direct emission of CH_4 from enteric fermentation in Chapter 10 04;

Table 1
Classification of activities (source categories) according to EMEP/CORINAIR (2001) and attribution to the Selected Nomenclature for Air Pollutants numbes (SNAP 97, EMEP/CORINAIR, 2001) for gases from animal metabolic processes (enteric fermentation)

Category	Activity	SNAP[1]	NH_3	N_2O	NO	CH_4[2]	NMVOC	PM
Methane emissions from animal husbandry (enteric fermentation)	Dairy cows	10 04 01				S		
	Other cattle	10 04 02				S		
	Sheep	10 04 03				S		
	Fattening pigs	10 04 04				S		
	Horses	10 04 05				S		
	Mules and asses	10 04 06				S		
	Goats	10 04 07				S		
	Laying hens	10 04 08						
	Broilers	10 04 09						
	Other poultry	10 04 10						
	Fur animals	10 04 11						
	Sows	10 04 12				S		
	Camels	10 04 13						
	Buffalo	10 04 14						
	Any other animals	10 04 15						

In previous Guidebook editions, Chapter 10 04 dealt with CH_4 emissions both from enteric fermentation and from manure storage.

[1] Structure of SNAP: SNAP level 1 denotes the aggregated sector in which the emission is occurring (e.g. 10: agriculture); SNAP level 2 describes the disaggregated sector (e.g. 10 04: enteric fermentation); SNAP level 3 deals with the various emitters in this detailed sector (e.g. 10 04 01: enteric fermentation, dairy cows). In sector 10, the Guidebook chapters normally describe methods for SNAP level 2.

[2] The degree of detailing and disaggregation: S, simpler methodology (equivalent to Tier 1 in IPCC nomenclature).

Table 2
Classification of activities (source categories) according to EMEP/CORINAIR (2001) and attribution to the Selected Nomenclature for Air Pollutants numbers (SNAP 97, EMEP/CORINAIR, 2001) for gases emitted from manure management

Category	Activity	SNAP	NH_3	N_2O	NO	CH_4	NMVOC	PM
Manure management regarding organic compounds	Dairy cows	10 05 01				S, D	FE	
	Other cattle	10 05 02				S, D	FE	
	Fattening pigs	10 05 03				S, D	FE	
	Sows	10 05 04				S, D	FE	
	Sheep	10 05 05				S		
	Horses	10 05 06				S		
	Laying hens	10 05 07				S		
	Broilers	10 05 08				S		
	Other poultry	10 05 09				S		
	Fur animals	10 05 10						
	Goats	10 05 11				S		
	Mules and asses	10 05 12						
	Camels	10 05 13						
	Buffalo	10 05 14						
	Any other animals	10 05 11						
Manure management, regarding nitrogen compounds	Dairy cows	10 09 01	S, I, D	S	S			
	Other cattle	10 09 02	S, I, D	S	S			
	Fattening pigs	10 09 03	S, I, D	S	S			
	Sows	10 09 04	S, D	S	S			
	Sheep	10 09 05	S, D	S	S			
	Horses	10 09 06	S, D	S	S			
	Laying hens	10 09 07	S	S	S			
	Broilers	10 09 08	S, D	S	S			
	Other poultry	10 09 09	S, D	S	S			
	Fur animals	10 09 10	S					
	Goats	10 09 11						
	Mules and asses	10 09 12						
	Camels	10 09 13	S					
	Buffalo	10 09 14	S					
	Any other animals	10 09 15						

FE, first estimate (gives the order of magnitude of an emission; database not representative); S, simpler methodology (equivalent to Tier 1 in IPCC nomenclature); I improved methodology (using combination of partial emission factors and national data in a simpler methodology to a considerable extent); D, detailed methodology (equivalent to Tier 2 in IPCC nomenclature); organic compounds include CH_4 and NMVOC. For the detailed methodology see Tier 2 in IPCC (1997, 2000); (SNAP 10 09 has been reallocated in 2002, in line to changes to the Nomenclature for Reporting (NFR, the UNECE equivalent to the IPCC Common Reporting Format CRF). It now mirrors the 10 05 ordering.

- direct emission of CH_4 and NMVOC from manure management in Chapter 10 05;
- direct emission NH_3 and N_2O from manure management in Chapter 10 09;
- indirect emissions of N_2O due to atmospheric deposition of ammonium and nitrate resulting from agricultural emissions of NH_3 and NO in Chapter 10 02.

At least Chapter 10 02 presupposes the knowledge of the amount of N returned to soil, and this information is not yet obtained from the other chapters.

In the AEIG, an introductory chapter gives an overview on the somewhat confusing assignment of various sources and trace gases to the respective chapters.

4.2. Recent activities

The mass flow approach has been developed to describe fluxes within the ‘‘leaky pipe system’’ mentioned above. In this approach, the mass flows of total N, total ammoniacal N, total C and volatile solids are to be traced from their origin to their final incorporation into soil, including the secondary effects of emitted and deposited species (Fig. 3). Several attempts are being made at present to establish emission inventories using the mass flow approach, such as in the UK (Webb and Misselbrook, 2004), in Switzerland (Menzi et al., 2003) and Germany (Dämmgen et al., 2004). The respective authors jointly develop, compare and test the calculation procedures, which depict the integrated mass flow concept within the EAGER group (Menzi et al., in press). This group also deals with the major inadequacies, which presently aggravate the construction of ‘‘good’’ inventories:

- Activity data below official statistics have to be gathered adequately. This includes details of grazing (duration of grazing period, time spent grazing per day, etc.), housing (housing type, mucking frequency, etc.), slurry and manure processing (type and frequency), slurry and manure storage (facilities and duration) as well as spreading techniques and times including methods of incorporation. Questionnaires are being developed and tested to ascertain these data.

