STANDARDIZED TESTING PROCEDURES FOR ASSESSING AMMONIA AND ODOR EMISSIONS FROM ANIMAL HOUSING SYSTEMS IN THE NETHERLANDS

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Abstract. *The Green Label measurement protocol (GL protocol) was developed in the mid nineties to evaluate the ammonia emission of low emission housing systems and other mitigation measures in the Netherlands. The measurements are used to assign official emission factors to low emission housing systems, used in farm permit procedures. More recently a new multi-site sampling approach has been developed, based on the experiences with the GL protocol and results from a statistical analysis of an extensive ammonia emission database. The objective of this paper is to describe and explain the evolution process from the GL protocol to the multi-site approach. Key features of the GL protocol are: evaluation at one farm location, long measurements during winter and summer periods, continuous high frequency sampling, ranges to stay within for critical management factors. In 2005 a statistical analysis was performed on a large ammonia emission database of pig housing systems that provided estimates of so called between farm(σ^2_b), within farm (σ^2_w) and instrumental measurement variances that determine the accuracy with which the mean ammonia emission of a housing system can be measured. The analysis demonstrated that both σ^2_b and σ^2_w of housing systems varied in the range of 30 - 40% (relative standard deviations). The large size of σ^2_b implies that the accuracy of the GL protocol is strongly limited by its single farm approach. Recently a new multi-site sampling approach has been approved based on four farm locations where at each location six independent 24h sampling intervals are distributed over one year. The multi-site approach allows for a less intensive and less costly measuring effort for each location, whereas the accuracy of the mean yearly ammonia emission of a low emission housing system is drastically improved.*

Keywords . *ammonia, odor, emission, animal housing, measurement method.*

INTRODUCTION

In many parts of the world large scale livestock operations are increasingly concentrated in regions with favorable production conditions and close access to consumer markets. In Europe main swine and poultry producing areas can be found in the north (e.g. Denmark, Niedersachsen in Germany, the Netherlands, Brittany in France,) and the south (Lombardy in Italy, Catalonia and Galicia in Spain). Expansion and specialization have enabled higher productivity level at the farms and, without doubt, improved farmers' income and living standards in recent decades. However there are drawbacks that are related to animal welfare and health issues and, especially where animal production has been concentrated in restricted areas, environmental pollution. Main environmental concerns are related to the emissions of ammonia, odor and more recently PM10 and greenhouse gases. In the Netherlands this intensification process started in the sixties, initiating the development of a regulatory framework to control odor nuisance and to protect natural ecosystems. From 1990 on it became clear that large scale implementation of emission mitigation techniques on farm level was required to meet national and EU ammonia emission ceilings. A number of measures were imposed including mandatory manure application techniques and cover of all liquid manure storages. At the same time the implementation of new housing systems with low ammonia emission was stimulated under the so called Green Label framework, an agreement between agricultural industry and government. In this approach an evaluation scheme was required to assign ammonia emission factors to housing systems. For this purpose a measurement and evaluation protocol (Groen Label, 1996) was developed (referred to as GL protocol) that had to be applied before housing systems were allowed on the Green Label list with approved low emission housing systems and other mitigation measures. Although Green Label has been incorporated since 2000 in the national regulatory framework to control ammonia emission from livestock production (Infomil, 2008), the GL protocol still has been in use for assessing low emission housing systems and mitigation measures like air scrubbers. Similar to the GL protocol using the same setup, an odor measurement protocol was developed for assigning odor emission factors to livestock housing systems (Ogink & Klarenbeek, 1997). More recently new approaches have been developed, based on the experiences with the GL protocol and statistical analysis of extensive ammonia emission databases (Mosquera & Ogink, 2005), that will lead to the replacement of the GL protocol in 2008 (Ogink et al., 2008). The new approach introduces a strongly modified measurement strategy. New protocols, using the same modified measurement strategy based on multi-site sampling, are defined for the emissions of ammonia, odor, PM10/PM2.5, methane and nitrous oxide.

The objective of this paper is to describe and explain the evolution process from the GL protocol to the multi-site approach. First the main characteristics of the GL protocol will be shortly summarized. The lessons learnt from the GL approach, including its main shortcomings will be outlined in the second part. In the third section the modified measurement strategy will be introduced and discussed. The main conclusions and implications will be summarized at the end of this section.

