A Model Tool for Estimation of NH_3 Emissions from AFOs

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May 2, 2011
Ammonia Emissions and Nitrogen Conservation Workshop
Columbus, Ohio

Background

- Emissions from livestock operations are an environmental concern, in particular, NH3
- Continuous monitoring of airflow and gas concentrations from facilities to establish emission levels recognized by EPA.
- However, such approaches are time intensive, costly and limited in applicability to individual operations.

Presentation

- Present theory for N-loss (NH_3 emissions kg/animal/yr) using chemical analysis and mass balances (ash, nitrogen) based on N/ash ratios.
- Apply mass balance approach to 2 caged layer systems – belt/composting & deep pit
- Compare results with estimates based on airflow and NH_3 concentrations in the exhaust air, literature values

Theory

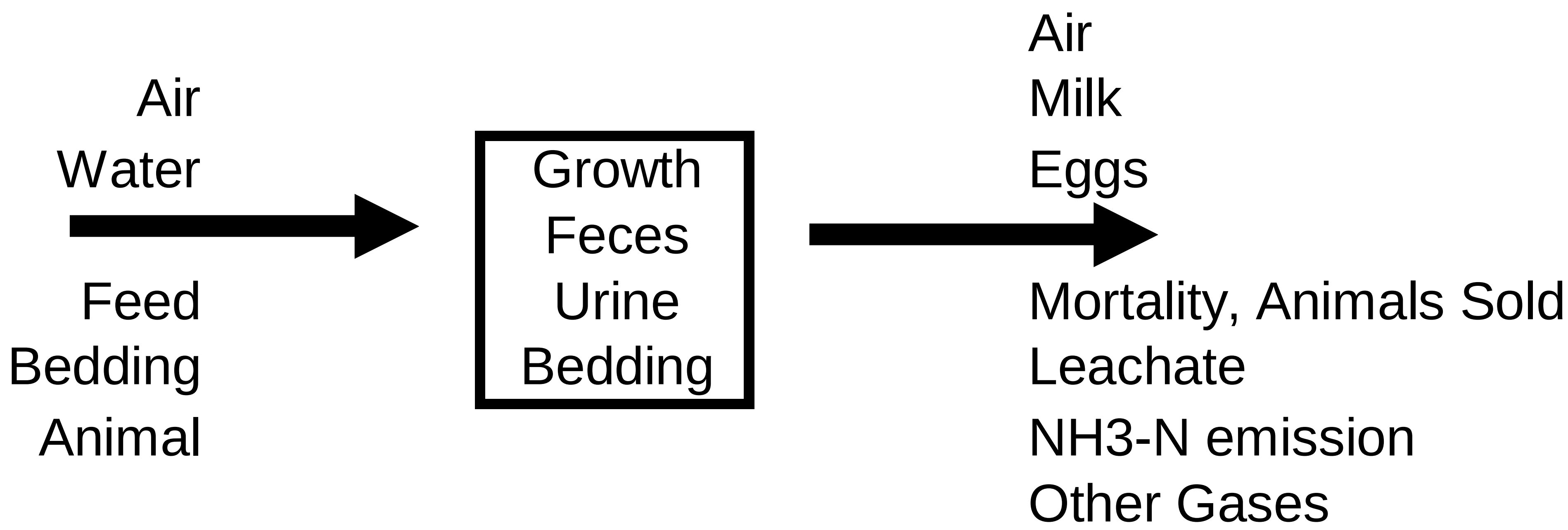
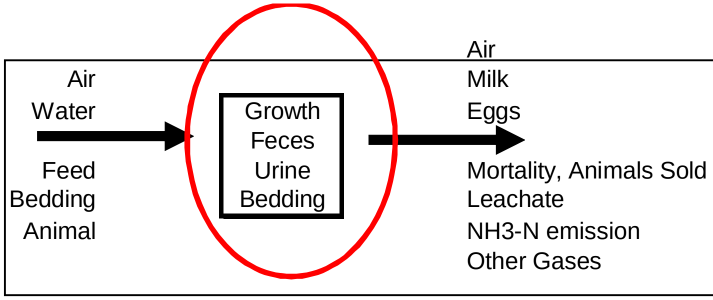


