How do NH_3 emissions relate to nitrogen use efficiency of livestock production?

Groenestein, C.M.[1], Hutchings, N.J.[2] , Haenel, H.D.[3], Amon, B.[4], Menzi, H.[5], Mikkelsen, M.H.[6], Misselbrook, T.H.[7], van Bruggen, C.[8], Kupper, T.[9], Webb, J.[10]

[1] Wageningen UR Livestock Research, De Elst 1, 6708 WD Wageningen, www.wageningenur.nl/en/livestockresearch, karin.groenestein@wur.nl
[2] Dept. of Agroecology, Aarhus University, Research Centre Foulum, 8830 Tjele, Denmark
[3] Thünen Institute of Climate-Smart Agriculture (TI-AK), Bundesallee 50,38116 Braunschweig, Germany
[4] Leibniz Institute for Agricultural Engineering, Max-Eyth-Allee 100, 14469 Potsdam, Germany
[5] Agroscope, Inst. For Livestock Sciences, P.O. Box 64, CH-1725 Posieux, Switzerland
[6] Dept. of Environmental Science, Frederiksborgvej 399, 4000 Roskilde, Denmark
[7] Sustainable Soils and Grassland Systems, Rothamsted Research, North Wyke, Devon, UK, EX20 2SB
[8] Organisation, address, city, state, postcode, website, Email
[9] Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences Laenggasse 85 CH-3052 Zollikofen
[10] Ricardo Ltd, Gemini Building, Harwell, UK. OX11

Abstract
Ammonia (NH_3) emissions from livestock production systems can be substantial but difficult to measure. Here we explore the relationship between NH_3 emissions, the emission intensity (NH_3-N emitted/product N) and the more easily measured feed Nitrogen Use Efficiency (NUE). Using a conceptual model, we find that the relationship between emission intensity and NUE is equivalent to that between NH_3-N emission and feed N intake. Furthermore, there is a linear relationship between the two, with a slope that is dependent on characteristics of the animal and its feed, and the manure management system. This is illustrated using data taken from the emission inventories of six European countries, which found a linear relationship, with much variation within a commodity type. Using the same data, we show how the effects of animal and feed characteristics can be separated from those of the manure management system.

Key Words
Nitrogen Use Efficiency, ammonia, livestock

Introduction
Ammonia emissions account for a major proportion of the loss of N from livestock production systems (Sutton, 2011). In 2013, agriculture accounted for 93% of total ammonia (NH_3) emissions in Europe and manure generated during livestock production and manure management accounts for about two thirds of European agricultural NH_3 emissions. These emissions cause environmental pollution, create human health problems and reduce the fertilizer value of the manure (Webb, 2013). The indicator ‘emission intensity’ is often used when comparing greenhouse emissions per unit of agricultural products (Casey, 2005) and here we adapt this approach to NH_3 emissions. However, whilst emission per unit product is a useful indicator of variations in the emissions from different systems producing the same product, it is somewhat less useful when comparing among various products. We prefer here to calculate an NH_3 emission intensity (EI) as kg NH_3-N per kg product N, as it allows us to compare emissions both across products and among systems producing the same commodities.

Ammonia can be emitted from manure from several sources on livestock farms; housing, manure storage, field-applied manure and excreta deposited during grazing. Measuring NH_3 emissions from a single source on a farm is expensive; doing so from multiple sources prohibitively so. It is therefore relevant to seek an indicator that can be estimated or measured more readily in practice, at the farm scale. Norton (2015) recommended Nitrogen Use Efficiency (NUE) i.e. the ratio of output-N per unit input-N as an indicator of nutrient performance for N. This paper therefore examines the conceptual relationship between the NH_3 emission intensity and NUE and then uses this to explore differences between livestock production systems in Europe. Since the main livestock products are milk, meat and eggs, we chose to focus on dairy cattle, beef cattle, finisher pigs, laying hens and broiler chickens.

Methods
NH_3 is volatilised from total ammoniacal nitrogen (TAN) in manure (Sommer, 2006). The production of TAN from N in feed is shown in Figure 1.

