Ammonia Emissions of Pullets and Effects of Stocking Density

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Summary and implications

Data on ammonia (NH_3) emissions from pullets (pre-laying hens) are non-existent, despite the large differences in nutritional and environmental conditions between raising pullets and laying hens. Different stocking densities (SD's) in housing the birds may be used as a result of certain industry animal welfare guidelines. The objectives of this study were to determine NH_3 emission rate (ER) of pullets during the growth period (4-18 wk of age), and to assess the effect of SD on NH_3 ER of pullets and laying hens during a 6-d manure accumulation time (MAT).

Data to date showed that there was no significant SD effect on NH_3 ER in mg/pullet or mg/kg N intake; however, SD significantly affected NH_3 ER in mg/kg manure, with the HD leading to higher NH_3 ER per kg manure mainly after 3-d MAT. The results from this study help set a foundation for further field-scale measurement of NH_3 emissions, and ultimately development of best management practices to effectively reduce NH_3 emissions from egg production operations.

Introduction

Among all substances emitted from poultry production facilities, ammonia (NH_3) is the predominant pollutant gas due to the nature of the manure. Laboratory experiments performed by Ning (2008) showed that NH_3 emission rate (ER) from laying hens (W-36) depends on manure accumulation time (MAT). However, the documented studies (e.g., Liang et al., 2005) on NH_3 emissions from laying hens do not include pullets (i.e., hens < 18 wk of age, pre-laying), even though pullets are an integral part of the egg operation. Information is also meager concerning the impact of housing stocking density (SD) of the birds on NH_3 ER.

The objectives of this study were a) to delineate NH_3 ER of pullets vs. bird age and MAT, and b) to assess SD effects on NH_3 ER of pullets and layers. Results from this research will help filling a literature gap on pullet NH_3 emission, and provide insight on the impact of production management (SD) practices on NH_3 emissions.

Materials and Methods

Dynamic gas emission chambers system

The study was conducted using four dynamic gas emission chambers (Figure 1) at the Iowa State University Livestock Environment and Animal Physiology Laboratory II (LEAP Lab II). A full description of the system was given by Ning (2008).

Samples of the exhaust air from each chamber were successively taken by a sampling pump (20 L/min capacity) at 10 min intervals, with the first 8 min for stabilization and last 2 min for measurement. This sampling sequence yielded a measurement cycle of 50 min for the entire system (including 10 min for the ambient air). A photoacoustic multi-gas analyzer was used to measure the concentrations of NH_3 and CO_2 in the inlet and outlet air streams. The analyzer was challenged weekly and calibrated, as needed. Electronic balances with analog outputs were used to measure feeder and manure pan weights. A programmable measurement and control module interfaced with a PC was used to control the air sampling sequence and log the analog outputs of the sensors at 10 s intervals.

To assess and ensure the integrity of the dynamic emission system, CO_2 recovery tests using 100% ethanol (C_2H_5OH) lamps were conducted prior to the beginning of the experiment and repeated every other week, as performed by Ning (2008) and described by Scott and Hillman (1983).

Pullet handling and experimental design

The Hy-Line W-36 pullets used in this study were procured from a commercial farm in Iowa. Two batches of 28 pullets (two-wk apart in age) at initial age of 2 wk were acquired. The pullets were randomly allotted to the four chambers, two chambers with 8 birds in each and the other two chambers with 6 birds in each, thereby yielding two SD's. After 12-d measurement, the pullets inside the emission chambers were returned to the holding cages at the same SD as used during measurement. The data collection was repeated with the second batch. The two batches were switched every two weeks until birds from the second batch reached 18 wk of age. All the birds were kept at comfortable environmental conditions of 21.1-23.3°C and 40-50% relative humidity.

