Integration of nitrous oxide (N_2O), nitrogen oxides (NO_x) and diatomic nitrogen (N_2) emissions into N-flow models for the determination of ammonia emissions

Evaluation based on a literature review

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15.02.2017

Commissioned by the Federal Office for the Environment

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Summary

The ammonia (NH_3) emission calculations for the Swiss agriculture are currently performed using the Agrammon model. In contrast to equivalent N-flow models, Agrammon does not account for losses of oxidized reactive N-species nitrous oxide (N_2O) and nitrogen oxides (NO_x) and diatomic nitrogen (N_2) at the different emission stages. To omit these N-compounds leads to comparatively higher NH_3 emissions in the Agrammon model. The aim of the present literature review is to report on available emissions and emission factors (EFs), their ranges in order to provide an overview on the actual state of knowledge and a base for the extension of the model Agrammon, for emissions of N_2O, NO_x and N_2.

The study included ca. 160 articles. Moreover, information was collected from guidelines for national greenhouse gas inventories.

The standard EF of 2% N_2O–N of N_{ex} according to IPCC (2006) for grazing is somewhat higher than data from the literature. In contrast, data from housings and manure storage from the literature are substantially higher than the EF according to IPCC. EFs for manure application coincide well.

Overall, the mean N_2O emission factors estimated based on the present literature studies coincide well with the standard values of IPCC (2006) for manure application but are higher for housing, manure storage and lower for grazing. The variability of the emissions is large and difficult to explain. For NO_x and N_2, the availability of data is very limited. For the determination of NH_3 emissions, only EFs from losses of N_2O, NO and N_2 from housing and manure storage are relevant. Although the numbers according to IPCC (2006) seem to be underestimated we suggest using these standard values for the Agrammon model in order to ensure consistency regarding the methods applied in the inventories on ammonia and greenhouse gas emissions

1 Introduction and aims

In 1999, ammonia (NH_3) was included as an air pollutant in the Gothenburg Protocol. The protocol aims at reducing acidification, eutrophication and ground-level ozone, within the framework of the Convention on Long-range Transboundary Air Pollution, CLRTAP (UN/ECE, 1999). Member countries of the convention have to report regularly on the amount of NH_3 emitted and to achieve national emission ceiling values. This is done by means of mass flow models which simulate the mass flow of nitrogen (N) and total ammoniacal nitrogen (TAN) from excretion by livestock animals through the stages of the manure handling chain (grazing, housing/exercise yard, manure storage and application). The NH_3 emission calculations for Swiss agriculture are currently performed using the Agrammon model (Kupper et al., 2015). In contrast to other models such as NEMA for the Netherlands (van Bruggen et al., 2014) and NARSES for the United Kingdom (Webb et al., 2004), Agrammon does not account for losses of oxidized reactive N-species nitrous oxide (N_2O) and nitrogen oxides (NO_x) and diatomic nitrogen (N_2) at the different emission stages. To omit these N-compounds leads to comparatively higher NH_3 emissions in the Agrammon model.

The aim of current study is to investigate emissions of N_2O, NO_x and N_2 from the emission stages grazing, housing/exercise yard, manure storage and application from livestock production. For this, a literature review was carried out related to papers published on these topics and the emission factors used in other emission models were reported. Available emissions and factors are listed and commented. Factors influencing the emissions are provided as well but in an extensive manner. Mechanisms driving the emissions were not investigated. The present literature study reports on available emissions and emission factors, their ranges in order to provide an overview on the actual state of knowledge and a base for the extension of ammonia emission models, namely the model Agrammon, for emissions of N_2O, NO_x and N_2.

2 Material and methods

A literature research on peer reviewed articles was carried out encompassing the emission stages grazing, housing/exercise yard, manure storage and application considering systems which produce liquid and solid manure. Approximately 160 articles were included. Moreover, information was collected within the European Agricultural Gaseous Emissions Inventory Researchers Network (EAGER), from the EMEP/EEA air pollutant emission inventory guidebook (EEA, 2013, 2016) and from the IPCC guidelines for national greenhouse gas inventories (IPCC, 2006). Still, the present study cannot be considered as a complete review.

The emissions of different systems are reported pragmatically according to the specifications prevailing in the literature. They are given as emission relative to the inflow in the emission stage, i.e. N_2O-N of N excreted (N_{ex}), for grazing, percent of initial N for solid manure storage and N_2O-N of N applied for spreading of slurry or solid manure. For housings, emissions are denoted kg N_2O per animal or per livestock unit (LU) and year (kg N_2O an^{-1} y^{-1}) and for slurry storage g N_2O m^{-2} y^{-1} is used. These specifications are usually denoted as emission factors (EFs). In the present report, the term "emission" is synonym to "EFs". The reporting of the data is related here to N_2O. Data for NO_x and N_2 are scarce and are given as far as they were available.

The term NO_x as used here refers to the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). It seems likely that NO is often used as synonym to NO_x in the literature since both terms nitric oxide and nitrogen oxides are simultaneously used where NO occurs as acronym only. Here, the term „NO" will only be used if it unambiguously stands for NO, i.e. nitric oxide. If there are doubts regarding the wording comments are given in footnotes.

The database collated within this literature study cannot be considered as exhaustive and either as completely error free due to the large database, the necessity to recalculate and transform the data and due to the limited availability of time. It might be worth to mention that some valuable review papers have been published (Chadwick et al., 2011; Hou et al., 2015; Li et al., 2015; VanderZaag et al., 2011) where further information on emission factors and mitigation options related to N_2O emissions can be obtained. They might include older papers not considered in this study, more information on mitigation options and on principal mechanisms relevant for N_2O, NO_x and N_2 emissions. The latter two points were not part of the present study.

3 Results

3.1 Grazing

3.1.1 Overview on available data

A total of 13 studies on N_2O measurements from grazing were found. Among these, one study worked with N^{15} labeled urine and dung (Wachendorf et al., 2008) and one study included NO (Maljanen et al., 2007). Studies on N_2 emissions from grazing were not found. Ten experiments investigated the emissions released from excreta applied in a simulated grazing pattern. Excreta were mostly obtained from dairy cows. Two references refer to emissions obtained from grazed plots (Rafique et al., 2011; Velthof, Oenema, 1997). Additional studies used artificial urine solutions (e.g. Anger et al., 2003; van Groenigen et al., 2005). They were excluded from the dataset although they may exhibit similar levels of emissions as the studies which are based on real excrements. Five references which report on emission factors used in emission models are included. An overview on the data is given in the Appendix 1 (Table 12 to Table 14).

3.1.2 Emissions of N_2O

Yamulki et al. (1998) measured N_2O emissions from cattle dung and urine applied to six separate experimental areas over a period of 15 months which were representative for an entire grazing season. The experimeatal area was located in UK. Application of livestock excreta increased N_2O emissions signifcantly over that measured from unamended control plots. They found emissions of 1% N_2O-N relative to the N excreted (N of N_{ex}) with urine and of 0.53% N of N_{ex} with dung. Flessa et al. (1996) determined EFs of 3.8% N of N_{ex} for urine and 0.5% N of N_{ex} for dung with an EF per animal of 3.2% N of N_{ex}. Velthof, Oenema (1997) give N_2O emissions from grazing for dairy cows of 2.5% and of 6% N of N_{ex} for mineral soils and peat soils, respectively. These data are based on Velthof et al. (1996) which were obtained from grazed plots. Studies based on grazing compiled by Oenema et al. (1997) exhibited EFs ranging from 0.2 to 9.99% N of N_{ex} They suggest an overall mean EF of 2% N of N_{ex}, with a possible range of 0.5 to 3.0% for grazing. Rafique et al. (2011) determined an average EF of 1.8% N of N_{ex} determined at eight sites in Ireland over two years at a fertilization of about 300 kg N ha^{-1} y^{-1} with higher emisisons at greater N-input levels. More frequent grazing lead to a higher EF. In another Irish study, Burchill et al. (2014) report a range between 0.5% and 1.6% N for grazed perennial ryegrass/white clover-based pastures with an annual stocking density of 2.35 cows ha^{-1}. Emissions of up to 7.2% N measured in Ireland as well over two years were reported from Hyde et al. (2006).

Bell et al. (2015) measured emissions from applications of cattle urine and dung within three seasonal experiments over twelve months in Scotland. The application timings were spring, summer and fall. Emissions from urine varied from 0.2% to1.1% N_2O-N of N applied (N of N_{appl}). They were greater than for dung (0.1-0.2% N of N_{appl}). Emissions in summer were higeher by a factor of 2 for dung and by a factor of approx. 3 to 5 for urine in summer as compared to spring or fall. Mean EFs were 0.53% N of N_{appl} for urine and 0.14% N of N_{appl} for dung. These numbers correspond with EFs of 0.04% and 0.15% N_2O-N of N_{appl} for dung reported by van der Weerden et al. (2011) and Rochette et al. (2014), respectively. For urine, the number published by van der Weerden et al. (2011) and Rochette et al. (2014) of 0.29% and 0.31% N of N_{appl}, respectively, lie in a similar range as the values of Bell et al. (2015).

The N_2O emission factor for urine determined for New Zealand ranged from 0.02 to 1.52% N of N_{appl} (Luo et al., 2008). In contrast to Bell et al. (2015), the emissions were strikingly higher in winter and spring compared to the summer season. Rafique et al. (2011) found N_2O fluxes being five times greater at 17 °C than that at 5 °C soil temperature. Similarly, the N_2O emissions increased with increasing water filled pore space (WFPS) with maximum N_2O emissions occurring at 60–80% WFPS. Virkajarvi et al. (2010) found N_2O-N emission from grass pastures of 0.6–1.4% N of N_{appl} for the control plots (without excreta but fertilized at an annual rate of 220 kg ha^{-1} N), and additional losses of 0.4–0.9% N of N_{appl} for the urine and 0.7–4.5% N of N_{appl} for the dung-treated areas, respectively. After one year, the N_2O emissions from the urine or dung plots did not differ from those from the control plots. Emissions from the winter season were significant. In the same experiment, unfertilized plots sawn with grass clover mixtures emitted more N_2O than the grass pastures Maljanen et al. (2007) determined emissions of N_2O being at 0.24% N of N_{appl} and 0.28% N of N_{appl} for urine and dung, respectively, after application in fall. Zaman, Nyuyen (2012) reported an emission factor for spring and fall season urine applications of 0.6% and 2.3% N of N_{appl}, respectively, for New Zealand. N_2O emissions from urine determined by Berneze et al. (2015) in UK were 0.66% N of N_{appl}.

Van Groenigen et al. (2005) conclude that compaction leads to a considerable increase in the N_2O emissions, mainly through higher WFPS. Dung addition may have the same effect. Seasonal variations seemed mainly be driven by differences in WFPS. They suggest that mitigation strategies should focus on minimizing the grazing period with wet conditions leading to WFPS > 50% avoiding areas in pastures with high livestock density and on avoiding grazing under moist soil conditions. Similarly, Rafique et al. (2011) found N_2O emissions being greater with increasing WFPS with maximum N_2O emissions occurring at 60–80% WFPS. Lampe et al. (2006) provided valuable general information on rates of N_2O emission, the effect of cattle grazing and the type (mineral fertilizer, cattle slurry) and amount of N supply on the flux of N_2O from a sandy soil based on a field study: N_2O emissions from permanent grassland managed as a mixed system (two cuts followed by two grazing cycles) were monitored over eleven months during 2001-2002 in northern Germany using the closed chamber method. The results suggest that N fertilizer application and grazing caused only short-term increases of N_2O flux rates whereas the major share of annual N_2O was emitted from the soil N pool. The grazing period contributed 31-57% to the cumulative N_2O emission and the significantly increased N_2O fluxes during freeze-thaw cycles (Dec. to Feb.) 26%, respectively. Rafique et al. (2012) found emission peaks immediately after grazing animals were removed from the pasture and after grass cutting. N_2O fluxes correlated well with soil ammonium concentrations but less with nitrate contents.

To summarize, all studies determined higher losses from urine than from dung except for Maljanen et al. (2007), Virkajarvi et al. (2010) and Wachendorf et al. (2008) who found higher N_2O emissions relative to the N_{appl} from dung than from urine. Two studies measured N_2O emissions at different seasons over the year (Bell et al., 2015; Luo et al., 2008). It is not clear if the emissions are higher during the warm season or the cold season. Influencing factors comprise the soil type, the N level in the soil and the state of the soil. Anger et al. (2003) found that N_2O emissions are correlated to the levels of fertilization with mineral N. Peat soils exhibited clearly higher N_2O emissions than other soil types (Oenema et al., 1997). Heavy soils like clay release more N_2O than light sandy soils (Oenema et al., 1997; Rochette et al., 2014). Compaction can lead to a considerable increase in the N_2O emissions (van Groenigen et al., 2005). Uchida and Clough (2015) state in their review that nitrous oxide emissions from winter-grazed pastures may be relevant. The magnitude of N_2O emissions may be influenced by direct excretal returns and plant activity. Adjustments of microbes and microbial community compositions to cold temperatures may also impact N_2O emissions. While lower soil temperatures are generally expected to diminish the microbial activity, the increased availability of C, NO_3^- and soil moisture under winter grazed pastures may enhance denitrifier activity.

3.1.3 Emissions of NO_x

Maljanen et al. (2007) determined nitric oxide (NO) emissions from urine and dung patches. NO emission from urine plots during the grazing season measured over 110 days accounted for 0.14% N of N_{appl} and during the fall over 62 days for 0.06% N of N_{appl}. From the dung, NO emissions ranged between 0.01% and 0.03% N of N_{appl}. NO accounted on average from 14% (fall) to 34% (summer) to total $(NO+N_2O)$–N emissions.

3.1.4 Emission factors used in models

IPPC (2006) list an emission factor for N_2O for dairy, non-dairy and buffalo, poultry of 2% N (i.e. 0.02 kg N_2O–N/kg of nitrogen excreted) and for pigs and for sheep and other animals of 1% N. It is based on several studies cited in IPCC (1996) reporting a range from 0.002 to 0.098 kg N_2O–N/kg of nitrogen excreted and lead to “overall reasonable average emission factor for animal waste excreted in pastures” of 0.02 kg N_2O–N/kg of nitrogen excreted. Dämmgen et al. (2006) use an EF of 2% N as given in IPPC (2006) for dairy, non-dairy and buffalo. Van Bruggen et al. (2014) use an EF of 3.3% N. Chadwick et al. (1999) give an EF of 0.5-1% N on the basis of Yamulki et al. (1998). Cardenas et al. (2013) determined an average EF of 0.4% N for UK (range: 0.13% N for England, 1.10% for Scotland).

EFs for NO are provided by Dämmgen et al. (2006) and van Bruggen et al. (2014) which are 0.7% N and 1.2% N, respectively[1]. EEA (2013) does not list an EF that specifically refers to grazing. N_2 is considered by Dämmgen et al. (2006). According to the proportions for the calculation of the emissions from mineral fertilizers, a 7fold amount of N_2O and NO was assumed yielding an EF of 14% N for N_2.

[1] Both sources use the term NO although it seems likely that NO_x is meant since the methodologies described are used for the modeling stipulated by the CLRTAP where NO_x has to be reported (pers. communication, D. Bretscher, agroscope).

3.2 Housing

3.2.1 Overview on available data

The following number of studies on N_2O measurements from housings was available: cattle: 12; pigs: 12; poultry: 7.

The data are presented in the form of emissions per animal, livestock unit (LU) or per animal place and per year which were derived from the available studies. Emission factors were estimated as follows:

$$EF_{N2O,hous} = EF_{N2O,meas} \times 28/44 \times N_{ex}$$

where $EF_{N2O,hous}$ is the emission factor in percent of N excreted, $EF_{N2O,meas}$ the measured emission in kg N_2O per animal/LU/animal place and year, 28/44 the conversion factor for transformation of N_2O to N_2O-N and N_{ex} the N excreted per animal or animal place and year. The N excretion was obtained from the literature or from unpublished data[2].

3.2.2 Emissions of N_2O

3.2.2.1 Cattle

Emission measurements were mainly performed using dairy cows. The major part of the dataset originates from loose housings producing slurry. The emissions amount to approx. 1 kg N_2O per animal or per LU and year (kg N_2O an^{-1} y^{-1}; Table 1). The variability is high however. Leytem et al. (2013) and Samer et al. (2012) found values which are higher by more than one order of magnitude than the average given in Table 1 for loose housings. The results published by Samer et al. (2012) can be considered as erroneous. An explanation thereof might be by the measured flows which were not corrected for the inflow concentrations (pers. communication A. Neftel, agroscope).

Tied housings systems produce significantly lower emissions (approx. 0.2 kg N_2O an^{-1} y^{-1}). However, the number of measurement is low. Systems producing slurry or slurry and solid manure do not differ in the emission level (Amon et al., 2001b). For the latter, only two studies are available. At higher temperatures increasing N_2O emissions were found (Jungbluth et al., 2001). However, data from Zhang et al. (2005) and Samer et al. (2012) do not provide an indication of a dependency between the emission level and the season when the measurements were carried out (Appendix 1, Table 15).

Zhang et al. (2005) compared the emissions from different floor types and manure handling systems. The emission rates were dependent on the floor type and the manure-handling method. The lowest emission was found for buildings with solid floors with smooth surface, scraper and drain. Slatted floors, manure treatment with acid (data not included for the emission calculation in Table 1), scraper on the slatted floor surface exhibited reduced emissions as well.

