Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Evaluation of sampling strategies for estimating ammonia emission factors for pig fattening facilities

Tim Ulens [a,b], Matthijs R.J. Daelman [c], Julio Mosquera [d], Sam Millet [b], Mark C.M. van Loosdrecht [c], Eveline I.P. Volcke [e], Herman Van Langenhove [f], Peter Demeyer [a,*]

[a] Institute for Agricultural and Fisheries Research (ILVO), Technology and Food Science Unit, Burgemeester Van Gansberghelaan 115-1, 9820 Merelbeke, Belgium
[b] Institute for Agricultural and Fisheries Research (ILVO), Animal Sciences Unit, Scheldeweg 68, 9090 Melle, Belgium
[c] Department of Biotechnology, Delft University of Technology, Julianalaan 67, 2628BC Delft, Netherlands
[d] Wageningen UR Livestock Research, PO Box 338, 6700AH Wageningen, Netherlands
[e] Department of Biosystems Engineering, Ghent University, Coupure Links 653, 9000 Gent, Belgium
[f] Department of Sustainable Organic Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Gent, Belgium

ARTICLE INFO

Article history:
Received 18 May 2015
Received in revised form
14 September 2015
Accepted 23 September 2015
Published online 22 October 2015

Keywords:
Ammonia
Emission factor
Sampling strategy
Animal housing
Monitoring
Pig husbandry

Determining ammonia emission factors (EF) for fattening pig facilities is important from both a regulatory and a research point of view. However, measurements to determine an EF can be time consuming and costly. Several reduced sampling strategies were developed in the past to reduce the costs and measuring time, by taking into account parameters that influence NH_3 emissions. A methodology to evaluate the precision and accuracy of estimated EFs solely as a function of the sampling frequency and strategy is demonstrated. This evaluation was done by using two long-term, high frequency datasets which both contained measurements during two consecutive pig fattening periods. These datasets were subjected to simulated sampling strategies. Long-term, low-frequency grab sampling proved to be more accurate than short-term monitoring. Repetitive short-term sampling events result in increased precision, but as this entails higher investment in time and money it is imperative to strike the balance between desired precision and available resources. A method to help as set guidelines to decide upon the number of short-term sampling events or the length of a long-term, low-frequency monitoring strategy is presented.

* *Corresponding author*. Tel.: +32 92722764.
E-mail address: peter.demeyer@ilvo.vlaanderen.be (P. Demeyer).

http://dx.doi.org/10.1016/j.biosystemseng.2015.09.009

Nomenclature

a	Number of animal places
C_i	Incoming NH_3 concentration (mg m^{-3})
C_o	Outgoing NH_3 concentration (mg m^{-3})
ε	Relative error
ER	Emission rate (g h^{-1})
EF	Emission Factor (kg NH_3 $year^{-1}$ (animal place)$^{-1}$)
LAE	Low-Ammonia-Emission
μ	Average
N	Number of emission rates
n	Number of sampling instances
Q	Ventilation rate (m^3 h^{-1})
σ	Standard deviation

1. Introduction

Animal husbandry has an adverse impact on the environment with ammonia (NH_3) as one of the major pollutants. Emissions of NH_3 to the atmosphere, and deposition in the environment, can cause acidification and eutrophication (Cole, Todd, & Wing, 2000; Fangmeier, Hadwigerfangmeier, Vandereerden, & Jager, 1994). Therefore, NH_3 was the first gas in agriculture subjected to mandatory emission reductions. As a consequence, low-ammonia-emission (LAE) housing systems were introduced in Flanders since 2004. Pig and poultry farmers in Flanders are obliged to use officially approved LAE housing systems when renovating, expanding or building new animal housing. Innovative farmers can also ask permission to build new LAE housing systems but the reduction potential towards NH_3 has not yet been established through measurements. The NH_3 emission from these housing systems has to be measured by an officially approved (research) institute in order to determine an emission factor (EF). This is traditionally done by frequently measuring (at least every hour) NH_3 concentrations and ventilation rates over long periods (>200 d for fattening pigs), covering both warm and cold seasons. However, the costs associated with this methodology are high because of the expensive equipment required and the man-hours involved (up to € 50,000) (Dekock, Vranken, Gallmann, Hartung, & Berckmans, 2009).

