REPORTS OF THE FINNISH ENVIRONMENT INSTITUTE 37 | 2017

Calculation of atmospheric nitrogen and NMVOC emissions from Finnish agriculture

Description of the revised model

Juha Grönroos, Joonas Munther and Sari Luostarinen



Finnish Environment Institute

REPORTS OF THE FINNISH ENVIRONMENT INSTITUTE 37/2017

Calculation of atmospheric nitrogen and NMVOC emissions from Finnish agriculture

Description of the revised model

Juha Grönroos, Joonas Munther and Sari Luostarinen

REPORTS OF THE FINNISH ENVIRONMENT INSTITUTE 37 | 2017
Finnish Environment Institute
Centre for Sustainable Consumption and Production

Author(s): Juha Grönroos, Joonas Munther and Sari Luostarinen
Subject Editor: Riina Antikainen

Publisher and financier of publication: Finnish Environment Institute (SYKE)
P.O. Box 140, FI-00251 Helsinki, Finland, Phone +358 295 251 000, syke.fi

Layout: Juha Grönroos
Cover photo: Pentti Sormunen / Vastavalo.fi

The publication is available in the internet (pdf): syke.fi/publications | helda.helsinki.fi/syke and in print: syke.juvenesprint.fi

ISBN 978-952-11-4901-6 (pbk.)
ISBN 978-952-11-4902-3 (PDF)
ISSN 1796-1718 (print)
ISSN 1796-1726 (online)

Year of issue: 2017

ABSTRACT

Calculation of atmospheric nitrogen and NMVOC emissions from Finnish agriculture - Description of the revised model

Agricultural gaseous nitrogen emissions are mostly related to manure management, grazing and fertilisation. These emissions include ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO) and di-nitrogen (N_2). Most of the non-methane volatile organic compounds (NMVOC) emissions originate from livestock farming, but also from cultivated crops. All these emissions are inventoried and reported for the UN Convention on Long-range Transboundary Air Pollution (CLRTAP), EU National Emission Ceilings Directive (2001/81/EC) and the UN Framework on Climate Change (UNFCC). In Finland, a specific national model for gaseous nitrogen emissions from agriculture has been used for the inventory since 1998.

The revised calculation model documented here is tied to the Finnish Normative Manure System, which provides data on manure quality and quantity for various livestock categories. The emission calculation follows the flow of total ammoniacal nitrogen (TAN) and total nitrogen (N) through the manure management systems, starting from excretion and ending at manure spreading. The main manure management phases considered in the calculation are livestock housing, manure storing and manure field application. The calculation also embeds estimations on emissions from grazing and outdoor yards, as well as emissions from the use of mineral fertilisers. The nitrogen calculation model provides data for the calculation of agricultural NMVOC emissions. All calculations are constructed in compliance with the Tier 2 method of the EMEP/EEA emission inventory guidebook (2016).

Keywords: agriculture, manure, nitrogen, ammonia, NMVOC, emissions, calculation models

Maataloudesta peräisin olevien ilmaan kohdistuvien typpi- ja NMVOC-päästöjen laskenta - Päivitetyn laskentamallin kuvaus

Maatalouden kaasumaiset typpipäästöt ilmaan muodostuvat pääasiassa kotieläinten lannan käsittelyssä, laidunnuksessa ja lannoitteiden käytössä. Näihin päästöihin kuuluvat ammoniakki (NH_3), dityppioksidi (N_2O), typpioksidi (NO) ja typpikaasu (N_2). Myös muiden haihtuvien orgaanisten yhdisteiden kuin metaanin (NMVOC) päästöistä suurin osa vapautuu kotieläintuotannosta, mutta osin myös viljelykasveista. Päästöt raportoidaan vuosittaisissa inventaarioissa YK:n ilman epäpuhtauksien kaukokulkeutumista koskevan yleissopimuksen (CLRTAP), Euroopan parlamentin ja neuvoston ilman epäpuhtauksien päästörajadirektiivin (2001/81/EY) ja YK:n ilmastonmuutosta koskevan puitesopimuksen (UNFCC) mukaisesti. Suomessa typpipäästöjä on arvioitu kansallisella laskentamallilla vuodesta 1998 lähtien.

Tässä kuvattava päivitetty maatalouden kaasumaisten typpipäästöjen laskentamalli kytkeytyy rinnan kehitettyyn Suomen normilanta -järjestelmään, joka tuottaa eläinluokittaisia tietoja lannan ominaisuuksista ja määrästä. Kaasumaisten typpipäästöjen laskennassa seurataan ammoniumtypen (TAN) ja kokonaistypen (N) kulkeutumista eri lannankäsittelyjärjestelmissä erityksestä peltoon. Laskennassa erotellaan eläinsuojassa, lantavarastossa ja levityksessä lannasta vapautuvat päästöt. Mallissa arvioidaan myös eläinten laiduntamisesta ja jaloittelusta sekä mineraalilannoitteiden käytöstä aiheutuvat päästöt. Laskentamalli tuottaa pohjatietoja erillisenä laskentana toteutettavaan maatalouden NMVOC-laskentaan. Laskennat on kehitetty noudattaen Euroopan ympäristökeskuksen Tier 2 -menetelmän mukaista ohjeistusta kansallisiin olosuhteisiin soveltaen.

Asiasanat: maatalous, lanta, typpi, ammoniakki, NMVOC, päästöt, laskentamallit

SAMMANDRAG

Beräkning av atmosfäriskt kväve och NMVOC-utsläpp från det finska jordbruket - Beskrivning av den uppdaterade beräkningsmodellen

Utsläppen av gasformiga kväveutsläpp beror främst på gödselhantering, betning och användning av mineralgödsel. Dessa utsläpp omfattar ammoniak (NH_3), dikväveoxid (N_2O), kväveoxid (NO) och kvävegas (N_2). Även de flesta utsläppen av andra flyktiga organiska föreningar än metan (NMVOC) härstammar från djurhållning, men delvis även från odlingsgrödor. Alla dessa utsläpp inventeras och rapporteras årligen i enlighet med FN: s konvention om långväga gränsöverskridande luftföroreningar (CLRTAP), Europaparlamentets och rådets direktiv om nationella utsläppstak för vissa luftföroreningar (2001/81/EG) och FN:s ramkonvention om klimatförändringar (UNFCC). I Finland har utsläppen beräknats med den nationella beräkningsmodellen sedan 1998.

Den reviderade beräkningsmodellen som dokumenteras här är knuten till det finska normativa gödselsystemet, vilket ger data om gödselkvalitet och kvantitet för olika djurkategorier. Utsläppsberäkningen följer flödet av totalt ammoniumkväve (TAN) och totalt kväve (N) genom gödselhanteringssystemen, från utsöndring till gödselspridning. I beräkningen skiljer man på utsläppen från gödseln i stall, i lager och i spridning. Modellen uppskattar också utsläppen från betning och djurgårdar utomhus, liksom även spridning av mineralgödselmedel. Beräkningsmodellen ger data för beräkning av NMVOC-utsläpp från jordbruket. Alla beräkningar är uppbyggda i enlighet med Tier 2-metoden i EMEP/EEA-guiden för inventering av utsläpp av luftföroreningar (2016).

Nyckelord: Jordbruk, gödsel, kväve, ammoniak, NMVOC, emissioner, kalkylmodeller

PREFACE

Emissions and losses to the environment are the starting point of environmental pollution problems. Information on emissions is a requirement for understanding environmental problems and for monitoring progress towards solving them. The required information is provided by emission inventories.

National emissions of ammonia, other air pollutants and greenhouse gases are annually reported in response to obligations under international conventions and protocols. To compile an emission inventory, all sources of the pollutants must be identified and quantified. Agriculture is one of the reported emission source categories. For ammonia, it is also the most important one.

In Finland, a specific national model for ammonia and other gaseous nitrogen emissions from agriculture has been used for the emission inventory since 1998. The model has been updated regularly in order to comply with the emission calculation guidelines. Recently, the calculation of non-methane volatile organic compounds (NMVOC) emissions has also been included in the model.

The latest model upgrade was realised during the years 2014-2017, simultaneously with the development of the Finnish Normative Manure System. This report documents the updated model. The work was carried out in co-operation between Finnish Environment Institute (SYKE) and Natural Resources Institute Finland (Luke). It was funded by the Ministry of the Environment.

CONTENTS

Abstract **3**

Tiivistelmä **4**

Sammandrag **5**

Preface **6**

Terms and abbreviations **9**

1 Introduction **11**
1.1 Agricultural gaseous nitrogen emissions: sources, impacts and controlling 11
1.1.1 Ammonia 11
1.1.2 Nitrous oxide 12
1.1.3 Nitric oxide and di-nitrogen 12
1.2 Agricultural gaseous nitrogen emission inventory in Finland 12
1.3 NMVOC emissions from agriculture 13
1.4 Aim of the study 13

2 Calculation of nitrogen emissions **14**
2.1 Emissions from manure management 14
2.1.1 General system description 14
2.1.2 Detailed description of emission calculation methods for gaseous N compounds 17
2.1.2.1 Excreted nitrogen in manure management systems 17
2.1.2.2 Calculation of inhouse emissions 19
2.1.2.3 Calculation of emissions from manure storing 20
2.1.2.4 Calculation of emissions from manure application 23
2.1.2.5 Calculation of emissions from grazing and yards 26
2.2 Emissions from mineral N-fertilisers 26
2.3 Basic model parameters 27
2.3.1 Nitrogen excretion rates 27
2.3.2 Nitrogen mineralisation and immobilisation 28
2.3.3 Unabated emission rates and emission abatement factors 28
2.3.3.1 Ammonia 28
2.3.3.2 Other nitrogen emissions 28
2.3.4 Temperature correction factors for ammonia 34
2.4 Activity data 35
2.4.1 Animal numbers and use of mineral fertilisers 35
2.4.2 Manure management data 35
2.4.3 Bedding material use and properties, cleaning water mixed with manure 36

3 Calculation of NMVOC emissions **37**
3.1 Emissions from manure management 37
3.1.1 Emissions from housing 38
3.1.2 Emissions from silage feeding 38
3.1.3 Emissions from silage storage 39
3.1.4 Emissions from manure storage 39
3.1.5 Emissions from field application of manure 40
3.1.6 Emissions from grazing 40
3.1.7 Activity data 41
3.1.8 Emission factors 41
3.2 Emissions from cultivated crops 42

3.2.1 Calculation of NMVOC emissions from cultivated crops 42
3.2.2 Activity data 43
3.2.3 Emission factors 44

4 Conclusions 45

Appendix 1. Nitrogen excretion rates, as kg total N/animal place/year (1980 – 2015) 47

Appendix 2. Manure management data for 2005 and 2015 and prediction for 2020 50

MANURE TYPES	
Deep litter	A solid manure type in which urine is absorbed into the bedding material and manure is removed only seldom (e.g. after each batch)
Dung	A solid manure type from source-separating manure management system, a mixture of faeces, bedding material and a small amount of absorbed urine
Excreta	Faeces and urine directly from animal
Faeces	The solid excreta of animals
Farmyard manure (FYM)	A solid manure type in which faeces and urine are mixed with large amounts of bedding (usually straw)
Manure	Usually a mixture of faeces and urine with or without bedding material and cleaning water, depending on the type of animal housing system
Slurry	A liquid manure type in which faeces, urine, small amount of bedding material and all cleaning waters are mixed together to form a sludge-like manure with dry matter content below 15%
Solid manure	A general term for all solid/dry manure types (deep litter, farmyard manure, dung)
Urine	The liquid excreta of animals OR source-separated urine collected separately from dung

OTHER TERMS	
Ammonia (NH_3)	Inorganic form of nitrogen
Ammonium nitrogen (NH_4^+)	Inorganic, positively charged form of ammonia
Bedding material	Material placed on the floors of livestock houses with solid floors or partially slatted floors to provide some comfort to the animals and to absorb moisture and urine. Commonly straw, chopped straw, sawdust, wood shavings, sand, peat. Rubber or plastic mats may also be provided for animals to lie on.
Di-nitrogen (N_2)	Molecular nitrogen, nitrogen gas
Excretion	The excreta remaining from animal feed after growth and products (milk, meat, eggs)
Finnish Normative Manure System (FNMS)	A model for calculating manure quantity and quality in Finland
Litter	See: Bedding material
Nitric oxide (NO)	An oxide of nitrogen.
Nitrous oxide (N_2O)	An oxide of nitrogen, commonly known as laughing gas. Has a significant global warming potential as greenhouse gas.
Outdoor yard	See: yard
Total ammoniacal nitrogen (TAN)	The total amount of ammonium and ammonia nitrogen contained in e.g. livestock manures.
Total nitrogen (N)	Total Kjeldahl nitrogen
Uric acid nitrogen	Nitrogen in the uric acid of poultry excreta (uric acid = the main end product of the protein metabolism of birds)
Yard	Outdoor, unroofed area for handling, exercise and feeding of livestock.

ABBREVIATIONS	
AAP	Annual average population
CLRTAP	Convention on Long-range Transboundary Air Pollution
DL	Deep litter
DM	Dry matter
EEA	European Environment Agency
EF	Emission factor
EMEP	Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
FYM	Farmyard manure
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
Ktot	Total kalium
MJ	Megajoule
N	(Total) nitrogen
N_2	Di-nitrogen
N_2O	Nitrous oxide
NH_3	Ammonia
NH_4^+	Ammonium nitrogen
NMVOC	Non-methane volatile organic compounds
NO	Nitric oxide
Ntot	Total nitrogen
$PM_{2,5}$ / PM_{10}	Particulate matter 2.5/10 micrometers or less in diameter
Psol	Soluble i.e. plant available phosphorus
Ptot	Total phosphorus
S	Slurry
SMS	Solid manure system
SS	Solid separation system
SSD	Dung in solid separation system
SSU	Urine in solid separation system
TAN	Total ammoniacal nitrogen
TCF	Temperature correction factor
tot-N	Total nitrogen
UAN	Uric acid nitrogen
UNECE	United Nations Economic Commission for Europe
UNFCC	UN Framework on Climate Change
VS	Volatile solids

1 Introduction

1.1 Agricultural gaseous nitrogen emissions: sources, impacts and controlling

Most agricultural gaseous nitrogen emissions are related to manure management and fertilisation (Figure 1). Ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO) and di-nitrogen (N_2) are lost during agricultural practices. As most of them have adverse environmental effects, they are inventoried (EMEP/EEA 2016, IPCC 2006) and regulated under the UN Convention on Long-range Transboundary Air Pollution (CLRTAP), the EU National Emission Ceilings Directive (2001/81/EC) and the UN framework on climate change (UNFCC).