Two SD's were tested: high SD (HD) and low SD (LD). For birds at 4 to 6 wk of age, the HD and LD were, respectively, 155 and 206 cm^2/bird (24 and 32 in^2/bird), i.e., the LD birds having 33% more floor space; for birds at 6 to 14 weeks of age, HD = 310 cm^2/bird (48 in^2/bird) and LD = 413 cm^2/bird (64 in^2/bird - 33% more space). To achieve the respective SD levels, the number of birds per chamber or cage was 8 for the HD and 6 for the LD for pullets at 4-6 wk of age; but 4 birds for the HD and 3 birds for LD for pullets older than 6 wk of age.

To complete the randomization process and avoid chamber effect on measurements, groups of birds under the same SD regimen switched chambers on a weekly basis, so that by the end of the trial, all SDs would have been run in all four chambers at each age.

Figure 1. ISU multi-chamber dynamic air emissions measurement system.

Analyzed variables

The calculated NH_3 ER was further processed to cumulative emission (in mg per bird) for 1, 2, 3, 4, 5 and 6 d of MAT. In addition, dynamic manure production and feeding events were monitored and recorded

Daily feed use was calculated based on the initial and final feeder weights for that day. The feed N use was calculated based on the feed use and the crude-protein (CP) content of the diet. Crude protein was divided by 6.25 to yield the feed N content. Daily manure accumulation, incorporating the effect of moisture evaporation, was calculated as the difference in readings between the initial and final weights of the manure pan. Cumulative feed N use and manure weight were calculated for 1, 2, 3, 4, 5 and 6 d of MAT. Cumulative NH_3 ER was calculated in mg/bird, g/kg N use and mg/kg “as-is” manure. Also, the NH_3-N emission was calculated in mg/bird.

The treatment effects were evaluated using t-test. A difference with p-value equal to or less than 0.05 was considered significant. For the purposes of this paper, we did not analyze the effect of manure accumulation time (MAT) on the variables, even knowing that the effect may exist. The best model to analyze this effect is still being discussed

Results and Discussions

Data on bird feed use, feed N use, manure weight, and NH_3 ER in various units over the 6-d MAT at different pullet ages are summarized in Tables 1 to 4. Based on the data shown in the tables, there was no significant difference (P = 0.06 – 0.46) in feed use between the two SD regimens for most of the ages and for all days of MAT. This outcome indicates that the reduced floor space allocation did not seem to adversely affect feed use.

Results from the t-test revealed significant differences in per-bird “as-is” manure weight between the SD regimens (p = 0.02 – 0.05) for most of the ages and MAT, with the HD manure weight being greater. The difference presumably arose from greater moisture evaporation for the LD manure because of larger exposed surface area per unit weight of manure. The larger number of birds under HD was also associated with a higher indoor RH, e.g., averaging 44% as compared to 37% for LD for the 8-wk trials. The lower RH and greater vapor pressure gradient between the manure surface and the ambient air for LD would be more conducive to moisture loss of the manure. Manure samples were collected at the end of the 6-d MAT and were analyzed for moisture content to confirm these speculations (Figure 2).

Cumulative NH_3 emissions (in mg/bird) shown in Tables 1 to 4 indicate that for all ages and days of MAT, they did not seem to be affected by SD (p = 0.055 – 0.5). Cumulative NH_3 emission did increase, in an exponential fashion with bird age (wk), as expressed in Equations 1 and 2 using the combined ER values for both SD’s at the 3^{rd} and 6^{th} d of MAT, respectively. The reason for combining the HD and LD values was that there was no significant difference between the two SD regimens.

$$\text{Cumu. } NH_3 \text{ ER} = 0.058\, e^{0.383*AGE} \quad (R^2=0.95) \quad (1)$$

$$\text{Cumu. } NH_3 \text{ ER} = 1.288\, e^{0.281*AGE} \quad (R^2=0.77) \quad (2)$$

