Sensitivity analysis of mechanistic models for estimating ammonia emission from dairy cow urine puddles

Dennis J.W. Snoek a*, Johannes D. Stigter b, Nico W.M. Ogink c, Peter W.G. Groot Koerkamp ac

a Farm Technology Group, Wageningen University, P.O. Box 317, 6700 AH Wageningen, The Netherlands
b Biometris, Department of Mathematical and Statistical Methods, Wageningen University, P.O. Box 100, 6700 AC Wageningen, The Netherlands
c Wageningen UR Livestock Research, P.O. Box 65, 8200 AB Lelystad, The Netherlands

Ammonia (NH₃) emission can cause acidification and eutrophication of the environment, is an indirect source of nitrous oxide, and is a precursor of fine dust. The current mechanistic NH₃ emission base model for explaining and predicting NH₃ emissions from dairy cow houses with cubicles, a floor and slurry pit is based on measured data from a limited number of studies. It requires input values for numerous variables, but the empirical equations for the model parameters in the literature vary. Furthermore, many of the input variables cannot be assessed accurately, and their actual influence on the prediction is unknown. We aimed to improve NH₃ emission modelling, by assessing the contribution to the variation in NH₃ emission of each input variable and each model parameter related to a single urine puddle. We did so for 27 candidate models, created by each possible combination of three equations per model parameter: the acid dissociation constant, Henry’s law constant, and the mass transfer coefficient. After analysing each candidate model with a Global Sensitivity Analysis we found that at least 71% of the model variation in NH₃ emission for each candidate model was explained by five puddle related input variables: pH, depth, area, initial urea concentration and temperature. NH₃ emission was not sensitive to the other four variables: air temperature, air velocity, maximum rate of urea conversion and the Michaelis–Menten constant for urea conversion. Based on these results we recommend simplifying the model structurally and reducing the number of input variables.
1. Introduction

Ammonia (NH₃) emission can cause acidification and eutrophication of the environment. NH₃ is also an indirect source of the greenhouse gas nitrous oxide (N₂O) (IPCC, 1996) and is a precursor of fine dust particles. To lower NH₃ emissions in the EU, member states are required to set a National Emission Ceiling (NEC) (EU, 2001; UNECE, 1999). Twenty-five of the 27 EU member states complied with the 2010 NEC set by the European Commission. The total emission of ammonia in the Netherlands in that year was 122 kt, which was 4.9% below NEC 2010 (EEA, 2012). However, local and regional emission and deposition still cause a high overload in the Dutch environment with cubicles, plus walking and feeding-alleys, which together provide a total area of 3.5 m² per cow. There is a slurry pit underneath the whole house, and a slatted concrete floor in the cow walking area. They estimated that one urine puddle occupies an area of 0.8 m². In such a typical dairy cow house about 70% of NH₃ emission is emitted from the slatted floor.

Monteny et al. (1998) developed a conceptual mechanistic computer model in order to understand and predict NH₃ emissions from dairy cow houses. Called the Monteny model, it describes the physical and chemical processes involved and quantitatively determines the NH₃ emission according to model parameters, using input variables related to the characteristics of a urine puddle, air, floor and pit. Similar mechanistic NH₃ emission models have been developed and validated against measurements in a limited number of studies for cows (Elzing & Monteny, 1997; Montes, Rotz, & Chaoui, 2002; Zhang, Day, Christianson, & Cortus, Lemay, Barber, Hill, & Godbout, 2008; Liang, Westerman, & Arogo, 2002; Zhang, Day, Christianson, & Jepson, 1994). In this study we focus on the general mechanistic NH₃ emission model theory.

The Monteny model is currently used by the Dutch Ministry of Infrastructure and Environment to assess the NH₃ emission from dairy cow houses that are applying new NH₃ mitigation techniques, and also to obtain preliminary emission factors that are used when granting permits. This assessment is later followed by full-scale measurements in commercial houses in accordance with a prescribed protocol.
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