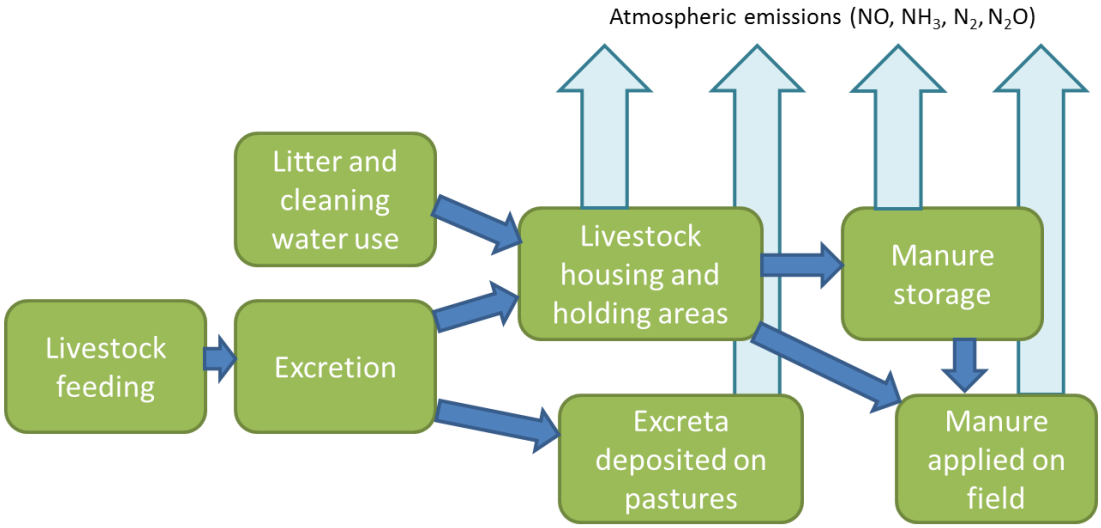


Figure 1. Gaseous nitrogen emissions in manure management of livestock production.

1.1.1 Ammonia

Ammonia (NH_3) is a colourless gas known for its foul odour. It forms equilibrium with its ionised form ammonium nitrogen (NH_4^+) in solutions depending on temperature and pH. The higher they are, the higher the proportion of ammonia susceptible to volatilisation into the atmosphere. Volatilisation depends on the solution temperature, surface area exposed and the resistance of ammonia transport into the atmosphere.

Ammonia causes harmful environmental impacts via acidification and eutrophication. It is also a precursor in secondary particle formation ($PM_{2.5}$ and PM_{10}) causing adverse health effects on humans, and an indirect source of greenhouse gas emissions (nitrous oxide; see below).

Ammonia is formed during biological degradation of organic nitrogen compounds e.g. in animal metabolism, soils, manure management and waste treatment and disposal. Approximately 90% of ammonia emissions are released in agriculture, the main source being the nitrogen excreted by livestock into manure. Thus, actions to control ammonia emissions are mainly directed to reducing nitrogen in animal feeding and to minimising emissions during manure management (housing, grazing, outdoor yards, storage) and utilisation (fertiliser use). In principle, manure should be collected quickly into covered storages and spread on fields with low-emission application methods.

1.1.2 Nitrous oxide

Nitrous oxide (N_2O) is a potent greenhouse gas (GHG), being over 300 times stronger than carbon dioxide per mass unit. Its major source is natural and agricultural soil, more precisely denitrification of nitrate during the biological activity of soil microbiota. The main anthropogenic source of nitrous oxide emissions is thus via nitrogen fertilisation, spread either as mineral fertilisers or manure and other organic fertilisers.

Nitrous oxide emissions can best be minimised with precise nitrogen fertilisation. This means using the right dose with consideration of the soil characteristics and the crop produced, and spreading preferably during vegetative season and with low-emission application methods.

In addition to direct nitrous oxide emissions, emissions of ammonia and nitrogen oxides to the atmosphere and leaching of nitrogen fertilisers to the waters cause indirect nitrous oxide emissions.

1.1.3 Nitric oxide and di-nitrogen

Nitric oxide (NO) is involved in stratospheric ozone formation with adverse effects on human health and plant growth. Nitric oxide is released during manure management, but the share of agricultural NO emissions in total emissions is modest, approximately 7% (EMEP/EEA 2016a). Specifically nitric oxide is released in nitrification occurring in the surface layer of stored manure and after land application in soils.

Di-nitrogen (N_2) is the main result of denitrification in which nitrate is converted into gaseous nitrogen. The atmosphere is largely comprised of di-nitrogen gas (78%), and di-nitrogen formation is not an emission as such. Because emissions of N_2 affect the nitrogen content in livestock manure, and consequently the emissions of the other gaseous nitrogen compounds, it is included into the emission calculation system.

1.2 Agricultural gaseous nitrogen emission inventory in Finland

Inventories for agricultural gaseous emissions are made to control and report them as part of the emission ceilings set in the UN Convention on Long-range Transboundary Air Pollution (CLRTAP), EU National Emission Ceilings Directive (2001/81/EC) and the UN framework on climate change (UNFCC). Air pollutant inventory is made according to the EMEP/EEA (2016) joint guidelines, and agricultural GHG-emission inventory according to the IPCC (2006) guidelines. They both provide three-tiered instructions for emission calculations. The guidelines aim to provide procedures to compile emission inventories meeting the quality criteria for Transparency, Consistency, Completeness, Comparability and Accuracy (TCCCA criteria) and estimation methods and emission factors for inventory compilers at various levels of sophistication (Tiers 1-3). The Tier 1 approach is the simplest method relying on default emission factors and statistics. The Tier 2 approach uses country-specific data and emission factors, and thus requires more background data. The Tier 3 approach refines the calculations with more detailed descriptions and data and using e.g. sophisticated models. The guidelines are periodically updated and thus the national calculations/models also require updating. The aim and good practice is to use the best available data which then defines which Tier to use.

Since 1998, Finnish ammonia emissions originating from livestock manure have been calculated with the national nitrogen model, which is based on the nitrogen flow approach. In this approach, the flow of total ammoniacal nitrogen (TAN) and total nitrogen (tot-N) are followed through the manure management system so that the more NH_3 and other nitrogen compounds are emitted at the previous stage of the manure management system, the less TAN and tot-N remain available for emissions at later stages. The model includes also ammonia emission calculation for mineral N-fertilisers.

The documentation of the previous calculation systems were published by Grönroos et al. in 1998 (in Finnish) and in 2009 (in English). Originally, the model was used only for ammonia emission modelling, but it was later supplemented with N_2O, NO and N_2 emission calculation.

1.3 NMVOC emissions from agriculture

Non-methane volatile organic compounds (NMVOC) are a collection of organic compounds that differ widely in their chemical composition but display similar behaviour in the atmosphere. NMVOCs contribute to the formation of ground-level (tropospheric) ozone, which can damage crops and many materials as well as have potential adverse effects on human health. Some NMVOCs are directly hazardous to humans.

Emissions of NMVOCs in agriculture are mostly released from silage, different stages of manure management and from grazing animals. NMVOC is also released by naturally growing vegetation and cultivated crops.

1.4 Aim of the study

The main aim of the study was to update and expand the model used for calculating the agricultural nitrogen emissions to the atmosphere to meet the most recent requirements of the emission inventory guidelines of UNECE (EMEP/EEA 2016) and UNFCCC (IPCC 2006). The most important task was to change the nitrogen flow approach used from mainly total nitrogen to entirely total ammoniacal nitrogen (TAN). However, calculation of direct nitrous oxide (N_2O) emissions is still based on total nitrogen as described in IPCC inventory guidelines.

The model calculates ammonia (NH_3) and direct and indirect nitrous oxide (N_2O) emissions (originating from manure management and managed soils). Also, nitric oxide (NO) and di-nitrogen (N_2) emissions from manure management and nitric oxide emissions from application of manure and mineral fertilisers are calculated (Table 1).

These changes enabled the establishment of the Finnish Normative Manure System (see: Luostarinen et al. 2017) which was tied to the model simultaneously with the model revision. Additionally, NMVOC emission calculation for manure management, manure applied to soils, urine and dung deposited by grazing animals and cultivated crops was also added to the calculation system (see Table 1 and chapter 3).

Table 1. Emissions included into the agricultural emission calculation model by emission source category (NFR).

NFR code	Category name	NH_3	NOx	N_2O direct	N_2O indirect	N_2	NMVOC
3B	Manure management (livestock categories: see chapter 2.1.1)	x	x	x	x	x	x
3Da1	Inorganic N-fertilisers (includes also urea application)	x	x	x	x		x
3Da2a	Animal manure applied to soils	x		x	x		x
3Da3	Urine and dung deposited by grazing animals	x		x	x		x
3De	Cultivated crops						x

2 Calculation of nitrogen emissions

2.1 Emissions from manure management

2.1.1 General system description

This chapter covers the calculation of gaseous nitrogen emissions as ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO) and di-nitrogen (N_2).

The calculation of the gaseous nitrogen emissions from manure management is based on the nitrogen flow approach, as described in the previous Finnish ammonia and nitrous oxide emission calculation documentations (Grönroos et al. 1998; Grönroos et al. 2009), and in the UNECE and UNFCCC emission inventory guidebooks. In the method used, the pathways of nitrogen are followed starting from nitrogen excretion of the livestock and ending at application of manure to the fields (Figure 2). In each manure management stage, the gaseous losses of nitrogen are calculated. The calculation is made per different livestock categories (Tables 2a and 2b) and manure management systems.

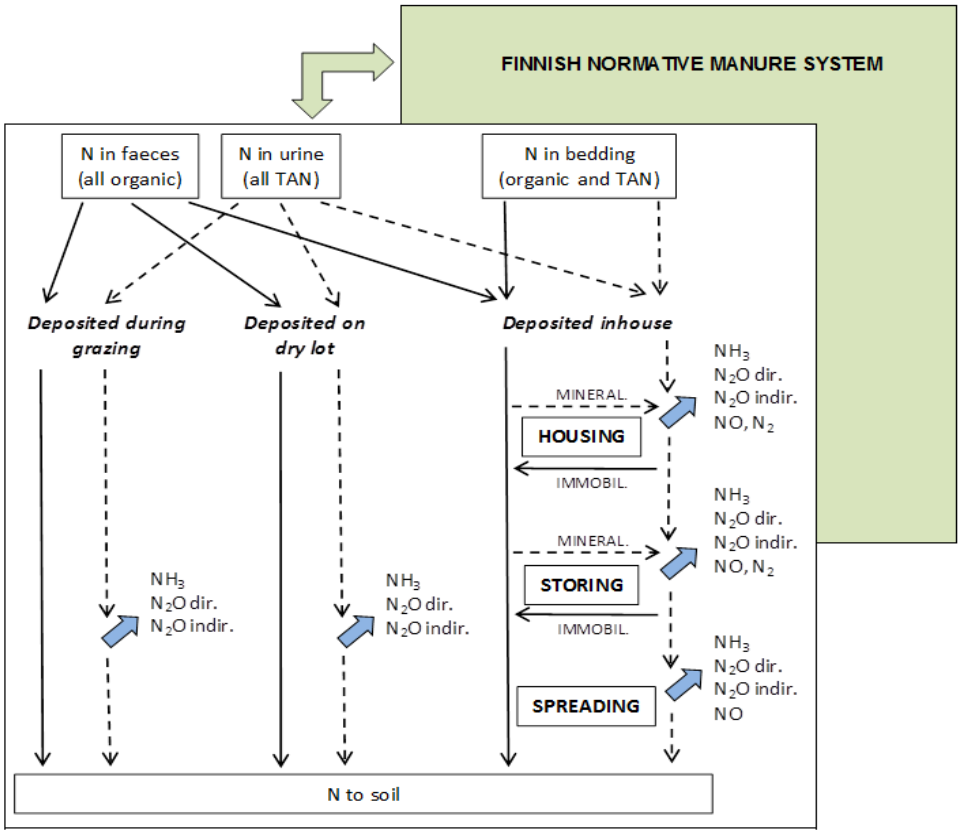


Figure 2. Schematic diagram of the N flows in manure management (incl. manure application, grazing and dry lots (outdoor yards) and the related gaseous nitrogen emission model used for calculating the NH_3, N_2O, NO and N_2 emissions from manure management in Finland. Nitrogen transformation processes (immobilisation and mineralisation) are shown, as well as the link between emission calculation model and the Finnish Normative Manure System (see text for more information). Broad blue arrows: emissions of N-compounds to the atmosphere. Emissions are calculated separately for different livestock categories and manure management systems. For clarity, all manure management systems are not shown in figure.

In general, the Finnish agricultural ammonia emission calculation model follows the principles of Tier 2 method described in the emission inventory guidebook (EMEP/EEA 2016). However, it has some features which move it strongly towards the Tier 3 method. These are a greater number of livestock categories and manure types than listed under Tier 2, inclusion of emission abatement measures, and application of temperature correction factors.

The manure management systems considered are (manure type acronym in brackets):

- slurry (S)
- deep litter (DL)
- solid manure system (SMS), divided into two separate systems:
    - farm yard manure system (FYM; urine absorbed in bedding material)
    - solid separation system (SS; urine and faeces managed separately, produces two types of manure: faeces with bedding (dung; SSD), and urine (SSU)).

As opposed to the total nitrogen in previous model versions, nitrogen flow approach is now applied to total ammoniacal nitrogen (TAN) of manure in each stage of the manure management system. Consequently, the emissions of gaseous nitrogen compounds (except nitrous oxide) are estimated based on the TAN content in manure. Because the effects of dietary changes or nitrogen transformation during the manure management chain affect manure TAN content, and because TAN is the basis for ammonia and other forms of gaseous nitrogen emissions, more precise emission estimates are now reachable.

Due to the needs of nitrous oxide emission calculation, the content of total nitrogen in manure and bedding materials were also included into the nitrogen flow approach. Moreover, the revised model considers also the transformation of manure nitrogen during manure storage, i.e. immobilisation of solid manure TAN to organic form and mineralisation of slurry organic nitrogen to TAN.

The main manure management phases considered in the calculation model are:

- animal housing,
- manure storing,
- manure spreading (included in the category of managed soils in GHG emission inventory).

Moreover, emissions from grazing and outdoor yards are estimated. In the GHG emission inventory, emissions from grazing are included in the category of managed soils.

The emission calculation model is one part of the Finnish Normative Manure System (Luostarinen et al. 2017). The normative manure system is used to calculate manure quality and quantity data for various livestock categories, to be used e.g. in policymaking, research, technology development and manure fertilisation plans on farms. The major inputs from the normative manure system to the emission calculation model are nitrogen excretion rates for each animal category (divided between faeces and urine) and the effects of nitrogen transformation processes to the quantity of TAN in different stages of manure management.

Table 2a. Animal categories considered in the emission calculation model; the detailed categorisation. The animal categories are the same as those in the Finnish Normative Manure System (Luostarinen et al. 2017).

Cattle	
• Dairy cow, high yielding	• Bull, indigenous (1-2 yrs)
• Dairy cow, indigenous	• Bull, indigenous (>2 yrs)
• Suckler cow, high yielding	• Calf, female, beef (< 6 m)
• Suckler cow, indigenous	• Calf, female, beef (6-12 m)
• Heifer, beef (>2 yrs)	• Calf, female, dairy (< 6 m)
• Heifer, beef (1-2 yrs)	• Calf, female, dairy (6-12 m)
• Heifer, dairy (>2 yrs)	• Calf, female, indigenous (< 6 m)
• Heifer, dairy (1-2 yrs)	• Calf, female, indigenous (6-12 m)
• Heifer, indigenous (>2 yrs)	• Calf, male, beef (< 6 m)
• Heifer, indigenous (1-2 yrs)	• Calf, male, beef (6-12 m)
• Bull, beef (>2 yrs)	• Calf, male, dairy (< 6 m)
• Bull, beef (1-2 yrs)	• Calf, male, dairy (6-12 m)
• Bull, dairy (>2 yrs)	• Calf, male, indigenous (< 6 m)
• Bull, dairy (1-2 yrs)	• Calf, male, indigenous (6-12 m)
Pigs	
• Farrowing sow + piglets (<10-12 kg)	• Fattening pig (>50 kg)
• Gestating sow	• Weaned pig (<30 kg)
• Mating sow	• Weaned pig (<50 kg)
• Boar (50- kg)	
Poultry	
• Laying hen breeder	• Chicken
• Cockerel (laying hen breeder, male)	• Growing turkey
• Broiler	• Turkey breeder, hen
• Broiler breeder, hen	• Turkey breeder, male
• Broiler breeder, male	• Other poultry
Other animals	
• Horse	• Goatling
• Pony (120-140 cm)	• Fox breeder, female
• Pony, little (<120 cm)	• Fox breeder, male
• Ewe	• Fox grower
• Ram	• Mink breeder, female
• Lamb	• Mink breeder, male
• Doe	• Mink grower
• Puck	• Reindeer

Table 2b. Animal categories considered in the emission calculation model; the simpler categorisation. The animal categories are the same as those in the Finnish Normative Manure System (Luostarinen et al. 2017).