Table 1: Emissions obtained from the literature from housings of dairy cows for nitrous oxide (N_2O) in kg N_2O per cow or LU and per year. n=number of datasets; individual data are given in the Appendix 1, Table 15

	Tied housing		Loose housing		
	Slurry	Slurry/solid manure	Slurry*	Slurry/solid manure	Deep litter
n	1	1	22	-	3
	kg N_2O per animal or LU y^{-1}				
Average	0.22	0.23	0.90	-	0.70
Median	-	-	0.56	-	0.73
Min	-	-	0.05	-	0.46
Max	-	-	2.98	-	0.91

*Values from Leytem et al. (2013) and Samer et al. (2012) which are significantly higher (i.e. up to 22 kg N_2O per animal or LU y^{-1}) are not included.

[2] Average value of 120 kg N per cow and year for European countries, derived from unpublished data obtained from K. Groenestein, Livestock Research, Wageningen UR.

Based on the average given in Table 1 (i.e. 0.90 kg N_2O an^{-1} y^{-1} converted to 0.58 kg N_2O-N an^{-1} y^{-1} as described in section 3.2.1) and an N excretion of 120 kg N per cow and year the resulting $EF_{N2O,hous}$ amounts to 0.5% of N_{ex} for loose housing systems. For tied housing systems, it would be 0.1% of N_{ex} (based on one study). Owen and Silver (2015) calculated an $EF_{N2O,hous}$ of 6.2% of N_{ex}. They used an emission of 10 kg N_2O an^{-1} y^{-1} and N_{ex} of 105 kg N.

For beef cattle, the emissions ranged from 0.1 to 0.2 kg N_2O an^{-1} y^{-1} for loose housings producing slurry and solid manure (one study available: Amon et al., 2001a). $EF_{N2O,hous}$ calculated for beef cattle is between 0.2 and 0.3% of N_{ex} (N excretion of 40 kg N per head and year. The data available for NO_x and N_2 do not allow the deriving EFs thereof as for N_2O (section 3.2.3).

3.2.2.2 Pigs

Emission measurements were mainly available for fattening pigs for conventional housing systems with fully or partly slatted floors. The major part of the dataset originates from deep litter or straw flow systems (denominated deep litter here). For fully slatted floors, the mean emissions amount to 0.13 kg N_2O per animal place per year (kg N_2O $anpl^{-1}$ y^{-1}) and for partly slatted floors to 0.05 kg N_2O $anpl^{-1}$ y^{-1} (Table 2). The variability is small for systems with a slatted floor if the maximum value found is excluded (i.e. 4.13 kg N_2O $anpl^{-1}$ y^{-1}; Hoeksma et al., 1993). Deep litter systems emit about five times more N_2O than housings with fully slatted floors. The average emission amounts to 0.89 kg N_2O $anpl^{-1}$ y^{-1} and ranges from 0.01 to 4.13 kg N_2O $anpl^{-1}$ y^{-1}. It has to be mentioned that the emissions per animal place and year were not corrected for the empty time between the production cycles.

Table 2: Emissions obtained from the literature from housings of fattening pigs for nitrous oxide (N_2O) in kg N_2O per animal place and per year. n=number of datasets. Individual data are given in the Appendix 1, Table 16

	Fully slatted floor	Partly slatted floor	Deep litter
n	14*	4	38
kg N_2O animal place^{1} y^{-1}			
Average	0.13	0.05	0.89
Median	0.12	0.05	0.27
Min	0.01	0.01	0.01
Max	0.29	0.09	4.13

* Maximum value from Hoeksma et al. (1993) (4.13 kg N_2O $anpl^{-1}$ y^{-1}) not included

Weaned piglets emit about 0.02 and 0.2 kg N_2O $anpl^{-1}$ y^{-1} for systems with a slatted floor and deep litter, respectively. Emissions from fully slatted floors for gestating sows and nursing sows are similar to the ones from fattening pigs (Appendix 1, Table 17). Emissions derived from the review of Philippe and Nicks (2015) are 0.14, 0.11, 0.03 and 0.02 kg N_2O $anpl^{-1}$ y^{-1} for fattening pigs, gestating sows, nursing sows and weaned piglets, respectively. The low value for nursing sows is striking and might be due to the limited database. Philippe and Nicks (2015) do not provide an explanation.

Based on the average values given in Table 2 for fattening pigs and an N excretion of 12 kg N per animal place and year, the estimated $EF_{N2O,hous}$ ranges between 0.7% of N_{ex} for fully slatted floor systems and 4.7% of N_{ex} for deep litter. Using the median value would produce an EF of 1.4% of N_{ex} for the deep litter system. Average $EF_{N2O,hous}$ for weaned piglets, dry sows and nursing sows are in a similar range (0.1% of N_{ex} to 0.7% of N_{ex} for fully slatted floors; 2.5% of N_{ex} to 7.1% of N_{ex} for deep litter). Based on a review of 39 experiments, Rigolot et al. (2010) determined emission factors of 6% of N_{ex} from housings of fattening pigs with solid manure systems.

According to Philippe and Nicks (2015), absolute N_2O emissions from slurry based systems remain quite low, whatever the type of slatted floor. The emissions of deep litter systems are higher and driven by the N_2O production in the course of nitrification (Groenestein, Van Faassen, 1996). Several authors cited by Philippe and Nicks (2015) found reductions in emissions with increasing amounts of bedding material. Higher aeration of the litter and/or increased temperatures may explain this finding. Bedding material was found to influence N_2O emissions for fattening pigs. In most cases, the observed emission was lower for straw and higher for sawdust with an average difference amounting to a factor of 4 (Nicks et al., 2002).

3.2.2.3 Poultry

Emission measurements were mainly available for deep litter and aviary systems. The number of data is sparse however. The emissions from laying hens range between 0.01 kg N_2O anpl^{-1} y^{-1} and 0.2 kg N_2O anpl^{-1} y^{-1} for the different systems. The variability in emissions within the systems is large. Fabbri et al. (2007) found N_2O emissions from laying hens kept in a deep pit system and a ventilated belt housing system of close to zero. Neser (2001) determined N_2O concentrations slightly higher than the detection limit. The calculated emissions were 0.01 kg N_2O anpl^{-1} y^{-1} from cages and an aviary system and 0.02 kg N_2O anpl^{-1} y^{-1} from deep litter. No differences were observed between the summer and the winter period. Brunsch, Hörnig (2003) observed N_2O emissions from broilers between approx. 0.001 kg N_2O anpl^{-1} y^{-1} 0.05 kg N_2O anpl^{-1} y^{-1} which is somewhat lower than the emissions from laying hens. The emission did not vary significantly between day 20 and 40 of the fattening period.

Table 3: Emissions obtained from the literature from housings of laying hens and broilers for nitrous oxide (N_2O) in kg N_2O per animal place and per year. n=number of datasets. Individual data are given in the Appendix 1, Table 18

	Laying hens			Broiler
	Cages	Deep litter	Aviary system	Deep litter
n	1	8	5	4
kg N_2O animal place^{-1} y^{-1}				
Average	0.01	0.04	0.01	0.02
Median	0.01	0.01	0.01	0.01
Min	0.01	0.00	0.00	0.00
Max	0.01	0.16	0.03	0.05

Based on the average value given in Table 3 and an N excretion of 0.75 kg N per animal place and year for lying hens, the $EF_{N2O,hous}$ is ca. 0.7% of N_{ex}, 3.3% and 1.0% of N_{ex} for laying hens housed in systems with cages, deep litter and aviaries, respectively. For broilers an average N excretion of 0.45 kg N per animal place and year was used. The resulting $EF_{N2O,hous}$ is 2.7% of N_{ex} for broilers.

3.2.3 Emissions of NO_x

Hasson et al. (2015) measured NO_x emissions downwind from a livestock facility. The housings for dairy cows, silage piles and lagoons receiving the slurry were located upwind from the measurement site. The silage pile and the related operations were considered as the main sources of NO_x. Emissions from the animal housings were not discussed as a source.

Emissions of NO were found by Groenestein and van Faassen (1996) to be 0.09 kg NO and 0.35 kg NO anpl^{-1} y^{-1} for fattening pigs kept in two different deep litter systems. For the reference system (fully slatted floor) no NO and N_2O emissions were measured. Data for N_2 were not found in the literature.

3.2.4 Emission factors used in models

Emission factors used in models do not differentiate between animal categories. Distinct EFs are used for animals kept in systems producing slurry and systems producing solid manure. The emissions include the stages housing and storage of the manure. Table 4 shows the emission factors used in models. They are obtained or derived from the IPCC guidelines (IPCC, 2006). Additionally, the values calculated based on the values obtained from the literature in the present report are displayed. It turns out that the values used in models are mostly lower than the EFs calculated here. Especially for pigs and poultry, calculated values are higher by one order of magnitude. This seems to be confirmed by Rigolot et al. (2010). They stated that N_2O emissions from pigs housing may vary between 1% and 19% of total N excreted, respectively. Moreover, they estimated N_2 emissions based on a ratio (N_2O/N_2) equal to 1 : 5. This divergence is even more striking if one considers that the data from the literature refer to housings only and the IPCC guidelines (IPCC, 2006) include emissions from housing and from storage. Discrepancies between such standard values and data from experiments have often been discussed (e.g. Owen, Silver, 2015).

Table 4: Emission factors used in models for housing including manure storage for cattle, pigs, poultry, sheep and goats for nitrous oxide (N_2O) nitric oxide (NO) and diatomic nitrogen (N_2) in percent of N excreted into the housing and emission factors calculated from literature data based on average values (avg) and median (med) values of emissions (see sect. 3.2.2.1 to 3.2.2.3) for N_2O

		Models			Calculated		
		N_2O*	NO**	N_2**	N_2O avg	N_2O med	
Cattle	Slurry	0.2%	0.2%	2.0%	0.5%	0.3%	***
Cattle	Deep litter	0.5%	0.5%	2.5%	0.4%	0.4%	***
Pigs	Slurry	0.2%	0.2%	2.0%	0.7%	0.6%	#
Pigs	Deep litter	0.5%	0.5%	2.5%	4.7%	1.4%	#
Poultry	Liquid manure with/without litter	0.1%	0.1%	1.0%	-	-	
Poultry	Solid manure with/without litter	0.1%	0.1%	0.5%	3.3%	1.2%	##
Poultry	Manure without litter from manure belt systems	0.1%	0.1%	0.5%	1.0%	0.4%	###
Sheep	Deep litter	0.5%	0.5%	2.5%	-	-	
Goats	Deep litter	1.0%	1.0%	5.0%	-	-	

*IPCC (2006)

**van Bruggen et al. (2014), data from Mosquera, Hol (2011) (which are included in Table 1 and Table 2, i.e. dairy cows, fattening pigs but not for the other livestock categories) are probably used as the basis for the numbers. It is likely that NO_x is meant instead of NO (see footnote 1, page 6)

***data based on emissions from dairy cows loose housings, n=22 (slurry) and 3 (deep litter)

#data based on emissions from fattening pigs, n=14 (slurry) and 38 (deep litter)

##data based on emissions from laying hens deep litter, n=8

###data based on emissions from laying hens aviary systems, n=5

3.3 Exercise yards

The emission data for exercise yards were derived from Webb et al. (2001). They measured emissions from collecting yards, feeding yards, feeding/loafing areas and self-feed silage areas. Such facilities cannot be directly compared to exercise yards which are considered as walking areas operated due to promoting animal welfare (Van Caenegem, Krötzl Messerli, 1997). The data of Webb et al. (2001) range between 70 and 160 mg N_2O m^{-2} y^{-1}. Owen and Silver (2015) report emissions from hardstandings of 300 mg m^{-2} y^{-1} which is somewhat higher. It is difficult to estimate emission factors relative to the N excretion of the animals since the amont of N excreted onto the yards was not provided in Webb et al. (2001). Owen and Silver (2015) report emissions of 400 mg N_2O $head^{-1}$ y^{-1}. This amount is small relative to the amount of N excreted (i.e. 0.0002% total N excreted).

Additionally, Owen and Silver (2015) report emissions from corrals (mostly open lots) which can be considered as facilities similar to exercise yards with unpaved floors of 30 g N_2O m^{-2} y^{-1} or 1500 g N_2O $head^{-1}$ y^{-1}. The highest corral N_2O emissions were measured in late spring when a combination of warmer temperatures and moist soils occurred. Owen and Silver (2015) hypothesized that under such conditions nitrification and denitrification is enhanced.

The conclusions of the review carried out by Uchida and Clough (2015) on winter grazed pastures may be relevant for grass paddocks used as exercise yards all over the year.

3.4 Manure storage

3.4.1 N_2O emissions from slurry

Measurement results from slurry storage were found in 13 studies yielding a total of 29 datasets (Table 5, Appendix 1, Table 19). More than half of them were carried out in pilot scale facilities, three under laboratory conditions and three of them were on farm measurements. The calculated average emissions vary over two orders of magnitude (from ca. 10 to ca. 200 g N_2O m^{-2} y^{-1}). Overall, covered stores and slurry storage tanks having a surface crust exhibit higher emissions. Owen and Silver (2015) report emissions of ca. 50 g N_2O m^{-2} y^{-1} for uncovered tanks for storage of dairy manure. Anaerobic lagoons emitted ca. 90 g N_2O m^{-2} y^{-1}. These data are not included in Table 5. It is difficult to discriminate the emission level of cattle slurry from the one of pig slurry based on the available data. Emissions in the order of 100 g N_2O m^{-2} y^{-1} were measured for slurry tanks with a straw cover. This finding is confirmed by Petersen et al. (2013), Sommer et al. (2000) and VanderZaag et al. (2009) who compared slurry storage with and without a straw cover and found substasntially higher emissions for the latter. Aguerre et al. (2012) found an increase in emissions of cattle slurry after the formation of a natural crust.

Sneath et al. (2006) and Stinn et al. (2014) stated that N_2O from an uncovered slurry store was almost zero which complies with the results of Sommer et al. (2000), Park et al. (2011), Rodhe et al. (2012) and van der Weerden et al. (2014) who detected no or very low emissions from uncovered slurry stores. Loyon et al. (2007) did not detect N_2O from a slurry store of raw pig slurry but found emissions when a biological aerobic treatment by intermittent aeration was applied. Nevertheless, it is difficult to state whether a cover reduces N_2O emissions or not. VanderZaag et al. (2010) found a reduction by 68% when cattle slurry was covered with a PVC sheet. The study of Rodhe et al. (2012) did not show a clear distinction of N_2O emissions from an uncovered store and a tank coverd with a plastic sheet for pig slurry. Amon et al. (2007) detected a statistically significant difference between pig slurry stored in a tank with a solid cover and an uncovered one during the cool season but not for the warm season. Clemens et al. (2006) found higher emissions from cattle slurry covered with a wooden lid during summer but the opposite during the winter period. Berg et al. (2006) found higher N_2O emissions for pig slurry covered with perlite, leca balls and straw compared to uncovered stored slurry.

Table 5: Emissions obtained from the literature from storage of slurry from cattle and pigs for nitrous oxide (N_2O) in g N_2O per m^2 and per year. n= number of datasets. Individual data are given in the Appendix 1, Table 19

	Cattle			Pigs		
	covered	uncovered	Crust	covered	uncovered	Crust with straw
n	4	15	2	6	9	4
	g N_2O m^{-2} y^{-1}					
Average	11.1	36.2	164	191	148	113
Median	11.2	28.8	164	138	3.1	100
Min	0.0	0.0	65.7	0.0	0.0	0.0
Max	21.9	231	263	446	535	251

Other influencing factors investigated are the dry matter content of the slurry, the season and slurry treatment. Wood et al. (2012) observed increasing N_2O emissions with increasing dry matter content of the slurry. Petersen et al. (2013) and Ross et al. (1999; cited in Jungbluth et al., 2001) measured higher emissions from cattle slurry and from pig slurry in summer compared to winter. Rodhe et al. (2012) observed the highest values for pig slurry with a straw cover during the warm period. Amon et al. (2007) however, did not find a similar influence of the season for pig slurry. Rodhe et al. (2015) found emissions from untreated and digested cattle slurry, both stored uncovered, which were almost zero. Digested cattle slurry stored under a wooden roof exhibited larger emissions which were generally higher in summer than in winter. Sommer et al. (2000) investigated both untreated and digested slurry. They found highest N_2O volatilization from the latter.

Van der Weerden et al. (2014) found in an incubation study that addition of sawdust enhanced N_2O emissions up to 1% of the initial slurry-N content, compared with <0.01% for untreated slurry and slurry amended with straw generally had an intermediate effect. Extending the storage period to seven months increased emissions from all treatments. Fangueiro et al. (2008a) studied the N_2O release from untreated cattle slurry during winter storage in comparison to the fractions after solid-liquid separation with a screw press at the laboratory scale. They found substantially higher emissions from the slurry fractions after treatment. This was mainly due to the high N_2O losses observed from the solid fraction.

3.4.2 N_2O emissions from solid manure

Measurements from solid manure storage were obtained from 19 studies yielding a total of 51 datasets (Table 6, Appendix 1, Table 20). For stacked cattle manure, emissions are at approx. 0.7% N_2O-N of initial N. Individual results vary over a wide range (0%-4% N). Emissions from deep litter manure are lower by one order of magnitude but only a few measurement results are available. The emissions from composted cattle manure are similar to the losses from stacked manure. N_2O emissions from pig stacked and composted manure are similar but clearly higher than from cattle manure (ca. 3% N). Camp et al. (2013) measured for pig and cattle farmyard manure (FYM) losses of ca. 3% and 1% of initial heap total N content, respectively, which is greater than the IPCC default value of 0.5% (data not included in Table 6).

In the study of Camp et al. (2013), N_2O losses were surprisingly higher than NH_3 emissions. Thorman et al. (2007) found that N_2O emissions for the cattle and pig FYM heaps were much greater than those from the broiler litter heaps (0.17%–0.81%; although these were measured over a shorter, 5–6 month, period and consequently were likely to have resulted in an underestimation of cumulative emissions). Owen and Silver (2015) report emissions of 0.3 kg N_2O m^{-2} y^{-1}.