GREEN LABEL PROTOCOL FOR THE MEASUREMENT OF AMMONIA EMISSION

The Green Label protocol was developed to evaluate mainly new housing systems equipped with modified pen designs and manure removal techniques to lower ammonia emission. All main animal categories took part, each with their own specific housing systems. In a later phase, evaluation of different types of air scrubbers connected to animal housings also were included. The main goal of the evaluation was to estimate accurately the mean annual ammonia emission from the investigated system, expressed per available animal place (kg NH_3 year^{-1} animal place^{-1}). The protocol was developed and described by an independent technical working group that evaluated all measurements carried out according to this protocol and that advised on the certification of Green Label housing systems (Groen Label, 1996). The main elements are:

- Housing systems can only be evaluated under real farm conditions. The majority of measurements have been carried out at commercial farms. In some cases experimental stations were used that applied standard management. The protocol defines the minimum number of animals during evaluation.
- The evaluation focuses at sampling and measuring at a single farm location. To ensure that this single location is representative during the measurement, ranges for all critical management factors that may affect ammonia emission are defined in the protocol. These ranges should represent standard management for feeding, hygiene and ventilation, and are monitored during the measurement period. Furthermore minimum technical performance levels are defined to ensure representativeness.
- The measurement strategy defines two sampling periods that represent the cold and the warm season. For each animal category the sampling period is specified in the protocol. In general for animal categories without growth cycles (laying hens, sows, dairy cattle) minimum sampling periods are 4 weeks in summer and 4 weeks in winter. For categories with growth cycles (fattening pigs, broilers) full cycles during both summer and winter time have to be measured.
- The ammonia emission has to be monitored on an intensive 'continuous' basis, i.e. every 5-10 minutes a measuring cycle has to be performed. Rules are specified for data handling and calculations. Concentration and ventilation rates have to be aggregated to 1 hour average values. The average daily emission is calculated from the 1 hour averages, only if enough hourly averages are present, otherwise missing values are recorded. The overall mean emission is calculated from the 24 hour means.
- Methods and equipment to be used for concentration and ventilation rate measurements are described in a special technical guide (van Ouwerkerk et al., 1993) that lists all allowed approaches. For ammonia concentration the NO_x-monitor using the chemoluminesence principle is the preferred method because of its low detection threshold. Ventilation rate is determined by making use of fan wheel anemometers in ventilations shafts that are before and after measurement periods calibrated in wind tunnels. The methods from the technical guide are mandatory unless the Green Label working group allows other methods because of technical restrictions. For example in case of air scrubbers use is made of the impinger method instead of the NO_x-monitor because of the extreme humidity in the outlet air.
- All evaluations have to be reported according to guidelines that include a clear description of the evaluated mitigation system, used measurement methods and farm conditions as outlined before, results, and discussion of the results and functioning of the system.

The vast majority of measurements were carried out by a specialized team within the former institute for agricultural and environmental engineering (IMAG), but in smaller numbers also by groups within the applied research centers for pigs and poultry. All these groups are integrated now in the Animal Sciences Group of Wageningen University and Research Centre. In total about 80-90 system evaluations, based on the GL protocol, have been published in public technical reports. Initially measurements were fully or to a large extent financed by government funds to stimulate the development and implementation of low emitting housing systems. In a later phase the funding role of industry became increasingly important.

The GL protocol served as a basis for an odor measurement protocol that was used in the odor research programs from 1997 on for quantifying odor emissions from housings of the main animal categories. The same framework was used with the difference that continuous sampling of ammonia was replaced by 5 times sampling in summer and 5 times in winter time during a 2-hours period between 10 and 12 a.m. Odor samples were analyzed according the NVN2820 olfactometry standard that was replaced in 2004 by the European standard EN13725. Details of this odor measurement protocol are described by Ogink and Groot Koerkamp (2001).

LEARNING BY DOING: LESSONS FROM THE GREEN LABEL PROTOCOL

The GL protocol facilitated a standardized process of routine evaluation of a wide variety of housing systems in all main animal categories. It is at the basis of the regulatory list that specifies all available housing systems and their assigned ammonia emission factors in the Netherlands. This list and the system descriptions can be accessed at the website of the Infomil agency (Infomil,

2008) and is yearly updated with new systems. The ammonia factors are used in license procedures for modification and new construction of livestock facilities and are one of the critical factors that in many cases determine the scale of operation. Given their impact on livestock industry and environmental protection their reliability and accuracy are considered important by all involved parties.