Cattle	
• Dairy cow	• Bull >1 yr
• Suckler cow	• Calf <1 yr
• Heifer >1 yr	
Pigs	
• Sow (with piglets)	• Fattening pig (>50 kg)
• Boar (>50 kg)	• Weaned pig (<50 kg)
Poultry	
• Laying hen breeder (female)	• Turkey
• Cockerel (laying hen breeder, male)	• Other poultry
• Broiler	• Growing turkey
• Broiler breeder, hen	• Turkey breeder, hen
• Broiler breeder, male	• Turkey breeder, male
• Chicken	• Other poultry
Other animals	
• Horse	• Fox and racoon
• Pony	• Mink and fitch
• Sheep	• Reindeer
• Goat	

2.1.2 Detailed description of emission calculation methods for gaseous N compounds

2.1.2.1 Excreted nitrogen in manure management systems

The calculation of gaseous nitrogen compounds starts from the excreted TAN of each animal category (as kg TAN per animal place per year; see chapter 2.3.1 and Appendix 1). Similar to other agricultural ammonia emission inventories (e.g. Velthof et al. 2012, Haenel et al. 2016), it is assumed that the fraction of TAN in nitrogen excretion is equal to the amount of nitrogen excreted in urine. This is the nitrogen fed and digested but not converted into animal products. The undigested nitrogen in feed is supposedly excreted as faecal nitrogen.

For poultry, the approach of the German documentation for emission calculation (Haenel et al. 2016) is followed. Uric acid nitrogen (UAN) excreted by poultry is considered completely TAN and the basis for emission calculation. However, as the Finnish Normative Manure System calculates only total nitrogen excretion for poultry, the proportion of UAN is here assumed to be 70% of the total nitrogen, following the default value presented in EMEP/EEA (2016a, Table 3.9). Nitrogen excretion values per animal category and year are based on national data as explained in chapter 2.3.1.

TAN excreted is divided between the following locations in which excreta is deposited:

a) TAN excreted inhouse (m_{build_TANex}) eq. *(1)*
b) TAN excreted during grazing (m_{graz_TANex}) eq. *(2)*
c) TAN excreted on yards (m_{yards_TANex}) eq. *(3)*

based on the fraction (X) of the year the animals spend in buildings, on yards and grazing:

$$m_{build_TANex} = X_{build} \cdot TAN_{ex} \quad (1)$$

$$m_{graz_TANex} = X_{graz} \cdot TAN_{ex} \quad (2)$$

$$m_{yards_TANex} = X_{yards} \cdot TAN_{ex} \quad (3)$$

Where,

X_{build}, X_{graz}, X_{yards} = fractions of the year (as %; Appendix 2)

TAN_{ex} = annual animal category specific TAN excretion values (as kg TAN per animal place per year; Appendix 1)

Because total nitrogen excretion values are needed for N_2O calculations, respective proportions are calculated also for total N excreted. TAN (and total N) excreted inhouse are divided between different manure management systems (similar division is made for TAN and tot-N excreted on yards):

$$m_{build_S_TANex} = X_S \cdot m_{build_TANex} \quad (4)$$

$$m_{build_DL_TANex} = X_{DL} \cdot m_{build_TANex} \quad (5)$$

$$m_{build_SMS_TANex} = X_{SMS} \cdot m_{build_TANex} \quad (6)$$

$$m_{build_FYM_TANex} = X_{FYM} \cdot m_{build_SMS_TANex} \quad (7)$$

$$m_{build_SS_TANex} = X_{SS} \cdot m_{build_SMS_TANex} \quad (8)$$

$$m_{build_SSU_TANex} = X_{SSU} \cdot m_{build_SS_TANex} \quad (9)$$

$$m_{build_SSD_TANex} = X_{SSD} \cdot m_{build_SS_TANex} \quad (10)$$

In the solid separation system (SS), faeces and urine are not separated completely. It was assumed that 23% of excreted urine (and urine TAN) is absorbed to bedding material and faeces in animal shelter. This is based on the data on the usage and the liquid absorption capacity of different bedding materials. Additionally, 5% of faeces (and faecal nitrogen) was assumed to be mixed with urine before urine is removed to urine storage. Values for TAN excreted inhouse in each manure management system (i.e. manure TAN ($m_{build_mms_TAN}$)), are then used as a starting point for emission calculation (see also Figure 2).

In the case of tot-N, tot-N in bedding materials is added to the tot-N content in manure excreted inhouse, based on the information on the use of bedding materials in each manure management system (kg per animal place per year; see Luostarinen et al. 2017) and the nitrogen content of bedding materials (Table 13):

$$m_{build_mms_N} = m_{build_mms_Nex} + m_{build_mms_Nbed} \quad (11)$$

Where,

mms = manure management system (S, DL, FYM, SSD or SSU) (as % of animals in each animal category; Appendix 2)

N_{ex} = total N excreted (kg)

N_{bed} = total N in bedding material (kg)

2.1.2.2 Calculation of inhouse emissions

In addition to the inhouse manure TAN values ($m_{build_mms_TAN}$), ammonia emissions from housing for each animal category, manure management system and year are based on the following information:

- unabated emission factors for housing (as % of manure TAN; Tables 4 to 9)
- use of emission abatement measures during housing (as % of manure; Appendix 2)
- emission reduction efficiency of each abatement measure (as %; Tables 4 to 9)
- temperature correction factor for housing (as % of abated emission value; chapter 2.3.4)
- for deep litter only: immobilisation rate of manure TAN during housing (as % of manure TAN).

Immobilisation of deep litter TAN during housing

The influence of nitrogen mineralisation and immobilisation processes for manures stored inhouse is calculated momentarily only for deep litter because other manure types are stored inhouse only for a relatively short time or are removed from the building instantly. Following the German inventory (Haenel et al. 2016), it is assumed that 40% of deep litter TAN is immobilised during inhouse storing (see also chapter 2.3.2 of this document). Modified mass (mm) of deep litter TAN ($mm_{build_DL_TAN}$) is calculated based on the changes due to immobilisation as expressed in equation *(12):*

$$mm_{build_DL_TAN} = m_{build_DL_TAN} - (m_{build_DL_TAN} \cdot F_{imm}) \quad (12)$$

Where,

mm = modified mass

F_{imm} = immobilisation factor (40% of fresh manure TAN)

Emissions during housing

For ammonia emission estimates per each livestock category and manure type, the unabated and non-temperature corrected emission is calculated first. Then, based on the prevalence and efficiency of the emission abatement measures in animal houses, an abated emission level is calculated (abated emissions are subtracted from the unabated emission level). Finally, using temperature correction factor for housing, temperature corrected emission value is calculated. This process is described in equation *(13):*

$$E_{build_mms_NH3\text{-}N} = ((m_{build_mms_TAN} \cdot EF_{build_mms_NH3\text{-}N}) - (\Sigma (m_{build_mms_TAN} \cdot EF_{build_mms_NH3\text{-}N} \cdot X_{build_mms_am} \cdot AF_{build_mms_am}))) \cdot TCF \quad (13)$$

Where,

$m_{build_mms_TAN}$ = mass of TAN excreted inhouse in manure management system

$EF_{build_mms_NH3\text{-}N}$ = unabated emission factor as % of $m_{build_mms_TAN}$

mms = manure management system

am = abatement measure

$X_{build_mms_am}$ = share of abatement measure in manure management system (frequency of emission abatement measure, % of manure)

$AF_{build_mms_am}$ = abatement factor (emission reduction efficiency, %) of the abatement measure in manure management system

TCF = temperature correction factor

Note that for deep litter, a modified mass of TAN, i.e. $mm_{build_DL_TAN}$ is used instead of $m_{build_DL_TAN}$.

For other gaseous nitrogen losses (as well as for indirect nitrous oxide emissions due to volatilisation of ammonia and nitric oxide), emission factors in Tables 10 and 11 are used:

$$E_{build_mms_N2O\text{-}N} = m_{build_mms_N} \cdot EF_{build_mms_N2O} \quad (14)$$

$$E_{build_mms_NO\text{-}N} = m_{build_mms_TAN} \cdot EF_{build_mms_NO} \quad (15)$$

$$E_{build_mms_N2_N} = m_{build_mms_TAN} \cdot EF_{build_mms_N2} \quad (16)$$

Where,

N = total nitrogen

TAN = total ammoniacal nitrogen

mms = manure management system

EF = emission factor

The remaining TAN (TAN ex housing, i.e. $m_{storage_mms_TAN}$) is used as an input for calculating emissions from manure storing and is calculated as described in equation *(17)*:

$$m_{storage_mms_TAN} = m_{build_mms_TAN} - E_{build_mms_NH3\text{-}N} - E_{build_mms_N2O\text{-}N} - E_{build_mms_NO\text{-}N} - E_{build_mms_N2_N} \quad (17)$$

2.1.2.3 Calculation of emissions from manure storing

Ammonia emissions from manure storing for each animal category, manure management system and year are based on the following information:

- amount of TAN entering the manure storage (= kg TAN ex housing; $m_{storage_mms_TAN}$)
- mineralisation rate of manure organic nitrogen during slurry storing and immobilisation rate of manure TAN during solid manure storing
- unabated emission factors for manure storing (as % of TAN; Tables 4 to 9)
- shares of emission abatement measures during manure storing (as % of manure; Appendix 2)
- emission reduction efficiency of each emission abatement measure (as %; Tables 4 to 9)
- temperature correction factor for manure storing (as %, chapter 2.3.4).

For slurry systems, also the following information is needed to calculate emissions from filling slurry tanks and slurry aeration:

- share of slurry removed to storage above slurry surface level (Appendix 2)
- share of aerated slurry during slurry storing (Appendix 2)
- share of slurry aerated using low-emission aeration practices (Appendix 2)
- unabated emission factor for slurry tank filling (as % of TAN; Tables 4 to 9)
- unabated emission factor for slurry aeration (as % of TAN; Tables 4 to 9)
- emission abatement factor for aerating using low-emission aeration practices (as %; Tables 4 to 9).

Emissions from filling slurry storage

For slurry system, the NH_3-N emission due to filling slurry storage above slurry surface level is calculated as follows and assuming that filling below slurry surface level does not increase ammonia emissions:

$$E_{fill_s_NH3\text{-}N} = ((m_{storage_s_TAN} \cdot X_{fill_s_above} \cdot EF_{fill_s_NH3\text{-}N}) - (\Sigma_{am}(m_{storage_s_TAN} \cdot X_{fill_s_above} \cdot EF_{fill_s_NH3\text{-}N} \cdot X_{storage_s_am} \cdot AF_{storage_s_am}))) \cdot TCF \quad (18)$$

Where,

s	= slurry system
am	= abatement measure
$X_{fill_s_above}$	= share of slurry removed to storage above slurry surface level (as % of slurry)
$EF_{fill_s_NH3\text{-}N}$	= unabated emission factor for filling above slurry surface (as % of $m_{storage_mms_TAN}$)
$X_{storage_s_am}$	= share of slurry storing abatement measure (frequency of emission abatement measure, % of slurry)
$AF_{storage_s_am}$	= abatement factor (emission reduction efficiency, %) of the abatement measure in slurry system
TCF	= temperature correction factor

Mineralisation and immobilisation

The influence of nitrogen mineralisation and immobilisation processes during manure storing on manure TAN content is estimated. For slurry, 10% of organic nitrogen is supposed to be mineralised during storing (EMEP/EEA 2016, Velthof et al. 2012). For solid manures (except deep litter which is stored outdoor only for a relatively short time and the immobilisation is assumed to take place during inhouse storing), 40% of TAN is immobilised during storing, following the German inventory (Haenel et al. 2016). The method described in EMEP/EEA emission inventory guidebook (2016a) was not used (0.0067 kg N kg^{-1} straw) because immobilisation rate depends on the amount of bedding material, and in certain cases, where bedding material use is high, calculated immobilisation rate is higher than the original TAN content in manure resulting negative values for manure TAN content.

Modified mass of TAN ($mm_{storage_mms_TAN}$) is calculated based on the changes due to mineralisation (liquid manure types, eq. *(19)*) or immobilisation (solid manure types, eq. *(20)*):

$$mm_{storage_liquid_TAN} = m_{storage_liquid_TAN} + ((m_{storage_liquid_N} - m_{storage_liquid_TAN}) \cdot f_{min}) \quad (19)$$

$$mm_{storage_solid_TAN} = m_{storage_solid_TAN} - (m_{storage_solid_TAN} \cdot F_{imm}) \quad (20)$$

Where,

f_{min}	= mineralisation factor (10% of liquid manure organic nítrogen)
F_{imm}	= immobilisation factor (40% of solid manure TAN)

Note that for slurry, $m_{storage_liquid_TAN}$, $m_{storage_liquid_N}$ and $mm_{storage_liquid_TAN}$ represent the nitrogen in the beginning of the storage period, excluding the nitrogen lost as ammonia during storage filling.

