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Abstract

Considerable progress has been made toward collection of baseline data on air emissions from U.S. animal feeding operations. However, limited data exist in the literature regarding turkey air emissions. The project described in this paper continuously monitored ammonia (NH3) and particulate matter (PM) emissions from turkey production houses in Iowa (IA) and Minnesota (MN) for one year (2007-2008), with IA monitoring Hybrid tom turkeys (6-20 wk of age) and MN monitoring Hybrid hens (6-12 wk of age). Mobile air emission monitoring units (MAEMUs) were used in the continuous monitoring. Based on the one-year measurement at the IA and MN sites, each involving three flocks of birds, the cumulative NH3 emission (mean ± SE) was 144 ± 11 g/bird marketed for the tom turkeys and 104 ± 4 g/bird marketed for the hen turkeys, both including downtime emissions. The cumulative PM10 emission (mean ± SE) was 29 ± 3.7 g/bird marketed for the tom turkeys and 5 ± 2.6 g/bird marketed for the hen turkeys. The cumulative PM2.5 emission (mean ± SE) was 3.8 ± 0.8 g/bird marketed for the tom turkeys (not monitored for the hen turkeys).

Keywords

Air emission, ammonia, particulate matter, turkeys, national air emissions inventory

Disciplines

Bioresource and Agricultural Engineering

Comments

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Air Emissions from Tom and Hen Turkey Houses in the U.S. Midwest

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Abstract. Considerable progress has been made toward collection of baseline data on air emissions from U.S. animal feeding operations. However, limited data exist in the literature regarding turkey air emissions. The project described in this paper continuously monitored ammonia (NH_3) and particulate matter (PM) emissions from turkey production houses in Iowa (IA) and Minnesota (MN) for one year (2007-2008), with IA monitoring Hybrid tom turkeys (6-20 wk of age) and MN monitoring Hybrid hens (6-12 wk of age). Mobile air emission monitoring units (MAEMUs) were used in the continuous monitoring. Based on the one-year measurement at the IA and MN sites, each involving three flocks of birds, the cumulative NH_3 emission (mean ± SE) was 144 ± 11 g/bird marketed for the tom turkeys and 104 ± 4 g/bird marketed for the hen turkeys, both including downtime emissions. The cumulative PM_{10} emission (mean ± SE) was 29 ± 3.7 g/bird marketed for the tom turkeys and 5 ± 2.6 g/bird marketed for the hen turkeys. The cumulative $PM_{2.5}$ emission (mean ± SE) was 3.8 ± 0.8 g/bird marketed for the tom turkeys (not monitored for the hen turkeys).

Keywords. Air emission, ammonia, particulate matter, turkeys, national air emissions inventory

Introduction

As with other animal feeding operations (AFOs), turkey production facilities generate and emit gases and particulates. Some of the pollutants have been designated as hazardous gases by the U.S. Environmental Protection Agency (EPA), such as ammonia (NH_3) and hydrogen sulfide (H_2S), because of their potential impact on the health of the animals and workers. Particulate matters of 10 μm or smaller in diameter (PM_{10}) create ambient air quality concerns when released into the atmosphere. Ammonia emissions from AFOs have been estimated to represent the largest portion of the national NH_3 emissions inventory in the United States. A comprehensive review by the National Academy of Science (NAS, 2003) regarding air emissions called for collection of baseline emission data and development of process-based models to predict such air emissions. Recently a multi-state (IA, KY, PA) project funded by the USDA-IFAFS Program was completed that quantifies NH_3 emissions from representative U.S. broiler and layer houses (Liang et al., 2005; Wheelers et al., 2006). In 2005 an Air Compliance Agreement (ACA) was reached between EPA and certain sectors of the U.S. livestock and poultry industries, namely, broiler, laying hen, swine, and dairy industries. The ACA studies will yield more baseline data on air emissions from U.S. AFOs. As a part of the ACA studies, emissions of specified gaseous (NH_3, H_2S, and non-methane hydrocarbons) and PM (total suspended particulate or TSP, PM_{10}, and $PM_{2.5}$) from two commercial broiler houses in Western Kentucky have been continuously quantified for one-year period (Burns et al., 2007) and some of the results have been reported. However, the turkey industry was not a part of the ACA and there had been no studies that continually quantify air emissions from U.S. turkey facilities.