From the nineties on the GL measurements contributed significantly to the knowledge of underlying processes related to the emission of ammonia and other gaseous compounds. Gradually a strong basis of on farm measurement experience was built up, that involved not only an efficient organization of measurements, but also extensive knowledge of the role of a wide variety of farm management factors that is of high importance for a proper interpretation of the recorded data. However, as more and more datasets became available, it became clear that emission factors possibly were not that accurate as suggested by the decimals used in the regulatory list. Measurement on housing systems with minor design differences, showed much larger deviations than expected from the system differences alone. Another aspect that drew increased attention and caused concern was the cost level of the GL protocol.

An insight in the mechanisms that determine the accuracy of protocols for emission factors was presented as early as 1997 in a study by Ogink and Klarenbeek (1997). Although this study dealt with the accuracy of odor measurements carried out with a measurement strategy based on the GL protocol, the principles of the presented statistical variance component model could be used as well for other emission components. However to make use of this approach reliable estimates were required of different variance components that can only be derived from a large quantity of measurements sets that were not available at that time. In 2005, having sufficient available ammonia emission datasets, Mosquera and Ogink (2005) carried out a statistical analysis with the same variance component model to estimate the required variance components for assessing the accuracy of the GL protocol. The model is based on distinguishing between three variance layers in the sampling design:

- Between-farm variance (σ^2_b): variance resulting from factors and variables that cause systematic differences between farm locations within the same housing system. Such factors can be related to different management practices between farms, like different feeding- and ventilation regimes, different hygiene standards, but also small differences in pen layout within the same system.
- Within-farm variance(σ^2_w): variance resulting from factors and variables that cause day to day fluctuations in emissions of a specific farm location. Such factors can be related to seasonal factors that affect ventilation levels and correlated emission levels throughout the year, but also production factors like present animal numbers and mass, feed intake and manure excretion.
- Instrument measurement variance (σ^2_m) : variance resulting from random measurement error of instruments used in emission measurements. Both instruments used for measuring concentrations and instruments used for determining air flows are subject to this type of error.

Each variance component attributes to the overall measurement variance of the mean emission of a housing system (σ^2_{total}) as described in the model equation below:

$$\sigma^2_{total} = \frac{\sigma^2_b}{k} + \frac{\sigma^2_w}{k \cdot l} + \frac{\sigma^2_m}{k \cdot l \cdot m}$$

The equation reflects σ^2_{total} in a sampling design with k farm locations, l measurement events within each location and m measurements within each measurement event on a location. The model shows that the between farm component σ^2_b plays a key role in the magnitude of the overall measurement variance, because it can only be downscaled by k. Factor k, representing the number of locations, plays a key role as it affects the contribution of all variance components In the GL protocol k=1, i.e. measurements are carried out on a single location, meaning that σ^2_{total} can never be smaller than σ^2_b . For ammonia emission Mosquera & Ogink (2005) demonstrated that both σ^2_b and σ^2_w of housing systems varied in the range of 30 - 40%, when expressed as relative standard deviations. These values were found in statistical analyses carried out for the pig category: fatteners, sows, farrowing sows, piglets. Our impression is that the same order of magnitude is to be expected for housing systems in poultry and cattle. Similar findings for large between farm variation in odor emission were found by Ogink & Klarenbeek (1997) and later in a more extended analysis by Mol & Ogink (2002). From these findings the following conclusions and implications can be formulated:

- The GL protocol neglects sampling in the variance layer that represents important systematic differences between farms as a result of different management practices. Despite having ranges defined in the protocol for critical management factors, variation between farms remains very large, much larger than ever anticipated before. Increasing the number of farm locations in the sampling design is the only way to downscale this type of variance and thus to improve overall accuracy.
- For the purpose of estimating the mean annual emission of a housing system, high measurement frequencies during sampling periods that may take several weeks up to two times four months (in case of fattener cycles) do not contribute

to the overall accuracy at all. Given the size of σ^2_b and the dominating role of k in the component model, it can be easily calculated that for example decreasing replication number l from 60 to 6 does not increase overall accuracy. Here cost reductions can be implemented by applying less frequent sampling schemes without affecting accuracy. However, for the purpose of gaining insight in the emission process high frequency sampling schemes can be very useful.

- High frequency sampling of emissions produces data sets that show strong autocorrelation patterns both on hourly and daily basis. From a statistical point of view independent observations that are derived from a restricted number of sampling intervals randomly distributed in time, can be as informative as high numbers of autocorrelated observations based on continuous sampling.
- Sampling periods in the GL protocol are restricted to one specific summer and one specific winter period. A more reliable and unbiased estimate of the yearly mean can be derived by randomly sampling over the whole year instead of restricted periods.
- Measuring instruments should at all times be unbiased, i.e. systematic measurement error should be avoided. However, random measurement error is of much less importance as it can easily be downscaled by the number of replications in the sampling scheme (k x l x m).