Emissions during manure storing

After calculating the modified mass of TAN in the previous phase, the unabated and non-temperature corrected emission is calculated. Then, based on the frequency and efficiency of the emission abatement measures for manure storing (use of different manure storage covers), an abated emission level is calculated, i.e. abated emissions are subtracted from the unabated emission level. Finally, using the temperature correction factor for storing, temperature corrected emission value is calculated:

$$E_{storage_mms_NH3\text{-}N} = ((mm_{storage_mms_TAN} \cdot EF_{storage_mms_NH3\text{-}N}) - (\Sigma_{am}(mm_{storage_mms_TAN} \cdot EF_{storage_mms_NH3\text{-}N} \cdot X_{storage_mms_am} \cdot AF_{storage_mms_am}))) \cdot TCF \quad (21)$$

Where,

$mm_{storage_mms_TAN}$	= modified mass of TAN
$EF_{storage_mms_NH3\text{-}N}$	= unabated emission factor (as % of $mm_{storage_mms_TAN}$)
mms	= manure management system
am	= abatement measure
$X_{storage_mms_am}$	= share of abatement measure (frequency of emission abatement measure, % of manure
$AF_{storage_mms_am}$	= abatement factor (emission reduction efficiency, %) of the abatement measure in manure management system
TCF	= temperature correction factor

Emissions from slurry aeration

NH_3-N emission due to slurry aeration is considered as an emission source during slurry storing. In addition to the share of aerated slurry and the use of ammonia abatement measures during storing, also information on aeration practices is needed (aeration is/is not done using low-emission practices). The calculation proceeds as follows (unabated emission from aeration minus abated emission from aeration due to slurry storage covering minus abated emission due to low-emission aeration practices):

$$E_{aer_s_NH3\text{-}N} = \{[(mm_{storage_s_TAN} \cdot X_{aer_s} \cdot EF_{aer_s_NH3\text{-}N}) - (\Sigma_{am}(m_{storage_s_TAN} \cdot X_{aer_s} \cdot EF_{aer_s_NH3\text{-}N} \cdot X_{storage_s_am} \cdot AF_{storage_s_am}))] - [((mm_{storage_s_TAN} \cdot X_{aer_s} \cdot EF_{aer_s_NH3\text{-}N}) - (\Sigma_{am}(m_{storage_s_TAN} \cdot X_{aer_s} \cdot EF_{aer_s_NH3\text{-}N} \cdot X_{storage_s_am} \cdot AF_{storage_s_am}))) \cdot (X_{aer_s_red} \cdot AF_{aer_s_red})]\} \cdot TCF \quad (22)$$

Where,

s	= slurry system
aer	= aeration
am	= abatement measure
X_{aer_s}	= share of aerated slurry (as % of stored slurry)
$EF_{aer_s_NH3\text{-}N}$	= unabated emission factor for slurry aeration (as % of $mm_{storage_s_TAN}$)

$X_{storage_s_am}$ = share of slurry storing abatement measure (frequency of emission abatement measure, % of slurry)

$AF_{storage_s_am}$ = abatement factor (emission reduction efficiency, %) of the abatement measure in slurry system

$X_{aer_s_red}$ = share of aerated slurry which is aerated using low-emission aeration practices NH_3-N losses (as % of aerated slurry)

$AF_{aer_s_red}$ = abatement factor for aerating using low-emission aeration practices

TCF = temperature correction factor

For other gaseous nitrogen losses, emission factors presented in Tables 10 and 11 are used:

$$E_{storage_mms_N2O\text{-}N} = m_{storage_mms_N} \cdot EF_{storage_mms_N2O} \quad (23)$$

$$E_{storage_mms_NO\text{-}N} = mm_{storage_mms_}TAN \cdot EF_{storage_mms_NO} \quad (24)$$

$$E_{storage_mms_N2_}N = mm_{storage_mms_TAN} \cdot EF_{storage_mms_N2} \quad (25)$$

Where,

N = total nitrogen,

TAN = total ammoniacal nitrogen, and

mms = manure management system

The remaining TAN (TAN ex storing, i.e. $m_{applic_mms_TAN}$) is used as an input in calculating emissions from manure application, and is calculated as follows:

$$m_{applic_mms_TAN} = mm_{storage_mms_TAN} - E_{storage_mms_NH3\text{-}N} - E_{aer_s_NH3\text{-}N} - E_{storage_mms_N2O\text{-}}N - E_{storage_mms_NO\text{-}N} - E_{storage_mms_N2_N} \quad (26)$$

Note that for slurry, $mm_{storage_mms_TAN}$ includes the reduction of TAN due to the evaporation of NH_3-N during slurry storage filling. Note also that NH_3-N emission due to aeration ($E_{aer_s_NH3\text{-}N}$) is applied only for slurry.

2.1.2.4 Calculation of emissions from manure application

Ammonia emissions from manure application for each animal category and manure management system are based on the information on:

- amount of TAN in the manure to be applied (=TAN ex storing; $m_{applic_mms_TAN}$)
- shares of the three main manure application sites: arable land, stubble, plant covered land (Appendix 2)
- for liquid manures, shares of the three main manure application methods in each application sites: injection, trailing hose, broadcast spreading (Appendix 2)
- shares of incorporation methods (ploughing, harrowing) and incorporation time (time between application and incorporation; less than 4 hours, 4-6 hours, 6-12 hours, 12-24 hours, more than 24 hours) for the manure applied on soil surface (Appendix 2)
- unabated emission factors for manure application, separately for each three main application sites, representing emissions from broadcast spreading without incorporation (as % of TAN; Tables 4 to 9)

- use of emission abatement measures of manure application, separately for each three main application sites (as % of manure; Appendix 2)
- emission reduction efficiency of each abatement measure (as %; Tables 4 to 9)
- temperature correction factor for manure application (as % of abated emission level, chapter 2.3.4).

Manure TAN allocation between application sites

Manure TAN is allocated between the three manure application sites (arable land, al; stubble, st; plant covered land, pcl) as follows:

$$m_{applic_mms_al_TAN} = m_{applic_mms_TAN} \cdot X_{applic_mms_al} \quad (27)$$

$$m_{applic_mms_st_TAN} = m_{applic_mms_TAN} \cdot X_{applic_mms_st} \quad (28)$$

$$m_{applic_mms_pcl_TAN} = m_{applic_mms_TAN} \cdot X_{applic_mms_pcl} \quad (29)$$

Where,

$X_{applic_mms_al}$, $X_{applic_mms_st}$ *and* $X_{applic_mms_pcl}$ = shares of the different manure application sites (arable land, al; stubble, st; plant covered land, pcl) (as %; Appendix 2)

Emission calculation

The emission calculation is straightforward for application on plant covered land (pcl) because manure is not incorporated into the soil after application. First, an unabated and non-temperature corrected emission is calculated. Then, based on the frequency and efficiency of the emission abatement measures (only possible for liquid manures: band spreading or injection), an abated emission level is calculated by subtracting the abated emissions from the unabated emission. Finally, the temperature correction factor is used (equation 30). If abatement measures cannot be used (e.g. in case of solid manure application on plant covered soil), the emission level is equal to the unabated emission, corrected with the temperature correction factor.

$$E_{applic_mms_pcl_NH3\text{-}N} = \left((m_{applic_mms_pcl_TAN} \cdot EF_{applic_mms_pcl_NH3\text{-}N}) - \left(\sum_{am} (m_{applic_mms_pcl_TAN} \cdot EF_{applic_mms_pcl_NH3\text{-}N} \cdot X_{applic_mms_pcl_am} \cdot AF_{applic_mms_am})\right) \cdot TCF\right) \quad (30)$$

Where,

mms	= manure management system
pcl	= plant covered land (as manure application site)
am	= abatement measure
$EF_{applic_mms_pcl_NH3\text{-}N}$	= unabated emission factor for plant covered land application in manure management system (as % of $mm_{applic_mms_pcl_TAN}$; Tables 4 to 9)
$X_{applic_mms_pcl_am}$	= share of abatement measure for plant covered land application in manure management system (frequency of emission abatement measure, % of manure; Appendix 2)
$AF_{applic_mms_am}$	= abatement factor (emission reduction efficiency, %) of the abatement measure in manure management system (Tables 4 to 9)

The same principle is used also for solid manure application on arable land (al) and on stubble (st), where different incorporation methods represent the abatement measures, and no injection or band spreading are used.

For liquid manure application on arable land (al) and on stubble or grassland to be terminated (st), the equation shall not only consider the different main application methods (mam; broadcast spreading, band spreading, injection), which may also have emission abatement properties, but also the incorporation methods (the secondary abatement measures) used when manure is applied using broadcast or band spreading. After the abated emission is calculated, the temperature correction factor is used.

The equation for liquid manure application on arable land (al) is presented in equation *(31)*:

$$E_{applic_mms_al_NH3\text{-}N} = (\sum(m_{applic_mms_al_TAN} \cdot EF_{applic_mms_al_NH3\text{-}N} \cdot X_{applic_mms_al_mam} \cdot (1\text{-}AF_{applic_mms_mam}) \cdot X_{applic_mms_al_am} \cdot (1\text{-}AF_{applic_mms_am})) \cdot TCF) \quad (31)$$

Where,

mms	= manure management system (in this case, slurry or urine)
al	= arable land (as manure application site)
mam	= main application method (injection/band spreading/broadcast spreading)
am	= abatement measure (the secondary abatement measures, i.e. manure incorporation methods)
$EF_{applic_mms_al_NH3\text{–}N}$	= unabated emission factor for arable land application (as % of $mm_{applic_mms_al_TAN}$; Tables 4 to 9)
$X_{applic_mms_al_mam}$	= share of main application method for arable land application (frequency of main manure application method, % of manure; Appendix 2)
$AF_{applic_mms_mam}$	= abatement factor (emission reduction efficiency, %) of the main manure application method (mam) in manure management system (for broadcast spreading this factor is zero; Tables 4 to 9)
$X_{applic_mms_al_am}$	= share of secondary abatement measure for arable land application (frequency of emission abatement measure, i.e. incorporation methods, % of manure; Appendix 2)
$AF_{applic_mms_am}$	= abatement factor (emission reduction efficiency, %) of the secondary abatement measure in manure management system (Tables 4 to 9)

For injection, no secondary abatement measures are used and considered in the calculation. The same equation is also used for liquid manure application on stubble (st). For other gaseous nitrogen losses (as well as for indirect nitrous oxide emissions due to volatilisation of ammonia and nitric oxide), emission factors presented in Tables 10 and 11 are used (equations 32 and 33):

$$E_{applic_mms_N2O\text{-}N} = m_{applic_mms_N} \cdot EF_{applic_mms_N2O} \quad (32)$$

$$E_{applic_mms_NO\text{-}N} = m_{applic_mms_TAN} \cdot EF_{applic_mms_N} \quad (33)$$

Where,

N	= total nitrogen
TAN	= total ammoniacal nitrogen

mms = manure management system

For manure application, di-nitrogen (N_2) emissions are not calculated.

2.1.2.5 Calculation of emissions from grazing and yards

Ammonia emissions from manure excreted during grazing and on outdoor yards for each animal category are based on the following information:

- amount of TAN excreted during grazing and on yards (m_{graz_TANex} and m_{yards_TANex})
- unabated emission factors (EF) for ammonia emissions (Tables 4 to 9)
- temperature correction factor (TCF) for grazing and yards (chapter 2.3.4).

Ammonia emissions from grazing and yards are calculated applying temperature correction factors (TCFs; chapter 2.3.4):

$$E_{graz_NH3\text{-}N} = m_{graz_TANex} \cdot EF_{graz_NH3\text{-}N} \cdot TCF_{graz} \quad (34)$$

$$E_{yard_NH3\text{-}N} = m_{yards_TANex} \cdot EF_{yards_NH3\text{-}N} \cdot TCF_{yards} \quad (35)$$

Additionally, N_2O-N emissions from grazing and yards, NO-N emissions from grazing, and indirect N_2O-N emissions (due to volatilisation of NH_3-N and NO-N) are calculated using emission factors presented in Tables 10 and 11:

$$E_{graz_N2O\text{-}N} = m_{graz_Nex} \cdot EF_{graz_N2O} \quad (36)$$

$$E_{graz_NO\text{-}N} = m_{graz_TANex} \cdot EF_{graz_NO} \quad (37)$$

$$E_{yard_N2O\text{-}N} = m_{yard_Nex} \cdot EF_{yard_N2O} \quad (38)$$

Where,

N = total nitrogen

TAN = total ammoniacal nitrogen

2.2 Emissions from mineral N-fertilisers

Ammonia emissions from the use of mineral N-fertilisers were calculated separately for different fertiliser types using the emission factors presented in the EMEP/EEA Emission Inventory Guidebook (EMEP/EEA 2016b, Table 3-2). Due to the low soil pH and low average annual temperature in Finland, the 'normal pH' emission factors for cool climate were applied. The total amount of nitrogen sold annually in Finland was divided over fertiliser types using the information obtained from Yara Finland Ltd (Toimela 2016) and Natural Resources Institute Finland (Mattila 2016; Table 3). EMEP/EEA emission factors presented in Table 3 are based on the emissions from surface applied fertilisers. In Finland, however, placement fertilisation is typically used for cereals. According to the EMEP/EEA (2016b, A1.2.2), fertiliser-N that is immediately incorporated into the soil will not be a source of ammonia as the NH_4^+ ions are absorbed onto soil colloids or nitrified. Thus, N-fertilisers used in Finland were divided between fertilisers spread using placement fertilisation and fertilisers applied on soil surface (typically grassland).

For nitric oxide, the emission factor of 0.04 kg NO_2 kg^{-1} fertiliser-N applied (EMEP/EEA 2016b) was used. This corresponds to 1.2% of fertiliser-N applied. For nitrous oxide, emission factor of 0.01 kg N_2O kg^{-1} fertiliser-N applied was used (IPCC 2006).

Table 3. Distribution of mineral N-fertilisers used in Finland by fertiliser type (%), distribution of each fertiliser type by application method (placement fertilisation or spread on soil surface, %), and ammonia emission factors (EFs for normal pH, cool climate) for different fertiliser types applied.

Spread as:	% of applied fertiliser-N	Spread using placement fertilisation (%)	Spread on soil surface (%)	EF for fertiliser-N spread on soil surface (kg NH_3 kg^{-1} N)
Ammonium nitrate	0.0%	65	35	0.019
Anhydrous ammonia	0.0%	65	35	0.015
Ammonium phosphates	0.2%	65	35	0.05
Ammonium sulphate	0.4%	65	35	0.09
Calcium ammonium nitrate	30.5%	65	35	0.008
Calcium nitrate	0.1%	65	35	0.01
Ammonium solutions (AN)	0.0%	65	35	0.015
Ammonium solutions (Urea AN)	0.0%	65	35	0.098
Urea ammonium sulphate	0.0%	65	35	0.098
Urea	0.6%	65	35	0.155
Other NK and NPK	68.2%	65	35	0.05

2.3 Basic model parameters

2.3.1 Nitrogen excretion rates

For the calculation of gaseous nitrogen emissions from animal husbandry, nitrogen excretion values (in the form of total nitrogen (tot. N) and total ammoniacal nitrogen (TAN) are needed for each livestock category, as kg tot-N or kg TAN per animal place per year. TAN is a part of total nitrogen and the origin of gaseous nitrogen emissions. For mammals, it is assumed that all urine nitrogen is TAN and all faecal nitrogen is organically bound.

Animal-specific nitrogen excretion rates (total nitrogen excretion divided into urine and faeces) are derived from the Finnish Normative Manure System (Luostarinen et al. 2017). The basis of the nitrogen excretion rates is the nutrient balance calculations carried out by Natural Resources Institute Finland (Luke). Excretion rate is obtained by subtracting the nitrogen included in animal products and growth from the nitrogen intake through feeding. The most important input data for the calculations are:

- annual feed consumption of the animals
- characteristics of different fodder compounds
- statistics of milk, meat and egg production, and slaughter weights.

At the moment, nitrogen excretion values calculated separately for urine and faeces are only available for 2014 and the previous model version used total nitrogen excretion values,. Therefore, the time series for 1980 – 2015 and the projections for 2020, 2025 and 2030 are only available for total nitrogen excretion rates (Appendix 1). For the emission time series, the 2014 data of the proportion of nitrogen excreted in urine is used for all years.

For poultry, the approach described in the German emission calculation documentation was used (Haenel et al. 2016). There, uric acid nitrogen (UAN) excreted by poultry is considered to be completely TAN and used as the basis for emission calculation. Currently for poultry, only total nitrogen excretion values are produced in the Finnish Normative Manure System. The proportion of UAN is therefore assumed to be 70% of total nitrogen (the default value presented in EMEP/EEA 2016a, Table 3.9).

2.3.2 Nitrogen mineralisation and immobilisation

For untreated slurry, it was assumed that 10% of the organic nitrogen entering manure storage is converted to TAN during storing (mineralisation; EMEP/EEA 2016a, Veltohof et al. 2012).

