ECONOMICS OF CONTROLLING AMMONIA EMISSION FROM COMMERCIAL LAYER FARMS[1]

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Primary Audience: Regulators, Legislators, Economists, Egg Producers, Researchers

SUMMARY

This article presents a model to calculate the level of ammonia emission from commercial layer houses. The first part of the model calculates nitrogen excretion; the second part gives the total ammonia emission from layer houses, manure storage, and manure application. The results show that improved application methods can reduce the ammonia emission in a region at a lower cost than low-nitrogen feed or manure belt drying systems. Results of the separate measures for reducing ammonia emission are not additive. As there are no direct revenues from lowering ammonia emission, governmental regulations requiring such measures, as implemented in the Netherlands, will increase costs for U.S. poultry producers.

Key words: Ammonia, economics, lagoons, layers, model, nitrogen, poultry, waste management

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DESCRIPTION OF PROBLEM

Acidification of the environment caused by atmospheric deposition (acid rain) is a serious problem. Nitrogen compounds in the form of nitrogen oxides (NO_x), ammonia (NH_3), and certain chemical combinations of ammonia (NH_x) contribute to acidification. Ammonia contributes more than 40% of the total nitrogen deposition in Europe, with great variation among regions [1]. In the Netherlands, a country with a high density of poultry and pig farms, it is estimated that livestock production is responsible for about 90% of the ammonia emission.

This study presents a model to calculate the level of ammonia emission from the commercial layer sector. Applying this model will demonstrate the effects of different strategies for reducing ammonia emission. Here we have

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[1] The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products mentioned, nor criticism of similar products not mentioned.

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used it to determine which combination of measures may reduce ammonia emissions to targeted levels and the associated costs at the farm level. Examples are given for the Netherlands and the United States.

MATERIALS AND METHODS

MODEL DEVELOPMENT

To effectively represent a nitrogen balance model relevant to ammonia emission, it is important to understand the nitrogen flow in egg production. Figure 1 illustrates the nitrogen flow (N-flow) and ammonia emission for commercial layers. Ammonia is released during deposition in the layer house, during storage of manure, during manure application as such, and from field surfaces. For this article, emission from field surfaces is considered to occur during application. For each of these processes techniques are available to control ammonia emission. In addition, changes in the nitrogen content of the feed and/or dietary modifications (feed enzymes, etc.) influence emissions during all three processes.

Based on the N-flow as presented in Figure 1, a model was developed to calculate the total ammonia emission of commercial layer farms. In the first part of the model N input minus N deposition for growth and egg production results in N excretion. Table 1 gives an overview of the formulas to calculate the N excretion [2]. The second part of the model calculates the amount of ammonia emission that occurs in the layer house, during manure storage, and during manure application. This model can be written as the following equations:

Ammonia emission in the layer house:

$$EH = \sum_{1 \text{ to } i} (N * H_i * E_i) \qquad (1)$$

EH	ammonia emission in grams of nitrogen (g N) of all layer houses in a given area
i	housing system
N	N excretion per layer (EX)
H	percentage of hens in each housing system in the area (i)
E	emission coefficient (percentage of the N excretion) for each housing system (i). (Any type of house may be used.)