Fig. 1. Flow diagram of inputs, storage, outputs of animal production system

Variables and nomenclature used in mass balance equations

Variables	Subscript
θ = time, day	i =
m_i = mass of i, kg	6, growth of animals in system
mi' = mass flow rate, kg/day	7, feces in system
$dmi/d\theta$ = rate of change, kg/day	8, urine in system
x_{Ni} = nitrogen content, dec	9, bedding in system
x_{Ai} = ash content, dec.	10, air out of system
Ri - x_{Ni}/x_{Ai}, nitrogen to ash ratio, dec	11, milk out of system
Ni = total nitrogen in i, kg/day	12, eggs out of system
Subscript	13, mortality, animals sold out of system
i = …….	….14, leachate
1, air in	….15, NH3-N emission
2, water in	A, ash
3, feed in	N, nitrogen
4, bedding in	M, manure
5, animals in	

Theory

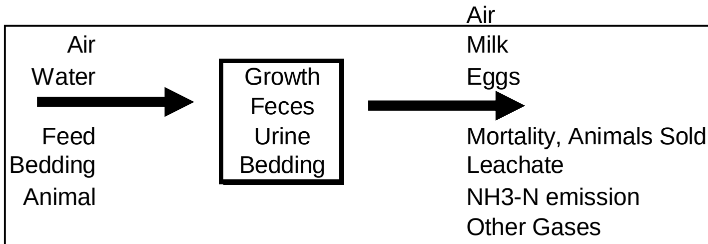


$$N_{storage} = N_{in} - N_{out}$$

$$\sum_{i=6}^{9} x_{N_i} \frac{dm_i}{d\theta} \cong \sum_{i=1}^{5} x_{N_i} m_i' - \sum_{i=10}^{14} x_{N_i} m_i' - N_{15}$$

$$N_{15} \leq \sum_{i=1}^{5} x_{N_i} m_i' - \sum_{i=6}^{9} x_{N_i} \frac{dm_i}{d\theta} - \sum_{i=10}^{14} x_{N_i} m_i'$$

Theory

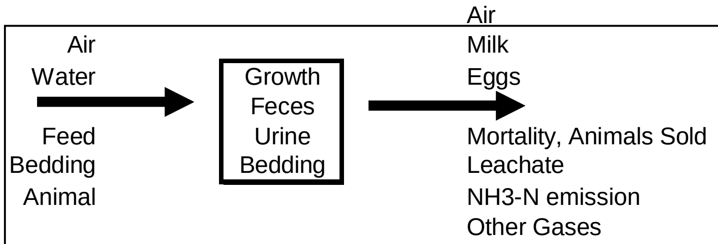


$$N_{15} \leq = \sum_{i=3}^{5} x_{N_i} m_i' - x_{N6} \frac{dm_6}{d\theta} - \sum_{i=7}^{9} x_{N_i} \frac{dm_i}{d\theta} - \sum_{i=11}^{14} x_{N_i} m_i'$$

The final form assumes N in the air entering the system passes through the system and no N is in the water entering the system.

The term $\sum_{i=7}^{9} x_{N_i} \frac{dm_i}{d\theta}$ is total nitrogen in the manure.

Feces, Urine, Bedding.



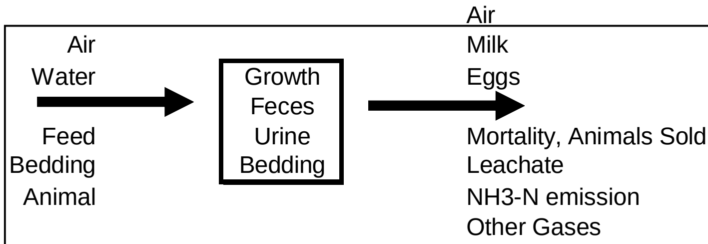
Theory

Ash in system:

$$\sum_{i=6}^{9} x_{A_i} \frac{dm_i}{d\theta} = \sum_{i=1}^{5} x_{A_i} m_i' - \sum_{i=10}^{14} x_{A_i} m_i'$$