Cumulative NH_3-N ER values (mg/bird) are also presented in Tables 1 to 4. The percentage of cumulative feed N use that was lost as NH_3-N was also calculated and presented, with the maximum being 1.0 % following 6-d MAT for pullets at 18 weeks of age (for both SD regimens). In a study involving high-rise layer houses (where manure was stored in-house for one year), Yang et al. (2000) reported that percentage of N intake lost as NH_3-N varied from 25% to 41%, depending on manure moisture content. The main reason for such a huge difference in the percentages between the current study and the study by Yang et al. (2000) was the difference in manure handling in that manure in the high-rise houses continued to emit ammonia for one year whereas manure in the current study emitted ammonia for 6 d. The drastic difference in ammonia emission for different manure handling schemes was also reported by Liang et al. (2005) when comparing ammonia emission from high-rise vs. manure-belt layer houses. Liang et al. (2005) showed that manure-belt layer houses with daily or semi-weekly manure removal emit less than 10% of the NH_3 as compared to high-rise layer houses where manure was stored in the houses for approximately one year. Furthermore, an estimation made from the results reported by Liang et al. (2005) showed that approximately 3.6% of the feed N intake is emitted as NH_3-N for the manure-belt layer houses. Since the conditions of the experiment described in this paper more resembles those in a manure-belt house (although temperature in the commercial barn could be considerably warmer in summer), our value of 1.0% relatively paralleled the 3.6 % for layers in the commercial manure-belt barn, especially considering that the pullets were in the growing period and depositing part of the feed N in body tissue.

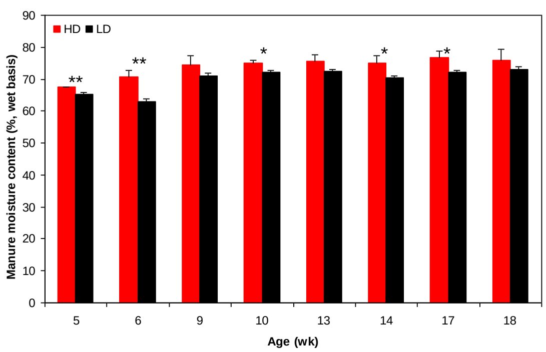

Figure 2. Manure moisture content at the last day of MAT (* and ** indicate significance level of P<0.05 and P<0.01, respectively).

The cumulative NH_3 ER in mg/kg of "as-is" manure was significantly affected by SD for most MAT and pullet ages (p = 0.0001 – 0.03). The results also showed that for most MAT and pullet ages, LD yielded higher cumulative NH_3 emission per kg of "as-is" manure weight. This outcome was associated with the greater manure weight for the HD regimen. Besides, manure moisture content (MC) for the last day of accumulation was lower for the LD manure (P = 0.009 – 0.041). The overall averages of MC were 74 % for HD manure and 70% for LD manure (Figure 2). The lower LD MC may have caused its NH_3 ER to be slightly lower. Yang et al. (2000) concluded that the ratio of manure NH_3 loss to N intake was directly proportional to manure MC.

Figure 3 shows how daily NH_3 ER changed both with pullet age and MAT. It can be seen that for birds at about 18 wk, the daily ER was higher for the first day than for the second day, and then the ER started going up again. This behavior presumably arose from the residual NH_3 in the system. This behavior was not observed for pullets at younger ages presumably because of the much lower magnitude of NH_3 ER.

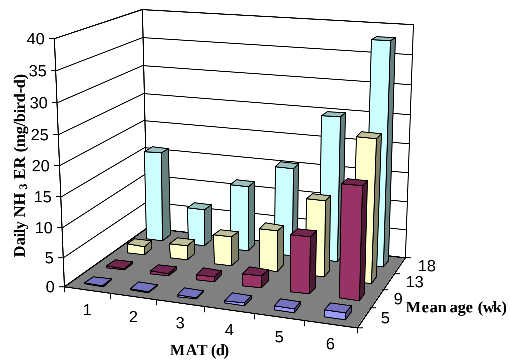

Figure 3. Daily NH_3 ER for W-36 pullets as a function of mean age (4 to 18 wks) and MAT (1 to 6 d).

Conclusions

1. Ammonia (NH_3) emission of pullets increases with bird age, following an exponential pattern.
2. Cumulative NH_3 emission also increases exponentially with manure accumulation time.
3. Stocking density (SD) did not significantly affect NH_3 emission on a per-bird or per unit of N use basis (up to 18-wk age); however, SD did affect NH_3 emission on the basis of per kg "as-is".