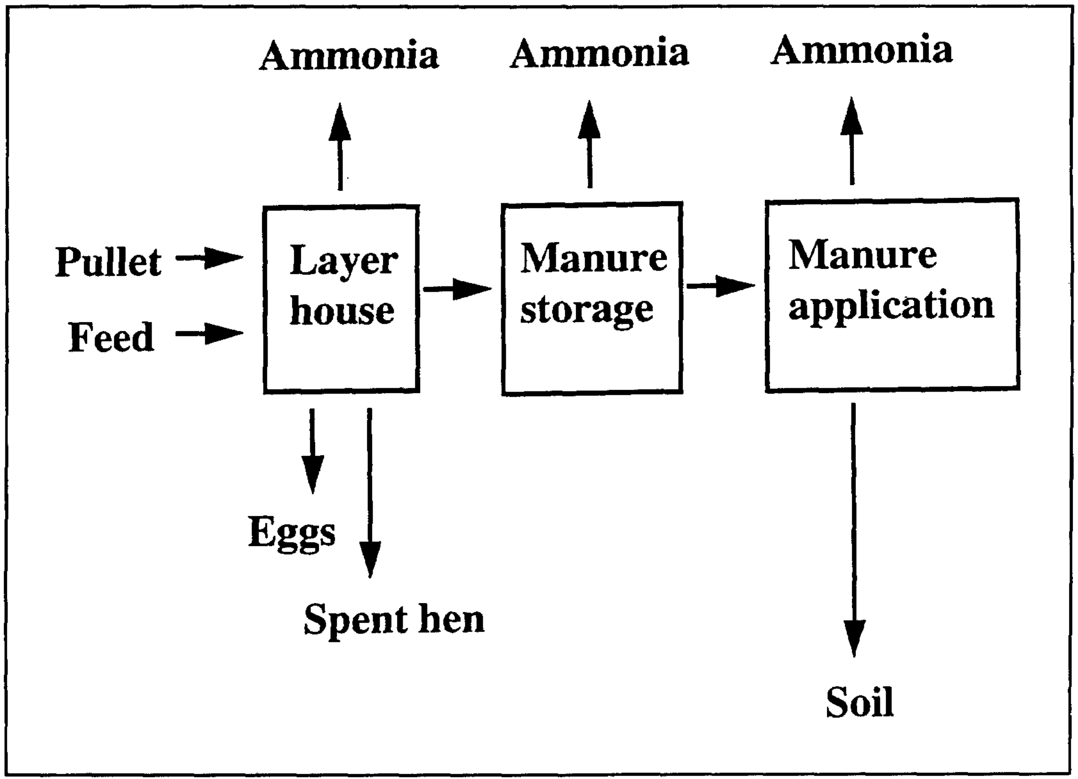

FIGURE 1. Nitrogen flow for commercial layers (Adapted from Horne [2])

Ammonia emission during storage:

$$ES=\sum_{1\ \text{to}\ i}(N * H\,i * E\,i) \tag{2}$$

ES ammonia emission (g N) during storage in a given area
i storage system
N N in manure (EX–EH)
H percentage of hens for which the manure is stored in system (i)
E emission coefficient (percentage of the amount N) for each storage system (i).

Ammonia emission during application:

$$EA=\sum_{1\ \text{to}\ i}(N * H\,i * E\,i) \tag{3}$$

EA ammonia emission (g N) during application in a given area
i application system
N N in manure after storage (EX–EH–ES)
H percentage of hens for which the manure is applied by system (i)
E emission coefficient (percentage of the amount N) for each application system (i).

Total ammonia emission:

$$ET=EH+ES+EA \tag{4}$$

This model will calculate the total ammonia emission for a commercial layer population on different farms with several housing systems and methods of manure storage and application in a given area (Equation 4). This method assumes that the ammonia emission during housing is a percentage of the nitrogen in the manure (N excretion) (Equation 1). The ammonia emission during storage is a percentage of the nitrogen component in manure after emission in the layer house (Equation 2). Ammonia emission during application is a percentage of the nitrogen in manure after storage (Equation 3). The amount of N available to the soil and plants can therefore be calculated by subtracting the total ammonia emission (ET) from the excretion (EX). By changing the N excretion or the ammonia abatement process one can determine the degree of ammonia level reduction in a given area.

NITROGEN EXCRETION DATA

Egg production and feed intake are important data in calculating N excretion. Table 1 also gives an overview of the technical results of a single-cycle commercial layer flock used to calculate nitrogen excretion [2]. It is assumed that the nitrogen content of eggs is 1.92% and the deposition through body weight gain of the hen during the laying period is 17 g N/bird. The nitrogen content of protein is 16% [3]. From these data, we determined nitrogen input, deposition, and excretion, and ammonia emission for the general situation in the Netherlands in 1990 (Table 2). We then used the model to determine the effect of management modifications on this initial situation.