Rearranged equation for ash: Feces, Urine, Bedding

$$\sum_{i=7}^{9} x_{A_i} \frac{dm_i}{d\theta} = \sum_{i=3}^{5} x_{A_i} m_i' - x_{A6} \frac{dm_6}{d\theta} - \sum_{i=11}^{14} x_{A_i} m_i'$$



Theory

From sampling and lab analysis find N/A, R_M. But

$$R_M = \sum_{i=7}^{9} x_{N_i} \frac{dm_i}{d\theta} \Big/ \sum_{i=7}^{9} x_{A_i} \frac{dm_i}{d\theta}$$

Plug into equation for N loss:

$$N_{15} \le \sum_{i=3}^{5} x_{N_i} m_i' - x_{N6} \frac{dm_6}{d\theta} - \sum_{i=11}^{14} x_{N_i} m_i' - R_m \left[\sum_{i=3}^{5} x_{A_i} m_i' - x_{A6} \frac{dm_6}{d\theta} - \sum_{i=11}^{14} x_{A_i} m_i' \right]$$

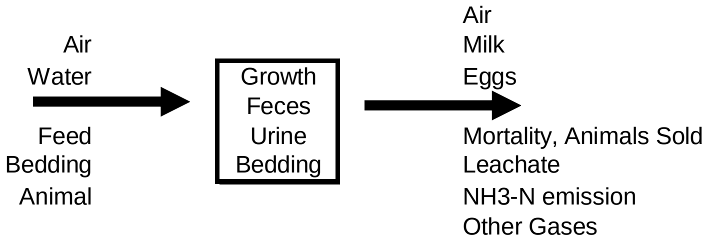
Need R_m but no weights on manure (feces, urine, bedding, 7,8,9).

Advantages of Method

- No weighing of manure required.
- Sampling & lab analysis <<< cost continuous NH3 measurement and airflow measurement.
- Prediction of maximum ammonia loss more reliable based on error analysis (??).
- Can be used with naturally ventilated building.

Limitations of Method

- Requires obtaining representative samples for feed and analysis of feeds. For dairy may be difficult with wide range of feedstuffs, compared to swine or poultry.
- Requires obtaining representative samples for bedding and its analysis. For dairy, may be difficult, especially if sand is used and/or bedding recycled compared to swine or poultry where no bedding is used.
- Requires estimating change in body mass (growth) of animal. Evaluations over short time periods for some animals (i.e. laying hens) may lead to small errors if assume change is zero.



m_5', m_{12}', m_{13}' and $m_{14}' \cong$ zero

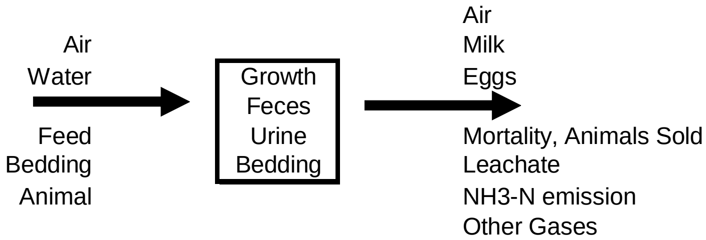
$$N_{15} \leq x_{N3} m_3' + x_{N4} m_4' - x_{N6} \frac{dm_6}{d\theta} - x_{N11} m_{11}'$$

$$- R_m \left[x_{A3} m_3' + x_{A4} m_4' - x_{A6} \frac{dm_6}{d\theta} - x_{A11} m_{11}' \right]$$

$$EM_{NH3\text{-}N} = 365\, N_{15}/n_b \quad (\text{kg } NH_3\text{-N cow}^{-1}\ \text{yr}^{-1})$$

n_b number of cows in the building.

feed, bedding, calf growth, milk, manure R_m [i.e. N/A]