The objective of this joint research project between Iowa State University and University of Minnesota was to continuously quantify NH_3 and PM emissions from representative turkey barns in the Midwest over a one-year period. Specifically, IA monitored emissions from tom (male) turkeys and MN monitored hen (female) turkeys. Both sites used the same Hybrid strain. The aerial emissions are presented in terms of both daily emission and per bird marketed.

Materials and Methods

Tom Turkey House at Iowa Site

A commercial turkey barn in central Iowa was continuously monitored for NH_3, PM_{10}, and $PM_{2.5}$ emissions for a 16-month period (May 2007 – August 2008, Table 1). The east-west oriented turkey barn (18.3 x 102 m; 60 x 335 ft) used combined cross and tunnel ventilation and static pressure controlled curtain inlets (fig. 1). Four space furnaces (73.2 kW; 250,000 Btu/hr each) were distributed in the barn (21.3 m or 70 ft apart) to provide space heating in cold weather. The barn had a wooden sidewall on the north and a 1.5 m (5 ft) permeable Nylon curtain on the south. The barn had five 61-cm (24-in) diameter sidewall fans spaced at 18.3 m (60 ft) apart, one 123-cm (48-in) and six 132-cm (52-in) diameter tunnel fans. The sidewall fans were used for cold weather ventilation whereas the tunnel fans used for warm weather ventilation. At five weeks of age, the Hybrid tom turkeys were moved from the brooder barn to the grow-out barn where they were raised till market age of 20-21 weeks. Standard commercial diets were fed *ad lib* to the birds during the study. Prior to onset of the monitoring, the barn was cleaned, disinfected and bedded with rye hulls. Top dressing of 14,000 kg (30,800 lb) rye hulls was applied after each flock and 409 kg (900 lb) aluminum sulfate (Alum, 50 lb/1000 ft^2) was applied on top of the new bedding (a typical production practice). Continuous light was used. An automatic bird scale (Model RSC-2, Rotem, Petach Tikva, Israel) was placed in the barn to continuously monitor bird weight (fig. 2). Daily bird mortality was also recorded.

Hen Turkey House at Minnesota Site

A hen turkey barn at the U-More Park's turkey research farm near Rosemount, MN was continuously monitored for NH_3 and PM_{10} emissions over a 10-month period (Oct 2007 – July 2008; Table 2). The hen grow-out turkey barn (13.7 x 12.2 m; 45 x 40 ft) used a traditional negative pressure ventilation system consisting of: sidewall exhaust fans, gravity baffled ceiling inlets, actuated-controlled sidewall inlets, and a direct fired L.P.Gas heater "(60,000 BTU/hr) that was regulated with a Phason Supra controller (fig. 2). The barn's sidewall fans consisted of three 61-cm (24-in), one 91-cm (36-in) fan, and one 30-cm (12-in) diameter blade fans. At five weeks of age, the Hybrid hen turkeys were moved from a brooder barn to thise grow-out barn where they were raised till market age of 12 weeks. Standard commercial diets were fed *ad lib* to the birds during the study. Prior to onset of the monitoring, the barn was cleaned, disinfected and bedded with wood shavings. Daily bird mortality was also recorded.

State-of-the-art mobile air emissions monitoring units (MAEMUs) were used to conduct the continuous measurement. Burns et al. (2006) provided a detailed description of the MAEMU. NH_3 and CO_2 concentrations were measured with a multi-gas photoacoustic analyzer (1412, INNOVA AirTech Instruments, Denmark) at the IA site; whereas a chemiluminescence NH_3 analyzer (TEI 17C, Thermal Electron Corp. Waltham, MA) and two photoacoustic CO_2 analyzers were used at the MN site.