Acknowledgements

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Table 1. Cumulative feed use, feed nitrogen (N) use, manure weight and ammonia emission of W-36 pullets over 6-day period at two cage stocking densities (SD): pullet age = 4 - 5 wk; pullet body weight = 220 - 349 g; HD = 155 cm^2/bird; LD = 206 cm^2/bird (mean ± SE).

Variables		**Manure Accumulation Time (MAT, d)**					
		1	2	3	4	5	6
No. of observations	HD	5	5	5	5	4	4
	LD	5	5	5	5	4	4
Feed use, g/bird	HD	30 ± 1	60 ± 2	89 ± 2	120 ± 2	152 ± 4	174 ± 6
	LD	29 ± 1	58 ± 2	87 ± 3	119 ± 4	151 ± 5	184 ± 7
Feed N use, g/bird	HD	0.927 ± 0.015	2.0 ± 0.1	2.8 ± 0.1	3.8 ± 0.1	4.7 ± 0.1	5.4 ± 0.2
	LD	0.895 ± 0.015	1.80 ± 0.06	2.7 ± 0.1	3.7 ± 0.1	4.7 ± 0.2	5.7 ± 0.2
Manure weight (as is), g/bird	HD	26 ± 3	51 ± 5 ^{a}	73 ± 6 ^{a}	95 ± 8 ^{a}	120 ± 11	139 ± 2 ^{a}
	LD	20 ± 1	40 ± 3 ^{b}	58 ± 3 ^{b}	78 ± 4 ^{b}	99 ± 5	119 ± 9 ^{b}
NH_3 emission, mg/bird	HD	0.23 ± 0.08	0.49 ± 0.12	0.75 ± 0.15	1.3 ± 0.1 ^{x}	2.1 ± 0.1 ^{x}	2.8 ± 0.8
	LD	0.09 ± 0.01	0.18 ± 0.12	0.40 ± 0.12	0.7 ± 0.2 ^{y}	1.1 ± 0.2 ^{y}	2.5 ± 0.8
NH_3 – N emission mg/bird	HD	0.19 ± 0.07	0.40 ± 0.10	0.62 ± 0.12	1.0 ± 0.1 ^{x}	1.7 ± 0.1 ^{x}	2.3 ± 0.7
	LD	0.074 ± 0.008	0.15 ± 0.10	0.33 ± 0.10	0.56 ± 0.12 ^{y}	0.92 ± 0.20 ^{y}	2.1 ± 0.7
NH_3 emission, g/kg N use	HD	0.25 ± 0.36	0.30± 0.7	0.27 ± 0.21	0.337 ± 1.12	0.44 ± 0.07	0.52 ± 0.25
	LD	0.10 ± 0.07	0.10 ± 0.7	0.15 ± 0.33	0.18 ± 0.24	0.24 ± 0.25	0.44 ± 0.33
NH_3 emission, mg/kg manure (as is)	HD	9 ± 1 ^{a}	10 ± 3 ^{a}	10 ± 3	13 ± 2	17 ± 1	20 ± 2
	LD	4 ± 2 ^{b}	4 ± 1 ^{b}	7 ± 4	9 ± 3	11 ± 3	21 ± 4

Values for the two stocking densities of each variable followed by different letters are significantly different (**a** and **b** for $0.01 < P \leq 0.05$, and **x** and **y** for $P \leq 0.01$.

Table 2. Cumulative feed use, feed nitrogen (N) use, manure weight and ammonia emission of W-36 pullets over 6-day period at two cage stocking densities (SD): pullet age = 8-9 wk; pullet body weight = 580 - 770 g; HD = 310 cm^2/bird; LD = 413 cm^2/bird (mean ± SE).