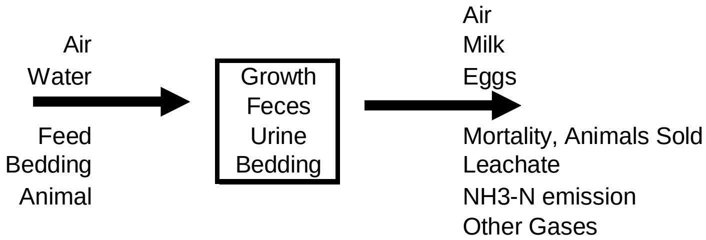
$$m_4', m_5', \frac{dm_6}{d\theta}, m_9', m_{11}', m_{12}', m_{13}' \text{ and } m_{14}' \cong \text{zero}$$

$$N_{15} \le x_{N_3} m_3' - x_{N6} \frac{dm_6}{d\theta} - R_m \left[x_{A_3} m_3' - x_{A6} \frac{dm_6}{d\theta} \right]$$

$$EM_{NH3\text{-}N} = 365\, N_{15}/n_b \quad (\text{kg } NH_3\text{-N hog}^{-1}\ \text{yr}^{-1})$$

n_b number of hogs in the building.

feed, body growth, manure R_m [i.e. N/A]



$$m_4',\ m_5',\ \frac{dm_6}{d\theta},\ m_{11}',\ m_{13}' \text{ and } m_{14}' \cong \text{zero}$$

$$N_{15} \leq x_{N_3} m_3' - x_{N_{12}} m_{12}' - R_m \left[x_{A_3} m_3' - x_{A_{12}} m_{12}' \right]$$

$$EM_{NH3\text{-}N} = 365\ N_{15}/n_b \quad (\text{kg } NH_3\text{-N hens}^{-1}\ \text{yr}^{-1})$$