Table 1 assumes that the protein level of layer feed is 17.2%. Significantly, research in-

TABLE 1. Example calculations of nitrogen excretion/yr/hen housed for one 409-day laying period followed by house cleaning[A]

INPUT DATA	
Laying period, days	409
Cycle length including house cleaning, days	427
Egg production/hen housed, kg	20.2
Feed/hen housed, kg	45.3
Protein in layer feed, %	17.2
FORMULAS	
N input from feed, g = feed (kg) * protein (%) * 16% N in protein	
N deposition in eggs, g = eggs (kg) * 1.92% N	
N deposition for growth, g = weight gain hen (kg) * N (%)	
N excretion per cycle, g = input – (deposition in eggs + deposition for growth)	
N excretion per year/hen housed (Ex), g = excretion per cycle * 365/[cycle length (e.g. 427 days)]	

[A] Data from Horne [2].

TABLE 2. Nitrogen input, deposition, and excretion and ammonia emission[AB]

	NITROGEN/HEN/CYCLE	NITROGEN/HEN/YR
	g	g
NITROGEN		
Input (feed) 45.3 × 0.172 × 0.16 =	1247	1066
Deposition (eggs) 20.2 × 0.0192 =	388	331
Deposition (growth)	17	15
Excretion	842	720[C]
AMMONIA EMISSION		
Poultry house	66	
Storage	12	
Application	114	
Total	192	
Available in soil as fertilizer (720 – 192) =	528	

[A] Based on data in Table 1 and calculations with the model.

[B] The cycle length is 427 days based on 409 laying days and 18 cleaning days.

[C] Calculated from 842 × (365/427) = 720.

dicates that there is a marked potential for reducing laying hens' nitrogen excretion without any major reduction in egg mass output [4]. Low-protein diets containing 14% crude protein are sufficient for high performance of laying hens when supplemented with DL-methionine and L-lysine HCL [5]. Adding more synthetic amino acids to feed with a lower protein level will be more expensive. Using such a feed with 15% protein, which will meet the essential amino acid requirements of layers, the extra costs are $0.12/100 kg feed, which is $0.05/layer/yr [6].

HOUSING SYSTEMS

Ammonia emission levels vary among housing systems. Houses that store the droppings as slurry below the cages have much higher ammonia emission levels than houses with belt batteries where the manure is either directly removed wet or dried on the belt. The emission from houses with manure belts with and without drying is about the same [7]. Based on research, literature, and assumed evaporation rates of ammonia from manure, the Dutch government has published emission factors for various housing systems [8]. Table 3 gives an overview of the ammonia emission per layer per year and the ammonia emission coefficient.

Methods to lower ammonia emission in layer houses typically limit the time that manure is in the house. This can be achieved through weekly or daily removal of slurry by manure removal belts. Using air movement to accelerate the drying of manure also lowers the ammonia emission [9]. Table 3 shows that manure belt systems can be classified as low ammonia emission systems. Dutch poultry farmers are presently investing in manure belt systems and moving away from open slurry storage and high-rise systems. In Pennsylvania the high-rise system is used in almost 90% of the houses [10]. The lagoon system is used on 30% of North Carolina farms. Research based on measurements of nutrient intake and mineral concentration in the manure of eight flocks in Pennsylvania high-rise facilities showed that approximately 42% of the feed nitrogen is lost to the atmosphere as ammonia N [11]. This figure is close to the 44.2% measured in the Dutch situation. In North Carolina some layer farms use a system in which the manure is flushed to a lagoon. No data are available on the ammonia emission from layer houses using this system. In our calculations, it is assumed that the ammonia emission in such a layer house is equal to that in a system with open slurry storage below the cages (System 1 in Table 3). Most of the emission would occur from the lagoon.