For solid manure (deep litter, FYM and dung) the same approach was used as is described by Haenel et al. (2016): 40% of TAN entering storage is converted to organic nitrogen during storing (immobilisation). However, in the case of deep litter system, immobilisation takes place already during housing, and no immobilisation is considered for deep litter storing. Additionally, for FYM of laying hen, TAN immobilisation is not considered because no bedding material is used.

The method described by EMEP/EEA (2016a) was not used (0.0067 kg N kg^{-1} straw) because immobilisation rate depends on the amount of bedding material, and in certain cases, where bedding material use is high, calculated immobilisation rate is higher than the original TAN content in manure resulting negative values for manure TAN content.

2.3.3 Unabated emission rates and emission abatement factors

2.3.3.1 Ammonia

The unabated emission factors (proportion of TAN volatilised in different manure management phases) are based on the EMEP/EEA (2016a, Table 3.9; see Tables 4 to 9 of this report).

For reindeer, only emissions from grazing are considered. The same emission factors are applied as those used for cattle.

The emission abatement factors of different emission abatement measures are acquired from the studies of Bittman et al. (2014) and Webb et al. (2006) (see Tables 4 to 9).

2.3.3.2 Other nitrogen emissions

Emission factors used for calculation of other gaseous nitrogen emissions (nitrous oxide, nitric oxide, di-nitrogen) are obtained from EMEP/EEA (2016a) and IPCC (2006) guidebooks (see Tables 10 and 11).

For other nitrogen emissions than ammonia, no emission abatement factors are applied.

Table 4. Unabated emission factors for cattle (unabated EF; % of TAN) and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Cattle						
Stage	**Abatement measure**	**Slurry**	**Deep litter**	**FYM**	**Urine**	**Dung**
Housing	***Unabated EF***	***20 or 6.6****	***27***	***19 or 6.6****	***20 or 6.6****	***19 or 6.6****
	rapid urine separation			15	20	
	flushing	60				
	improved cleaning	10		10	10	10
	increased manure removal frequency	10		10	10	10
	biological or chemical air scrubbers	85	85	85	85	85
	cooling of slurry channels	30				
Storing	***Unabated EF***	***20***	***27***	***27***	***20***	***27***
	tight roof (concrete)	95			95	
	floating cover	60			60	
	natural crust	40				
	roof of solid manure storage		10	10		10
	filling the solid manure storage from the bottom			30		30
	tent, roof	80				
	filling storage from the top	*5*				
	filling storage from the bottom	*0*				

***Emission factor for loose housing (first value) and tied housing (second value).**

Table 5. Unabated emission factors for pigs (unabated EF; % of TAN) and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Pigs						
Stage	**Abatement measure**	**Slurry**	**Deep litter**	**FYM**	**Urine**	**Dung**
Housing	***Unabated EF***	***25***	***45***	***26***	***25***	***26***
	rapid urine separation			15	20	
	flushing	60				
	improved cleaning	10		10	10	10
	increased manure removal frequency	25		10	10	10
	biological or chemical air scrubbers	85	85	85	85	85
	cooling of slurry channels	30				
Storing	***Unabated EF***	***14***	***45***	***45***	***14***	***45***
	tight roof (concrete)	95			95	
	floating cover	60			60	
	natural crust	40				
	roof of solid manure storage		10	10		10
	filling the solid manure storage from the bottom			30		30
	tent, roof	80				
	filling storage from the top	*5*				
	filling storage from the bottom	*0*				

Table 6. Unabated emission factors for poultry (unabated EF; % of TAN) and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Poultry				
Stage	**Abatement measure**	**Slurry**	**Deep litter**	**FYM**
Housing	***Unabated EF***	***41***	***30***	***41***
	rapid urine separation	60		85
	flushing			10
	improved cleaning			60
	increased manure removal frequency	10		10
	biological or chemical air scrubbers	85	85	
Storing	***Unabated EF***	***14***	***20***	***14***
	tight roof (concrete)	95		
	floating cover	60		
	natural crust	40		
	roof of solid manure storage		10	10
	filling the solid manure storage from the bottom			30
	tent, roof	80		
	filling storage from the top	*5*		
	filling storage from the bottom	*0*		

Table 7. Unabated emission factors for sheep and goat (unabated EF; % of TAN), and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Sheep and Goats			
Stage	**Abatement measure**	**Deep litter**	**FYM**
Housing	***Unabated EF***	***22***	***22***
	rapid urine separation		*15*
	improved cleaning		*10*
	increased manure removal frequency		*10*
	biological or chemical air scrubbers	*85*	*85*
Storing	***Unabated EF***	***28***	***28***
	roof of solid manure storage	*10*	*10*
	filling the solid manure storage from the bottom		*30*

Table 8. Unabated emission factors for horse and pony (unabated EF; % of TAN) and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Horses and Ponies			
Stage	**Abatement measure**	**Deep litter**	**FYM**
Housing	***Unabated EF***	***22***	***22***
	rapid urine separation		*15*
	improved cleaning		*10*
	increased manure removal frequency		*10*
	biological or chemical air scrubbers	*85*	*85*
Storing	***Unabated EF***	***35***	***35***
	roof of solid manure storage	*10*	*10*
	filling the solid manure storage from the bottom		*30*

Table 9. Unabated emission factors for fur animals (unabated EF; % of TAN) and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Fur animals		
Stage	**Abatement measure**	**FYM**
Housing	***Unabated EF***	***40***
	rapid urine separation	0*
	improved cleaning	0*
	increased manure removal frequency	0*
	biological or chemical air scrubbers	0*
Storing	***Unabated EF***	***35***
	tight roof (concrete)	0*
	floating cover	0*
	natural crust	0*
	roof of solid manure storage	10

*** Not used/possible in fur animal production**

Table 10. Emission factors used for calculating nitrous oxide (N_2O) losses from manure management (including manure application) and grazing (IPCC 2006).

Emission source category	EF (% of tot-N excreted)
Manure management:	
- daily spread	0.0%
- solid storage	0.5%
- yards	2.0%
- liquid/slurry - WITH natural crust cover	0.5%
- liquid/slurry - WITHOUT natural crust cover	0.0%
- uncovered anaerobic lagoon	0.0%
- pit storage below animal confinements	0.2%
- anaerobic digester	0.0%
- burned for fuel or as waste	0.0%
- burned for fuel or as waste	0.0%
- cattle and swine deep bedding - NO MIXING	1.0%
- cattle and swine deep bedding - ACTIVE MIXING	7.0%
- composting - In-Vessel	0.6%
- composting - Static Pile	0.6%
- composting - Intensive Windrow	10.0%
- composting - Passive Windrow	1.0%
- poultry manure with litter	0.1%
- poultry manure without litter	0.1%
- aerobic treatment - NATURAL	1.0%
- aerobic treatment - FORCED	0.5%
Managed soils (N additions)	1.0%
Grazing of cattle, poultry and pigs	2.0%
Grazing of sheep and other animals	1.0%
INDIRECT N_2O-N (due to volatilisation of NH_3 and NO)	1.0%

Table 11. Emission factors used for calculating of nitric oxide (NO) and di-nitrogen (N_2) losses from manure management and manure application (EMEP/EEA 2016a).

Parameter	Emission source	Emission factor
NO-N	Inhouse, slurry	NA
	Inhouse, solid manure	NA
	Storage, slurry	0.01% of TAN
	Storage, solid manure	1.0% of TAN
	Application, solid and liquid manure, and mineral N	1.2% of tot-N applied
N_2	Inhouse, slurry	NA
	Inhouse, solid manure	NA
	Storage, slurry	0.3% of TAN
	Storage, solid manure	30.0% of TAN

2.3.4 Temperature correction factors for ammonia

As mentioned above, the unabated emission factors were acquired from the EMEP/EEA Guidebook 2016 (EME/EEA 2016a, Table 3.9 (see Tables 4 to 9 of this report). The values (proportion of TAN volatilised in different manure management phases) are based on studies representing climatic conditions different from those in Finland. The most important distinction can be found in outdoor temperature (Table 12). Cowell and ApSimon (1996) assumed that a rise of 3˚C in temperature increases volatilisation of ammonia by 10%, based on Oldenburg (1989). The difference of 6˚C in the annual average outdoor temperature between Finland and Central Europe (Table 12) would thus mean a reduction of 20% in ammonia volatilisation giving a correction factor of 0.8 for Finland. However, the temperature difference varies over the year with the largest difference in winter and the smallest in summer.

In Finland, manure is mainly spread in spring (April and May), and summer (June and July). The application of manure in autumn (August - November) has decreased in recent years because of administrative restrictions on the rate and timing of manure application especially in autumn. Winter application of manure is prohibited. Considering this, the difference in the average temperature is calculated separately for each the three periods of manure application (Table 12). The calculation is simplified by assuming that in spring all manure is applied to bare soil, in summer to plant covered soil, and in autumn to stubble, which are the most common surfaces for each application period.

The effect of temperature difference on ammonia emissions from manure application is then estimated according to the values presented in Table 5I of the EMEP/CORINAIR Emission Inventory Guidebook (EEA 2007). A reduction in temperature from 10˚C to 5˚C lowers ammonia emission by 25…50% for cattle slurry and 33…60% for pig slurry. A 30% reduction is estimated for the Finnish spring and autumn periods of manure application, in which the difference in the average temperature is about 5˚C compared to Central Europe. This gives a temperature correction factor of 0.7 for spring and autumn. In summer, however, the average temperature in Finland is only 0.8˚C lower. A reduction of 5% in ammonia emission from manure application is estimated and a temperature correction factor of 0.95 is used for summer applications.

The ammonia emissions from manure storage and other manure management in outdoor conditions are corrected with the factor 0.8, which is based on the difference of 6˚C over the whole-year average temperature between Finland and Central Europe (Table 12). There are no significant differences in the indoor temperatures of animal buildings, but the higher outdoor temperatures in Central Europe result in a need for greater ventilation, which increasingly affects emissions. In non-isolated animal shelters, the indoor temperature closely follows the outdoor temperature. For these reasons, a temperature correction factor of 0.9 was used for animal houses.

For mineral fertilisers, no temperature factor was used because the emission factors for cool climate include the temperature impact.

Table 12. Average outdoor temperature (°C) in Finland (mean of Jokioinen, Jyväskylä and Oulu) and in Central Europe (mean of Hannover (Germany), De Bilt (the Netherlands) and Birmingham (England) in 1961–1990 (The Weather Network 2008).

Region	Whole year	April–May	June–July	August–Nov.
Finland	3.3	5.1	15.0	6.3
Central Europe	9.2	10.0	15.8	11.5
Difference	5.9	4.9	0.8	5.2

2.4 Activity data

2.4.1 Animal numbers and use of mineral fertilisers

Numbers of cattle, pigs, poultry, goats and sheep and the use of mineral N-fertilisers for the years 1990–2015 were acquired from Statistics Services of Natural Resources Institute Finland. Numbers of horses and ponies were based on the statistics of Suomen Hippos, the Finnish Trotting and Breeding Association, the numbers of fur animals on the statistics of the Finnish Fur Breeders' Association and the numbers of reindeer on the statistics of the Reindeer Herders' Association.

Estimated animal numbers and mineral N-fertiliser use for the years 2016–2030 were based on the Dynamic Regional Sector Model of Finnish Agriculture, Dremfia (Lehtonen 2001) except for fur animals and reindeer, for which the numbers were estimated from existing statistics assuming that there will not be major changes in the coming years.

2.4.2 Manure management data

Manure management data includes the following information, on annual basis, for each animal category:

- shares of manure management systems (% of animals) as
    - slurry
    - deep litter
    - farm yard manure FYM (urine absorbed in litter)
    - solid manure (urine separated; produces two kind of manure: dung and urine)
- detailed management practices of each manure type (including data on emission abatement measures (% of manure in each animal and manure category)
- time spent on pasture and outdoor yards annually (per animal category).

Detailed information on manure management for the years 2005 and 2015 and estimates for the year 2020 are reported in Appendix 2.

The agricultural ammonia emission estimates since 2012 are based on the manure management data collected from livestock farms in the end of 2013 (results partly published in the appendixes of Grönroos 2014). In Finland, there is no systematic collection of information on manure management systems and application methods. Because of this, manure management data for years prior to 2012 were based on scattered data from the Information Centre of the Ministry of Agriculture and Forestry and expert interviews, collected between 1995-2009 for the emission modelling purposes (see also Grönroos et al. 2009). Some changes were made to the old data due to the information acquired from the farm survey in 2013. For example, the survey provided new information on cattle grazing period which was previously overestimated and is now corrected.

2.4.3 Bedding material use and properties, cleaning water mixed with manure

Only limited amount of data on bedding material usage are available in Finland. Similarly, the data on volume of cleaning water mixed with manure is poor. For more detailed information on bedding material use, see Luostarinen et al. (2017). Data on litter properties were acquired from Kapuinen 1992 and Kapuinen 1996 and are presented in Table 13.

Table 13. Quality of bedding materials (Kapuinen 1992 and Kapuinen 1996).

Bedding material	**Density** (kg/m^3)	**DM** (% of fresh weight)	**Ntot** (% of fresh weight)	**Ptot** (% of fresh weight)	**Psol** (% of fresh weight)	**Ktot** (% of fresh weight)
Peat	200	43%	0.34%	0.01%	0.01%	0.01%
Saw dust	285	50%	0.16%	0.02%	0.01%	0.05%
Straw baled	90	95%	0.45%	0.05%	0.03%	1.40%
Straw loose	40	95%	0.45%	0.05%	0.03%	1.40%
Straw pelletised	640	95%	0.45%	0.05%	0.03%	1.40%
Straw shredded	75	95%	0.45%	0.05%	0.03%	1.40%
Wood chips	81	80%	0.25%	0.03%	0.01%	0.08%

3 Calculation of NMVOC emissions

3.1 Emissions from manure management

Emission sources of non-methane volatile compounds (NMVOC) are categorised by source activity and by animal species. The animal categorisation is in unison with the categorisation described Chapter 2.1. According to the EMEP/EEA Guidebook (2016) emissions of NMVOC in manure management originate from:

- silage storage and feeding
- manure in the animal houses
- outdoor manure storages
- field application of manure
- grazing of animals.

Emissions are calculated separately for silage storage and feeding, housing, manure storage and field application of manure. The emissions are calculated for every animal category with annually calculated parameters (where available). In each activity, emissions are calculated for the count of one animal. The animal- and year-specific emissions are then multiplied by average annual population. The corresponding equation is presented in equation *(39):*

$$E_{i,j} = AAP_{i,j} * \left(E_{silage_{store}} + E_{silage_{feed}} + E_{house} + E_{manure_{storage}} + E_{manure_{application}} + E_{grazing}\right)_{i,j} \quad (39)$$

Where,

i	= livestock category
j	= active year
$AAP_{i,j}$	= annual average population within the calculated livestock category in the given year
$E_{silage_{store}}$	= emissions from silage storage
$E_{silage_{feed}}$	= emissions from silage feeding
E_{house}	= emissions from housing
$E_{manure_{storage}}$	= emissions from manure stored in barns and outside storages
$E_{manure_{application}}$	= emissions from field application of manure
$E_{grazing}$	= emissions from grazing

3.1.1 Emissions from housing

Emissions from housing are estimated based on the time that the livestock spends in buildings. The time animals spend indoors is estimated annually (see: Appendix 2). The emission values are calculated with equations (40) and (41) which are similar to each other, with the exception of primary activity data (gross feed intake as (MJ/a) and volatile solids excreted (kg/a)) being different for cattle and other livestock.