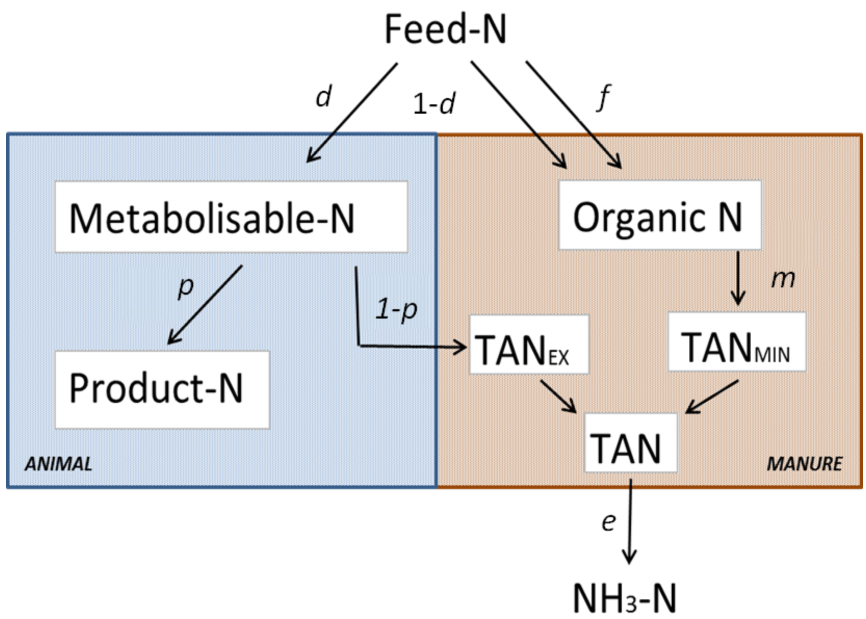

Figure 1. Schematic overview of NH_3 emission and product N from feed N (Feed-N); *d*= apparent digestibility of feed, *p*=proportion of metabolisable N deposited in product, *f* = feed waste, *m*=fraction of organic N mineralised to TAN, *e*= fraction of TAN emitted as NH_3-N, TAN_{EX} = excreted TAN, TAN_{MIN} = TAN from mineralised organic N.

A proportion *d* of the feed N (*Nfeed*; kg) is digested and absorbed by the livestock, yielding an amount of metabolisable protein N. A proportion *p* of the metabolisable protein is then converted to N in milk, meat or eggs. The N retained in animal protein (*Nproduct*; kg) is therefore:

$$NProduct = dpNfeed \qquad \text{(Eq. 1)}$$

The remainder (1-*p*) of the N in metabolisable protein N is excreted to the urine (considered here to be TAN_{EX}). The indigestible proportion of the feed N (1-*d*) is excreted as organic N in the faeces. Additional organic N is contributed by spilt feed and bedding. For simplicity, we assume here that this contribution can be expressed as a fraction *f* of the feed N. A proportion (*m*) of the organic N can be mineralized, and thus also contributes an amount of TAN (TAN_{EX}). The TAN produced (TAN; kg) is therefore:

$$TAN = Nfeed\,(d(1-p)+m\,((1-d)+f)) \qquad \text{(Eq. 2)}$$

A proportion (*e*) of the TAN volatilizes as NH_3 from manure in housing, storage, after land application and from excreta deposited during grazing. The NH_3-N emission is therefore:

$$NH_3\text{-}N = eNfeed\,(d(1-p)+m\,((1-d)+f)) \qquad \text{(Eq. 3)}$$

The NH_3-N emission per unit of N in product (kg kg^{-1}) can be calculated from:

$$NH_3\text{-}N/Nproduct = (eNfeed\,(d(1-p)+m\,((1-d)+f)))/(dpNfeed) \qquad \text{(Eq. 4)}$$

Noting from (Eq. 1) that:

$$dp = Nproduct/Nfeed = \mathrm{NUE}$$

Equation 4 can be written to define the emission intensity:

$$EI = NH_3N/Nproduct = (e\,(d(1-p)+m((1-d)+f)))/\mathrm{NUE} \qquad \text{(Eq. 5)}$$

This equation shows that the *EI* will be related to the inverse of the NUE and that the nature of that relationship will depend on a combination of feed/animal characteristics (*d*, *p*; i.e. TAN_{EX}) and manure management system characteristics (*f*, *m*, *e*).

To illustrate the value of the conceptual approach, data on feed N intake, production, TAN excretion and NH_3 emission from livestock production was obtained from the national NH_3 inventories of The Netherlands NL), Switzerland (CH), UK, Germany (DE), Austria (A) and Denmark (DK).