Variables		**Manure Accumulation Time (MAT, d)**					
		1	2	3	4	5	6
No. of observations	HD	5	5	5	5	5	4
	LD	5	5	5	5	5	4
Feed use, g/bird	HD	31 ± 4	66 ± 8	100 ± 11	134 ± 14	169 ± 19	226±23
	LD	33 ± 4	68 ± 9	106 ± 13	143 ± 17	179 ± 22	234 ± 26
Feed N use, g/bird	HD	0.86 ± 0.10	2 ± 1	3 ± 1	4 ± 1	5 ± 1	6 ± 1
	LD	0.92 ± 0.12	2 ± 1	3 ± 1	4 ± 1	5 ± 1	7 ± 1
Manure weight (as is), g/bird	HD	51 ± 8	84 ± 10	126 ± 15	168 ± 19	208 ± 22	251 ± 26
	LD	39 ± 9	85 ± 14	123 ± 23	166 ± 27	205 ± 32	246 ± 36
NH_3 emission, mg/bird	HD	0.4 ± 0.2	1 ± 1	2 ± 1	3 ± 2	13 ± 3	29 ± 17
	LD	0.11 ± 0.05	0.31 ± 0.16	1 ± 1	4 ± 3	13 ± 8	34 ± 24
NH_3 – N emission mg/bird	HD	0.3 ± 0.2	0.7 ± 0.7	1 ± 1	2 ± 1	11 ± 2	24 ± 14
	LD	0.09 ± 0.04	0.26 ± 0.13	0.8 ± 0.4	3 ± 2	10 ± 7	28 ± 20
NH_3 emission, g/kg N use	HD	0.5 ± 0.6	0.5 ± 1.0	0.6 ± 0.6	1 ± 1	2.8 ± 0.3	5 ± 1
	LD	0.1 ± 0.6	0.2 ± 0.6	0.3 ± 0.6	1 ± 1	2.6 ± 0.2	5 ± 3
NH_3 emission, mg/kg manure (as is)	HD	8 ± 1 ^{x}	11 ± 1 ^{a}	13 ± 2 ^{x}	17 ± 3 ^{y}	62 ± 3	116 ± 5 ^{a}
	LD	3 ± 1 ^{y}	4 ± 1 ^{b}	8 ± 2 ^{y}	22 ± 4 ^{x}	63 ± 8	138 ± 7 ^{b}

Values for the two stocking densities of each variable followed by different letters are significantly different (**a** and **b** for 0.01< P ≤ 0.05, and **x** and **y** for P ≤ 0.01.

Table 3. Cumulative feed use, feed nitrogen (N) use, manure weight and ammonia emission of W-36 pullets over 6-day period at two cage stocking densities (SD): pullet age = 12-13 wk; pullet body weight = 1000 - 1040 g; HD = 310 cm^2/bird; LD = 413 cm^2/bird (mean ± SE).

Variables		Manure Accumulation Time (MAT, d)					
		1	2	3	4	5	6
No. of observations	HD	5	5	5	5	5	4
	LD	5	5	5	5	5	4
Feed use, g/bird	HD	41 ± 5	90 ± 7	140 ± 8	195 ± 13	204 ± 12	298 ± 13
	LD	48 ± 6	102 ± 7	156 ± 8	211 ± 9	228 ± 16	326 ± 18
Feed N use, g/bird	HD	1.0 ± 0.1	2.2 ± 0.2	3.5 ± 0.2	4.8 ± 0.3	5.1 ± 0.3	7.4 ± 0.3
	LD	1.2 ± 0.1	2.5 ± 0.2	3.9 ± 0.2	5.2 ± 0.2	5.7 ± 0.4	8.1 ± 0.4
Manure weight (as is), g/bird	HD	60 ± 5	120 ± 9 [a]	174 ± 14 [a]	237 ± 22 [a]	290 ± 30	349 ± 25 [a]
	LD	48 ± 6	88 ± 12 [b]	130 ± 18 [b]	176 ± 25 [b]	240 ± 48	337 ± 55 [b]
NH_3 emission, mg/bird	HD	2 ± 1	10 ± 1	18 ± 2	37 ± 7	60 ± 18	97 ± 26
	LD	1.0 ± 0.5	7 ± 3	22 ± 10	38 ± 24	54 ± 44	107 ± 69
NH_3 – N emission mg/bird	HD	2 ± 1	8 ± 1	14.5 ± 1.6	30 ± 6	49 ± 15	80 ± 21
	LD	0.8 ± 0.4	6 ± 2	18 ± 8	31 ± 20	44 ± 36	88 ± 57
NH_3 emission, g/kg N use	HD	2 ± 1	4 ± 1	5.0 ± 0.1	7.6 ± 0.2 [x]	11.9 ± 0.2 [x]	13.1 ± 0.2
	LD	0.8 ± 0.7	3 ± 1	5 ± 1	7.3 ± 0.6 [y]	9.6 ± 0.5 [y]	13.2 ± 0.5
NH_3 emission, mg/kg manure (as is)	HD	32 ± 6	80 ± 1	10 ± 2 [x]	154 ± 2 [x]	207.0 ± 0.2 [a]	277.9 ± 0.2 [x]
	LD	21 ± 6	80 ± 8	169 ± 8 [y]	216 ± 7 [y]	225 ± 7 [b]	317 ± 7 [y]

