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A NATIONAL MODEL FOR ESTIMATING POTENTIAL REDUCTIONS IN AMMONIA EMISSIONS AND THEIR COSTS

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The National Ammonia Reduction Strategy Evaluation System (NARSES) is a simple, process-based, model of national ammonia (NH_3) emissions. The emissions component of NARSES regards ammonia as originating from a pool of total ammoniacal-N (TAN) in livestock excreta. Ammonia may be volatilized from this TAN pool at any stage of manure management, until the TAN is absorbed onto soil colloids. This concept of a TAN pool from which ammonia may be successively lost, but to which no newly-generated TAN is added, allows calculation of the consequences of reducing NH_3 emissions at one stage of manure management (upstream) on emissions at later stages (downstream).

More than half of the N excreted by mammalian livestock is in the urine, and between 65 and 85% of urine-N is in the form of urea (Jarvis et al., 1989). Urea is rapidly hydrolyzed by the extracellular enzyme urease to ammonium bicarbonate thus providing the main source of NH_3. Urine also contains compounds such as allantoin which may be broken down to release NH_3 (Whitehead et al., 1989). Together, these compounds with the potential to break down to NH_3, are referred to as TAN. In contrast, the majority of N in livestock faeces is not readily degradable (Van Fassen and Van Dyke, 1987). Only a small percentage of this N is urea or NH_4^+ (Etalla and Kreula, 1979) suggesting a limited NH_3 volatilization potential for faecal N. In a field trial Petersen et al. (1998) found NH_3 losses from dung to be negligible. Thus, during manure management, the pool of TAN may be regarded as being changed only by losses, mainly as NH_3 volatilization. This is an accurate description for liquid manures (slurries) but where litter is introduced there may also be significant losses by nitrification, denitrification, and especially, N immobilization. Clearly other factors, such as temperature, pH, windspeed and the surface area of fresh urine or slurry exposed to the air, influence NH_3 emissions. However, for the purpose of estimating national annual NH_3 emissions these effects have been considered to be, on average, constant.

HOUSING EMISSIONS

Studies carried out in buildings housing livestock have found a good relationship between TAN in excreta and NH_3 emissions. Smits et al. (1995), using a mechanically-ventilated dairy cow house, found a reduction of 25% in cp intake reduced the urea content of slurry by 42% and NH_3 emissions by 39%. Cahn et al. (1998) investigated the effect of cp intake on NH_3 emissions from growing pigs. Ammonia emissions from buildings decreased by 50% and changed little (from 32 to 30%) when expressed as a % of urine-N.

The calculation of NH_3 emission in NARSES is based on the emission factors (EFs) used in the Inventory of Ammonia Emission for the UK (IAEUK, Misselbrook et al., 2001). The IAEUK is based on data from studies carried out within the UK. In the IAEUK NH_3 emissions during housing are expressed as g LU^{-1} d^{-1} for each of the major livestock classes enumerated in the June Census. A livestock unit (LU) is equivalent to a 500 kg dairy cow. Emissions expressed as g LU^{-1} d^{-1}, may be converted to % of TAN excreted using data on the average weight of each livestock class, the number of days each class is housed, and the annual TAN excretion by the livestock class.

Table 1. Percent of N and TAN emitted as ammonia in livestock buildings

Livestock	Manure/Housing	Ammonia emissions as % N	Ammonia emissions as % TAN
All cattle)	Slurry	18.5	31.0
Except calves)	FYM	12.5	21.0
Calves	FYM	3.5	6.0
Sheep	FYM	13.5	22.5
All pigs except weaners	Slurry	18.0	25.5
Weaners	Slurry	10.5	15.0
Sows and boars	FYM	16.5	23.5
Fatteners and weaners	FYM	24.0	34.0
Laying Hens	Manure	29.5	37.0
Broilers and turkeys	Litter	21.0	26.5

In order to ensure that the amount of TAN at the next stage of manure management was calculated accurately, account needed to be taken of any other gaseous N losses and of immobilization of TAN by straw. Losses of N_2O from poultry manure were calculated, as % TAN excreted, using these data. The immobilization of TAN in litter is calculated as 1 kg N per 150 kg straw added, in the middle of the range of immobilization reported by Kirchmann and Witter, (1989) for C:N ratios of between 18 and 36:1, since UK cattle manure will typically have an C:N ratio of *c*. 20. Moreover, since straw has a C:N ratio of *c*. 100, and mixing of straw and excreta is poor, then some of the TAN in urine is likely to be immobilized where it is voided to fresh straw. These calculations are, however, based on limited data and reflect the need for work to establish more precisely the processes taking place in litter-based manures.