Table 6: Summary of emissions obtained from the literature for storage of solid manure from cattle and pigs for nitrous oxide (N_2O-N) in percent of initial N. n=number of datasets. Individual data are given in the Appendix 1, Table 20; FYM: farmyard manure

	Dairy cows			Beef cattle			Pigs		
	Stacked FYM	Deep litter	Composted FYM	Stacked FYM	Deep litter	Composted FYM	Stacked FYM	Deep litter	Composted FYM
n	20	3	9	11	-	-	2	-	8
	Percent (%) of initial N								
Average	0.76	0.04	0.50	0.77	-	-	2.92	-	3.04
Median	0.39	0.06	0.38	0.60	-	-	2.92	-	2.50
Min	0.00	0.01	0.26	0.00	-	-	2.63	-	0.05
Max	4.32	0.06	1.50	2.30	-	-	3.20	-	9.90

Moore et al. (2011) reported a total of 70 g N_2O (= 44.5 g N) per megagram of broiler litter which was lost. Hence, N_2O losses comprised 24% of the gaseous N lost during storage. Loyon et al. (2007) did not detect N_2O from the storage of solids obtained from solid–liquid separation of pig slurry. This contrasts to the findings of Hansen et al. (2006) who observed losses of 4.8% of the initial nitrogen content from solids separated from pig slurry.

Leytem et al. (2011) measured higher N_2O emission rates from manure piles in warmer months (May and June) than colder ones (September and March), but no correlations were found when all manure pile data were pooled.

Fukumoto et al. (2003) stated that N_2O emissions started around the middle stage of the composting period when NH_3 emissions and the temperature of the compost material began to decline. They found emissions to be lower in small scale piles compared to larger piles (due to the number and size of anaerobic sites inside the compost pile). Hellmann et al. (1997; obtained from Hansen et al., 2006), observed a delay for N_2O emissions in a pile of pig manure which is caused by the fact that most nitrifying and denitrifying microorganisms are not thermophilic. Production of N_2O by nitrifying and denitrifying processes thus only takes place after heat production has diminished.

Covering the heap with an airtight material reduced N_2O emissions by 99% in the study of Hansen et al. (2006). This indicates that nitrification processes, and thereby denitrification processes, were restricted by low gas-phase oxygen concentrations within the covered material, thus reducing N_2O production (Hansen et al., 2006). This seems to be in line with the experiment of Mulbry and Ahn (2014) who found lower N_2O emissions in static piles of dairy manure as compared to piles turned after 2 to 5 weeks after the establishment of the piles. Yamulki (2006) found that addition of straw to FYM decreased N_2O emissions

Moral et al. (2012) measured total N losses over a 52 days period from storage of cattle FYM resulting in emissions of 16% of initial heap N, with emissions of NH_3, N_2O, N_2 and leached N accounting for 1.5, 1.0, 5.2 and 0.4%, respectively, with 7.6% N unaccounted for. Losses of N_2 via denitrification were thus estimated to be greater than N losses via NH_3 and N_2O.

3.4.3 NO_x emissions from slurry

Hasson et al. (2015) mentioned that slurry stored in a lagoon is a possible source of NO_x. During their study, NO_x concentrations were therefore monitored in air sampled from a few centimeters above the surface of the lagoon. The measured concentrations of NO and NO_2 were indistinguishable from those measured 3 m above ground level, indicating that NO_x emissions from the lagoon were not significant.

3.5 Field application of manure

3.5.1 N_2O emissions from slurry

3.5.1.1 Collection of data

Data on application of slurry were obtained from 25 field studies yielding a total of 85 datasets (Table 7, Appendix 1, Table 21, Table 22). Experiments carried out at the laboratory scale were additionally included to evaluate influencing parameters. For deriving of emission factors, only field studies were considered and included in the corresponding tables.

3.5.1.2 Type of slurry

Mean values for broadcast application are at 0.4% N_2O-N and 0.8% N_2O-N for cattle and pig slurry (Table 7). Accordingly, higher emissions from pig slurry as compared to cattle slurry (2.17% N versus 0.73% N, respectively) was reported in the review carried out by Saggar et al. (2004). In a laboratory incubation experiment, Velthof et al. (2003) found similar emissions for slurry from cattle and poultry (0.5% to 3% N) but higher emissions for pig slurry (7.3 to 13.9% N). Chadwick et al. (2000) however measured higher emissions from dairy cow effluents than slurry from pigs.

Bhandral et al. (2009) did not find an impact of slurry separation (decanting in a tank by undisturbed storage over winter) on N_2O emissions. Thomsen et al. (2010) found slightly higher emissions for solid-liquid separated slurry and digested slurry applied by trailing hose or deep injection as compared to untreated pig slurry. Petersen (1999) observed higher emissions from untreated slurry (mixture of 55% cattle and 45% pig slurry) amounting to 0.35% N and 0.64% N in two different years as compared to the digested slurry. The latter consisted of a mixture of untreated livestock used in the experiment plus organic waste from slaughter houses and food processing industries added at a rate of 15% to 20%. In contrast, Eickenscheidt et al. (2014) found higher emissions from biogas digestates as compared to raw cattle slurry applied four times to experimental plots located at two grassland sites with drained organic soils where measurements were performed over approx. one year. On grassland, the N_2O emissions after 42 days from the application of fermented slurry onto grassland were considerably higher as compared to untreated slurry whereas on arable land the difference was small (Wulf et al., 2002). Severin et al. (2015) did not find significantly different emissions from untreated and anaerobically digested pig slurry in a mesocosm study carried out over a 37-day period.

Fangueiro et al. (2015a) studied the effect of solid-liquid separation and acidification for cattle slurry in a 92-day mesocosm study. Both treatments did not lead to statistically significant lower N_2O emissions. Fangueiro et al. (2010) found in an incubation study higher N_2O emissions from both the liquid and the solid fraction obtained from pig slurry as compared to the raw slurry. Higher emissions for the total of the liquid and the solid fraction than for the untreated cattle slurry was observed by Fangueiro et al. (2008b) after surface application to 1 m x 1 m experimental plots set up on a sward of perennial ryegrass. The emission of the latter amounted to 0.46% N_2O of the total N applied. Bertora et al. (2008) investigated the influence of solid-liquid separation and anaerobic treatment applied for slurry obtained from gestating sows on N_2O emissions in a 58-day mesocosm study. The slurry/slurry fractions were incorporated after application. N_2O emissions amounted to 4.8%, 2.6%, 1.8%, 1.0% and 0.9% for the untreated slurry, the liquid fraction of the untreated slurry, the liquid fraction of the anaerobically digested slurry and the undigested solid fraction. In contrast to most of the beforehand mentioned studies, they found lower emissions for the products after solid-liquid separation independent from anaerobic treatment or no treatment. Hou et al. (2015) stated in their meta-analysis that the effect of liquid fractions on N_2O emissions does not differ from that of raw slurry.

3.5.1.3 Application technique

Low emission application techniques trailing hose, injection and rapid incorporation showed average EFs between 0.6% and 1.7% of N applied (Table 7). Weslien et al. (1998) found emissions after trailing shoe application of pig slurry being at 0.8% N which is similar to broadcasting and application with a trailing hose. The data shown in Table 7 suggest that application techniques for NH_3 emission abatement induce higher losses of N_2O, namely when the slurry is incorporated. This is supported when experimental data comparing surface application with slurry injection or incorporation are displayed. As shown in Table 8, 6 out of 8 measurements yielded higher N_2O losses when slurry was injected as compared to surface application. In the two studies available, trailing hose exhibited higher losses than broadcasting. In contrast, incorporation showed in 3 out of 4 experiments lower emissions than surface application, i.e. broadcasting (n=2) or banding (n=2). Similarly, Fangueiro et al. (2015b) measured significantly higher emissions for injected cattle slurry than for surface application followed by immediate incorporation. Wulf et al. (2002) found significantly higher emissions when fermented slurry was injected than surface applied on both arable land and grassland while trailing hose and trailing shoe tended to decrease the emissions. Unfermended trail hose applied slurry emitted more N_2O than fermented slurry on grassland but vice versa for arable land.

Table 7: Emissions obtained from the literature from field application of slurry from cattle and pigs for nitrous oxide (N_2O-N) in percent of N applied. n=number of datasets. Individual data: Appendix 1, Table 21, Table 22

	Cattle				Pigs			
	Broadcast	Trailing hose	Injection	Incorporation	Broadcast	Trailing hose	Injection	Incorporation
n	26	8	13	18	18	10	13	10
	Percent (%) of N applied							
Average	0.6	0.6	1.0	1.7	0.8	0.8	1.7	1.6
Median	0.3	0.4	0.6	1.1	0.3	0.6	1.2	1.3
Min	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.1
Max	5.0	1.5	6.6	7.4	2.2	1.7	7.0	4.8

Table 8: Emissions obtained from the literature from field application: comparing of data from broadcast application and low emission technologies of slurry from cattle and pigs for nitrous oxide (N_2O-N) in percent of N applied. Individual data are given in the Appendix 1, Table 21, Table 22

	Broad-cast	Trailing hose	Injection	Incorpo-ration	Remarks	Reference
Cattle	0.27	1.01	-	-	Winter wheat, spring	Leick (2003)
Cattle	0.87	1.54	-	0.12	Barley, fall	Leick (2003)
Cattle	0.10	-	0.30	-	Grassland, clay soil	Velthof, Mosquera (2011)
Cattle	0.10	-	0.50	-	Grassland, sandy soil	Velthof, Mosquera (2011)
Cattle	0.77	-	0.60	-	Grassland, silt loam	Abalos et al. (2016)
Cattle	0.82	-	1.10	-	Grassland, silt loam	Abalos et al. (2016)
Cattle	5.02	-	6.63	-	Grassland, silt loam	Abalos et al. (2016)
Cattle	0.59	-	-	0.12	Maize, fall	Leick (2003)
Pigs	1.60	-	2.95	-	Grass on lysimeter	Vallejo et al. (2005)
Pigs	0.02	-	0.01	-	Deep injection, maize, no till	Sistani et al. (2010)
Pigs	0.01	-	0.03	-	Deep injection, maize, no till	Sistani et al. (2010)
Pigs	-	0.30	1.20*/1.50**	-		Thomsen et al. (2010)
Pigs	-	0.30	0.60**	-		Thomsen et al. (2010)
Pigs	-	1.35	-	0.46	Incorporated after appl., spring	Rodhe et al. (2012)
Pigs	-	0.77	-	0.97	Incorporated after appl., fall	Rodhe et al. (2012)

* Winged tine≈shallow injection; ** Straight tine≈deep injection

Agnew et al. (2010) found higher emissions with both cattle and pig slurry injection using chamber measurements 24 h after application. In the laboratory study of Fangueiro et al. (2015a), slightly higher N_2O emissions for injected slurry as compared to surface application were measured although the difference was not statistically significant. Flessa and Beese (2000) found in a 9 weeks mesocosm study using silty loam approx. 10-fold higher N_2O emissions when cattle slurry was injected than if it was broadcast at the surface. For three soil types, Severin et al. (2015) found that injection of digested or raw pig slurry induced significantly increased N_2O emissions compared to application with a trailing-hose followed by incorporation (mesocosm study over 37 days). In the emission inventory of the Netherlands, EFs of 0.9% N are used for all NH_3 low emission techniques while for broadcast application the EF is 0.4% N (van Bruggen et al., 2012).

This contrasts to the findings of several studies which investigated the influence of low emission technics, namely injection and rapid incorporation of slurry:

- Webb et al. (2010) provided several reasons why reduced-NH_3 emission application techniques would not always lead to greater emissions of N_2O: increasing the length of the diffusion path from the site of denitrification to the soil surface for injection or incorporation, greater proportion of denitrified N being emitted as N_2, the subsequent soil moisture status and hence aeration may not be suitable for increased N_2O production, the impact of subsequent weather on soil moisture content and WFPS will also effect subsequent emissions of N_2O.
- Velthof et al. (2003) showed that emissions of N_2O were greatest when pig manure was placed at a depth of 5 cm ($p < 0.05$) in one row row, least when placed at 10 cm ($p < 0.05$) and intermediate for surface application, thorough mixing and placement at 5 cm. These results suggest that injection or incorporation does not always increase emissions of N_2O.
- Sommer et al. (1996) found N_2O losses decreasing in the order injected > surface applied > mixed into the surface with differences beeing insufficient to support any hypothesis on effects of application technique on N_2O emissions.
- Mkhabela et al. (2008) found lower emissions after surface spreading of cattle manure and immediate incorporation to ca. 20 cm of depth using a moldboard plough and subsequently seeded to soyabeans or barley than without incorporation and seeded accordingly in four trails (two of them exhibited a statistically significant difference).

According to the review of Smith and Mukhtar (2015) cumulative N_2O emissions typically range from 0.1% to 3% of the total N applied following manure injection which complies with the data reported here. They state that only a few studies indicate a statistical difference in N_2O emissions when compared to surface application methods. Circumstances attributed to increased emissions vary among studies and include the concentration of readily metabolizable water-soluble carbon (C) in manure slurry compared to background levels in the soil, soil moisture conditions pre- and post-subsurface application that drive nitrification and denitrification processes, localized N form and oxygen concentration at the injection site, and injection depth, which can dictate the length of the diffusion path of N_2O to the atmosphere. The meta-analysis of Hou et al. (2015) revealed statistically higher emissions of N_2O (98%) for injection/incorporation of slurry compared with surface broadcasting.

3.5.1.4 Influencing factors related to slurry application

In most experiments where application at different times over the year was considered higher emissions were observed during cool seasons as compared to summer applications (e.g. Chadwick et al., 2000). According the study of Abalos et al. (2016) and several experiments cited therein, between approx. 40% up to 90% of N_2O emissions occur during the cold season (November to April). They mention five influencing factors: i) reduced plant uptake leading to increased rates of microbial transformations of N, ii) physical release of N_2O trapped by a diffusion barrier (e.g. an ice layer); iii) low temperatures causing microbial, mycorrhiza and fine root mortality resulting in a release of labile organic C and N into the soil; iv) freeze-thaw cycles generating disruption of soil aggregates which releases previously protected organic matter increasing substrate availability; v) increased N_2O: N_2 ratio due to the temperature sensitivity of the microbial enzyme nitrous oxide reductase.

Smith et al. (2008) found higher emissions of N_2O when slurry was applied after rain (3 experiments; difference statistically significant in 1 out of the 3 experiments) and with rain after slurry application (4 experiments; difference statistically significant in 2 out of the 4 experiments; one out of 4 experiments: higher emissions without rain). These results are similar to the outcomes of Sommer et al. (1996). Abalos et al. (2016) observed N_2O peaks the day after a major rainfall event (> 10 mm) during the vegetation period. However, according to the findings of Mkhabela et al. (2009), N_2O emissions were not affected by rainfall after application and either by slurry dilution (study carried out by using experimental plots in the field over 21 days).

Increasing amounts of pig slurry of up to 200 kg N ha^{-1} applied did not correlate with higher emissions in the laboratory incubation experiment of Velthof et al. (2003). This is in line with the results from Mkhabela et al. (2009). In this field study over 21 days, N_2O emissions were not affected by the application rates of either 60 m^3 ha^{-1} or 120 m^3 ha^{-1} pig slurry. Similar outcomes were reported by Agnew et al. (2010) for both liquid and solid cattle and pig manures. Smith et al. (2008) found the fraction of N applied which was emitted as N_2O was unchanged, or decreased, with an increasing application rate. In contrast, Jarecki et al. (2009) reported that a larger fraction of N was lost as N_2O when the application rate was increased. Rochette et al. (2000) found that the fraction of applied N emitted as N_2O-N increased from 1.23 to 1.65% when the application rate of pig slurry was doubled. Hansen et al. (1993) concluded from their field study that increasing levels of cattle slurry resulted in a reduction in N_2O emissions relative to the amount of TAN applied.

Bourdin et al. (2014) provide information on the influence of slurry dry matter content on N_2O emissions. Although their results are difficult to understand, it appears that a lower dry matter content increased the emissions.

3.5.1.5 Soil type

In a study using soil cores, Bender, Wood (2007) observed greatest cumulative emissions and highest peak rates of emission of N_2O directly following effluent applications from sandier soils as compared to heavier textured soil. Yamulki and Jarvis (2002) observed higher emissions of N_2O from compacted soils. This complies with the outcomes of Bhandral et al. (2003) who found a seven fold increase in N_2O emission when the soil was compacted. Similarly, Hansen et al. (1993) found higher N_2O emissions after application of a NPK fertilizer from compacted soil as copared to uncompacted soil but vice versa for cattle slurry. Athough for the latter, the difference was minor. N_2O emissions did not respond to the tillage system (i.e. till, no till) in the study of Yamulki and Jarvis (2002).

3.5.1.6 Emissions of NO and N_2

Vallejo et al. (2005) found in an experiment over 215 days an emission factor for NO following pig slurry application of 0.14% N for broadcast application and of 0.12% N for injection. They found an emission reduction for both N_2O and NO using the nitrification inhibitor dicyandiamide (DCD) for injected pig slurry by a factor of approx. 2. Yamulki and Jarvis (2002) concluded that fluxes of NO, NO_2 were independent from compaction but higher from the tilled treatments. The total of NO, NO_2 exceeded the N_2O-emissions by a factor of ca. 2.