To reduce these high costs, several researchers have tried to reduced sampling strategies for the determination EFs for NH_3. In the Netherlands, a slightly reduced sampling protocol was developed under the Green Label framework (Groen Label, 1996). The goal of this sampling protocol was to accurately estimate the mean annual NH_3 emission of a housing system. This protocol still had a very elaborate sampling protocol with measurements over two growth cycles (e.g. fattening periods), one in summer and one in winter, both on the same farm. Ammonia concentrations had to be measured continuously (i.e. every 5–10 min). Afterwards, hourly means were used in further calculations (Groen Label, 1996). This protocol is also currently used in Flanders to determine NH_3 emission factors. This extensive, more expensive and time consuming protocol was followed-up in The Netherlands using an alternative sampling protocol (a multiple-location approach), based on measurements at several (i.e. four) farms provided with the same housing system. This new protocol prescribes six sampling periods of 24 h for each farm location, distributed over the year and randomly taken over a period of two consecutive month period. For animal categories with growth production cycles (e.g. fattening pigs) measurements had to be equally divided over the production cycle (e.g. fattening period) (Ogink, Mosquera, & Hol, 2011). It was estimated that the total measurement error (expressed as standard deviation) for this new sampling protocol ranged between 15 and 20% (Mosquera, Hol, & Ogink, 2008; Ogink, Mosquera, & Melse, 2008). Recently, an alternative sampling protocol (a case-control approach) has been suggested (Ogink, Mosquera, & Hol, 2013). This approach is based on performing simultaneous measurements in both a newly proposed housing system (or in an existing housing system, but with application of a new management strategy; referred as "case" in this protocol) and a reference system (with known emission factor), both located at the same farm. The number of measurement periods per farm (six) and the conditions concerning spreading of the measurements over time remained the same, but the number of farms decreased from four to two. On the basis of the difference between the emissions from the reference system and the new housing system, the emission factor of the new housing system is estimated. These two alternative protocols (multiple-location approach and case-control approach) are incorporated in the international VERA protocols (VERA, 2011). Mosquera and Ogink (2011) investigated two alternative approaches to shorten the sampling protocol within the four farms. The sampling period was shortened from one year to six months, resulting in only three 24-h sampling periods per farm. Using the results from those six months, either solely or in combination with a mathematical model, led to a small increase in overall random measurement error of the mean emission (between 15.4 and 20.3% with the mathematical model, between 16.8 and 21.4% without the mathematical model) (Mosquera & Ogink, 2011).

Along with the protocols to determine housing system-specific emission factors, reduced building-specific NH_3 sampling strategies for fattening pigs were proposed by Vranken, Claes, Hendriks, Darius, and Berckmans (2004) and later refined by Dekock et al. (2009). In the final protocol, a linear model containing ventilation rate, mean weight of the animals and inside and outside temperature, measured at specific times, was used to model the NH_3 emission from a building. In total, four measurement periods (2 before day 70 and 2 after day 70 in the fattening period) per fattening period were needed to get a good estimate of the NH_3 emissions (i.e. a maximum deviation of less than 10% between the measured and simulated NH_3 emission). To get an EF for the building, three fattening periods had to be monitored (Dekock et al., 2009; Vranken et al., 2004).

Up to now, all reduced sampling strategies suggested in the literature take into account the parameters that influence NH_3 emissions, such as the increasing live weight of the pigs during a fattening period and the seasonal variations in NH_3 emissions. A different method, that does not take into account influencing parameters, was recently published for