Cattle:

$$E_{house} = MJ_i * X_{house_i} * EF_{house_i} \quad (40)$$

Other livestock:

$$E_{house} = VS_i * X_{house_i} * EF_{house_i} \quad (41)$$

Where,

i = livestock category

MJ_i = gross feed intake as (MJ/a)

VS_i = volatile solids excreted (kg/a)

X_{house_i} = annual proportion of time the livestock spends inside buildings (%)

EF_{house_i} = emission factor for emissions from housing

3.1.2 Emissions from silage feeding

Emissions from silage storage are estimated based on the time that animals spend in buildings and by estimating the fraction of silage feeding in the given livestock category. In order for the formula to be applicable, it has to be assumed that silage feeding always occurs inside animal houses.

Cattle:

$$E_{silage_{store}} = MJ_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage}\right)_i \quad (42)$$

Other livestock:

$$E_{silage_{store}} = VS_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage}\right)_i \quad (43)$$

Where,

i = livestock category

$EF_{silage_{feed}}$ = emission factor for silage feeding (see chapter 3.1.8)

$Frac_{silage}$ = proportion of silage as feed (%)

3.1.3 Emissions from silage storage

Emissions from silage storage are estimated as the share of stored silage in relation to silage on feeding table by introducing an estimate of the fraction of the stored silage to equations (*44*) and (*45*) (in bold):

Cattle:

$$E_{silage_{store}} = MJ_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage} * \boldsymbol{Frac_{silage_{store}}}\right)_i \quad (44)$$

Other livestock:

$$E_{silage_{store}} = VS_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage} * \boldsymbol{Frac_{silage_{store}}}\right)_i \quad (45)$$

Where,

i = livestock category

$Frac_{silage_{store}}$ = the relative share of stored silage in relation to silage on feeding table (%)

This model applies the guidebook (EMEP/EEA 2016) default of 0.25 for all animal species and all years, including species known not to be silage fed. Emission factors of silage feeding, however, are not cross-applied between species except with categories in close resemblance to each other. The model suggests emissions from silage storage to occur for all cattle, horses, sheep and goats.

3.1.4 Emissions from manure storage

The share of emissions from manure storage is assumed to possess the same ratio as with ammonia. The equation factorises NMVOC emissions from housing (*equation 46*) with the storage/building-ratio of ammonia emissions. Related ammonia emissions are calculated as described in chapters 0 and 2.1.2.3.

$$E_{manure_{storage}} = E_{NMVOC_{house}} * \left(\frac{E_{NH3_{storage}}}{E_{NH3_{building}}}\right)_i \quad (46)$$

Where,

i = livestock category

$E_{NMVOC_{house}}$ = NMVOC emissions from housing (Equations 40 and 41)

$E_{NH3_{storage}}$ = ammonia emissions from manure storage

$E_{NH3_{building}}$ = ammonia emissions from housing

3.1.5 Emissions from field application of manure

Emissions from field application of manure follows the same principle as emissions from manure storage, thus the equation substitutes the term of ammonia emissions from storage in equation (*47*) with ammonia emissions from field application of manure.

$$E_{manure_{application}} = E_{NMVOC_{house}} * \left(\frac{E_{NH3_{application}}}{E_{NH3_{building}}}\right)_i \quad (47)$$

Where,

i = livestock category

$E_{NMVOC_{house}}$ = NMVOC emissions from housing (Equations 40 and 41)

$E_{NH3_{application}}$ = ammonia emissions from manure application

$E_{NH3_{building}}$ = ammonia emissions from housing

3.1.6 Emissions from grazing

Emissions from grazing of animals are estimated with the assumption of the time spent in animal houses. The time animals spend indoors is estimated annually (see Appendix 2).

Cattle**:**

$$E_{graz} = MJ_i * (1 - X_{house_i}) * EF_{graz_i} \quad (48)$$

Other livestock:

$$E_{graz} = VS_i * (1 - X_{house_i}) * EF_{graz_i} \quad (49)$$

Where,

i = livestock category

MJ_i = gross feed intake as (MJ/a)

VS_i = volatile solids excreted (kg/a)

EF_{graz_i} = emission factor for grazing (see chapter 3.1.8)

X_{house_i} = annual proportion of time the animal spends inside animal house (%)

3.1.7 Activity data

The main parameters of gross feed intake (MJ), volatile solids excreted (VS) and annual average population (AAP) are provided by Natural Resources Institute Finland. Detailed increasing parameters such the share of time the animals spend in housing, fractions of silage storage and feeding are national values. Activity data is available for MJ and VS from the year 1990 onwards and for AAP from the year 1980 onwards. The animal classification varies between data sources. MJ is available for dairy cows, suckler cows, bulls (age over 1 year), heifers and calves (under 1 year). For VS primary data is available for dairy cows, suckler cows, bulls (age over 1 year), heifers, calves (under 1 year), swine in general, sows, piglets, fattening pigs, boars, weaned pigs, sheep, goats, horses, poultry in general, laying hens, chickens, cockerels, broiler hens, broilers, turkeys, other poultry (ducks), reindeer, fur animals in general, mink and fitch, fox and racoon.

3.1.8 Emission factors

Emission factors for manure management are based on the Tier 2 suggestions of EMEP/EAA Guidebook (2016). The used emission factors are presented in Table 14.

Table 14. Default NMVOC Tier 2 emission factors for livestock (EMEP/EAA Guidebook 2016).

NFR	Livestock	$EF_{silage_feeding}$	$EF_{building}$	$EF_{grazing}$	Unit
3B1a	Dairy cattle	2.00E-04	3.53E-05	6.90E-06	kg NMVOC kg/MJ feed intake
3B1b	Non-dairy cattle	2.00E-04	3.53E-05	6.90E-06	kg NMVOC kg/MJ feed intake
3B2	Sheep	1.08E-02	1.61E-03	2.35E-05	kg NMVOC/kg VS excreted
3B3	Swine (fattening pigs)		1.70E-03		kg NMVOC/kg VS excreted
3B3	Swine (sows)		7.04E-03		kg NMVOC/kg VS excreted
3B4d	Goats	1.08E-02	1.61E-03	2.35E-05	kg NMVOC/kg VS excreted
3B4e	Horses	1.08E-02	1.61E-03	2.35E-05	kg NMVOC/kg VS excreted
3B4gi	Laying hens		5.68E-03		kg NMVOC/kg VS excreted
3B4gii	Broilers		9.15E-03		kg NMVOC/kg VS excreted
3B4giii	Turkeys		5.68E-03		kg NMVOC/kg VS excreted
3B4giv	Other poultry (ducks, geese)		5.68E-03		kg NMVOC/kg VS excreted
3B4h	Other animals (fur animals)		5.68E-03		kg NMVOC/kg VS excreted
3B4h	Other animals (reindeer)		1.61E-03	2.35E-05	kg NMVOC/kg VS excreted

To accommodate the emission factors to the categorisation of livestock in the Finnish Normative Manure System (Appendix 1), the following applications are made:

- heifers: emission factor of dairy cattle applied
- bulls: emission factor of dairy cattle applied
- calves: emission factor of dairy cattle applied
- weaned pig (20-50kg): emission factor of swine (fattening pigs), possible overestimation.

3.2 Emissions from cultivated crops

According to Simpson et al. (1999), biogenic NMVOC is commonly released by naturally growing vegetation (trees and natural grasslands) and cultivated crops, including the cultivation of cereals, grasslands and silage. NMVOC-compounds emitted by agricultural crops may include e.g. isoprene, terpenes, alcohols, aldehydes, ketones and ethers.

3.2.1 Calculation of NMVOC emissions from cultivated crops

The methodology applied in calculating NMVOC emissions from cultivated crops is based on EMEP/EEA guidebook (2016) Tier 2 method which reproduces the calculation of Tier 1 emission factor of by substituting the guidebook Table 3-3 "*Estimation of NMVOC Tier 1 emission factor in kg/ha/a*" with national data, wherever possible. The recalculation is done for each year independently taking into account the annual changes within the relative crop distribution and mean dry matter.

Default emission factor for Tier 1 calculation is 0.86 kg of NMVOC per hectare. Tier 2 emission factor is calculated annually with equation (*50*):

$$EF_j = \sum \left(\mathrm{E_{i,NMVOC}} * 24 * 365 * Frac_{emit,i}\right) * m_{dm_i} * Frac_{i,j} \qquad (50)$$

Where,

i = crop species

j = active year

$\mathrm{E_{i,NMVOC}}$ = hourly emission flux of NMVOC per species (kg/dm^3/h)

$Frac_{emit}$ = fraction of the year during which the crop is emitting

m_{dm} = mean dry matter of crop (kg/ha/a)

$Frac_{i,j}$ = = fraction of species j in relation to the total of cultivated area and fallows for the year i

Table 15 shows the default values presented in the EMEP/EEA guidebook, which are used whenever national data are not available. Currently mean dry matter of crop m_{dm} and the fraction of species $Frac_{i,j}$ are national values (see Tables 16 and 17). For hourly emission flux of NMVOC, EMEP/EEA guidebook values are used and converted into annual values while taking into account the fraction of the year during which the crop is emitting.

Table 15. Default EMEP/EAA Guidebook 2016 values and corresponding national values for emission factor calculation.

Species	$E_{j,NMVOC}$	$Frac_{emit}$	m_{dm}	$Frac_{i,j}$
Wheat	2.60E-8	0.3	4700	0.35
Rye	1.41E-7	0.3	2800	0.05
Rape	2.02E-7	0.3	2500	0.1
Grass (15°C)	1.03E-8	0.5	9000	0.25
Grass (25˚C)	4.67E-8	0.5	9000	0.25

3.2.2 Activity data

All activity data is based on statistics collected by Natural Resources Institute Finland. Data from the use of arable land area is available from 1980 onwards. Crop yields (kg/ha/a) and harvested surface areas are available from 2000 onwards. Mean dry matter is derived from national statistics of species-specific yields per hectare by estimating their share of dry matter. Yield mean dry matter content remains constant throughout all years. Statistical data for yield per hectare is available for the years 2000-2015. For earlier years, values are estimated by analysing the trends of existing data. The values for the year 2015 are presented in Table 16.

Table 16. Crop yields per hectare and dry matter in Finland in 2015.

Species	Yield per hectare (kg/ha)	Yield mean dry matter content (kg/kg)	Mean dry matter m_{dm} (kg/ha)
Wheat	4100	0.86	3526
Rye	3420	0.86	2941
Barley	3470	0.86	2984
Oats	3480	0.86	2993
Mixed grain	3020	0.86	2597
Other grains	3020	0.86	2597
Peas	2130	0.86	1832
Potatoes	24310	0.22	5348
Sugar beet	32740	0.23	7530
Turnip rape and rape	1540	0.92	1417
Hay	3760	0.86	3234
Silage	15670	0.25	3918
Pasture	15670	0.2	3134
Other grassland	15670	0.2	3134
Other crops	9000	0.22	1980
Fallows	7835	0.21	1645

3.2.3 Emission factors

Table 17 presents the total cultivated area as thousands of hectares for all crop species accompanied with the calculational crop distribution (from the total of 2 241 000 hectares, including fallows and other grasslands).

The sum of all weighed EF's of Table 17 brings as a Tier 2 emission factor of 3.96E-01 kg NMVOC/ha/a for 2015. Table 18 presents the annual emission factors in five year intervals.

Table 17. Weighed emission factor and crop distribution in Finland in 2015.

Species	Cultivated area (1 000 ha)	Crop distribution (%)	NMVOC (kg/dm/a)	Weighted EF (kg NMVOC/ha/a)
Wheat	248.8	11.1 %	6.82E-05	2.67E-02
Rye	31.6	1.4 %	3.70E-04	1.53E-02
Barley	512.5	22.9 %	6.82E-05	4.65E-02
Oats	306.5	13.7 %	5.30E-04	2.17E-01
Mixed grain	36.4	1.6 %	6.82E-05	2.88E-03
Other grains	2.5	0.1 %	6.82E-05	1.98E-04
Peas	12.3	0.5 %	6.82E-05	6.86E-04
Potatoes	22.1	1.0 %	6.82E-05	3.60E-03
Sugar beet	12.5	0.6 %	6.82E-05	2.86E-03
Turnip rape and rape	56.8	2.5 %	5.30E-04	1.90E-02
Hay	85.7	3.8 %	4.51E-05	5.58E-03
Silage	492.3	22.0 %	4.51E-05	3.88E-02
Pasture	58	2.6 %	4.51E-05	3.66E-03
Other grassland	16.4	0.7 %	4.51E-05	1.03E-03
Other crops	75.1	3.4 %	4.51E-05	2.99E-03
Fallows	271.3	12.1 %	4.51E-05	8.98E-03

Table 18. Total cultivated crops as thousands of hectares and annual emission factors for crop cultivation of 2015 in Finland as kg NMVOC/ha/a.

Year	1980	1985	1990	1995	2000	2005	2010	2015
Total Cultivated Area (1000 hectares)	2372	2276.4	2271	2141.3	2186.8	2234.6	2253.3	2240.9
Emission Factor (kg NMVOC/ha/a)	0.482	0.470	0.513	0.431	0.477	0.399	0.358	0.396

4 Conclusions

In Finland, a specific national model for ammonia and other gaseous nitrogen emissions from agriculture has been used for the emission inventory since 1998. The model has been updated regularly in order to comply with the emission calculation guidelines.

The most recent model revision was carried out during the years 2014-2017, simultaneously with the development of the Finnish Normative Manure system (Luostarinen et al. 2017). At the same time, the model was developed to include the calculation of agricultural non-methane volatile organic compounds (NMVOC) emissions. After this revision, the calculation model meets the requirements of the EMEP/EEA (2016) and IPCC (2006) guidelines. In this report the emission calculation methods are described in detail.

In general, the calculation model follows the principles of Tier 2 method described in the emission inventory guidebook. However, especially the calculation of ammonia emissions has some features which move it strongly towards the Tier 3 method. These are a greater number of livestock categories and manure types than listed under Tier 2, inclusion of emission abatement measures, and application of temperature correction factors. However, regular updating of activity data, especially the information on current manure management practices, is a vital prerequisite for full utilisation of the model.

References

Bittman, S., Dedina, M., C.M., H., Oenema, O. & Sutton, M. A. (eds.). 2014. Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen. Edinburgh, UK, Centre for Ecology and Hydrology.

Cowell, D. & ApSimon, H. 1996. The MARACCAS Project – Assessing the potential and cost of ammonia emission abatement in Europe. London, Imperial College, Centre for Environmental Technology.

EEA. 2007. EMEP/CORINAIR Emission Inventory Guidebook – 2007. Group 10: Agriculture / Manure management regarding nitrogen compounds. European Environment Agency. Technical report No 16/2007.

EMEP/EEA. 2016. EMEP/EEA air pollutant emission inventory Guidebook 2016. 3.B Manure management. Copenhagen, European Environment Agency. EEA Report No 21/2016.

EMEP/EEA. 2016. EMEP/EEA air pollutant emission inventory Guidebook 2016. 3.D Crop production and agricultural soils. Copenhagen, European Environment Agency. EEA Report No 21/2016.

Grönroos, J. 2014. Maatalouden ammoniakkipäästöjen vähentämismahdollisuudet ja –kustannukset. Helsinki, Ympäristöministeriö. Ympäristöministeriön raportteja 26/2014.