Rubaek et al. (1996) reported that N_2 losses through denitrification after application of raw and digested cattle slurry applied with a trailing hose or by injection were low (< 2% of TAN) and one to three orders of magnitude lower than N lost through volatilization of ammonia, respectively. In contrast, Thompson, Meisinger (2004) found a higher total net denitrification loss from the surface-applied and incorporated slurry treatments of 11 and 17% of applied NH_4^+-N, respectively. Denitrification loss over the winter/early-spring period was appreciable but not substantial, even where NH_3 volatilization was restricted by immediate incorporation. Vallejo et al. (2005) determined emissions of NO_3^-, N_2, and NO relative to N_2O after pig slurry application as follows: NO_3^- similar to N_2O except for broadcast application; N_2 about five times the emissions of N_2O and emissions for NO being lower by ca. a factor of 10 as compared to N_2O (Table 9).

Table 9: Emissions of NO_3^-, N_2, and NO relative to N_2O after pig slurry application (Vallejo et al., 2005)

	N_2O	NO_3^-	N_2	NO
Broadcast application	100%	20%	380%	10%
Injection	100%	100%	550%	10%
Injection plus nitrification inhibitor dicyandiamide (DCD)	100%	190%	540%	5%

3.5.2 N_2O emissions from solid manure

3.5.2.1 Type of solid manure

Measurements from field application of solid manure were obtained from eight studies yielding a total of 37 datasets (Table 10, Appendix 1, Table 23). Average emissions for surface applied solid manure from cattle, pigs and poultry are 0.30%, 0.16% and 0.65% N applied, respectively. For pig manure, the major part of the datasets exhibit very low emissions (i.e. ≤0.05% N).

In the study of Webb et al. (2010), N_2O-N losses from layer manure, as a percentage of total manure N applied, (0.81%) were greater than from cattle FYM (0.55% of total N applied) and pig FYM (0.65% of total N applied) ($p < 0.068$) at the site Drayton in 2003. N_2O-N emissions from broiler manure were intermediate (0.71% of total N applied) and did not differ significantly from the other types of manure. The pattern of emissions was similar for the site Gleadthorpe with cattle manure exhibiting strikingly lower losses and manure from layers being slightly higher: cattle: 0.09% N[a]; pig: 0.59% N[b]; layer: 1.30% N[c]; broiler: 0.71% N[b] (values denoted with varying letters are significantly different, values denoted with the same letter are not significantly different ($p < 0.1$) while for the site Drayton 2005, only cattle manure exhibited a statistically significantly difference ($p < 0.1$) as compared to the other manure types (cattle: 0.30% N[a]; pig: 0.52% N[b]; layer: 0.51% N[b]; broiler: 0.49% N[b]). Median N_2O emissions after spreading of solid manure determined by Webb et al. (2012) were 3%, 0.3% and 0.6% TAN for cattle, pigs and poultry, respectively.

Table 10: Emissions obtained from the literature from field application of solid manure from cattle, pigs and for nitrous oxide (N_2O-N) in percent of N applied. n=number of datasets, Inc.: incorporation. Individual data are given in the Appendix 1, Table 23

	Cattle			Pigs			Poultry		
	Surface	Inc. plough	Inc. tillage	Surface	Inc. plough	Inc. tillage	Surface	Inc. plough	Inc. tillage
n	11	6	4	13	5	-	7	-	4
	Percent (%) of N applied								
Average	0.30	0.05	0.84	0.16	0.21	-	0.65	-	1.90
Median	0.30	0.02	0.82	0.04	0.08	-	0.71	-	1.80
Min	0.07	0.01	0.09	0.00	0.01	-	0.05	-	1.10
Max	0.55	0.12	1.64	0.65	0.86	-	1.30	-	2.90

It is interesting to examine the N_2O emissions of solid manure as compared to N_2O losses from slurry. When comparing the data given in Table 7 and Table 10 for both surface applied slurry and solid manure, it is difficult to detect a clear difference. In the study of Rochette et al. (2008), there was no consistent effect of manure type (slurry, solid manure) on N_2O emissions. Loro et al. (1997) reported higher emissions from solid beef manure than from liquid cattle manure. The former induced more sustained emission rates while the latter generally produced immediate denitrification and N_2O release. In contrast, Chadwick et al. (2000) observed higher emissions from pig slurry applied to the surface of grassland in comparison with surface applied solid pig manure. Similarly, Gregorich et al. (2005) give an average emission factor of 1.7% for slurry and 0.3% for solid manure spread in Canada (data not included in Table 7). Smith et al. (2008) found emissions for slurry and solid manure which were not different ($p < 0.05$), but in one out of the four experiments statistically significant higher emissions occurred from the slurry.

3.5.2.2 Incorporation after application

Incorporation by plough seems to decrease emissions compared to surface application and vice versa for incorporation by tillage (Table 10). Table 11 shows the results obtained from studies comparing the emissions from field application of manure left on the surface and incorporated. It is difficult to detect systematic differences. Agnew et al. (2010) did not find different emissions from cattle, pig and poultry solid manure with and without incorporation. The measurements were based on chamber measurements 24 h after application.

Webb et al. (2014) concluded that immediate incorporation of solid manures does not necessarily increase N_2O emissions and that soil type may play an important role. Similarly, Webb et al. (2012)

stated that measures reducing NH_3 emissions such as rapid incorporation do not always lead to increases in N_2O emissions. Gregorich et al. (2005) give an average emission factor of 1.3% for solid manure spread and incorporated in Canada which seems to be somewhat higher than the values reported in Table 10 and Table 11.

Table 11: Emissions obtained from the literature from field application comparing of data from application left on the surface and incorporated by plough, disc and tine for nitrous oxide (N_2O-N) in percent of N applied or in percent of TAN where denoted. Individual data are given in the Appendix 1, Table 23

	Surface	Plough	Disc	Tine	Remarks**	Reference
Various*	0.66	0.70	0.77	0.49		Webb et al. (2014)
Various*	0.31[a]	1.22[b]	0.73[a]	0.43[a]	$p < 0.002$	Webb et al. (2014)
Various*	0.57[a]	0.34[b]	0.42[b]	0.49[ab]	$p < 0.006$	Webb et al. (2014)
Cattle	0.16	0.12	0.09	-		Thorman et al (2007)
Cattle	12	7.3***	-	-		Webb et al. (2012)[#]
Cattle	0.23	0.08	0.11	-		Thorman et al. (2007)
Pigs	0.00	0.86	-	-		Thorman et al. (2007)
Pigs	0.00	0.09	-	-		Thorman et al. (2007)
Pigs	0.01	0.08	-	-		Thorman et al. (2007)
Pigs	0.01	0.01	-	-	45 days measurement	Webb et al. (2004)
Pigs	0.02	0.02	-	-	45 days measurement	Webb et al. (2004)
Pigs	0.3	3.5***	-	-		Webb et al. (2012)[#]
Poultry	0.1	8.9***	-	-		Webb et al. (2012)[#]

*Mean over manure from cattle, pigs, layers, broilers

** Different letters indicate a statistical significant difference

*** Incorporation either by plough or disc/tine

[#] Emissions reported as % of TAN

3.5.2.3 Soil type

Rochette et al. (2008) found cumulative N_2O emissions from solid manure being greater in the loam than in the clay soil in 2002, but vice versa in 2003. Webb et al. (2014) concluded that immediate incorporation may potentially lead to N_2O emission increases on coarse sandy soils.

4 Discussion and outlook

4.1 Grazing

The standard EF of 2% N_2O–N of N_{ex} according to IPCC mostly used in models for calculation of greenhouse gas emissions is based on older studies. More recent studies exhibit lower values in general and suggest that the standard EF tends to be high. NO was investigated in one study.

4.2 Housing and manure storage

In the present study, estimates for emission factors of N_2O for housings were as follows (averages):
- Cattle: 0.5% and 0.4% N for systems producing slurry and solid manure, respectively.
- Pigs: 0.7% and 4.7% N for systems producing slurry and solid manure, respectively.
- Poultry: 3.3% and 1.0% N for systems solid manure and from manure belt systems, respectively.

Emissions from slurry storage lie in an order of magnitude of 10 to 100 g N_2O m^{-2} y^{-1}. Transforming this data to an EF in percent of N entering the slurry manure tank by using the average numbers given in Table 5, slurry production and storage time according to Flisch et al. (2009) and N flows entering slurry storage according to Kupper et al. (2015) for dairy cows and fattening pigs results in EFs for cattle and pigs of 0.2% N and 0.5% N, respectively. EFs for solid manure as given in Table 6 range between 0.8% N (stacked manure) for cattle and 3% N (stacked manure) for pigs.

The EFs estimated in the present study for housings alone and for the sum of emissions from housings and manure storage are both higher than the standard values from IPCC (2006) which include emissions from housings and manure storage: cattle and pigs: 0.2% and 0.5% N for systems producing slurry and solid manure, respectively, and poultry: 0.1% N for all systems. It can thus be concluded that the standard values according to IPCC (2006) are likely to be substantially underestimated.

4.3 Manure application

Average N_2O EFs for the broadcast application of slurry from cattle and pigs determined in the present study are at 0.6% of N applied and 0.8% of N applied, respectively. For NH_3 low emission techniques, the average emissions are higher (up to 1.7% of N applied) although several authors stated that reduced-NH_3 emission application techniques would not always lead to greater emissions of N_2O. Emissions after the application of solid manure range from 0.3% to approx. 2% of N applied. Rapid incorporation of solid manure does not systematically lead to higher emissions. It should be noted that it was not checked whether the emissions from manure application reported in the literature were corrected for background emissions (i.e. emissions from soil without manure application) or not.

Abalos et al. (2016) compared N_2O emissions from a perennial grass-legume mixture with maize under real world conditions plot scale using micrometeorological measurements. Slurry application was carried out as commonly used by farmers (broadcasting and injection for the grass sward and broadcasting immediately followed by disking for maize). Over 3 years, statistically significant lower N_2O emissions were measured for the grassland compared to maize, even if the annual tenfold increased emissions for the perennial crop after ploughing in the last year was accounted for. Also yield scaled emissions were lower for the grass-legume mixture as compared to maize. The authors suggested that increasing the proportion of perennial crops in agricultural rotations may provide a promising option to mitigate N_2O emissions. Similarly, Rees et al. (2013) found annual emissions from arable sites greater than from grassland. N input to systems was shown to be the principal driver across the various sites included in the study.

Overall, the standard value according to IPCC (2006) of 1% N applied coincides with the range of numbers found in the literature for manure application. Although, while the emission factor for grassland determined by Rees et al. (2013) coincided well with this number, arable sites exhibited a significantly greater emission of N_2O relative to N added than would be predicted from IPCC default emission factors.

4.4 Integration of emission factors into the Agrammon model

Overall, the N_2O emission factors estimated based on the present literature studies coincide well with the standard values of IPCC (2006) for manure application but are higher for housing and manure storage and lower for grazing. However, the variability of the emissions is large and difficult to explain. For the determination of NH_3 emissions, only EFs from losses of N_2O, NO and N_2 from housing and manure storage are relevant. Although the numbers according to IPCC (2006) seem to be underestimated we suggest using these standard values for the following reasons:

- Chosing other values than the standard given by IPCC (2006) would lead to inconsistencies with models dedicated to report on emission of ammonia and greenhouse gases.
- The N_2O emission factors are low at each emission stage and thus only slightly influence the NH_3 emissions and thus potential errors remain limited.
- The decision making on appropriate emission factors is difficult due to the large variability of the data.

For NO_x and N_2, the availability of data is very limited. Thus, there is hardly any scope of action to choose other EFs than the ones provided by IPCC (2006). The implementation of emissions for N_2O, NO and N_2 in the Agrammon model as planned is shown in the Appendix 2. EFs as suggested by IPCC (2006) are applied except for values missing in the guidebook (e.g. values for N_2).

It might be worth to mention that the EMEP/EEA air pollutant emission inventory guidebook 2016 (EEA, 2016) suggests a procedure which differs from IPCC (2006). EEA (2016) uses EFs based on the TAN fraction in the manures. This approach was not followed here because the Swiss greenhouse gas inventory (Bretscher, 2013) is calculated on the basis of IPCC (2006) which uses EFs based on the N_{tot} fluxes. Moreover, using TAN or N_{tot} fluxes will not change the results since the EFs to be used for the TAN approach change proportionally to the TAN fraction as is shown in EEA (2016), Table A1.7.

5 Acknowledgement

Marcel Bühler (HAFL) is acknowledged for the thorough revision of the text.

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Appendix 1

Table 12: Emission factors (EFs) for nitrous oxide, N_2O in % N (N_2O-N as a % of N applied, or N excreted) used in emission models for grazing

Livestock cat.*	EFs	remarks	Reference	Country
All	3.3		van Bruggen et al. (2014)	NL
All	2		Dämmgen et al. (2006)	DE
DC, OC, Pig, Pou	2		IPCC (2006)	-
Sh, oth	1		IPCC (2006)	-
DC	0.5-1		Chadwick et al. (1998)	UK
OC	0.5-1		Chadwick et al. (1998)	UK
BC	0.5-1		Chadwick et al. (1998)	UK
FC	0.5-1		Chadwick et al. (1998)	UK
Sh, oth	0.2		Chadwick et al. (1998).	UK
Pig (outdoor)	0.3		Chadwick et al. (1998)	UK
Pou	0.57		Chadwick et al. (1998)	UK
nd	0.4		Cardenas et al. (2013)	UK

*Acronyms:

All	applied for all livestock categories
DC	Dairy Cows
OC	Other Cattle
CS	Calves suckling cows
BC	Beef cattle
FC	Fattening calves
Pig	Nursing pigs
Pou	Poultry
OA	Asses
sh	Sheep
oth	Other livestock categories
nd	not determined

Table 13: Emission factors (EFs) for nitrous oxide, N_2O, for grazing in % N (N_2O-N as % of N applied, or N excreted) determined from the studies given in the column "Reference"

Livestock cat.*	EFs	Remarks		Reference	Country
DC	1		Urine	Yamulki et al. (1998)	UK
DC	0.53		Dung	Yamulki et al. (1998)	UK
nd	2.5	mineral soils		Velthof et al. (1997)	NL
nd	6	peat soils		Velthof et al. (1997)	NL
nd	3.3	sand clay	Grassland	Oenema et al. (1997)	NL
nd	1	sand clay	Grassland	Oenema et al. (1997)	NL
nd	9.9	peat	Grassland	Oenema et al. (1997)	NL
nd	1.5	peat	Grassland	Oenema et al. (1997)	NL
nd	8	clay loam	Grassland	Oenema et al. (1997)	NL
DC	0.2	spring	Urine	Bell et al. (2015)	UK
DC	1.07	summer	Urine	Bell et al. (2015)	UK
DC	0.31	fall	Urine	Bell et al. (2015)	UK
DC	0.11	spring	Dung	Bell et al. (2015)	UK
DC	0.2	summer	Dung	Bell et al. (2015)	UK
DC	0.1	fall	Dung	Bell et al. (2015)	UK
DC	3.2		Urine/dung	Flessa et al. (1996)	DE
DC	3.8		Urine	Flessa et al. (1996)	DE
DC	0.5		Dung	Flessa et al. (1996)	DE
DC	0.3	sandy loam	Urine	Rochette et al. (2014)	CA
DC	1.1	clay	Urine	Rochette et al. (2014)	CA
DC	0.15	sandy loam	Dung	Rochette et al. (2014)	CA
DC	0.08	clay	Dung	Rochette et al. (2014)	CA
DC	0.04		Dung	van der Weerden et al. (2011)	NZ
DC	0.29		Urine	van der Weerden et al. (2011)	NZ
DC	0.08	fall		Luo et al. (2011)	NZ
DC	0.46	late spring		Luo et al. (2011	NZ
DC	0.02	summer		Luo et al. (2011)	NZ
DC	0.98	winter		Luo et al. (2011	NZ
DC	0.9		Urine	Virkajarvi et al. (2010)	FI
DC	0.4		Urine	Virkajarvi et al. (2010)	FI
DC	4.5		Dung	Virkajarvi et al. (2010)	FI
DC	0.7		Dung	Virkajarvi et al. (2010)	FI
DC	0.24		Urine	Maljanen et al. (2007)	FI
DC	0.28		Dung	Maljanen et al. (2007)	FI
nd	0.66			Barneze et al. (2015)	UK
DC	0.6	fall		Zaman, Nguyen (2012)	NZ
DC	2.3	spring		Zaman, Nguyen (2012)	NZ
DC	0.05		Urine	Wachendorf et al. (2008)	GE
DC	0.33		Dung	Wachendorf et al. (2008)	GE
nd	0.5-1.3		Artificial urine	Anger et al. (2003)	GE
nd	1.55		Artificial urine	van Groenigen et al. (2005)	NL
DC	1.81	09/2007-08/2009		Rafique et al. (2011)	IE
DC	0.5-1.6		Grazed grassland	Burchill et al. (2014)	IE
BC	0.2-2.2	2002	N-fertilized pasture	Hyde et al. (2006)	IE
BC	3.5-7.2	2003	N-fertilized pasture	Hyde et al. (2006)	IE

*Acronyms: see footnote of Table 12 in the Appendix 1.