The costs involved in changing to the manure belt system are estimated to be $0.30/layer/yr. This estimate is based on the

TABLE 3. Ammonia emission from manure during deposition in various housing systems, during storage, and during application in the Netherlands in 1990

LOCATION	AMMONIA EMISSION/HEN/YR	AMMONIA AS A % OF NITROGEN EXCRETION
	g N	%
HOUSING SYSTEM		
Open slurry storage below cages	68	9.4[A]
Manure removal belt with closed slurry storage	29	4.0[A]
High-rise house	317	44.0[A]
Manure belt with forced drying	29	4.0[A]
Deep litter system	147	20.4[A]
Manure flushing to lagoon	68	9.4[A]
STORAGE		
Manure dried on belts (to 40–50% dry matter)	41	6.3[B]
Manure flushed to lagoon	387	70.0[C]
APPLICATION		
Application on land of dry manure	71	11.0[D]
Application on land of slurry	174	27.1[D]

[A] Percentage calculated by dividing by 720 g N/hen/yr (Table 2).

[B] Percentage calculated by dividing by 720 – 66 = 654 (Table 2).

[C] Estimated from Barker [13].

[D] Percentage calculated by dividing by 720 – 66 – 12 = 642 (Table 2).

additional investment of $1.75 for manure belts when the producer is replacing the old cages. Annual costs of depreciation (10%), interest (4%), and maintenance (3%) are 17% of the investment.

Air filtration to remove ammonia as part of a ventilation system is another method of reducing ammonia emission [9]. Air filtration can be achieved by biofiltration or scrubbing. In the absence of technical complications, ammonia reduction of 80% can result. The cost is $2.10/layer/calendar year [2].

MANURE STORAGE SYSTEMS

When manure remains in open storage below the cages, the ammonia emission is considered to be part of the emission during housing. In systems using manure belts and removing dried manure to a storage area outside the layer house most ammonia emission will occur during storage. The ammonia emission is dependent on the dry matter content of the manure [12]. In North Carolina one form of manure storage is a lagoon. Besides acting as storage areas, lagoons also perform a treatment function by transforming nitrogen. Under the climatic conditions of North Carolina, anaerobic lagoons can volatilize 70% of the excreted nitrogen in gaseous form from the lagoon surface [13]. Table 3 gives an overview.

APPLICATION SYSTEMS

Land application of dry manure results in lower ammonia emission than application of a slurry [14]. The coefficients in Table 3 indicate the difference in ammonia emission. The ammonia emission during application on arable land can be reduced by 30% by plowing the manure under within 24 hr [14] and by up to 90% by plowing it under within 30 min [15]. The extra costs are $0.06/layer/yr. In North Carolina lagoon treatment of layer manure results in significantly reduced solids content in the lagoon liquid. This makes it possible to transport lagoon liquid through irrigation lines. Calculations for ammonia emission with this system are thus based on application of slurry used for irrigation of effluent.

RESULTS AND DISCUSSION

From the described model and the basic assumptions presented herein, the ammonia emission attributed to commercial layers can be calculated. The model can also be used to determine the level of ammonia emission reduction that can be achieved by adopting a single technique (reducing emission in feed, housing, or application) and the associated extra costs per layer per year, as well as the combination of measures that can reduce ammonia emission to a satisfactory level with the lowest costs at farm level.

Table 2 shows the nitrogen input, deposition, and excretion and the ammonia emission per layer per year during 1990 in the Netherlands. Based on the situation presented in Table 2, the independent results of a single technique to change ammonia emission and the costs are calculated. The following techniques are used:

- low nitrogen feed: layer feed protein level of 15% vs. 17.2%
- adapting housing: all cages have manure belts for drying
- adapting housing: addition of air filtration
- improved manure application: direct plowing under of slurry or dried manure during application, which can reduce ammonia emissions by as much as 90% [14, 15].

Table 4 shows the reduction in ammonia emission and associated costs. Improved manure application, by plowing under manure slurry or dried manure, is a relatively inexpensive method to reduce ammonia emission. This applies more to slurry manures than to lagoon liquids because of volume differences. Air filtration is a very expensive method.