Table 2. Comparison of manure analyses TAN as % total N in manure (prior to storage) with RB209

Manure type	% TAN IN FRESH EXCRETA	% TAN IN RB209	% TAN IN NARSES
Cattle slurry	60	50	52
Cattle FYM	60	25*	26
Pig Slurry	70	60	63
Pig FYM	70	25*	41
Sheep FYM	60	25*	34
Layer manure	70	50	54
Broiler and Turkey litter	70	40	53

* 'fresh' i.e. FYM prior to storage

Emissions of NH_3 and N_2O and TAN immobilization are regarded as taking place simultaneously, and hence the amounts of each are deducted from the estimate of TAN excreted. As a check on the working of the model, at the end of the housing period the ratio of TAN to total N in the manure is calculated for comparison with measurements of the N and TAN contents of manures. Typical manure analyses are given in RB209 (Anon. 2000). These, together with NARSES outputs, are compared in table 2. The agreement is generally reasonable, patricularly for slurries. At present, NARSES appears to be underestimating housing losses/immobilization of pig FYM and poutry litter.

STORAGE EMISSIONS

Muck and Steenhuis (1982) showed that urea concentration was one of the main factors determining NH_3 volatilization during storage. They concluded the main loss during anaerobic manure storage is NH_3 volatilization, with little loss through leaching/seepage or nitrification/denitrification. They found negligible N mineralization during storage.

In the IAEUK NH_3 emissions from stored manures as expressed as g m^{-2} d^{-1}, with the proviso that emission from stored farmyard manure only take place for the first 30 days of storage. Ammonia emissions are calculated as the product of EFs and the total area of each type of store. Taking these estimates together with the NARSES output of the amounts of N and TAN remaining in manures to be put into storage after losses and immobilization from buildings and hardstandings, emissions as a % of TAN entering the store may be determined. The results are as follows.

Table 3. Percent N and TAN emitted as NH_3 from manure stores

Livestock	Manure	Store	% N	% TAN
Cattle	Slurry	Circular tank	8.3	15.8
		Weeping wall	5.6	10.8
		Lagoon	41.7	79.9
	FYM		1.1	4.2
Pigs	Slurry	Circular Tank	2.7	3.8
		Lagoon	19.5	28.1
	FYM		2.3	4.6
Poultry	Layer manure		2.3	3.7
	Broiler litter		0.5	0.8

There are significant discrepancies in the estimates of NH_3 loss during storage used in NARSES with those quoted by workers outside the UK. Moreover, the differences are not consistent, NARSES estimates of NH_3 emission being greater for stored slurry and less for litter-based manures.

Although NARSES is a model of NH_3 emissions it was found necessary to estimate other losses of N during storage since the large differences in TAN observed between fresh and stored FYM could not be accounted for by NH3 emissions alone which are generally rather small. Losses of N_2O were calculated as % TAN put into store using data from the UK Inventory of N_2O emissions from Farmed livestock (Chadwick et al., 1999). A mean of 7.5% of TAN lost as N_2O was used for cattle, pig and poultry manure. The IPPC default EF for storage of FYM is 2% of N (IPPC/OECD, 1997), which for manures with *c.* 25% TAN, equates to an EF of 8% TAN. Few studies of gaseous emissions from stored manures even consider N_2 emissions. However, when conditions are created favourable to both nitrification and denitrification, as is the case in aerated slurry stores and in FYM heaps, N_2 emissions may take place. It is difficult to draw accurate conclusions from such scant data, but as a first approximation emissions of N_2 may be estimated as x 10 those of N_2O. In a study of losses during FYM storage Webb et al. (in prep) measured *c.* 1% of total N put into store was lost by leaching. Results from non-UK studies suggest an average of 12% of TAN leached would be a reasonable overall estimate, based on an assumption than at the beginning of storage TAN is 25% of total N.

During storage of cattle and pig FYM, the TAN content of the manure decreases from *c.* 25 to *c.* 10% of total N. This decrease is greater than would be expected from our current estimates of NH_3, N_2O, and N_2 emissions and N leaching. It seems likely therefore that more TAN is immobilized during storage. Emissions of NH_3, N_2O and N_2, N leaching and immobilization are regarded as taking place simultaneously, and hence the amounts of each are deducted from the estimate of TAN put into store. As a check on the workings of the model, at the end of the storage period, the ratio of TAN to total N in the manure is calculated for comparison with measurements of the N and TAN contents of manures. The manure analyses given in RB209 (Anon. 2000), together with NARSES outputs are given in Table 4.

Table 4. Comparison of manure analyses of % TAN (after storage) with RB209

Manure type	RB209	NARSES
Cattle slurry	50	46
Cattle FYM	10	10
Pig Slurry	60	62
Pig FYM	10	12
Sheep FYM	10	14
Layer manure	50	49
Broiler and Turkey litter	40	45

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