Table 14: Emission factors (EFs) for nitric oxide, NO and N_2 in % N (as a % of N applied, or N excreted)

Livestock cat.*	EFs	Remarks		Reference	Country
Experiments					
DC	0.14	NO	urine	Maljanen et al. (2007)	FI
DC	0.03	NO	dung	Maljanen et al. (2007)	FI
DC	0.06	NO	urine	Maljanen et al. (2007)	FI
DC	<0.01	NO	dung	Maljanen et al. (2007)	FI
Models					
All	*1.2*	NO**		van Bruggen et al. (2014)	NL
All	*2*	NO**		Dämmgen et al. (2006)	var.
All	*14*	N_2		IPCC (2006)	var

*Acronyms: see footnote of Table 12 in Appendix 1.
**It is likely that NO_x is meant (see footnote 1, page 6)

Table 15: Emissions factors (EFs) for nitrous oxide, N_2O, from housings of dairy cows in kg N_2O per animal or LU and year obtained from the literature

Tied housing		Loose housing		Remarks[#]		Reference	Country
Slurry	Slurry/SM*	Slurry	Deep litter				
0.22	0.23	-	-			Amon et al (2001b)	AT
-	-	0.29	-			Sneath et al, (1997)**	UK
-	-	0.58	-			Jungbluth et al. (2001)	DE
-	-	0.12	-	Solid concrete floor; delta scraper	s	Zhang et al. (2005)**	NL
-	-	0.29	-		w	Zhang et al. (2005)**	NL
-	-	0.00	-	Hot rolled asphalt; scraper & drain	s	Zhang et al. (2005)**	NL
-	-	2.17	-		w	Zhang et al. (2005)**	NL
-	-	0.51	-	Pre-manufactured concrete elements (grooves); scraper & drain	s	Zhang et al. (2005)**	NL
-	-	0.09	-		w	Zhang et al. (2005)**	NL
-	-	0.15	-		w	Zhang et al. (2005)**	NL
-	-	1.28	-	Pre-manufactured concrete elements (profiles); scraper & drain	s	Zhang et al. (2005)**	NL
-	-	0.00	-		w	Zhang et al. (2005)**	NL
-	-	0.88	-	Slatted floor; scraper in 40 cm deep channel	w	Zhang et al. (2005)**	NL
-	-	0.47	-		s	Zhang et al. (2005)**	NL
-	-	0.05	-	Slatted floor; back flushing	s	Zhang et al. (2005)**	NL
-	-	0.00	-		w	Zhang et al. (2005)**	NL
-	-	2.01	-	Slatted floor; circulation; without acid	s	Zhang et al. (2005)**	NL
-	-	2.98	-		w	Zhang et al. (2005)**	NL
-	-	0.90	-	Slatted floor; circulation; with acid	s	Zhang et al. (2005)**	NL
-	-	0.66	-		s	Zhang et al. (2005)**	NL
-	-	0.04	-		s	Zhang et al. (2005)**	NL
-	-	0.22	-		w	Zhang et al. (2005)**	NL
-	-	0.70	-	Circulation; scraper on slatted floor	s	Zhang et al. (2005)**	NL
-	-	0.77	-		w	Zhang et al. (2005)**	NL
-	-	1.68	-	Slatted floor; circulation; without additive	s	Zhang et al. (2005)**	NL
-	-	2.16	-		s	Zhang et al. (2005)**	NL
-	-	0.53	-		##	Joo et al. (2015)	US
-	-	1.81	-		w	Zhang et al. (2005)**	NL
-	-	0.23	-	Measurements in 4 houses denoted Rav Nb A 1.100		Mosquera, Hol (2011)	NL
-	-	0.21	-			Schneider (2006)	DE
-	-	0.23	-			Schneider (2006)	DE
-	-	-	0.91			Mosquera et al. (2005)	NL
-	-	-	0.73			Amon et al (2001)	AT
-	-	-	0.46			Webb et al. (2012)	NL
-	-	9.23	-			Leytem et al. (2013)	US
-	-	7.45	-			Leytem et al. (2013)	US
-	-	21.6	-		s	Samer et al. (2012)	DE
-	-	22.4	-		w	Samer et al. (2012)	DE

[#] s: summer; w: winter; [##] Measurements carried out in spring, summer, fall
* SM: solid manure, ** obtained from Jungbluth et al. (2001), *** obtained from Owen, Silver (2015)

Table 16: Emissions factors (EFs) for nitrous oxide, N_2O, from housings of fattening pigs in kg N_2O per animal place and year obtained from the literature

FS floor*	PS floor*	Deep litter	Remarks	Reference	Country
			kg N_2O animal place^{-1} y^{-1}		
4.13	-	-		Hoeksma et al. (1993)	NL
0.02	-	-		Hahne et al. (1999)	DE
0.14	-	-		Hahne et al. (1999)	DE
0.03	-	-		Kaiser (1999)**	DE
0.15	-	-		Stein (1999)**	DE
0.20	-	0.41		Philippe et al (2007a)	BE
0.24	-	0.25	Deep litter = sloped floor	Philippe et al (2007b)	BE
0.08	0.08	-		Philippe et al (2014a)	BE
0.20	-	-		Ngwabie et al. (2011)[#]	SE
0.29	-	-		Li et al. (2011)	USA
0.07	0.09	-		Guignand et al. (2010)	FR
0.17	-	-		Costa et al. (2009)	IT
0.06	-	-		Osada et al. (1998)	JP
0.11	-	-		Philippe et al. (2015)	BE
0.31[##]	-	-		Thelosen et al. (1993)**	NL
0.01	-	-		Mosquera, Hol (2011)	NL
-	0.02	-		Sneath et al. (1999)**	UK
-		1.90		Döhler (1993)**	DE
-	-	2.40		Döhler (1993)**	DE
-	-	4.13		Groenestein, Van Faassen (1996)	NL
-	-	2.75		Groenestein, Van Faassen (1996)	NL
-	-	0.59		Hoy et al. (1997)	DE
-	-	3.44		Hoy et al. (1997)	DE
-	-	1.55		Kaiser (1999)**	DE
-	-	3.07		Kaiser (1999)**	DE
-	-	1.09		Thelosen et al. (1993)**	NL
-	-	1.43		Stein (1999)**	DE
-	-	1.89		Stein (1999)**	DE
-	-	0.05		Kaiser (1999)**	DE
-	-	1.60		Hesse et al. (1994)**	DE
-	-	2.40		Hesse et al. (1994)**	DE
-	-	0.02	without daily manure removal	Amon et al. (2007)	DE
-	-	0.04	with daily manure removal	Amon et al. (2007)	AT
-	-	0.08	warm period	Amon et al. (2007)	AT
-	-	0.02	cool period	Amon et al. (2007)	AT
-	-	0.06	warm period	Amon et al. (2007)	AT
-	-	0.01	cool period	Amon et al. (2007)	AT
-	-	0.04	warm period	Amon et al. (2007)	AT
-	-	0.01	cool period	Amon et al. (2007)	AT
-	-	0.99		Webb et al. (2012)	n.a.
-	-	0.17	Straw used as litter material	Nicks et al. (2002)	FR
-	-	0.62	Sawdust used as litter material	Nicks et al. (2002)	FR
-	-	0.41	50 kg straw per pig	Philippe et al (2014b)	BE
-	-	0.32	75 kg straw per pig	Philippe et al (2014b)	BE
-	-	0.27	100 kg straw per pig	Philippe et al (2014b)	BE
-	-	0.25***	Existing saw dust litter (ESDL)	Robin et al. (1999)	FR
-	-	0.27***	66% ESDL 33% fresh saw dust	Robin et al. (1999)	FR
-	-	0.27***	33% ESDL 66% fresh saw dust	Robin et al. (1999)	FR
-	-	0.21***	fresh saw dust	Robin et al. (1999)	FR
-	-	0.14***	"BioPig"	Robin et al. (1999)	FR
-	-	0.18***	Chopped straw	Robin et al. (1999)	FR
-	-	0.18***	Straw pellets	Robin et al. (1999)	FR
-	-	0.25***	Chopped widow wood	Robin et al. (1999)	FR

*FS floor: fully slatted floor; PS floor: partly slatted floor, **obtained from Jungbluth et al. (2001), ***pigs with a live weight between approx. 30 and 50 kg; [#]obtained from Philippe, Nicks (2015); [##]the system was not clearly defined

Table 17: Emissions factors (EFs) for nitrous oxide, N_2O, from housings of other pig categories in kg N_2O per animal place and year obtained from the literature

Cat*	FS floor**	PS floor**	Deep litter	Remarks#	Reference	Country
	kg N_2O animal place^{-1} y^{-1}					
PP	0.02	-	-		Costa et al. (2009)	IT
PP	0.00	-	-		Cabaraux et al. (2009)	BE
PP	-	-	0.01	Straw used as litter material	Cabaraux et al. (2009)	BE
PP	-	-	0.07	Sawdust used as litter material	Cabaraux et al. (2009)	BE
PP	-	-	0.13	Straw used as litter material	Nicks et al. (2003)	BE
PP	-	-	0.51	Sawdust used as litter material	Nicks et al. (2003)	BE
PD	0.40	-	-		Costa et al. (2009)	IT
PD	0.20	-	-		Philippe et al. (2015)	BE
PD	0.02	-	-	The floor is not clearly defined.	Stinn et al. (2014)	IT
PD	-	-	1.15		Philippe et al (2013)	BE
PD	-	-	2.23	Corresponds to a multi area pen with littered area	Philippe et al (2013)	BE
PN	0.11	-	-		Costa et al. (2009)	IT
PN	0.13	-	-	The floor is not clearly defined	Stinn et al. (2014)	IT

*PP: weaned piglets; PD: dry sows; PN: nursing sows

**FS floor: fully slatted floor; PS floor: partly slatted floor,

Table 18: Emissions factors (EFs) for nitrous oxide, N_2O, from housings of laying hens and broilers in kg N_2O per animal place and year obtained from the literature

Laying hens			Broilers	Remarks	Reference	Country
Cage system	Deep litter	Aviary system	Deep litter			
kg N_2O animal place^{-1} y^{-1}						
-	0.017	-	-	Litter material: straw	Mennicken (1999)*	DE
-	0.043	-	-	Litter material: wood shavings	Mennicken (1999)*	DE
-	0.079	-	-	Litter material: wood shavings	Mennicken (1999)*	DE
-	0.155	-	-	Litter material: 3/4 straw 1/4 wood shavings	Mennicken (1999)*	DE
-	-	0.033	-		Sneath et al. (1999)*	UK
-	-	0.001	-		Neser et al. (1997)*	DE
-	-	0.005	-		Neser et al. (1997)*	DE
-	0.002	-	-		Neser et al. (1997)*	DE
-	0.012	-	-		Neser et al. (1997)*	DE
0.009	0.008	0.020	-		Neser (2001)	DE
-	-	0.000	-	Deep pit and ventilated belt	Fabbri et al. (2007)	IT
-	-	-	0.001		Brunsch, Hörnig (2003)	DE
-	-	-	0.006		Brunsch, Hörnig (2003)	DE
-	-	-	0.024		Miles et al. (2014)	US
-	-	-	0.045		Miles et al. (2014)	US

* obtained from Jungbluth et al (2001)

Table 19: Emissions obtained from the literature for storage of slurry from cattle and pigs for nitrous oxide (N_2O) in g N_2O per m^2 and per year. Acronyms given in the header row: LC: Livestock category; cov: covered storage tank; uncov: uncovered storage tank; crust: uncovered storage tank with a natural crust; E: experimental approach

LC#	cov	uncov	crust	E##	Remarks	Reference	Country
DC	21.9	0.0	65.7	p		Sommer et al. (2000)	DK
DC	-	-	30.0	l		Aguerre et al. (2012)	US
DC	-	26.4	-	f	conventional dairy farm	Sneath et al. (2006)[$]	FR
DC	-	4.7	-	f	organic dairy farm	Sneath et al. (2006)[$]	FR
DC	-	0.9	-	l		Fangueiro et al (2008a)	PR
DC	-	6.8	-	l		Ross et al. (1999)***	DE
DC	12.8	-	-	l		Ross et al. (1999)***	DE
DC	0.0	-	-	f	PVC cover	Sneath et al. (2006)	NL
DC	-	47.2	-	p	Non inoculated slurry (tank emptied before filling)	Wood et al. (2014)	CA
DC	-	41.8	-	p	Inoculated slurry (tank not emptied before filling)	Wood et al. (2014)	CA
DC	9.5	30.1	-	p	Trend towards higher emissions with increasing surface crust	VanderZaag et al. (2010)	CA
DC	-	4.6	-	p	0.3% DM for slurry	Wood et al. (2012)	CA
DC	-	8.5	-	p	1.3% DM for slurry	Wood et al. (2012)	CA
DC	-	9.7	-	p	3.2% DM for slurry	Wood et al. (2012)	CA
DC	-	28.8	-	p	5.8% DM for slurry	Wood et al. (2012)	CA
DC	-	46.1	-	p	8.2% DM for slurry	Wood et al. (2012)	CA
DC	-	45.5	-	p	9.5% DM for slurry	Wood et al. (2012)	CA
DC	-	0.0	-	p		Rodhe et al. (2015)	SE
PF	446*	342*	-	p	warm season	Amon et al. (2007)	AT
PF	424*	442*	-	p	warm season	Amon et al. (2007)	AT
PF	268**	535**	-	p	cold season	Amon et al. (2007)	AT
PF	-	5.9	-	l	Summer; strong increase of the emissions with increasing amount of straw	Ross et al. (1999)***	DE
PF	8.3	-	-	l	Summer	Ross et al. (1999)***	DE
PF	-	3.1	-	f	Winter	Ross et al. (1999)***	DE
PF	2.6	-	-	f	Winter	Ross et al. (1999)***	DE
PF	-	0.0	0.0	p	Winter	Petersen et al. (2013)	DK
PF	-	0.6	251	p	Summer; protected from rainfall	Petersen et al. (2013)	DK
PF	-	0.0	130	p	Summer; not protected from rainfall	Petersen et al. (2013)	DK
PF	0.0	0.5	71	p	Cover = plastic sheet; crust: straw cover	Rodhe et al. (2012)	SE

#DC: dairy cows; PF: fattening pigs

##Experimental approach: l: laboratory scale; p: pilot scale; f: on farm measurement

*The difference between the emissions from the storage with a solid cover and the uncovered storage is statistically not significant.

**The difference between the emissions from the storage with a solid cover and the uncovered storage is statistically significant.

***Cited in Jungbluth et al. (2001)

[$] Cited in Owen and Silver (2015)

Table 20: Emissions obtained from the literature for storage of solid manure from cattle and pigs for nitrous oxide (N_2O-N) in percent initial N. Acronyms given in the header row: LC: Livestock category

LC#	FYM	Deep litter	com-posted	M##	Remarks	Reference	Country
DC	0.567	-	0.360	p		Amon et al. (2001)	AT
DC	0.824	-	0.476	p		Amon et al. (2001)	AT
DC	0.000	-	-	f		Mosquera, Hol (2005)	NL
DC	0.300	-	-	p		Sommer et al. (2004)	DK
DC	2.831	-	-	l		Külling et al. (2001)	CH
DC	1.247	-	-	l		Külling et al. (2001)	CH
DC	0.726	-	-	l		Külling et al. (2001)	CH
DC	0.166	-	-	l		Külling et al. (2003)	CH
DC	0.069	-	-	l		Külling et al. (2003)	CH
DC	1.303	-	-	l		Külling et al. (2003)	CH
DC	0.853	-	-	l		Külling et al. (2003)	CH
DC	0.001	-	-	l		Külling et al. (2002)	CH
DC	0.002	-	-	l		Külling et al. (2002)	CH
DC	0.280	-	-	p	manure from organic farm	Yamulki (2006)	UK
DC	0.260	-	-	p	manure from organic farm with straw addition	Yamulki (2006)	UK
DC	0.700	-	-	p	manure from conventional farm	Yamulki (2006)	UK
DC	0.480	-	-	p	manure from conve. farm with straw addition	Yamulki (2006)	UK
DC	4.320	-	-	p		Thorman et al. (2007)	UK
DC	-	0.057	-	l		Külling et al. (2001)	CH
DC	-	0.008	-	l		Külling et al. (2001)	CH
DC	-	0.062	-	l		Külling et al. (2001)	CH
DC	-	-	0.300	-		Hüther (1999)**	DE
DC	-	-	1.500	-		Hüther (1999)**	DE
DC	0.169	-	-	p		Mulbry, Ahn (2014)	US
DC	-	-	0.415	p		Mulbry, Ahn (2014)	US
DC	-	-	0.477	p		Mulbry, Ahn (2014)	US
DC	-	-	0.262	p		Mulbry, Ahn (2014)	US
DC	-	-	0.385	p		Mulbry, Ahn (2014)	US
DC	0.0106	-	-	p		Ahn et al. (2011)	US
DC	-	-	0.370	p		Ahn et al. (2011)	US
BC	2.300	-	-	p	uncovered, stored conventionally	Chadwick (2005)	UK
BC	0.100	-	-	p	uncovered, stored conventionally	Chadwick (2005)	UK
BC	1.300	-	-	p	uncovered, stored conventionally	Chadwick (2005)	UK
BC	0.700	-	-	p	covered with Tarpaulin, compacted	Chadwick (2005)	UK
BC	2.100	-	-	p	covered with Tarpaulin, compacted	Chadwick (2005)	UK
BC	0.600	-	-	p	covered with Tarpaulin, compacted	Chadwick (2005)	UK
BC	0.001	-	-	p	low share of concentrate, storage in winter	Mathot et al. (2012)	BE
BC	0.193	-	-	p	low share of concentrate, storage in spring	Mathot et al. (2012)	BE
BC	0.001	-	-	p	high share of concentrate, storage in winter	Mathot et al. (2012)	BE
BC	0.224	-	-	p	high share of concentrate, storage in spring	Mathot et al. (2012)	BE
BC	1.000	-	-	p		Moral et al. (2012)	UK
PF	2.630	-	-	p		Thorman et al. (2007)	UK
PF	3.200	-	-	p		Espagnol et al. (2006)	FR
PF	-	-	0.800	p	high bulk density, low amount of straw	Sommer, Moller (2000)	DK
PF	-	-	0.050	p	low bulk density, high amount of straw	Sommer, Moller (2000)	DK
PF	-	-	0.220	p		Osada et al. (2001)	DK
PF	-	-	2.500	p		Espagnol et al. (2006)	FR
PF	-	-	9.900	p	unturned heap	Szanto et al. (2007)	NL
PF	-	-	2.500	p	turned heap	Szanto et al. (2007)	NL
PF	-	-	3.720	p	Small windrow size	Fukumoto et al. (2007)	JP
PF	-	-	4.640	p	Large windrow size	Fukumoto et al. (2007)	JP