Results

Figure 2 shows the relationship between emission intensity (*EI*) and 1/NUE. There is a roughly linear relationship between NH_3-N and feed N, with considerable variation within a product type. From Equation 5, we note that the slope of this relationship will be $e\ (d(1\text{-}p)+m((1\text{-}d)+f))$ and if extrapolated, it will intersect with the x-axis where NUE = 1 (all the feed N is deposited in the product). Furthermore, we note that since *Nproduct* appears in the definition of both *EI* and NUE, the relationship *EI* versus 1/NUE is identical to NH_3N versus *feedN*. As found by Leip (2013), the quantity of feed N required to produce one unit of N in the product was greatest for beef (about 5 kg kg^{-1}) and least for broiler chickens (about 2 kg kg^{-1}).

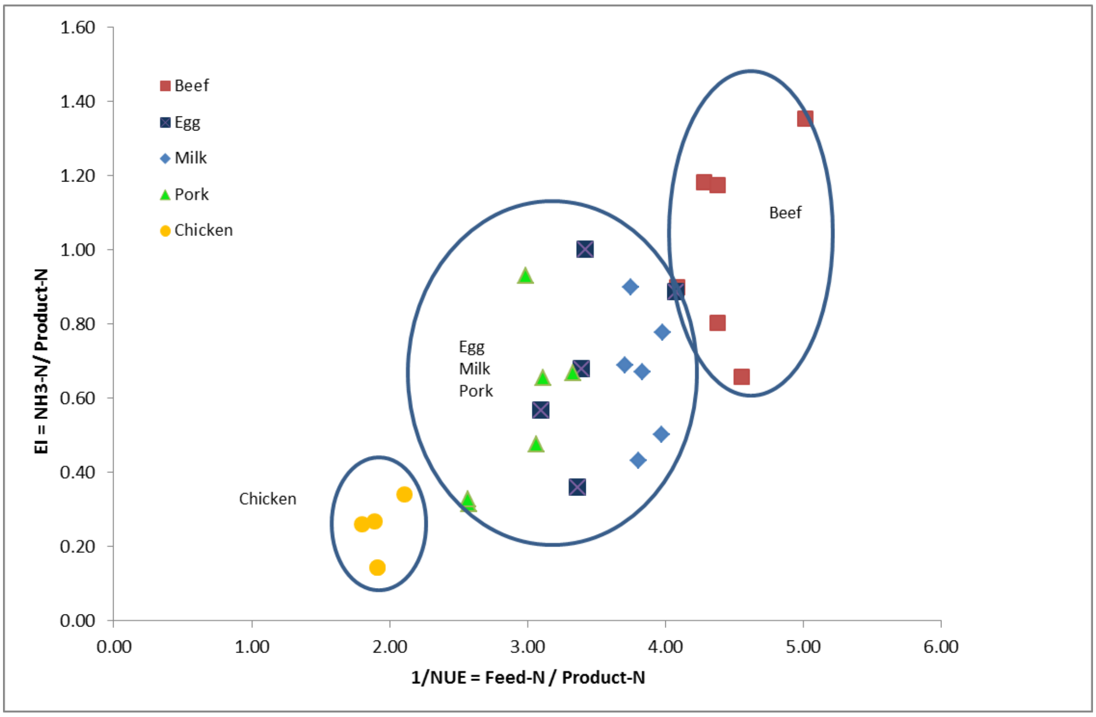

Figure 2. Relationship between EI (NH_3-N/N in product) and NUE for the 6 European countries

The origin of the variation in emission intensity within a product can be explored by separating out the contribution TAN_{EX} makes to NH_3 emission ($NH3_{TANex}$) from that made by TAN_{MIN} in the manure management system (MMS) ($NH3_{MMS}$). For any dataset containing estimates of NH_3-N emission and TAN excretion, we can calculate the mean NH_3-N emission ($NH3_{ave}$) and TAN excretion ($TANex_{ave}$). Using the subscript *i* to identify an individual element in the dataset, then:

$$NH3_{TANexi} = (TANex_i*(NH3_{ave}/TANex_{ave})-NH3_{ave})/NH3_{ave} \qquad \text{(Eq 6)}$$

$$NH3_{MMSi} = (TANex_{ave}*(NH3_i/TANex_i)-NH3_{ave})/NH3_{ave} \qquad \text{(Eq 7)}$$