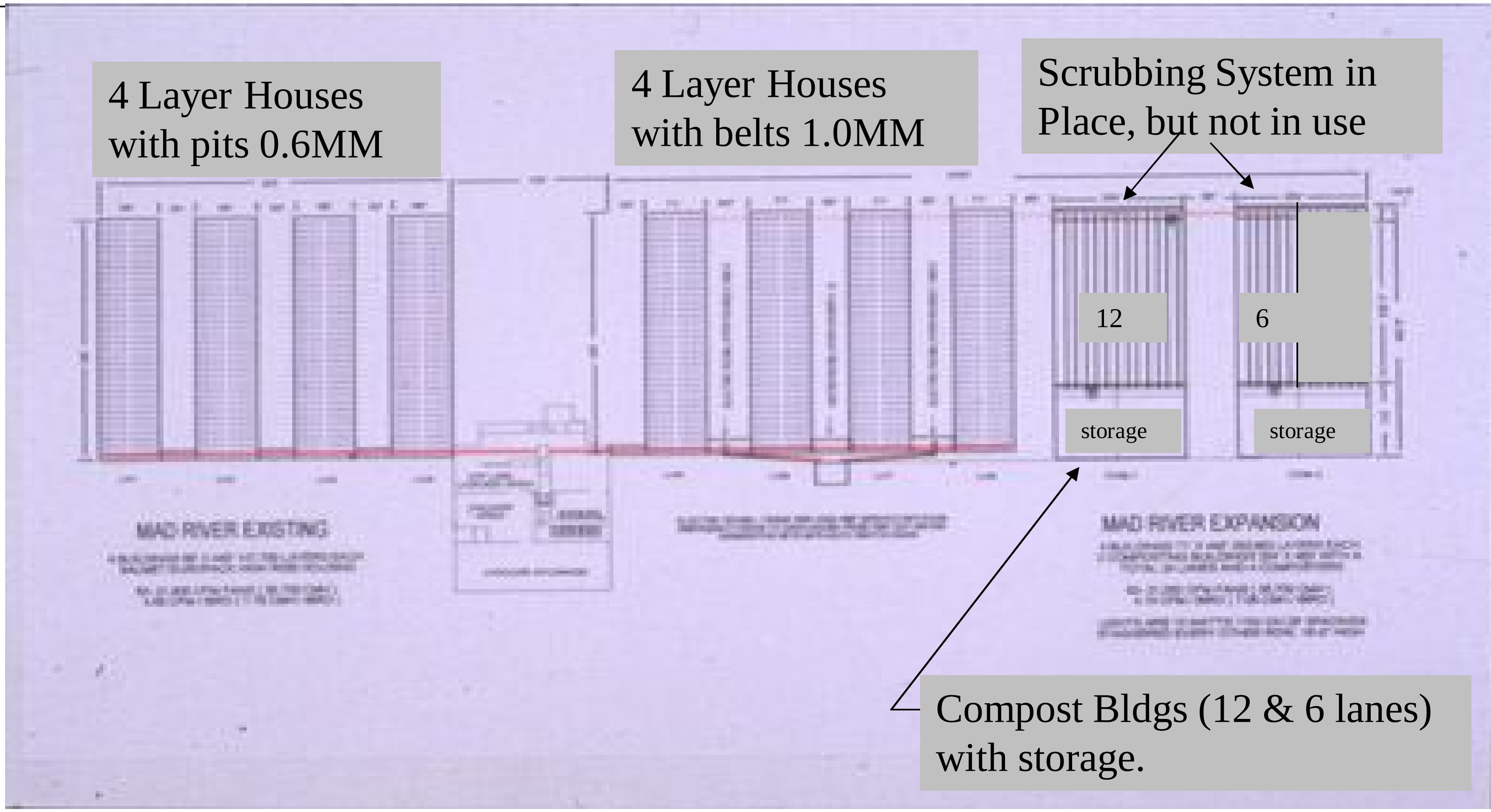
n_b number of birds in the building

feed, eggs, manure R_m [i.e. N/A]

Cage Layer Operation
Determining NH_3 Emissions

- Weight feed, count and weight eggs
- Perform chemical analysis N and ash of feed, eggs, manure, compost
- Apply the calculation for
  - Caged layer house with deep pit manure storage system
  - Caged layer house with belt system

Daylay Farms 1,600,000 birds



High Rise Deep Pit Layer House

Caged Layer - Deep Pit Building

- 4 buildings, 68’ x 440’
- 150,000 layers each building
- 36 side wall fans per building in pit area
- Each fan delivers 20,000 cfm (4.3 cfm/bird)
- Manure accumulates for a year

Battery of cages at Daylay with manure belt removal system under each cage.

Manure being scraped from belt onto cross conveyor for delivery to compost building. Manure dries on belt from 70% to 50-55% moisture. Manure never goes outside.

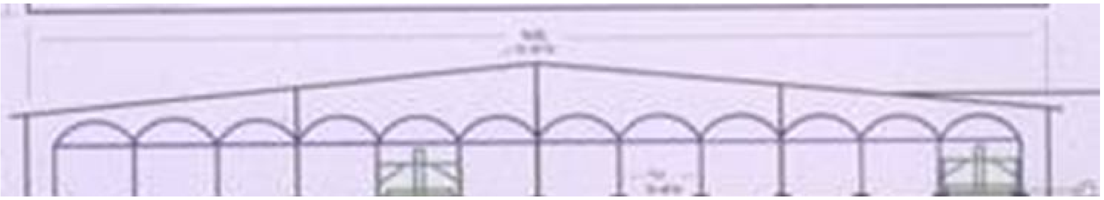
Caged Layer-Manure Belt Building

- **4 buildings, 71' x 440'**
- **250,000 layers each building**
- **9 fans/bldg – eight @ 105,000 cfm , one @ 84,000 cfm (3.7 cfm/bird)**
- **Manure removed by belt system every 3rd day**

Compost Building

Compost building & turning machine @ Daylay Farms. Windrows are aerated with forced ventilation.

Finished compost at Daylay Farms. Composted material 10-20% moisture and granular nature



Compost Buildings

- 12 lane compost building, 204' x 463' with storage
  – 8 exhaust fans @ 20,000 cfm
- 6 lane compost building, 102' x 463' with storage. – 4 exhaust fans @ 20,000 cfm
- Scrubber design to remove ammonia, go from 200 ppm to 20 ppm. This equipment in place but remains to be used.

Management Practices 'Daylay'

- Unload manure from high rise every 3 days
- Transfer by belt to compost building
- Piled at the input end of an aerated in-vessel composting system with turner
- Material turned every 3 days – moved 6 meters toward output end
- After 18 turns leaves composter & stored until marketed.