#DC: dairy cows; BC: beef cattle; PF: fattening pigs

##Experimental approach: l: laboratory scale; p: pilot scale; f: on farm measurement

* Data obtained from Webb et al. (2012)

**cited by Amon et al. (2001)

Table 21: Emissions obtained from the literature for field application of slurry from cattle for nitrous oxide (N_2O-N) in percent of N applied. Acronyms given in the header row: LC: Livestock category; Bcas: broadcast application; TH: trailing hose; Inj: Injection; Inc: rapid incorporation after application

LC#	Bcas	TH	Inj	Inc	Remarks	Reference	Country
DC	0.70	-	-	-	Fall; appl. rate rate: 250 m^3 ha^{-1}	Bhandral,et al. (2007)	NZ
DC	0.30	-	-	-	Winter; appl. rate rate: 250 m^3 ha^{-1}	Bhandral,et al. (2007)	NZ
DC	0.67	-	-	-	Grass	Bourdin et al. (2014)	IE
DC	0.77	-	0.60	-	Peren. grass-legume mixt., silt loam	Abalos et al. (2016)	CA
DC	0.82	-	1.10	-	Peren. grass-legume mixt., silt loam	Abalos et al. (2016)	CA
DC	5.02	-	6.63	-	Peren. grass-legume mixt., silt loam	Abalos et al. (2016)	CA
Cattle	1.48	-	-	-	Grassland, Cambisol	Flechard et al. (2005)	CH
Cattle	0.01	-	-	-	Grassland, Cambisol	Flechard et al. (2005)	CH
Cattle	0.14	-	-	-	Grassland, Cambisol	Flechard et al. (2005)	CH
Cattle	0.07	-	-	-	Grassland, Cambisol	Flechard et al. (2005)	CH
Cattle	0.47	-	-	-	Grassland, Cambisol	Flechard et al. (2005)	CH
Cattle	0.09	-	-	-	Grassland	Amon et al. (2006)	AT
Cattle	0.97	-	-	-	Grassland, spring	Chadwick et al. (2000)	UK
Cattle	0.12	-	-	-	Grassland, summer	Chadwick et al. (2000)	UK
Cattle	0	-	0.40	-	Grassland clay soil; 2007/2008	Velthof, Mosquera (2011)	NL
Cattle	0.10	-	0.70	-	Grassland sandy soil; 2007/2008	Velthof, Mosquera (2011)	NL
Cattle	0.20	-	0.90	-	Maize sandy soil; 2007/2008	Velthof, Mosquera (2011)	NL
Cattle	0.20	-	0.20	-	Grassland clay soil; 2008/2009	Velthof, Mosquera (2011)	NL
Cattle	0.10	-	0.50	-	Grassland sandy soil; 2008/2009	Velthof, Mosquera (2011)	NL
Cattle	0.90	-	0.80	-	Maize sandy soil; 2008/2009	Velthof, Mosquera (2011)	NL
Cattle	0.10	-	0.20	-	Grassland sandy soil; 2009	Velthof, Mosquera (2011)	NL
Cattle	0.20	-	0.90	-	Maize sandy soil; 2009	Velthof, Mosquera (2011)	NL
Cattle	-	-	0.11	-	Grassland umbric clay soil; 2001	Schils et al. (2008)	NL
Cattle	-	-	0.12	-	Grassland umbric clay soil; 2002	Schils et al. (2008)	NL
Cattle	0.27	1.01	-	-	Winter wheat, spring	Leick (2003)	DE
Cattle	0.59	-	-	0.12	Maize, fall	Leick (2003)	DE
Cattle	0.87	1.54	-	0.12	Barley, fall	Leick (2003)	DE
Cattle	-	0.92	-	-	Oilseed rape, Application in August	Sagoo et al. (2013)	UK
Cattle	-	0.42	-	-	Oilseed rape, Application in Sept.	Sagoo et al. (2013)	UK
Cattle	-	0.45	-	-	Oilseed rape, Application in February	Sagoo et al. (2013)	UK
Cattle	-	0.01	-	-	Winter wheat stubble, Appl. in Aug	Sagoo et al. (2013)	UK
Cattle	-	0.18	-	-	Winter wheat, Application in March	Sagoo et al. (2013)	UK
Cattle	-	0.17	-	-	Winter wheat, Application in May	Sagoo et al. (2013)	UK
Cattle	-	-	-	0.44	Incorporated after application, fall	Rodhe et al. (2015)	SE
Cattle	-	-	-	0.15	Incorporated after application, spring	Rodhe et al. (2015)	SE
DC	-	-	-	2.31	Clay, maize	Rochette et al. (2008)	CA
DC	-	-	-	1.01	Loam, maize	Rochette et al. (2008)	CA
DC	-	-	-	1.10	Wheat, silt clay	Pelster et al. (2012)	CA
DC	-	-	-	0.70	Wheat, sandy loam	Pelster et al. (2012)	CA
DC	-	-	-	4.10	Wheat, silt clay	Pelster et al. (2012)	CA
DC	-	-	-	1.10	Wheat, sandy loam	Pelster et al. (2012)	CA
DC	-	-	-	0.33		Bhandral,et al. (2009)	CA
DC	-	-	-	**2.59**	Maize; fall; silt loam*	Abalos et al. (2016)	CA
DC	-	-	-	**2.46**	Maize; spring; silt loam*	Abalos et al. (2016)	CA
DC	-	-	-	**2.70**	Maize; fall; silt loam*	Abalos et al. (2016)	CA
DC	-	-	-	**3.20**	Maize; spring; silt loam*	Abalos et al. (2016)	CA
DC	-	-	-	**7.41**	Maize; fall; silt loam*	Abalos et al. (2016)	CA
DC	-	-	-	**0.5****	Grassland	Louro et al. (2016)	ES

#DC: dairy cows

* Application technique: broadcasted and immediately incorporated by disking

** relative to the mineral fraction in the slurry

Table 22: Emissions obtained from the literature for field application of slurry from pigs for nitrous oxide (N_2O-N) in percent of N applied. Acronyms given in the header row: LC: Livestock category; Bcas: broadcast application; TH: trailing hose; Inj: Injection; Inc: rapid incorporation after application

LC#	Bcas	TH	Inj	Inc	Remarks	Reference	Country
Pigs	2.20	-	-	-	Fall	Bhandral,et al. (2007)	NZ
Pigs	0.60	-	-	-	Winter	Bhandral,et al. (2007)	NZ
Pigs	0.44	-	-	-	Grassland, spring	Chadwick et al. (2000)	UK
Pigs	0.12	-	-	-	Grassland, summer	Chadwick et al. (2000)	UK
Pigs	0.24	-	-	-	Grassland, fall	Chadwick et al. (2000)	UK
PF	2.10	-	-	-	$60 m^3/ha$; grassland, silt loam	Sherlock et al. (2002)	NZ
PF	1.40	-	-	-	Soja***	Whalen et al. (2000)	US
Pigs	1.10	-	7.00	-	Maize sandy soil; 2007/2008	Velthof, Mosquera (2011)	NL
Pigs	1.30	-	1.40	-	Maize sandy soil; 2008/2009	Velthof, Mosquera (2011)	NL
Pigs	0.10	-	1.10	-	Maize sandy soil; 2009	Velthof, Mosquera (2011)	NL
PF	1.60	-	2.95	-	Grass on lysimeter	Vallejo et al. (2005)	ES
Pigs	-	0.37	-	-		Meade et al. (2011)	IE
Pigs	-	0.35	-	-		Meade et al. (2011)	IE
Pigs	-	1.23	-	-	Application rate: 60 Mg ha^{-1} yr^{-1}; loam	Rochette et al. (2000)	CA
Pigs	-	1.65	-	-	Application rate: 120 Mg ha-1 yr-1; loam	Rochette et al. (2000)	CA
Pigs	-	0.30	1.20	-	Shallow injection barley	Thomsen et al. (2010)	DK
Pigs	-	-	1.50	-	Deep injection barley	Thomsen et al. (2010)	DK
Pigs	-	0.40	0.60	-	Deep injection winter wheat	Thomsen et al. (2010)	DK
PF	0.02	-	0.01	-	Deep injection, maize, no till	Sistani et al. (2010)	US
PF	0.01	-	0.03	-	Deep injection, maize, no till	Sistani et al. (2010)	US
Pigs	0.07	-	-	-	Stubble, June	Smith et al. (2008)	CA
Pigs	0.04	-	-	-	Stubble, Juli	Smith et al. (2008)	CA
Pigs	0.01	-	-	-	Stubble, August	Smith et al. (2008)	CA
Pigs	0.12	-	-	-	Stubble, September	Smith et al. (2008)	CA
Pigs	-	-	0.70	-	Oats, vertic cambisol	Perala et al. (2006)	FI
PF	-	0.39	0.36	0.47	Wheat, spring	Weslien et al. (1998)**	SE
PF	-	1.24	-	1.40	Rye, fall	Weslien et al. (1998)**	SE
PF	-	1.35	-	0.46	Incorporated after appli., spring	Rodhe et al. (2012)	SE
PF	-	0.77	-	0.97	Incorporated after appli., fall	Rodhe et al. (2012)	SE
Pigs*	-	-	-	3.10	Mean over 3 years, clay soil	Chantigny et al. (2010)	CA
Pigs*	-	-	-	2.40	Mean over 3 years, loam soil	Chantigny et al. (2010)	CA
Pigs	-	-	-	1.74*	Fall, loamy soil	Rochette et al. (2000)	CA
Pigs	-	-	-	2.73*	Spring, loamy soil	Rochette et al. (2000)	CA
PF	-	-	-	4.80	Wheat, silt clay	Pelster et al. (2012)	CA
PF	-	-	-	0.10	Wheat, sandy loam	Pelster et al. (2012)	CA
PF	-	-	-	2.00	Wheat, silt clay	Pelster et al. (2012)	CA
PF	-	-	-	1.10	Wheat, sandy loam	Pelster et al. (2012)	CA

PF: fattening pigs

* Farrow to finish operation

**Values for training shoe: 0.31% N (Wheat, spring); 1.21% N (Rye, fall)

***24 d measurement; August; corrected for background emission

Table 23: Emissions obtained from the literature for field application of solid manure for nitrous oxide (N_2O-N) in percent in percent of N applied. Acronyms given in the header row: LC: Livestock category

LC#	Surf	Inc. pl	Inc. ti	Remarks	Reference	Country
DC	-	-	1.64	Clay; cumulative emissions over 2 years	Rochette et al. (2008)	CA
DC	-	-	1.53	Loam; cumulative emissions over 2 years	Rochette et al. (2008)	CA
BC	0.2	-	-	Grass, fall	Chadwick, et al. (2000)	UK
BC	0.16	0.12	0.09	Bare soil, conventional straw rate	Thorman et al. (2007)	UK
BC	0.23	0.08	0.11	Bare soil; rich in litter	Thorman et al. (2007)	UK
BC	0.52	0.02	-	Bare soil; uncompacted manure	Webb et al. (2004)	UK
BC	0.47	0.02	-	Bare soil; compacted manure	Webb et al. (2004)	UK
BC	0.35	0.02	-	Bare soil; uncompacted manure	Webb et al. (2004)	UK
BC	0.38	0.01	-	Bare soil; compacted manure	Webb et al. (2004)	UK
Cattle	0.55	P	-	Stony loamy sand, Drayton 2003	Webb et al. (2014)	UK
Cattle	0.09	-	-	Loamy sand, Gleadthorpe	Webb et al. (2014)	UK
Cattle	0.30	-	-	Stony loamy sand, Drayton 2005	Webb et al. (2014)	UK
DC*	0.07	-	-	Grassland; derived volcanic ash, loamy;	Mori et al. (2011)	JP
PF	0	0.86	-	Stubble, conventional straw rate fresh manure	Thorman et al. (2007)	UK
PF	0	0.09	-	Stubble, conv. straw rate; stored over 365 d	Thorman et al. (2007)	UK
PF	0.01	0.08	-	Stubble, rich in litter cont.; stored over 365 d	Thorman et al. (2007)	UK
Pigs	0.01	0.01	-	Bare soil; uncompacted manure	Webb et al. (2004)	UK
Pigs	0.02	0.02	-	Bare soil; compacted manure	Webb et al. (2004)	UK
Pigs	0.02	-	-	Stubble, June	Smith et al. (2008)	CA
Pigs	0.04	-	-	Stubble, July	Smith et al. (2008)	CA
Pigs	0.05	-	-	Stubble, August	Smith et al. (2008)	CA
Pigs	0.1	-	-	Stubble, September	Smith et al. (2008)	CA
Pigs	0.65	-	-	stony loamy sand, Drayton 2003	Webb et al. (2014)	UK
Pigs	0.59	-	-	loamy sand, Gleadthorpe	Webb et al. (2014)	UK
Pigs	0.52	-	-	stony loamy sand, Drayton 2005	Webb et al. (2014)	UK
Pigs	0.05	-	-	Grass, fall	Chadwick, et al. (2000)	UK
LH	0.05	-	-	Grass, fall	Chadwick, et al. (2000)	UK
LH	0.81	-	-	stony loamy sand, Drayton 2003	Webb et al. (2004)	UK
LH	1.3	-	-	loamy sand, Gleadthorpe	Webb et al. (2004)	UK
LH	0.51	-	-	stony loamy sand, Drayton 2005	Webb et al. (2014)	UK
Broil	0.71	-	-	stony loamy sand, Drayton 2003	Webb et al. (2014)	UK
Broil	0.71	-	-	loamy sand, Gleadthorpe	Webb et al. (2004)	UK
Broil	0.49	-	-	stony loamy sand, Drayton 2005	Webb et al. (2004)	UK
Broil	-	-	1.1	Wheat, silt clay	Pelster et al. (2012)	CA
Broil	-	-	1.4	Wheat, sandy loam	Pelster et al. (2012)	CA
Broil	-	-	2.9	Wheat, silt clay	Pelster et al. (2012)	CA
Broil	-	-	2.2	Wheat, sandy loam	Pelster et al. (2012)	CA

#DC: dairy cows; BC: beef cattle; PF: fattening pigs; LH: laying hens; Broil: broilers

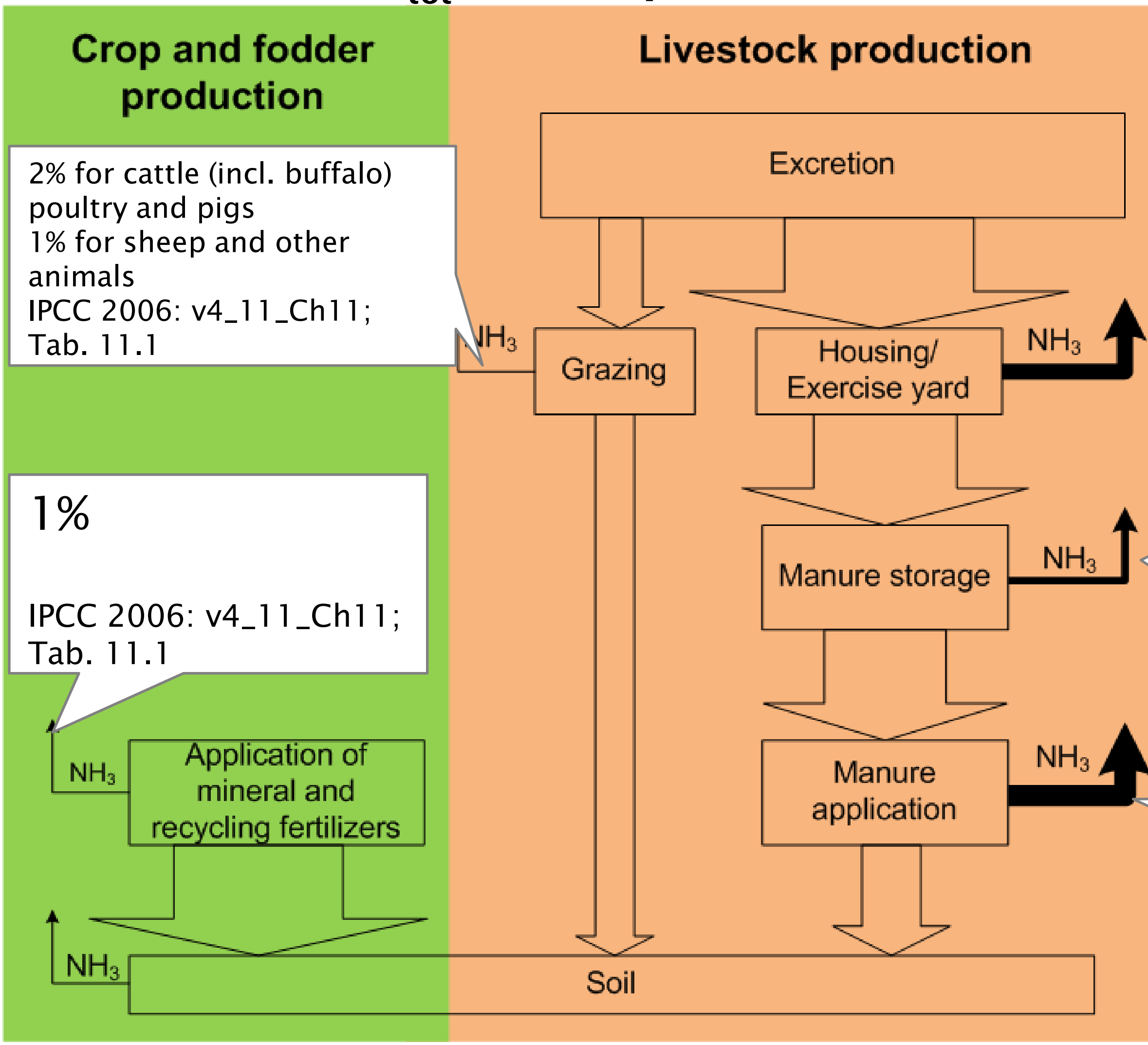
* saw dust or bark amended manure

Appendix 2

The following figures illustrate how the calculation of the emissions for N_2O, NO and N_2 will be implemented in the Agrammon model. For the modeling of ammonia emissions, only the N_2O, NO and N_2 emissions at the stages housing/exercise yard and manure storage are relevant. The emission factors related to the other emission stages as used for the Swiss greenhouse gas inventory (Bretscher, 2013) are shown for the sake of completeness.