TOWARDS A NEW APPROACH: MULTI-SITE SAMPLING

In 2004 an update of the ammonia emission protocol was commissioned that should make use of all new insights and experiences since the introduction of the GL protocol. This initiative was initiated by the earlier completed update of available measurement principles and instruments for the emission of gaseous compounds from livestock facilities carried out by a special working group (Mosquera et al., 2002; Mosquera, 2007). This initiative was also related to the first preliminary results of the extended statistical analysis on ammonia emission datasets (Mosquera and Ogink, 2004) that were made available to the technical working group that coordinates the assignment of ammonia emission factors. Both information sources offered the opportunity to drastically redesign the sampling strategy and make use of a wider range of measurement instruments. In addition to the modification of the ammonia protocol, new regulatory developments since 2006 asked for the definition of similar protocols for emissions of odor, PM10, methane and nitrous oxide. The completion of these protocols have been synchronized into one review and approval process. Drafts of these protocols have been approved and the final versions will be published before summer 2008. The main characteristics of the modified approach for ammonia emissions can be summarized as follows:

- Sampling will take place at four representative farm locations, i.e. k = 4. By doing so the overall accuracy is improved by a factor 2, compared to the earlier design of the ammonia protocol where one farm location was sampled.
- Instead of mandatory high frequency sampling over extended periods, a restricted number of 24 hour cumulative sampling periods is introduced, during each of which the mean ammonia concentration of ventilated air and the mean ventilation rate has to be determined. Diurnal variations are eliminated by sampling over 24 hours.
- For cumulative sampling over 24 hours the use of impingers setups is allowed, in which a known air flow is led through a series of washing bottles with acid solution that traps the ammonia. Impinger measurements are relatively simple, low cost and accurate.
- The number of independent sampling events on each farm location was set at six, i.e. l = 6. Sampling events are distributed over one year, being randomly taken in subsequent two month periods. By this procedure seasonal variations that influence concentrations and ventilation rates throughout a year are equally distributed and well balanced in the sampling scheme. For housing systems with production cycles that affect emission patterns, like broilers or fattening pigs, it is prescribed that measurements are equally divided over the growing period. Similarly, in cases where regular management practices can be expected to affect emission levels, care should be taken that these practices are incorporated in the sampling scheme in such a way that samplings are well distributed over these management practices. Sampling six times at one farm location was considered large enough to deal with the within-farm location variance and at the same time ensures that observations were sufficiently spread in time to be independent from each other.
- Ranges for critical management factors (like feed composition) are updated according to what is considered standard management.
- The number of measurement methods that can be used for determining the air flow is expanded, mainly using the array of methods described by Mosquera et al. (2002). This modification is especially of importance for animal housings with natural ventilation systems.

In practice emission measurements on farm locations will in many cases include all relevant emission components, such as ammonia, odor, greenhouse gases and PM10. Both for reasons of cost efficiency and for the interest of funding parties, measurements of different emission components are normally combined. This means that there is a practical need to harmonize the sampling scheme of these components, unless there is a very compelling technical reason to apply another scheme. As demonstrated for odor and ammonia, it is expected that the emissions of PM10 and greenhouse gases is also subject to considerable variation between farms. For these reasons, the ammonia emission sampling scheme is utilized in the protocols for the other gaseous compounds.

CONCLUSION

The multi-site approach basically represents a shift from intensive long term measurements on one site to less frequent sampling on more farm sites. It recognizes the importance of the earlier neglected variance layer that represents farm variations as a result of different farm management practices. The multi-site approach at the same time allows for a much less intensive and less costly measuring effort at each of the locations. The multi-site sampling strategy is mainly based on the interpretation of variation patterns that were analyzed for low emitting housing systems with modified pen designs and manure removal techniques. It is quite well possible that for other groups of mitigation measures, like for example the efficiencies of air purification techniques, variation patterns differ. The new protocol framework in principle allows for modifications of the sampling strategy in case of specified groups of measures. Such modifications have to be justified on basis of analysis of emission measurements where these measures are applied, and will be attached as special cases to the general protocol. This procedure automatically facilitates the use of new findings from the learning by doing process and is in line with our observation that measurement protocols should be designed on basis of knowledge of the variance behavior in real world practice.

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