The separate effects presented in Table 4 are not additive. Adoption of a lower protein level in the feed will lower nitrogen excretion and result in a lower emission during deposition in the poultry house, manure storage, and application. Thus, the total reduction associated with low-nitrogen feed is related to the application method. Table 5 shows two scenarios demonstrating the effect of these interactions. Scenario C combines an improved application method with low-nitrogen feed. Scenario D combines an improved application method with the adoption of poultry house manure belts. A low feed protein level in conjunction with improved manure application gives an additional 5% reduction. The impact of low-nitrogen feed on the total ammonia emission (16% alone) is reduced when combined with other methods (Table 4). Adapting housing in combination with improved manure application gives a total reduction in ammonia emission of 66%. Although the reduction is slightly higher, the costs are increased over those of Scenario C. In Scenario D more nitrogen is available for the soil than in the other combinations. In Scenarios B, C, and D costs are increased by \$0.06, \$0.11, and \$0.35/hen/yr, respectively. Implementing measures to decrease ammonia emission will in effect decrease the producer's income, since no direct revenues will result.

For the United States, the Netherlands data have been used to calculate the excretion per layer per year; ammonia emissions are calculated based on a North Carolina housing system in which manure is flushed to a lagoon. The lagoon effluent is spray-irrigated onto pasture. Table 5 gives an overview of the results with no measures to reduce ammonia emission and with all farms changing to manure belt systems for drying and removing manure to storage. As Table 5 shows the ammonia emission from a lagoon irrigation system (30% of North Carolina farms) is higher than that in the Netherlands. As a result, the amount of nitrogen available for the soil is low. Installing manure belts in all layer houses would reduce ammonia emission by 78%, and nitrogen available for the soil would increase by a factor of 12.

TABLE 4. Reduction of ammonia emission and the extra costs/layer/yr and per g N reduction

COSTS PER % ADOPTION	REDUCTION OF TOTAL EMISSION	EXTRA COSTS/HEN/YR	EXTRA COSTS/% N REDUCTION
	%	\$	\$
Low-nitrogen feed	16	0.05	0.003
Adapt housing: manure belts	21	0.30	0.014
Adapt housing: air filtration	26	2.10	0.081
Improved manure application of slurry	53	0.06	0.001

TABLE 5. Annual ammonia emission/layer/yr with different ammonia reduction scenarios

AMMONIA EMISSION	SCENARIO[A]					
	A	B	C	D	E	F
	g					
Poultry house	66	66	62	38	68	29
Storage	12	12	10	21	457	44
Application	114	11	9	7	18	73
Total	192	90	80	66	543	145
Available to Soil	528	630	503	653	40	575
Ammonia Reduction (%)		53	58	66		73
ANNUAL COST ($):						
Per hen	–	0.06	0.11	0.35	–	0.28
Per %NH_3 reduction	–	0.0011	0.0019	0.0054	–	0.0038

[A] A = Netherlands (NL) basic situation; B = NL improved land application; C = NL improved land application and low-nitrogen feed; D = NL Improved land application and improved housing with manure belts; E = United States (US) basic situation with lagoons and spray-irrigation onto pasture; F = US with manure belt systems for drying.

The extra cost of investment in manure belts is estimated to be $1.75/layer. The extra annual costs for depreciation, interest, and maintenance would be $0.30/layer/yr, assuming that the old cages are depreciated and replaced. The cost of additional land needed for manure application must also be considered. Other potential effects include the impact on groundwater and the cost of adding more N to the soil in land-limited areas. Such cases present a trade-off of reducing NH_3 emissions while increasing NO_3 leaching. In North Carolina these environmental concerns and costs have led to a gradual phase-out of lagoon systems in favor of high-rise layer houses.