Emission factors (EF) for N_2O

in kg N_2O-N/kg N
For systems with production of slurry or slurry and solid manure
in percent of N_{tot} at the inflow of the emission stage
relative to the N_{tot} in slurry



2% for cattle (incl. buffalo) poultry and pigs
1% for sheep and other animals
IPCC 2006: v4_11_Ch11; Tab. 11.1

1%

IPCC 2006: v4_11_Ch11; Tab. 11.1

EF based on the flow of N_{tot} into housing/exercise yard

- Cattle/pigs: 0.2%
- "Dry lot" is not considered

IPCC 2006: v4_10_Ch10; Tab. 10.21

1%

IPCC 2006: v4_11_Ch11; Tab. 11.1

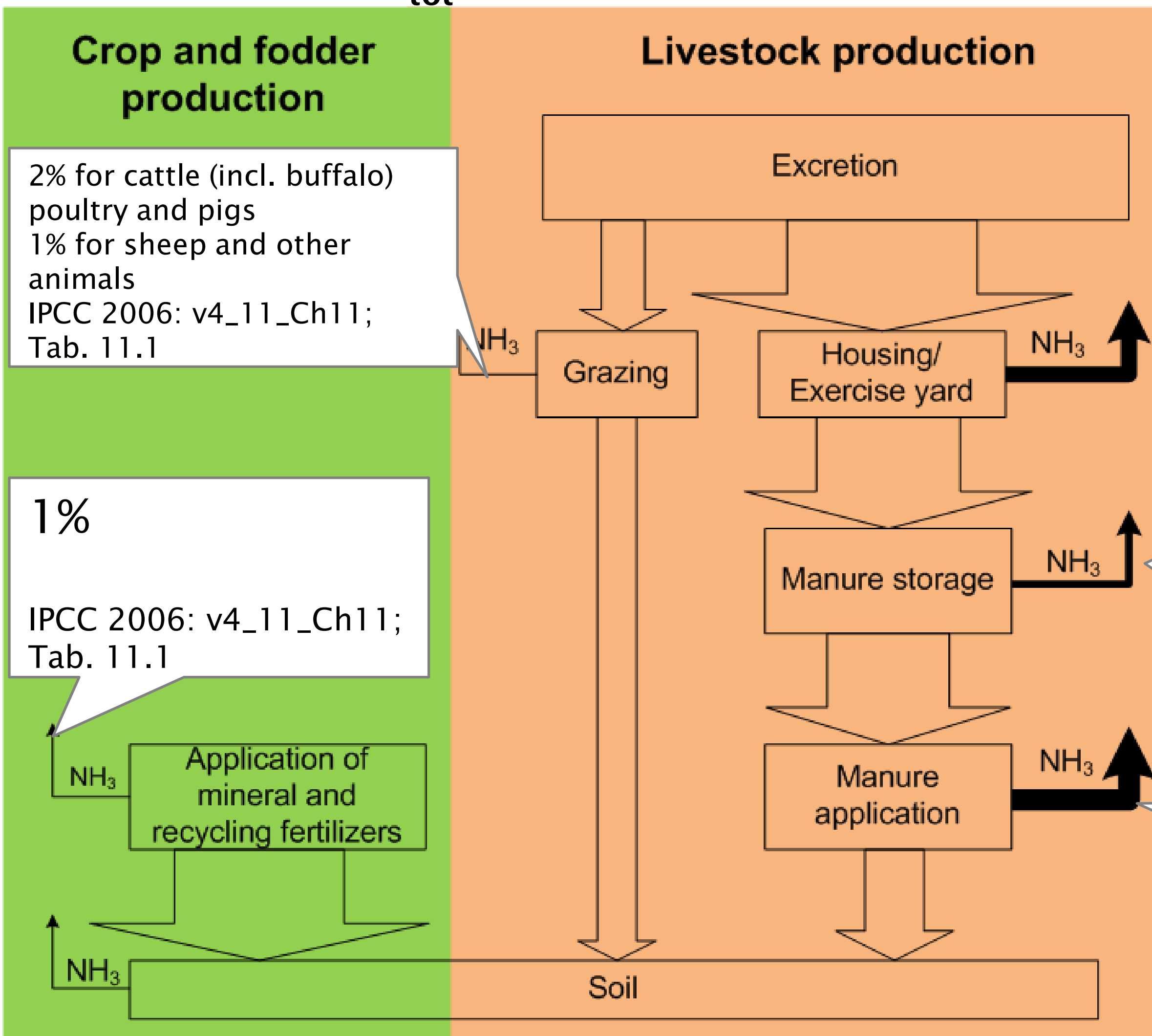
Emission factors (EF) for N_2O

in kg N2O-N/kg N

For systems with production of slurry and solid manure

in percent of N_{tot} at the inflow of the emission stage

relative to the N_{tot} in solid manure



2% for cattle (incl. buffalo) poultry and pigs
1% for sheep and other animals
IPCC 2006: v4_11_Ch11; Tab. 11.1

1%

IPCC 2006: v4_11_Ch11; Tab. 11.1

EF based on the flow of N_{tot} into housing/exercise yard

- Cattle: 0.5%
- “Dry lot” is not considered

IPCC 2006: v4_10_Ch10; Tab. 10.21

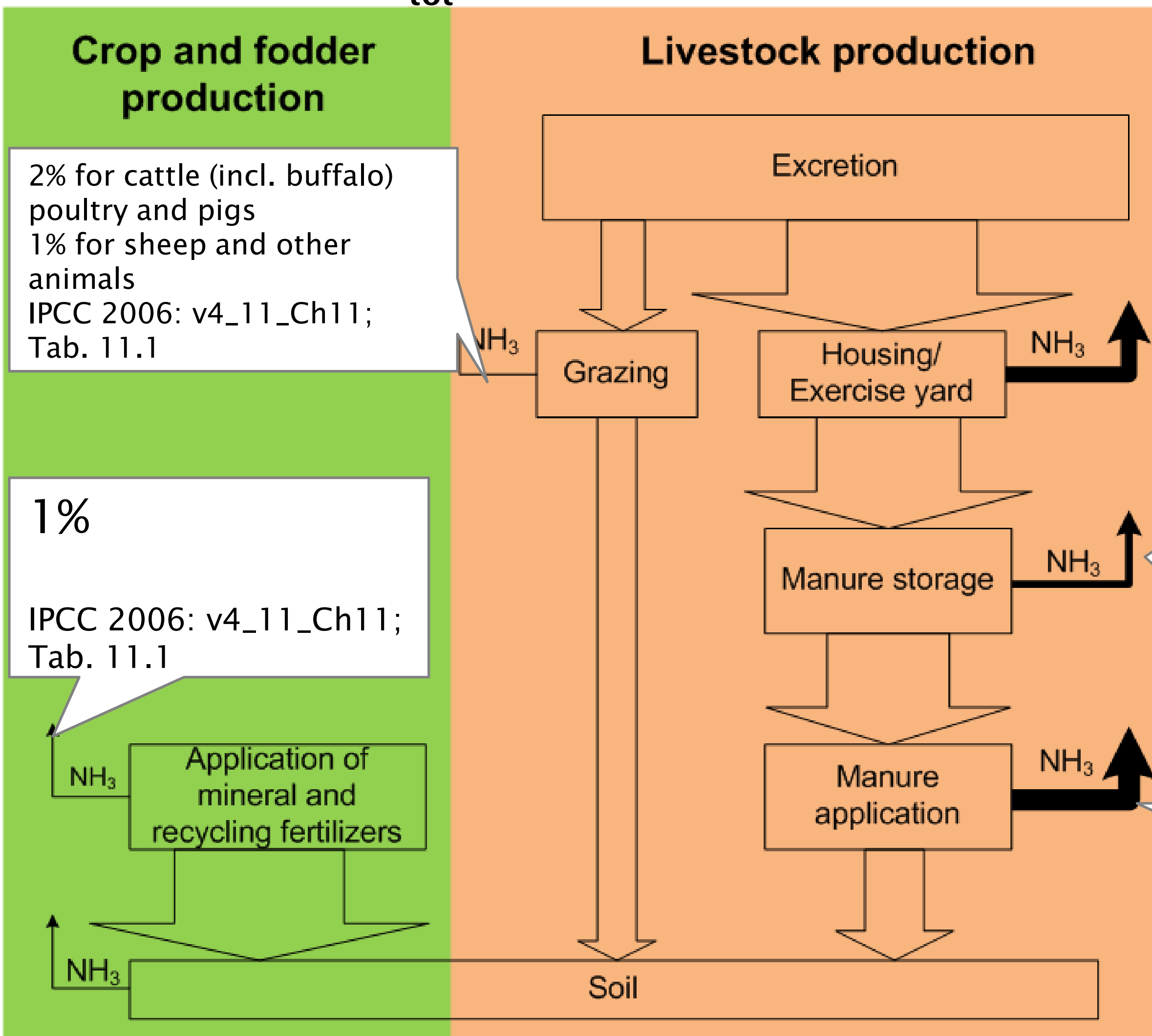
1%

IPCC 2006: v4_11_Ch11; Tab. 11.1

Emission factors (EF) for N_2O

in kg N_2O-N/kg N

For systems with production solid manure (deep litter, droppings from poultry) in percent of N_{tot} at the inflow of the emission stage relative to the N_{tot} in solid manure



2% for cattle (incl. buffalo) poultry and pigs
1% for sheep and other animals
IPCC 2006: v4_11_Ch11; Tab. 11.1

1%

IPCC 2006: v4_11_Ch11; Tab. 11.1

EF based on the flow of N_{tot} into housing/exercise yard

- All livestock categories except for poultry: 1% (active mixing is not considered)
- Poultry: 0.1%
- “Dry lot” is not considered

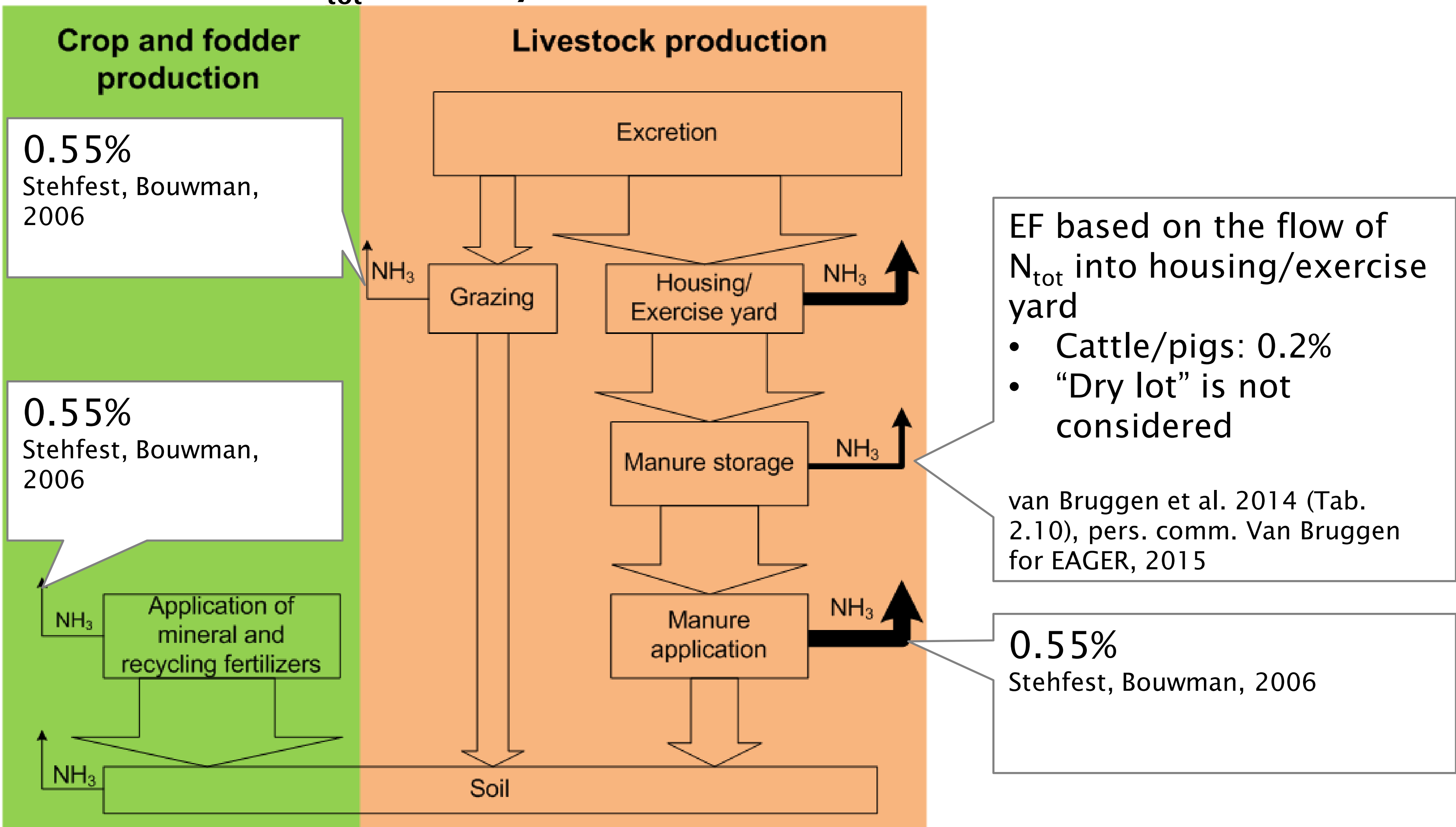
IPCC 2006: v4_10_Ch10; Tab. 10.21

1%

IPCC 2006: v4_11_Ch11; Tab. 11.1

Emission factors (EF) for NO

in kg NO-N/kg N
For systems with production of slurry or slurry and solid manure
in percent of N_{tot} at the inflow of the emission stage
relative to the N_{tot} in slurry