Air samples were drawn from two locations in the barn to account for potential spatial variations. One sampling was near the primary minimum ventilation sidewall fan and the other was near the center of the tunnel end of the barn. In addition to the in-barn sampling, an outside ambient air sample was taken at 120-min (IA site) and 70-min (MN site) intervals to provide the background concentration. The background gas or PM was subtracted from the exhaust amount in calculating air emissions from the barn. All air sampling lines were protected from in-line moisture condensation with insulation and temperature-controlled resistive heating cable.

Most turkey grow-out barns in the Midwest use natural ventilation (NV), making it a formidable task to measure ventilation rate (VR) of the barn with reasonable accuracy. Hence, in this study we converted portion of the turkey barn into fully mechanical ventilation (MV), allowing us to monitor the barn VR on a continuous basis. To maintain and reflect the otherwise naturally ventilated environment as much as possible, gas (CO_2 and NH_3) concentrations of the NV portion was monitored every 20 minutes (IA site) and 30 minutes (MN site). The readings of the gaseous concentrations of the NV portion were used to fine-tune the ventilation and thus microenvironment (e.g., litter condition) of the MV portion.

For the PM concentration measurements, tapered element oscillation microbalances (TEOMs) (Thermo Environmental Instruments Inc., Franklin, MA) were used. A set of TEOMs were placed at the sidewall location and another set near the tunnel end at the IA site. One TEOM with PM_{10} head was used at the minimum (12-in) fan location and another TEOM located outside (near the sidewall inlets) for the ambient (background) at the MN site. For the ambient (background) IA location, the PM_{10} and $PM_{2.5}$ TEOMs were collocated at the ambient air sampling location near the air inlet.

The VR for both the IA and MN barns was derived by using *in situ* calibrated fan curves from a fan assessment numeration system (FANS) (Gates et al., 2004). After the actual airflow curves were established for all the exhaust fans individually and in stage combinations, runtime of each fan was monitored and recorded continuously using an inductive current switch attached to the power supply cord of each fan motor (Muhlbauer et al., 2006). Analog output from each current switch was connected to the compact Fieldpoint modules. Concurrent measurement of the barn static pressure was made with static pressure sensors (Model 264, Setra, Boxborough, MA), for each half of the IA house and the for MN room. Summation of airflows from the individual fans during each monitoring cycle or sampling interval yielded the overall barn VR.

The relationship of the dynamic emission rate (ER) to gaseous and PM concentrations of inlet and exhaust air and building VR can be expressed as following:

$$[ER_G]_t = \sum_{e=1}^{2}[Q_e]_t\left([G]_e - \frac{\rho_e}{\rho_i}[G]_i\right)\times 10^{-6}\times\frac{w_m}{V_m}\times\frac{T_{std}}{T_a}\times\frac{P_a}{P_{std}} \quad [1]$$

$$[ER_{PM}]_t = \sum_{e=1}^{2}[Q_e]_t\left([PM]_e - \frac{\rho_e}{\rho_i}[PM]_i\right)\times 10^{-6}\times\frac{T_{std}}{T_a}\times\frac{P_a}{P_{std}} \quad [2]$$

where $[ER_G]_t$ = Gaseous emission rate of the house (g house^{-1} t^{-1}) during the sample integration time t

$[ER_{PM}]_t$ = PM emission rate of the house (g house^{-1} t^{-1})

$[Q_e]_t$ = Average VR of the house during sample integration time t under field temperature and barometric pressure (m^3 house^{-1} t^{-1})

$[G]_I$,$[G]_e$ = Gaseous concentration of incoming and exhaust ventilation air, parts per million by volume (ppm_v)

$[PM]_i$ = PM concentration of incoming ventilation air (ug m^{-3})

$[PM]_e$ = PM concentration of exhaust ventilation air (ug m^{-3})

w_m = molar weight of air pollutants, g mole^{-1}

V_m = molar volume of NH_3 gas at standard temperature (0°C) and pressure (1 atmosphere) (STP), 0.022414 m^3 mole^{-1}

T_{std} = standard temperature, 273.15 K

T_a = absolute house temperature, (°C+273.15) K

P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure for the site elevation, kPa

ρ_i, ρ_e = air density of incoming and exhaust air, kg dry air m^{-3} moist air

Results and Discussion

Daily mean outside temperature recorded during the measurement period averaged 8.8°C (IA) and 3.8°C (MN), and daily mean outside RH averaged 68% for both sites (Table 3).