Dry Solids and Moisture Loss from Composting of Caged Layer Manure

ID	pH	DM %	Ash %	N %	C/N	NH_3N ug/g	NO_3 ug/g
Manure Belt	8.0	52	31	5.9	5.8	6566	212
Compost	7.9	90	34	5.6	5.8	4847	213
Deep Pit	8.5	71	44	4.0	7.4	4783	94

Results
Manure RM

System	March	July
Manure Belt	0.1886	0.1934
Compost	0.1675	0.1642
Deep Pit	0.0645	0.0929

RESULTS

NH3-N emissions for Deep Pit, kg/bird/year

Test Period	Method Used	Manure N	NH3-N Emissions
March	Mass Balance	0.218	0.473
	Emission		0.550
July	Mass Balance	0.313	0.376
	Emissions		0.513

RESULTS

NH3-N emissions for Manure Belt & Compost Bldg, kg/bird/year

Test Period	Method Used	Manure N	Hse NH3-N	Com. Bldg NH3-N	System Emissions
March*	Mass Balance	0.565	0.054	0.071	0.125
	Emission		0.179	0.258	0.437
July	Mass Balance	0.553	0.038	0.098	0.136
	Emission		0.039	0.186	0.225

* Fans run intermittently

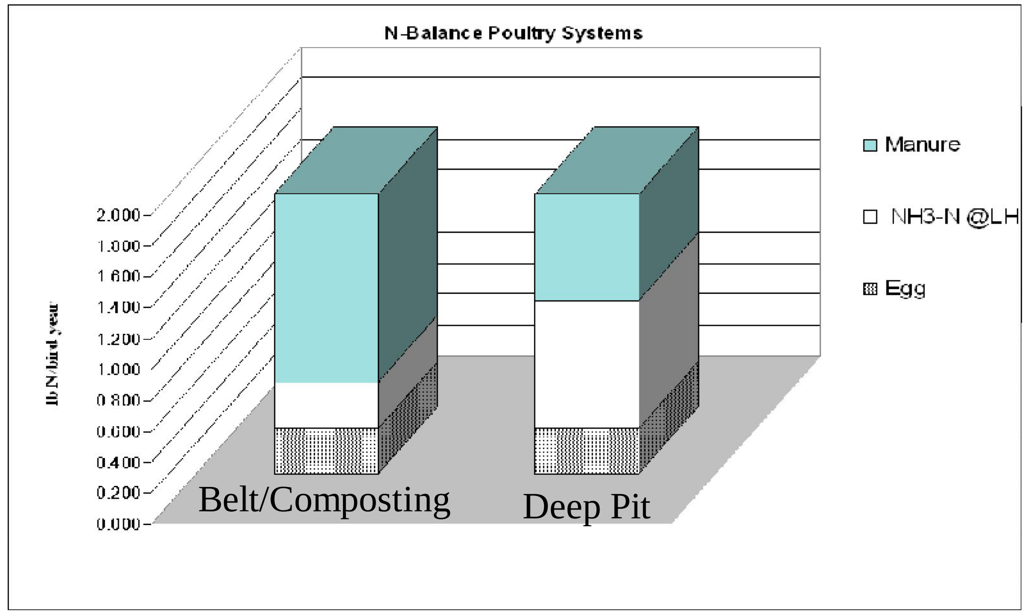
Results -

NH3 losses , kg/bird/yr , mass balance approach)

System	March	July
Deep Pit	0.573	0.457
Deep Pit (Battye et al 1994)	0.598	0.598
Belt & Compost Bldg	0.152	0.165

Nitrogen Balance for Daylay Farms

- Belt & composting system retained about 2x N of conventional deep pit system.
- Belt & composting had 1/3 nitrogen loss conventional deep pit.



Conclusions

- Mass balance approach easy to apply to cage layer operation.

Results

- Mass balance results on NH_3 emissions per bird less than literature for the Deep Pit Housing. Look at time of year effect.
- Belt system + composting system retained 2x the nitrogen and emitted 1/3 NH_3 of the deep pit system.

Questions?