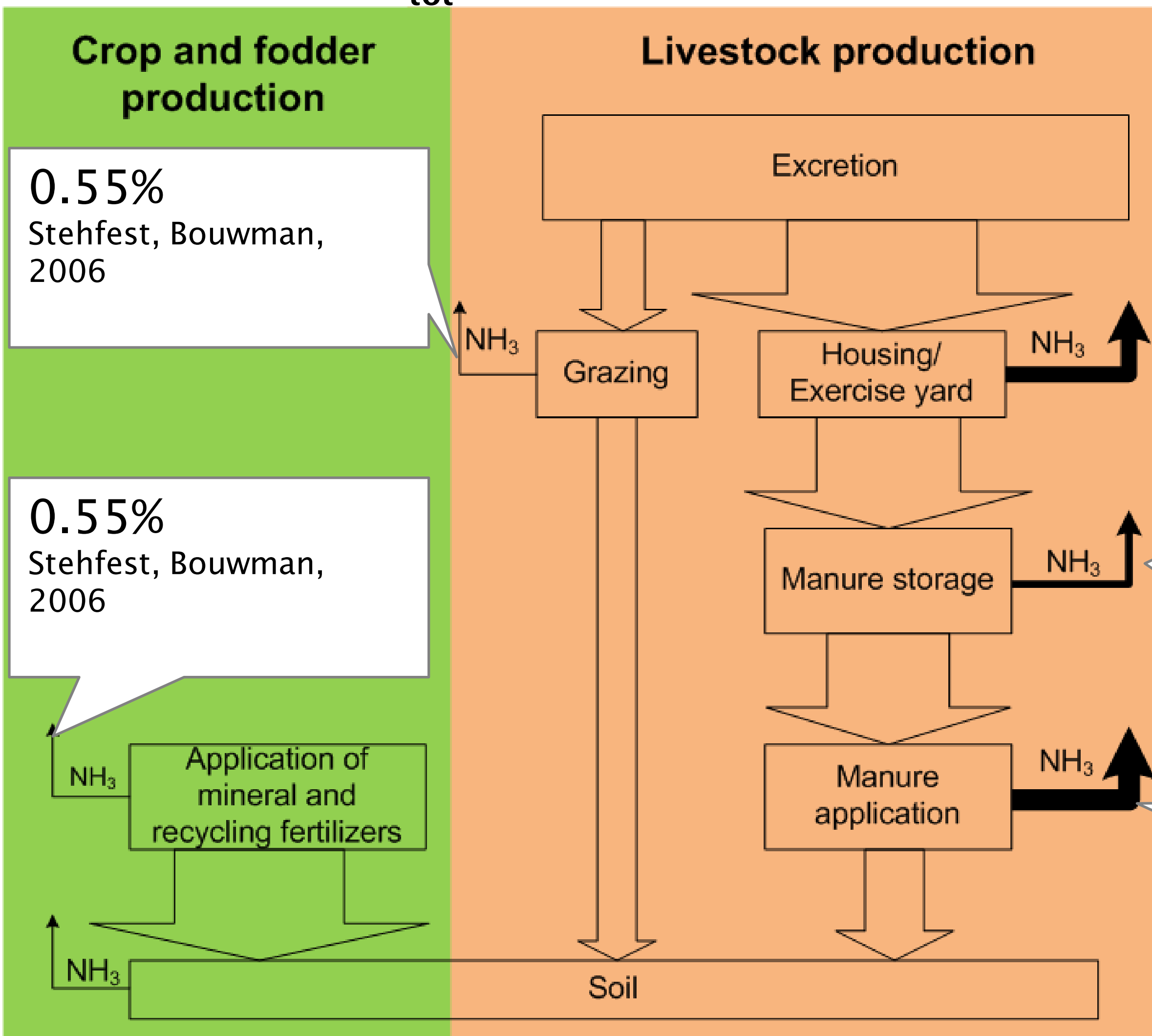
Emission factors (EF) for NO

in kg NO-N/kg N

For systems with production of slurry and solid manure

in percent of N_{tot} at the inflow of the emission stage

relative to the N_{tot} in solid manure



EF based on the flow of N_{tot} into housing/exercise yard

- Cattle: 0.5%
- "Dry lot" is not considered

van Bruggen et al. 2014 (Tab. 2.10), pers. comm. Van Bruggen for EAGER, 2015

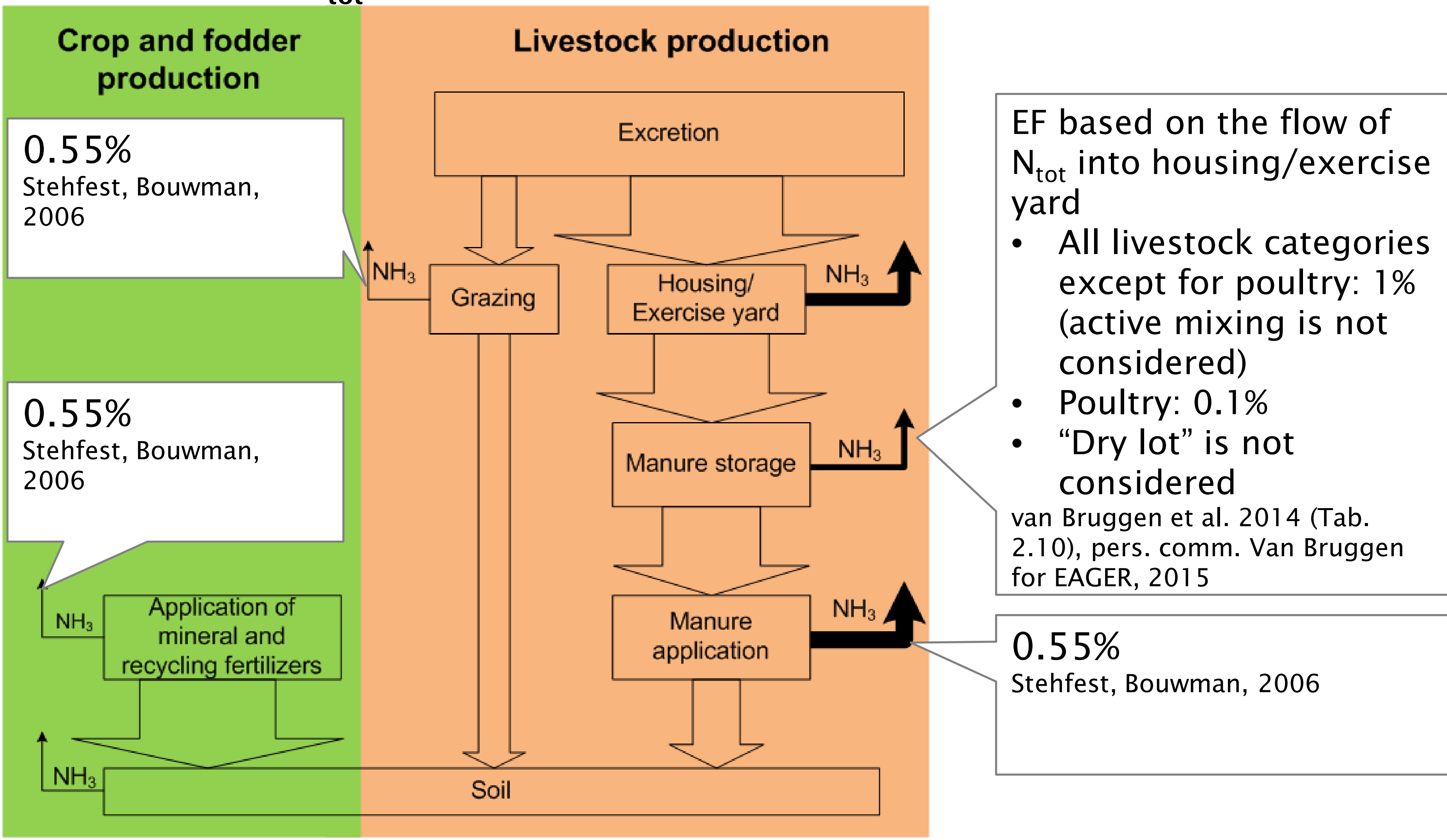
0.55%

Stehfest, Bouwman, 2006

Emission factors (EF) for NO

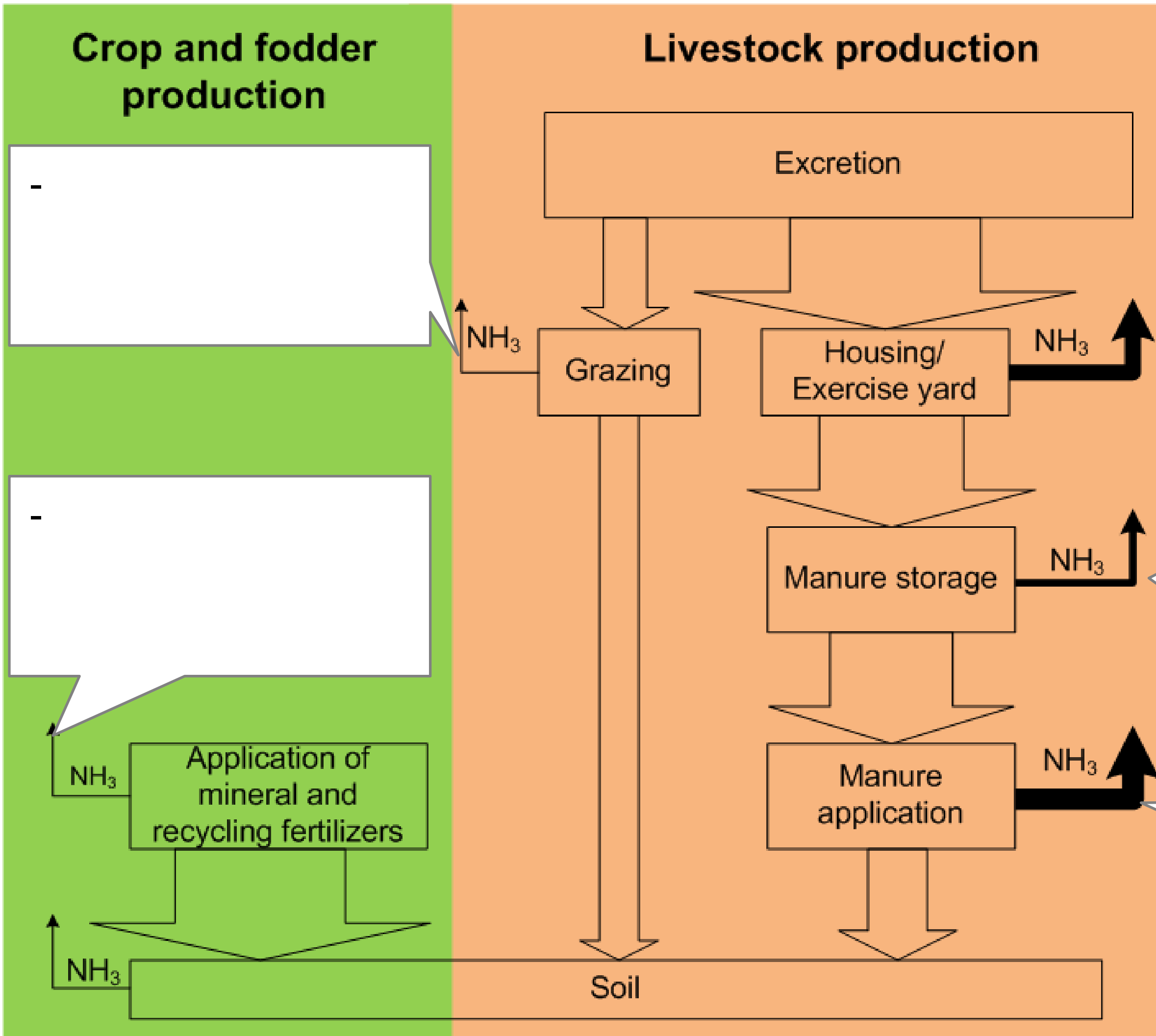
in kg NO-N/kg N

For systems with production solid manure (deep litter, droppings from poultry) in percent of N_{tot} at the inflow of the emission stage relative to the N_{tot} in solid manure



Emission factors (EF) N_2

For systems with production of slurry and solid manure in percent of N_{tot} at the inflow of the emission stage relative to the N_{tot} in solid manure



EF based on the flow of N_{tot} into housing/exercise yard

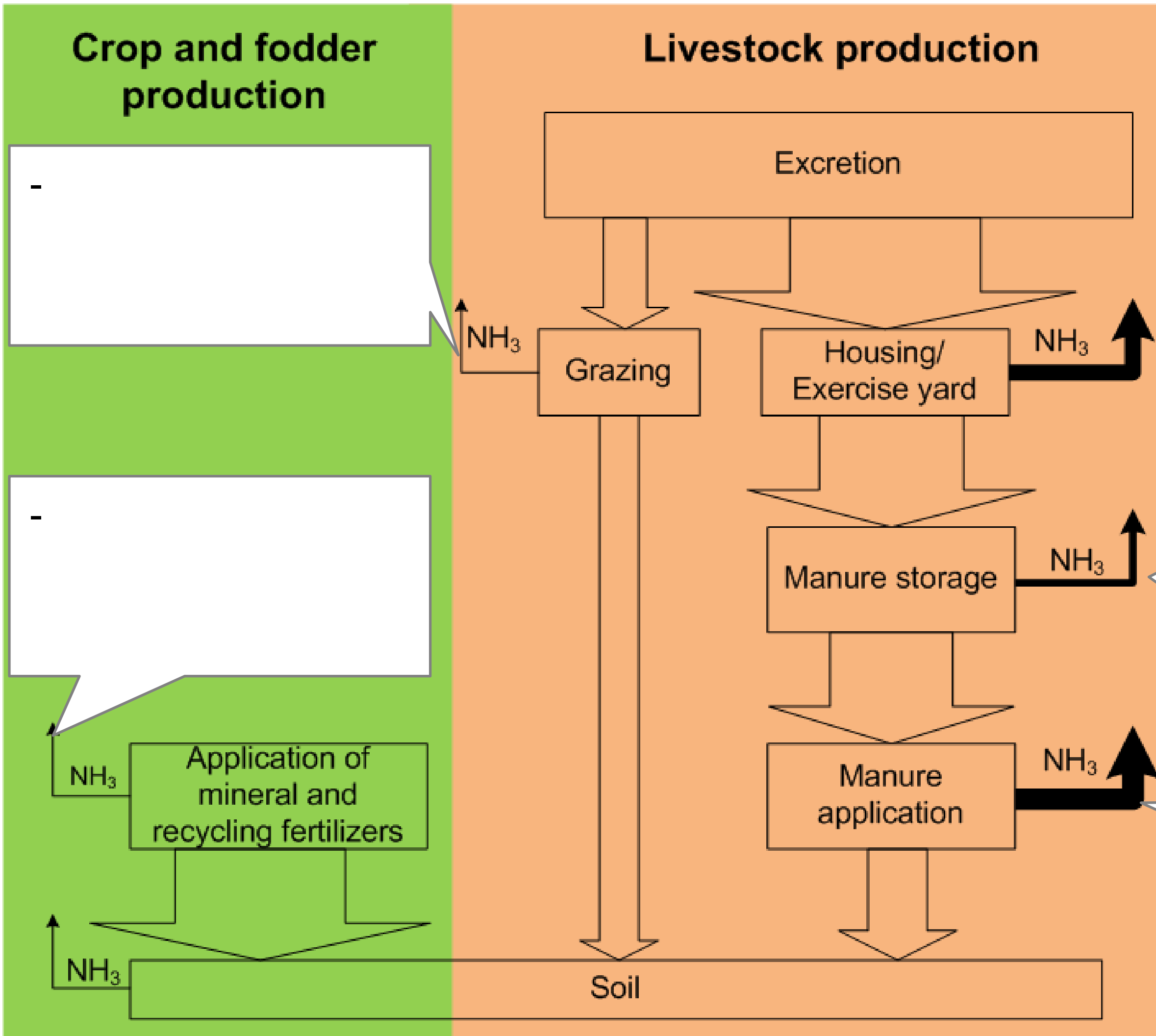
- Cattle: 2%
- “Dry lot” is not considered

van Bruggen et al. 2014 (Tab. 2.10), pers. comm. Van Bruggen for EAGER, 2015

-

Emission factors (EF) N_2

For systems with production of slurry and solid manure in percent of N_{tot} at the inflow of the emission stage relative to the N_{tot} in solid manure



EF based on the flow of N_{tot} into housing/exercise yard

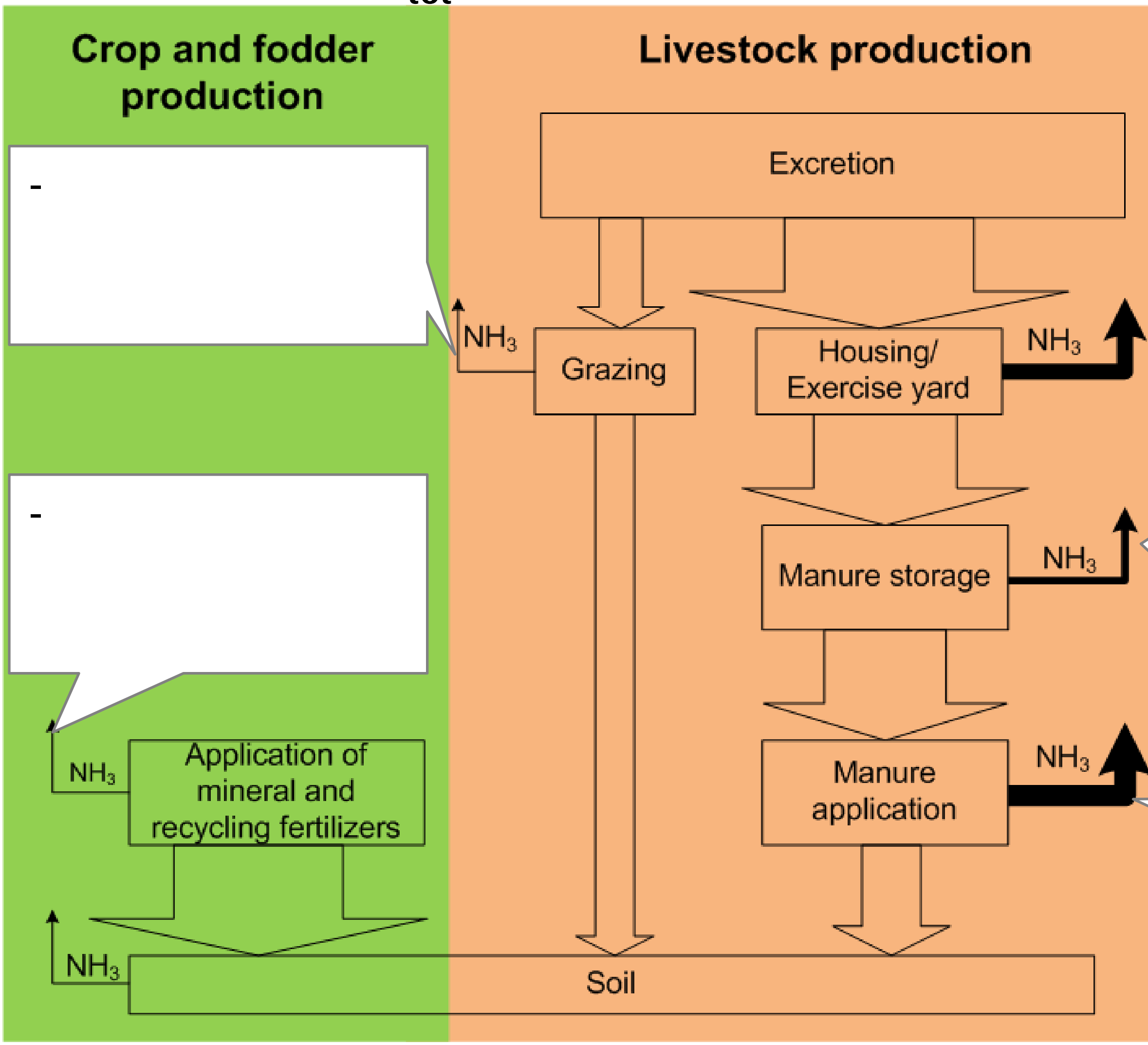
- Cattle: 2.5%
- "Dry lot" is not considered

van Bruggen et al. 2014 (Tab. 2.10), pers. comm. Van Bruggen for EAGER, 2015

-

Emission factors (EF) N_2

For systems with production solid manure (deep litter, droppings from poultry) in percent of N_{tot} at the inflow of the emission stage relative to the N_{tot} in solid manure



EF based on the flow of N_{tot} into housing/exercise yard

- All livestock categories except for poultry: 5% (active mixing is not considered)
- Poultry: 2.5%
- “Dry lot” is not considered

van Bruggen et al. 2014 (Tab. 2.10), pers. comm. Van Bruggen for EAGER, 2015