Grönroos, J., Mattila, P., Regina, K., Nousiainen, J., Perälä, P., Saarinen, K. & Mikkola-Pusa, J. 2009. Development of the ammonia emission inventory in Finland. Revised model for agriculture. Helsinki, Finnish Environment Institute. The Finnish Environment 8/2009.

Grönroos, J., Nikander, A., Syri, S., Rekolainen, S. & Ekqvist, M. 1998. Maatalouden ammoniakkipäästöt. Osa 1: päästöt ja niiden kehittyminen. Osa 2: Päästöjen vähentäminen ja vähentämiskustannukset. Helsinki, Suomen ympäristökeskus. Suomen ympäristö 206.

Haenel, H.-D., Rösemann, C., Dämmgen, U., Freibauer, A., Döring, U., Wulf, S., Eurich-Menden, B., Döhler, H., Schreiner, C. & Osterburg, B. 2016. Calculations of gaseous and particulate emissions from German agriculture 1990 - 2014: Report on methods and data (RMD). Submission 2016. Braunschweig, Thünen-Institut. Thünen Report, No. 39.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Japan, Institute for Global Environmental Strategies (IGES). https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Kapuinen, P. 1992. Naudanlihan tuotantomenetelmät ja -rakennukset. Vihti, Vakola. Vakolan tutkimusselostus 63.

Kapuinen, P. 1996. Kylmäkasvattamoiden kuivikepohjien toimivat vaihtoehdot. Vihti, Maatalouden tutkimuskeskus. Vakolan tutkumusselostus 74.

Lehtonen, H. 2001. Principles, structure and application of dynamic regional sector model of Finnish agriculture. Helsinki, Agrifood Research Finland, Economic Research (MTTL). Publications 98. (Academic dissertation).

Luostarinen, S., Grönroos, J., Hellstedt, M., Nousiainen, J. & Munther, J. 2017. Finnish Normative Manure System: System documentation and first results. Helsinki, Natural Resources Institute Finland. Natural resources and bioeconomy studies 48/2017.

Mattila, P. Distribution of other mineral N-fertilisers than those manufactured by Yara and used in Finland, by fertiliser type in 2015. (E-mail from Pasi Mattila, Natural Resources Institute Finland. May 16 2016).

Oldenburg, J. 1989. Geruchs und ammoniak emissionen aus der Tierhaltung [Odour- and ammoniakemission from animal production]. Darmstadt, Germany, Kuratorium für Technik und Bauwesen in der Landwirtschaft. KTBL-Schrift 333. (In German).

Simpson, D., Winiwarter, W., Borjesson, B., Cinderby, S., Ferreiro, A., Guenther, A., Hewitt, C. N., Janson, R., Khalil, A. M. K., Owen, S., Pierce, T. E., Puxbaum, H., Shearer, M., Skiba, U., Steinbrecher, R., Tarrasón, L. & Öquist, M. G. 1999. Inventorying emissions from nature in Europe. Journal of Geophysical Research 104(D7): 8113–8152.

Toimela, M. 2016. Distribution of mineral N-fertilisers by fertiliser type manufactured by Yara and used in Finland in 2015. (E-mail from Marko Toimela, Yara Finland Ltd. May 31 2016).

Velthof, G. L., van Bruggen, C., Groenestein, C. M., de Haan, B. J., Hoogeveen, M. W. & Huijsmans, J. F. M. 2012. A model for inventory of ammonia emissions from agriculture in the Netherlands. Atmospheric Environment 46: 248-255.

Webb, J., Ryan, M., Anthony, S. G., Brewer, A., Laws, J., Aller, M. F. & Misselbrook, T. H. 2006. Cost-effective means of reducing ammonia emissions from UK agriculture using the NARSES model. Atmospheric Environment 40(37): 7222–7233.

Appendix 1. Nitrogen excretion rates, as kg total N/animal place/year (1980 – 2015).

	Dairy cows	Suckler cows	Heifers >1 yr	Bulls >1 yr	Calves <1 yr	Sows (with piglets)	Fattening pigs (50- kg)	Boars	Weaned pigs (20-50 kg)	Laying hens	Broilers	Chickens	Cockerels	Broiler hens
1980	78.9	61.2	36.6	40.8	24.3	27.8	19.6	19.3	9.7	0.63	0.4	0.353	0.969	0.99
1981	79.9	61.2	36.7	41.3	24.5	27.8	19.4	19.3	9.6	0.63	0.4	0.353	0.969	0.99
1982	80.8	61.2	36.8	41.8	24.7	27.8	19.3	19.2	9.5	0.63	0.4	0.353	0.969	0.99
1983	81.7	61.2	36.9	42.3	24.9	27.7	19.2	19.1	9.4	0.63	0.4	0.353	0.969	0.99
1984	82.7	61.2	37.0	42.8	25.1	27.7	19.1	19.0	9.4	0.63	0.4	0.353	0.969	0.99
1985	83.6	61.2	37.1	43.4	25.4	27.7	18.92	18.9	9.28	0.57	0.428	0.353	0.969	0.99
1986	84.5	61.4	37.1	43.6	25.6	27.9	18.83	18.9	9.22	0.59	0.426	0.353	0.969	0.99
1987	85.2	61.7	37.3	43.8	26.1	28.1	18.32	19.4	8.92	0.56	0.457	0.353	0.969	0.99
1988	86.0	62.0	37.4	43.8	26.0	28.2	18.34	19.5	8.88	0.56	0.454	0.353	0.969	0.99
1989	88.0	62.2	38.4	45.4	26.6	28.0	18.30	19.3	8.85	0.55	0.452	0.353	0.969	0.99
1990	91.3	62.5	39.5	47.1	27.2	28.4	18.30	19.6	8.81	0.57	0.449	0.3526	0.969	0.99
1991	91.5	62.8	40.0	47.8	27.4	28.4	17.99	19.7	8.77	0.58	0.425	0.3559	0.969	0.99
1992	92.0	63.2	39.9	47.7	27.5	28.1	17.80	19.4	8.74	0.58	0.376	0.3592	0.969	0.99
1993	93.7	63.5	41.6	49.0	28.5	28.1	17.58	19.3	8.75	0.61	0.401	0.3624	0.969	0.99
1994	96.1	63.9	42.2	49.9	28.9	28.0	17.50	19.1	8.76	0.60	0.399	0.3657	0.969	0.99
1995	96.6	64.2	42.3	50.0	29.1	27.5	17.39	19.1	8.54	0.59	0.396	0.369	0.969	0.99
1996	96.8	64.6	42.6	50.6	29.3	27.9	17.30	19.1	8.42	0.61	0.366	0.3723	0.969	0.99
1997	99.4	65.0	43.3	51.1	29.7	27.7	17.31	19.8	8.47	0.60	0.363	0.3755	0.969	0.99
1998	100.6	65.3	43.6	51.7	30.1	28.1	17.44	19.9	8.50	0.61	0.416	0.3788	0.969	0.99
1999	103.8	65.6	44.1	52.4	30.9	28.5	17.47	17.9	8.56	0.61	0.414	0.3821	0.969	0.99
2000	107.7	66.0	45.5	54.1	32.0	28.8	17.47	17.8	8.61	0.62	0.411	0.3854	0.969	0.99
2001	110.5	66.3	46.6	56.0	32.9	28.4	17.50	18.9	8.65	0.60	0.409	0.3886	0.969	0.99
2002	112.9	66.7	47.8	58.9	33.9	28.5	17.58	19.2	8.71	0.59	0.406	0.3886	0.969	0.99
2003	115.4	66.8	48.8	61.5	35.1	28.5	17.48	19.4	8.78	0.61	0.430	0.3886	0.969	0.99
2004	118.3	68.3	50.1	63.3	36.2	28.9	17.45	19.6	8.80	0.62	0.428	0.3886	0.969	0.99
2005	120.0	67.8	50.4	63.8	36.6	29.1	17.47	20.1	8.87	0.60	0.425	0.3885	0.969	0.99
2006	121.7	68.1	51.2	64.9	37.1	29.3	17.60	20.5	8.94	0.58	0.422	0.3885	0.969	0.99
2007	123.5	68.1	52.2	66.7	38.0	29.2	17.57	20.5	8.97	0.57	0.446	0.3885	0.969	0.99
2008	124.7	68.7	52.8	66.9	38.3	29.4	17.60	20.3	9.00	0.57	0.479	0.3885	0.969	0.99

	Dairy cows	Suckler cows	Heifers >1 yr	Bulls >1 yr	Calves <1 yr	Sows (with piglets)	Fattening pigs (50- kg)	Boars	Weaned pigs (20-50 kg)	Laying hens	Broilers	Chickens	Cockerels	Broiler hens
2009	126.9	68.9	53.6	67.1	39.1	29.0	17.53	20.3	9.03	0.58	0.483	0.3885	0.969	0.99
2010	129.2	70.3	54.9	68.7	40.1	29.1	17.55	20.5	9.01	0.57	0.476	0.3885	0.969	0.99
2011	129.6	70.7	55.1	68.1	40.2	29.4	17.46	20.7	9.04	0.58	0.477	0.3885	0.969	0.99
2012	130.2	69.3	54.6	66.8	39.7	30.2	17.45	20.4	9.1	0.60	0.477	0.388	0.891	0.99
2013	130.6	69.7	54.6	67.0	39.8	30.7	17.40	20.6	9.1	0.60	0.50	0.4	0.9	1.0
2014	130.9	70.1	54.6	67.3	39.9	31.2	17.34	20.7	9.1	0.57	0.477	0.3885	0.969	0.99
2015	132.6	70.7	55.0	68.7	40.4	31.4	17.38	20.6	9.12	0.62	0.478	0.3885	0.97	0.99

Year	Turkeys	Other poultry	Sheep with lambs	Goats with goatlings	Horses	Ponies	Minks and fitches	Foxes and racoons	Reindeer
1980	1.074	0.62	8.5	10.70	61.8	43.7	1.244	2.13	10.70
1981	1.074	0.62	8.5	10.70	61.5	43.6	1.244	2.13	10.70
1982	1.074	0.62	8.5	10.70	61.2	43.5	1.244	2.13	10.70
1983	1.074	0.62	8.5	10.70	60.9	43.4	1.244	2.13	10.70
1984	1.074	0.62	8.5	10.70	60.5	43.3	1.244	2.13	10.70
1985	1.074	0.62	8.5	10.70	60.2	43.2	1.244	2.13	10.70
1986	1.076	0.62	8.5	10.70	60.2	42.9	1.244	2.13	10.70
1987	1.078	0.62	8.5	10.70	59.5	43.5	1.244	2.13	10.70
1988	1.078	0.62	8.5	10.70	59.6	43.4	1.244	2.13	10.70
1989	1.080	0.62	8.5	10.70	59.6	43.5	1.244	2.13	10.70
1990	1.080	0.62	8.46	10.70	59.4	43.4	1.244	2.13	10.70
1991	1.195	0.64	8.51	10.70	59.2	43.2	1.25	2.151	10.70
1992	1.206	0.63	8.58	10.70	59.1	43.2	1.256	2.172	10.70
1993	1.315	0.66	8.66	10.70	59.6	43.4	1.262	2.193	10.70
1994	1.240	0.66	8.73	10.70	60.1	43.9	1.268	2.214	10.70
1995	1.300	0.65	8.69	10.70	60.5	44.4	1.274	2.235	10.70
1996	1.285	0.67	8.85	10.70	60.5	44.2	1.28	2.256	10.70
1997	1.307	0.66	8.86	10.70	60.3	44.4	1.286	2.277	10.70
1998	1.336	0.67	8.97	10.70	60.0	44.3	1.292	2.298	10.70

Year	Turkeys	Other poultry	Sheep with lambs	Goats with goatlings	Horses	Ponies	Minks and fitches	Foxes and racoons	Reindeer
1999	1.363	0.67	9.15	10.70	60.0	44.2	1.298	2.319	10.70
2000	1.423	0.68	9.32	10.70	60.1	44.1	1.305	2.340	10.70
2001	1.422	0.66	9.46	10.70	60.3	44.1	1.305	2.423	10.70
2002	1.479	0.64	9.57	10.70	60.5	44.2	1.305	2.505	10.70
2003	1.483	0.67	9.60	10.70	60.8	44.2	1.305	2.588	10.70
2004	1.532	0.68	9.64	10.70	61.0	44.0	1.305	2.670	10.70
2005	1.536	0.66	9.88	10.70	61.0	43.6	1.305	2.753	10.70
2006	1.482	0.65	9.97	10.70	60.9	43.5	1.305	2.835	10.70
2007	1.497	0.64	9.97	10.70	61.0	43.3	1.305	2.918	10.70
2008	1.499	0.64	9.97	10.70	60.9	43.2	1.305	3.0	10.70
2009	1.595	0.64	9.97	10.70	61.2	43.4	1.305	3.0	10.70
2010	1.606	0.64	9.97	10.70	61.1	43.5	1.305	3.0	10.70
2011	1.583	0.64	9.97	10.70	61.3	43.5	1.305	3.0	10.70
2012	1.606	0.64	9.97	10.70	61.3	43.5	1.305	3.0	10.70
2013	1.60	0.64	10.0	10.70	61.5	43.8	1.305	3.0	10.70
2014	1.595	0.64	9.97	10.70	61.7	44.0	1.305	3.0	10.70
2015	1.629	0.64	9.97	10.70	61.9	44.3	1.305	3.0	10.70

Appendix 2. Manure management data for 2005 and 2015 and prediction for 2020.

All values: % of manure unless otherwise stated.

Table 1. General information on cattle manure management and grazing in Finland in 2005 and 2015 and as a prediction for 2020.

	Dairy cows			Suckler cows			Heifers			Bulls			Calves <1 yr		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Manure management															
Treated as slurry (%)	63	70	75	30	6	7	36	54	60	40	57	60	38	40	45
Treated as deep litter (%)	1	0	0	39	29	27	3	9	7	6	11	10	3	16	15
Treated as solid manure (%), of which	36	30	25	31	65	66	61	37	33	54	32	30	59	44	40
urine not separated (FYM, %)	50	23	23	50	91	91	50	58	58	50	88	88	50	63	63
urine separated (%)	50	77	77	50	9	9	50	42	42	50	12	12	50	37	37
Grazing															
Grazing period (days)	125	112	112	140	171	171	140	134	134	0	161	161	100	127	127
Grazed animals (%)	90	69	65	95	92	90	90	69	65	0	9	9	25	31	30
Animals inside in nights (%)	100	100	100	0	100	100	0	100	100	0	100	100	0	100	100
Time inside at night (h)	12	11	11	0	1	1	0	1,5	1,5	0	1	1	0	2	2
Manure excreted on pasture (%)	15	12	11	36	41	40	35	24	22	0	4	4	7	10	10

Table 2. General information on manure management and grazing of sheep, goats, horses, ponies, fur animals and reindeer in Finland in 2005 and 2015 and as a prediction for 2020.