The sum of $NH3_{TANex}$ and $NH3_{MMSi}$ expresses the extent to which the NH_3-N emission from element *i* deviates from the mean of the dataset. This is best illustrated by applying the method to the country emission dataset for broiler chicken and beef production used in Figure 2. If $NH3_{MMSi}$ is plotted against $NH3_{TANex}$ (Figure 3), the relative contribution to NH_3-N emission can be seen. For chicken, the variation in NH_3-N emission between countries can be explained by differences in the MMS; there is little variation in the TAN excretion. For beef, the NH_3-N emission in Switzerland (CH) is above the mean of the dataset, despite the

TAN excretion being below the mean of the dataset ($NH3_{TANex}$ is negative), because the $NH3_{MMSi}$ is much higher than the mean of the dataset (more positive). This is because animal welfare considerations demand that beef cattle have access to a floor area larger than in other countries and this leads to higher emissions. In contrast, the NH_3-N emission for beef in the UK is below the mean of the dataset. Here, beef production is mainly pasture-based, which results in the TAN excretion being above the mean of the dataset. However, this is outweighed by the much lower NH_3 emissions from the excreta deposited on pasture than from housed animals.

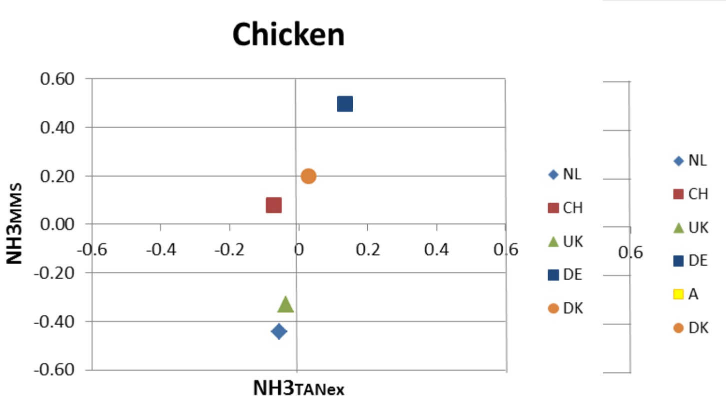

Figure 3. MMS versus TANex NH_3 emission from beef production in the six different countries; NL (light blue), CH (red), UK (green), DE (dark blue), A (yellow), DK (orange). Points above the dashed line represent emissions above the ensemble average and vice versa.

Conclusion

The NH_3 emissions associated with livestock production are logically related to the Nitrogen Use Efficiency of the system. When expressed across commodity production systems, the NH_3 emissions appear linearly related to feed N inputs, although there is much variation within systems. Within a commodity production system, separating the effect of TAN excretion from the effect of the manure management gives insight into the mechanisms underlying the emission of NH_3 and therefore where there may be scope for improvement.

References

Casey, J.W., Holden, N.M. (2005) The relationship between greenhouse gas emissions and the intensity of milk production in Ireland. Journal of Environmental Quality 34, 429-436.

Leip, A., Weiss, F., Lesschen, J.P., Westhoek, H. (2013) The nitrogen footprint of food products in the European Union. The Journal of Agricultural Science FirstView, 1-14.

Norton, R., Davidson, E., Roberts, D., (2015) Nitrogen use efficiency and nutrient performance indicators, GPNM Task Team Report and Recommendations. Position paper from the GPNM's Task Team Workshop, December 8, 2014 held at Washington, DC, revised April 8, 2015. Technical Paper 01/2015.

Sommer, S.G., Zhang, G.Q., Bannink, A., Chadwick, D., Misselbrook, T., Harrison, R., Hutchings, N.J., Menzi, H., Monteny, G.J., Ni, J.Q., Oenema, O., Webb, J. (2006) Algorithms determining ammonia emission from buildings housing cattle and pigs and from manure stores. Advances in Agronomy, Vol 89 89, 261-335.

Sutton, M.A., Howard, C.M., Erisman, J.W., Billen, G., Bleeker, A., Grennfelt, P., Grinsven, H.v., Grizzetti, B., (2011) European Nitrogen Assessment. Cambridge University Press.

Webb, J., Sorensen, P., Velthof, G., Amon, B., Pinto, M., Rodhe, L., Salomon, E., Hutchings, N., Burczyk, P., Reid, J., (2013) An Assessment of the Variation of Manure Nitrogen Efficiency throughout Europe and an Appraisal of Means to Increase Manure-N Efficiency, in: Sparks, D.L. (Ed.), Advances in Agronomy, Vol 119, pp. 371-442.