Values for the two stocking densities of each variable followed by different letters are significantly different (**a** and **b** for 0.01< P ≤ 0.05, and **x** and **y** for P ≤ 0.01.

Table 4. Cumulative feed use, feed nitrogen (N) use, manure weight and ammonia emission of W-36 pullets over 6-day period at two cage stocking densities (SD): pullet age = 16-18 wk; pullet body weight = 1021 - 1031 g; HD = 310 cm^2/bird; LD = 413 cm^2/bird (mean ± SE).

Variables		**Manure Accumulation Time (MAT, d)**					
		1	2	3	4	5	6
No. of observations	HD	5	5	5	5	5	5
	LD	5	5	5	5	5	5
Feed use, g/bird	HD	50 ± 3	104 ± 4	163 ± 5	218 ± 7	271 ± 8	322 ± 10
	LD	44 ± 3	97 ± 4	151 ± 5	204 ± 5	258 ± 5	313 ± 5
Feed N use, g/bird	HD	1.4 ± 0.1	2.9 ± 0.1	4.5 ± 0.1	6.0 ± 0.2	7.5 ± 0.2	8.9 ± 0.3
	LD	1.2 ± 0.1	2.7 ± 0.1	4.2 ± 0.1	5.6 ± 0.1	7.1 ± 0.2	8.6 ± 0.1
Manure weight (as is), g/bird	HD	44 ± 8	95 ± 10	148 ± 10	196 ± 10 [a]	240 ± 10 [x]	284 ± 11 [a]
	LD	40 ± 5	84 ± 6	122 ± 6	165 ± 5 [b]	201 ± 5 [y]	243 ± 7 [b]
NH_3 emission, mg/bird	HD	44 ± 22	52 ± 26	56 ± 28	65 ± 29	85 ± 30	121 ± 27
	LD	28 ± 13	33 ± 15	34 ± 16	35 ± 17	41 ± 19	53 ± 21
NH_3 – N emission mg/bird	HD	36 ± 18	43 ± 18	46 ± 23	53 ± 24	70 ± 25	99 ± 22
	LD	23 ± 11	27 ± 13	28 ± 13	29 ± 15	33 ± 15	43 ± 18
NH_3 emission, g/kg N use	HD	32 ± 18	18 ± 10	13 ± 7	11 ± 5 [a]	11 ± 4 [x]	14 ± 3 [a]
	LD	23 ± 12	12 ± 6	8 ± 4	6 ± 3 [b]	6 ± 3 [y]	6 ± 3 [b]
NH_3 emission, g/kg manure (as is)	HD	1.0 ± 0.7	0.6 ± 0.3	0.4 ± 0.2	0.3 ± 0.2	0.4 ± 0.1	0.4 ± 0.1
	LD	0.7 ± 0.4	0.4 ± 0.2	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1

Values for the two stocking densities of each variable followed by different letters are significantly different (**a** and **b** for $0.01 < P \leq 0.05$, and **x** and **y** for $P \leq 0.01$.