	Sheep & Goat			Horses & Ponies			Fur animals	Reindeer
	2005	2015	2020	2005	2015	2020	2005-2020	2005-2020
Manure management								
Treated as slurry (%)	0	0	0	0	0	0	0	-
Treated as deep litter (%)	90	50	50	0	13	13	0	-
Treated as solid manure (%), of which	10	50	50	100	87	87	100	-
urine not separated (FYM, %)	100	100	100	100	99	99	100	-
urine separated (%)	0	0	0	0	1	1	0	-
Grazing								
Grazing period (days)	130	153	153	140	180	180	-	365
Grazed animals (%)	90	90	90	95	97	97	-	100
Animals inside in nights (%)	0	100	100	0	100	100	-	0
Time inside at night (h)	0	2	2	0	6	6	-	0
Manure excreted on pasture (%)	32	35	35	36	36	36	-	100

Table 3. Percentages (%) of management methods for pig manure in Finland in 2005 and 2015 and as a prediction for 2020.

	Sows			Fattening pigs			Boars			Weaned pigs		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Treated as slurry (%)	30	82	90	80	98	100	30	82	90	80	90	90
Treated as deep litter (%)	5	0	0	5	1	0	5	0	0	5	4	4
Treated as solid manure (%), of which	65	18	10	15	1	0	65	18	10	15	6	6
urine not separated (FYM, %)	50	30	30	50	18	18	50	30	30	50	11	11
urine separated (%)	50	70	70	50	82	82	50	70	70	50	89	89

Table 4. Percentages (%) of management methods for poultry manure in Finland in 2005 and 2015 and as a prediction for 2020.

	Laying hens			Broilers	Chickens			Cockerels			Broiler hens	Turkeys	Other poultry
	2005	2015	2020	2005 – 2020	2005	2015	2020	2005	2015	2020	2005 - 2020	2005 - 2020	2005- 2020
Slurry	2	9	9	0	0	0	0	0	0	0	0	0	0
Deep litter	5	22	22	100	5	40	40	5	50	50	100	100	40
Solid manure	93	69	69	0	95	60	60	95	50	50	0	0	60

Table 5. Detailed information on slurry management in animal shelters and manure storages in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total slurry per animal species.

Abatement measures	**Slurry**								
	Cattle			Pigs			Poultry		
	2005	2015	2020	2005	2015	2020	2005	2015	2020
Animal shelter (% of manure)									
Improved cleaning of surfaces	5	13	14	5	14	20	0	0	0
Flushing	0	1	2	0	2	4	0	0	0
Manure removed more frequently	5	3	4	5	3	4	0	-	-
Rapid urine separation	-	-	-	-	-	-	-	-	-
Biological or chemical air scrubbers	0	0	0	0	1	2	0	-	-
Cooling of manure channels	-	0	0	-	6	12	-	-	-
Drying of manure on manure belt	-	-	-	-	-	-	-	-	-
Non-leaking drinking system	-	-	-	-	-	-	-	-	-
Manure storage (% of manure)									
No measures	30	0	0	60	38	27	60	38	27
Tight roof (concrete)	20	2	2	20	3	3	20	3	3
Semi-tight roof (floating covers)	10	5	5	10	27	33	10	27	33
Natural crust	30	73	73	0	0	0	0	0	0
Tent, roof	10	20	20	10	32	37	10	32	37
Filling of storage from the bottom	70	92	95	70	78	90	70	78	75

Table 6. Detailed information on deep litter management in animal shelters and manure storages in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total deep litter per animal species.

Abatement measures	**Deep litter**														
	Cattle			Pigs			Poultry			Sheep + Goat			Horses		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Animal shelter (% of manure)															
Improved cleaning of surfaces	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flushing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manure removed more frequently	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rapid urine separation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biological or chemical air scrubbers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cooling of manure channels	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drying of manure on manure belt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Non-leaking drinking system	-	-	-	-	-	-	-	37	42	-	-	-	-	-	-
Manure storage (% of manure)															
No measures	65	62	60	65	62	60	65	62	60	65	62	60	45	45	39
Tight roof (concrete)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Semi-tight roof (floating covers)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural crust	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tent, roof	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solid manure covering	35	38	40	35	38	40	35	38	40	35	38	40	55	55	61
Filling of storage from the bottom	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Additional information															
Percentage of deep litter stored after removal from animal shelter	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

Table 7. Detailed information on solid manure (FYM) management in animal shelters and manure storages in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total solid manure per animal species.

Abatement measures	**Solid manure (FYM)**														
	Cattle			Pigs			Poultry			Sheep + Goat			Horses		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Animal shelter (% of manure)															
Improved cleaning of surfaces	-	13	14	-	11	12	-	5	5	-	1	1	-	15	15
Flushing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manure removed more frequently	-	3	4	-	2	2	-	27	28	-	0	0	-	0	0
Rapid urine separation	-	1	2	-	5	5	-	0	0	-	0	0	-	0	0
Biological or chemical air scrubbers	-	0	0	-	1	1	-	4	5	-	0	0	-	0	0
Cooling of manure channels	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drying of manure on manure belt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Non-leaking drinking system	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manure storage (% of manure)															
Solid manure covering	35	44	55	35	44	55	35	44	55	35	44	55	60	61	61
Filling of storage from the bottom	25	33	35	25	49	50	25	0	0	25	0	0	25	0	0

Table 8. Detailed information on separately collected urine and dung management in animal shelters and manure storages in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total urine and dung per animal species.

Abatement measures	**Urine**						**Dung**					
	Cattle			Pigs			Cattle			Pigs		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Animal shelter (% of manure)												
Improved cleaning of surfaces	0	13	14	0	11	12	5	13	14	5	11	12
Flushing	-	-	-	-	-	-	-	-	-	-	-	-
Manure removed more frequently	-	-	-	-	-	-	0	3	4	0	2	2
Rapid urine separation	5	1	2	5	1	2	-	-	-	-	-	-
Biological or chemical air scrubbers	0	0	0	0	1	1	0	0	0	0	1	1
Cooling of manure channels	-	-	-	-	-	-	-	-	-	-	-	-
Drying of manure on manure belt	-	-	-	-	-	-	-	-	-	-	-	-
Non-leaking drinking system	-	-	-	-	-	-	-	-	-	-	-	-
Manure storage (% of manure)												
Tight roof (concrete)	75	7	8	75	8	8	-	-	-	-	-	-
Natural crust	-	-	-	-	-	-	-	-	-	-	-	-
Tent, roof, floating cover	-	65	72	-	71	72	-	-	-	-	-	-
Solid manure covering	-	-	-	-	-	-	35	44	55	35	44	55
Filling of storage from the bottom	-	-	-	-	-	-	25	38	35	25	49	50

Table 9. Detailed information on **slurry** application in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total slurry per animal species.

	Slurry								
Abatement measures	Cattle			Pigs			Poultry		
	2005	2015	2020	2005	2015	2020	2005	2015	2020
Type of surface for application									
Arable land	65	31	31	65	44	44	65	44	44
Plant covered land	20	44	44	10	31	31	10	31	31
Stubble	15	25	25	25	25	25	25	25	25
Application on arable land									
Injection	0	55	70	0	55	70	0	55	70
Band spreading	10	25	30	10	25	30	10	25	30
Broadcast spreading	90	20	0	90	20	0	90	20	0
Of manure spread on soil surface:									
No incorporation	10	9	0	10	7	0	10	7	11
Incorp. with ploughing < 4 h	0	9	10	0	14	15	0	14	15
Incorp. with ploughing < 12 h	0	12	14	0	10	11	0	10	11
Incorp. with ploughing > 12 h	0	20	22	0	19	20	0	19	20
Incorp. with harrowing < 4 h	5	15	16	5	23	24	5	23	24
Incorp. with harrowing < 12 h	45	14	16	45	12	13	45	12	13
Incorp. with harrowing > 12 h	40	20	22	40	16	17	40	16	17
Application on plant covered land									
Broadcast spreading	65	20	0	65	20	0	65	20	0
Band spreading	15	25	30	20	25	30	20	25	30
Injection	20	55	70	15	55	70	15	55	70
Application on stubble									
Injection	5	55	70	5	55	70	5	55	70
Band spreading	10	25	30	10	25	30	10	25	30
Broadcast spreading	85	55	0	85	55	0	85	55	0
Of manure spread on soil surface:									
No incorporation	10	8	0	10	7	0	10	7	0
Incorp. with ploughing < 4 h	5	13	14	5	11	12	5	11	12
Incorp. with ploughing < 12 h	40	14	15	40	20	21	40	20	21
Incorp. with ploughing > 12 h	45	26	27	45	21	22	45	21	22
Incorp. with harrowing < 4 h	0	14	15	0	14	15	0	14	15
Incorp. with harrowing < 12 h	0	12	13	0	13	14	0	13	14
Incorp. with harrowing > 12 h	0	14	16	0	14	16	0	14	16

Table 10. Detailed information on **deep litter** application in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total deep litter per animal species.

	Deep litter														
Abatement measures	Cattle			Pigs			Poultry			Sheep + Goat			Horses		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Type of surface for application															
Arable land	100	68	68	100	88	88	100	88	88	100	68	68	100	76	76
Plant covered land	0	32	32	0	12	12	0	12	12	0	32	32	0	24	24
Stubble	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Application on arable land															
No incorporation	10	1	0	10	4	0	10	4	0	10	1	0	10	4	0
Incorp. with ploughing < 4 h	0	14	15	0	13	14	0	13	14	0	14	15	0	13	14
Incorp. with ploughing < 12 h	20	16	16	20	12	13	20	12	13	20	16	16	20	16	17
Incorp. with ploughing > 12 h	20	28	28	20	29	30	20	29	30	20	28	28	20	28	27
Incorp. with harrowing < 4 h	10	15	15	10	13	14	10	13	14	10	15	15	10	10	11
Incorp. with harrowing < 12 h	20	3	3	20	13	14	20	13	14	20	3	3	20	13	14
Incorp. with harrowing > 12 h	20	23	23	20	14	15	20	14	15	20	23	23	20	16	17
Application on plant covered land															
Broadcast spreading	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 11. Detailed information on **solid manure (FYM)** application in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total solid manure per animal species.

	Solid manure (FYM)																	
Abatement measures	Cattle			Pigs			Poultry			Sheep + Goat			Horses			Fur animals		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Type of surface for application																		
Arable land	96	68	68	100	88	88	100	88	88	98	68	68	98	76	76	95	95	95
Plant covered land	4	32	32	0	12	12	0	12	12	2	32	32	2	24	24	5	5	5
Stubble	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Application on arable land																		
No incorporation	10	1	0	10	4	0	10	4	0	10	1	0	10	4	0	30	30	0
Incorp. with ploughing < 4 h	0	14	15	0	13	14	0	13	14	0	14	15	0	13	14	0	0	14
Incorp. with ploughing < 12 h	20	16	16	20	12	13	20	12	13	20	16	16	20	16	17	0	0	13
Incorp. with ploughing > 12 h	20	28	28	20	29	30	20	29	30	20	28	28	20	26	27	60	60	30
Incorp. with harrowing < 4 h	10	15	15	10	13	14	10	13	14	10	15	15	10	10	11	0	0	14
Incorp. with harrowing < 12 h	20	3	3	20	13	14	20	13	14	20	3	3	20	13	14	0	0	14
Incorp. with harrowing > 12 h	20	23	23	20	14	15	20	14	15	20	23	23	20	16	17	10	10	15
Application on plant covered land																		
Broadcast spreading	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 12. Detailed information on separately collected **urine and dung** application in Finland in 2005 and 2015 and as a prediction for 2020. Unit: percentage of total solid manure per animal species.

	Urine						**Dung**					
Abatement measures	Cattle			Pigs			Cattle			Pigs		
	2005	2015	2020	2005	2015	2020	2005	2015	2020	2005	2015	2020
Type of surface for application												
Arable land	50	17	17	50	23	23	96	68	68	100	88	88
Plant covered land	25	63	63	25	26	26	4	32	32	0	12	12
Stubble	25	20	20	25	51	51	-	-	-	-	-	-
Application on arable land												
Injection	0	55	70	0	55	70	-	-	-	-	-	-
Band spreading	10	25	30	10	25	30	-	-	-	-	-	-
Broadcast spreading	90	20	0	90	20	0	-	-	-	-	-	-
Of manure spread on soil surface:												
No incorporation	10	11	0	10	0	0	10	1	0	10	4	0
Incorp. with ploughing < 4 h	0	10	10	0	9	15	0	14	15	0	13	14
Incorp. with ploughing < 12 h	0	11	14	0	14	11	20	16	16	20	12	13
Incorp. with ploughing > 12 h	0	22	22	0	18	20	20	28	28	20	29	30
Incorp. with harrowing < 4 h	5	12	16	5	25	24	10	15	15	10	13	14
Incorp. with harrowing < 12 h	45	12	16	45	13	13	20	3	3	20	13	14
Incorp. with harrowing > 12 h	40	21	22	40	22	17	20	23	23	20	14	15
Application on plant covered land												
Broadcast spreading	65	20	0	65	20	0	100	100	100	100	100	100
Band spreading	15	25	30	15	25	30	-	-	-	-	-	-
Injection	20	55	70	20	55	70	-	-	-	-	-	-
Application on stubble												
Injection	5	55	70	5	55	70	-	-	-	-	-	-
Band spreading	10	25	30	10	25	30	-	-	-	-	-	-
Broadcast spreading	85	20	0	85	20	0	-	-	-	-	-	-
Of manure spread on soil surface:												
No incorporation	10	13	0	10	3	0						
Incorp. with ploughing < 4 hrs	5	14	14	5	12	12	-	-	-	-	-	-
Incorp. with ploughing < 12 h	40	13	15	40	14	21	-	-	-	-	-	-
Incorp. with ploughing > 12 h	45	27	27	45	26	22	-	-	-	-	-	-
Incorp. with harrowing < 4 h	0	10	15	0	18	15	-	-	-	-	-	-
Incorp. with harrowing < 12 h	0	6	13	0	14	14	-	-	-	-	-	-
Incorp. with harrowing > 12 h	0	17	16	0	15	16	-	-	-	-	-	-

Table 13. Shares of animal housing on Finnish cattle farms.

Manure type	Housing type	Dairy cow	Suckler cow	Heifer >1 yr	Bulls >1 yr	Calf <1 yr
Slurry	Tied stall	31%	38%	28%	10%	15%
	Loose warm	45%	24%	48%	30%	60%
	Loose semiwarm	23%	8%	12%	30%	20%
	Loose cold	1%	30%	12%	30%	5%
Deep litter	Tied stall	23%	0%	1%	0%	6%
	Loose warm	0%	2%	5%	5%	30%
	Loose semiwarm	24%	3%	19%	5%	25%
	Loose cold	53%	95%	75%	90%	39%
Farmyard manure	Tied stall	62%	4%	20%	7%	14%
	Loose warm	9%	1%	8%	3%	35%
	Loose semiwarm	2%	6%	8%	4%	20%
	Loose cold	27%	89%	64%	86%	31%
Urine	Tied stall	88%	30%	75%	80%	40%
	Loose warm	8%	0%	11%	8%	37%
	Loose semiwarm	1%	1%	4%	4%	10%
	Loose cold	3%	69%	10%	8%	13%
Dung	Tied stall	88%	30%	75%	80%	40%
	Loose warm	8%	0%	11%	8%	37%
	Loose semiwarm	1%	1%	4%	4%	10%
	Loose cold	3%	69%	10%	8%	13%

CALCULATION OF ATMOSPHERIC NITROGEN AND NMVOC EMISSIONS FROM FINNISH AGRICULTURE

FINNISH ENVIRONMENT INSTITUTE

SYKE

ISBN 978-952-11-4901-6 (pbk.)
ISBN 978-952-11-4902-3 (PDF)
ISSN 1796-1718 (print)
ISSN 1796-1726 (online)