- Though the emission factors and functions used at present are not considered totally insufficient, the database from which they have been derived is sometimes inadequate to very inadequate. Good inventories require national data rather than default values. Language barriers and the fact that much of the relevant literature is not directly available, impede progress. Often, data sets lack a thorough description of the methodologies applied and the conditions under which they were gathered. International co-operative programmes and research activities helped considerably to gather information. However, the applicability of these data for inventory making is sometimes limited.

In order to improve communication and to avoid misunderstanding, the terminology will rely on the new ‘‘Glossary of terms on livestock manure management’’ (Pain and Menzi, 2003).

4.3. Future activities

Measures for the reduction of trace gas emissions identified to be meaningful by using the integrated mass flow approach will have to be valued with respect to their cost efficiency and affordability. Cost curves will have to be adopted or generated to allow for the derivation of political and financial measures.

Trace gas emissions from animal production may result in changes of the atmosphere's energy balance (both warming and cooling effects), others may contribute to acidification and eutrophication and to tropospheric ozone formation and destruction as well as destruction of stratospheric ozone. The models used to describe deposition of acidifying and eutrophying species presuppose emission inventories with a higher resolution in time and space, preferably a resolution of days and 1 km × 1 km grid squares. A first step to be achieved by the emission inventories is a resolution of single months and the order of magnitude of EMEP grid squares (50 km × 50 km). This applies to emissions of NH_3 and CH_4 in particular.

Immobilization of TAN as well as mobilization of organic N will soon be incorporated into the approach.

The tools needed to provide complete and adequate inventories (in particular, worksheets) will have to be made available within LRTAP as technical support instruments in the near future.

5. Where EMEP/CORINAIR Guidebook and IPCC Guidelines could/should meet

The IPCC Guidelines aim at a comprehensive inventory of emissions of greenhouse gases. As a rule their atmospheric lifetime is long compared to their transmission properties. On the contrary, the UNECE Guidebook deals with species whose chemical behaviour in the atmosphere results in short lifetimes. They have an impact at the chemical climate rather than the physical climate. In principle, their impacts on vegetation and human health require emission inventories with a higher spatial and temporal resolution. Hence, the difference in the historical development of the strategies of the two emission inventory guidance documents is understandable.

In general, the two guidance documents avoid contradictory methods. As far as emissions from agriculture are concerned, the EMEP/CORINAIR Guidebook refers to the IPCC Guidelines, whenever their ‘‘own’’ gases are not really concerned, i.e. N_2O emissions from manure management or from fertilizer application as well as CH_4 emissions from enteric fermentation or manure management. However, when one wishes to really apply a mass flow concept, the N losses due to emissions of all N species have to be quantified. This definitely includes the emissions of N_2, for which none of the guidance documents has made a proposal yet.

The IPCC Guidelines provide a method to quantify emissions from manure management. However, they neither provide guidance to estimate the amount of N excreted by the animals, nor do they give more than a rough estimate of the losses, which occur before the spreading of slurry or manure. It is an important issue for pollution reduction that all technical measures leading to a reduction of emissions from housing, storage and spreading, will result in increased N_2O emissions from soils both as direct emissions and as indirect emissions from leaching. However, indirect emissions from deposited N will be reduced. Measures to reduce NH_3 emissions in animal husbandry are likely to affect CH_4 emissions.

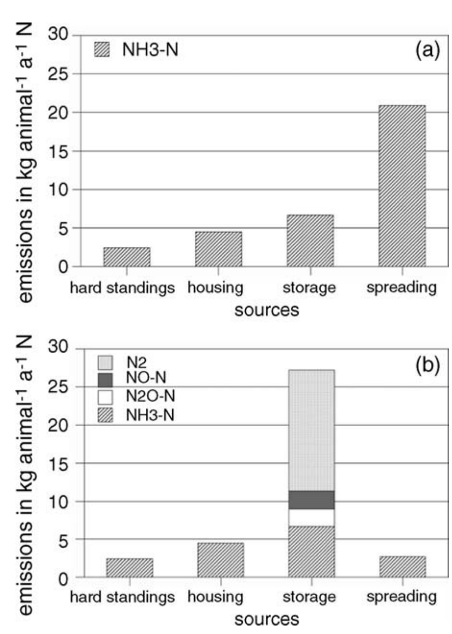


Fig. 6. Nitrogen losses during grazing, housing, storage and spreading calculated for NH_3 only (a) and all N species (b) for a dairy cow (8000 kg a^{-1} 1 milk) on straw, ‘‘normal’’ manure heap, spreading without incorporation.

Fig. 6a and b exemplary illustrate to what extent the emission pattern will change if all gases are included into the emission calculations: the mass flow calculation for a dairy cow on straw which accounts for NH_3 emissions only is shown in Fig. 6a. The major emission occurs during spreading. If one combines the ‘‘Guidebook emissions’’ with the ‘‘Guideline emissions’’ and bears in mind that N_2O emissions go along with NO and N_2 emissions, the picture changes significantly (Fig. 6b); N_2 losses are dominating, and NH_3 emissions during spreading are reduced, as the TAN pool is almost empty after the losses during storage.

In conclusion, a comprehensive emission inventory can be obtained by combining an updated Guidebook and updated Guidelines, where the methods describing a given source are complementary and cross-referenced throughout.

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