CONCLUSIONS AND APPLICATIONS

1. The presented model is a useful tool to show the effects of single or combined measures to reduce ammonia emission. This can be done on a farm, county, state, or country level.
2. The cheapest method to reduce ammonia emission is to improve the application technique. On arable land this can be done by plowing under the manure slurry or dried manure directly after application.
3. Ammonia emission varies widely among housing systems. Ammonia emission from high-rise houses is tenfold greater than from houses with manure belts.
4. Improved manure application combined with low-protein feed or a change to manure belt systems will reduce the total ammonia emission by more than 50%.
5. No direct revenues result from lowering ammonia emissions.

REFERENCES AND NOTES

1. **Klaassen, G.,** 1991. Past and future emissions of ammonia in Europe. Status Report 91-01. Intl. Inst. for Appl. Systems Analysis, Laxenburg, Austria.

2. **van Horne, P.L.M.,** 1993. Reduction of ammonia emission on layer farms. Research Report 488. Agric. Econ. Res. Inst. (LEI-DLO), The Hague, The Netherlands.

3. **Copoolse, J., A.M. Van Vuren, J. Huisman, W.M.M.A. Janssen, A.W. Jongbloed, N.P. Lenis, and F.J.M. Pijls,** 1990. The excretion of N, P, and K by farm animals, now and tomorrow. IVVO, Lelystad, The Netherlands.

4. **Summers, J.D.,** 1993. Reducing nitrogen excretion of the laying hen by feeding lower crude protein diets. Poultry Sci. 72:1473–1478.

5. **Bertram, H.L., J.B. Schutte, and E.J. Weerden,** 1989. Methionine and sulfur amino acid requirements for laying hens in a low protein diet. Pages 363–364 in: Proc. 7th European Symp. Poultry Nutr., Girona, Spain.

6. **Schutte, J.B. and S. Tamminga,** 1992. Nutritional methods to reduce the N and P excretion of poultry, pigs, and cattle. ILOB-Report I 92-3792b. ILOB-TNO/LUW-VV. Wageningen, The Netherlands.

7. **Kroodsma, W., R. Scholtens, and J. Huis in het Veld**, 1988. Ammonia emission from poultry housing systems. Report 96. Pages 7.1–7.13 in: Proc. CICR Seminar: Storing, Handling, and Spreading of Manure and Municipal Waste. Uppsala, Sweden.

8. **Netherlands Ministry of Agriculture**, 1991. Directive on ammonia emissions from livestock husbandry. Ministry of Agriculture, The Hague, The Netherlands.

9. **Groot Koerkamp, P.W.G.**, 1994. Review on emission of ammonia from housing systems for laying hens in relation to sources, processes, building design, and manure handling. J. Agric. Eng. Res. 59:73–87.

10. **Lorenz, E.S.**, 1997. Characteristics of Pennsylvania Layer Farms: 1996. M.S. Thesis, Pennsylvania State University, University Park, PA.

11. **Patterson, P.H. and E.S. Lorenz**, 1996. Manure nutrient production from commercial White Leghorn hens. J. Appl. Poultry Res. 5:260–268.

12. **Kroodsma, W., W. Brunnekreef, and D.A. Ehlhardt**, 1989. Possibilities for manure treatment and reduction of ammonia emissions on poultry farms. Pages 13–14 in: Proc. Themadag, Ede., The Netherlands.

13. **Barker, J.C.**, 1994. Livestock Manure Characteristics. Biological and Agricultural Engineering, North Carolina Cooperative Extension Service, Raleigh, NC.

14. **Pain, B.F. and J.V. Klarenbeek**, 1988. Anglo-Dutch experiments on odour and ammonia emissions from landspreading livestock wastes. IMAG Research Report 88-2, Wageningen, The Netherlands.

15. **Pain, B.F, V.R. Philips, J.F.M Huijsmans, and J.V. Klarenbeek**, 1991. Anglo-Dutch experiments on odour and ammonia emissions following the spreading of piggery wastes on arable land. IMAG-DLO Report 91-9, Wageningen, The Netherlands.