Ammonia and PM Concentrations

Daily mean NH_3 and PM concentrations in the two turkey barns during the four-flock monitoring are shown in Figures 5 and 6 and summarized in Tables 4 and 5. The NH_3, PM_{10} and $PM_{2.5}$ concentrations in the tom turkey barn averaged, respectively, 7.5 ppm, 1098 μg/m^3, and 136 μg/m^3. In the hen turkey barn, the mean NH_3 and PM_{10} concentrations were 10.8 ppm and 267μg/m^3, respectively. As expected, the concentrations showed strong seasonal and cyclic patterns with much lower levels in summer than in fall or winter, resulting from higher VR during the warm weather.

Ammonia Emissions

Figures 7 and 8 reveal daily NH_3 ER for the entire monitoring period, including grow-out and downtime (between flocks) periods. During grow-out period, daily NH_3 ER varied from 0 to 6.4 g/d-bird for the tom turkey barn and 0 to 15.2 g/d-bird for the hen turkey barn. The ER exhibited different patterns among the four flocks. Specifically, ER increased gradually throughout the spring-summer flocks (flock 1 in IA, flock 4 in MN), where they gradually increased for the first three and five weeks and then declined for the fall-winter flocks. The bedding or litter conditions did not show significant effect on the ER (P=0.37), presumably resulting from removal of significant amount of wet/caked litters and addition of new bedding after each flock. Due to the unexpected lower bird number and significant bird number changes of flock 1 at the IA site, data for this flock were considered not representative and thus excluded from the overall ER assessment. At the MN site, flock 3 started at six week of age, i.e., one week later than the others, and extra litter treatment was applied due to excessive ammonia. Consequently, this flock was excluded from the emission determination. Thus, the ER values of turkeys reported here were derived from flocks 2, 3, and 4 for toms and flock 1, 2, and 4 for hens. The cumulative NH_3 emission over the 15-wk grow-out period (6-20 wk) for the three flocks of tom turkeys at the IA site was 141.1 ± 11 g per bird grown or marketed (mean ± SE) (fig. 9). For the hen turkey barn at the MN site, the cumulative NH_3 emission over the 7-wk grow-out period (6-12) for the three flocks was 57 ± 6.3 g per bird grown or marketed (mean ± SE) (fig. 9). In comparison, the cumulative NH_3 emission for the tom turkey barn over the same 7-wk period was 68.7 ± 3.2 g/bird. There was no significant difference on the NH_3 emission between toms and hens when houses were occupied by birds (P-value = 0.17). However, the barn also continuously emitted considerable amount of NH_3 during downtime, averaging 0.21 g/bird-d (average 11-d downtime) and 1.4 g/bird-d (average 32-d downtime) for the tom and hen barn, respectively. The cumulative NH_3 emission from the barns increased to 143.5 ± 11 g/tom bird marketed over 15-wk period and 104 ± 9.5 g/hen bird marketed over 7-wk period when the downtime emission was included. Expressed on the basis of emission per kg of body weight gain, the annual mean NH_3 emission was 8.5 g per kg weight gain (3.8 g per lb weight gain) for the toms (3.0 birds/m^2 stocking density) and 18.8 g per kg weight gain (8.5 g per lb weight gain) for the hens (4.8 birds/m^2 stocking density).

PM Emissions

The daily PM_{10} and $PM_{2.5}$ ERs are shown in Figures 10, 11, and 12, respectively. At the IA site, the daily PM_{10} and $PM_{2.5}$ ER did not include the downtime period between flocks because the TEOMs were put away during birds harvesting. During grow-out period, daily PM_{10} ER varied from 0 to 1.6 g/d-bird for the toms and 0 to 0.33 g/d-bird for the hens.

The two turkey barns exhibited different PM_{10} emission patterns in that PM_{10} ER increased gradually till the middle of the flock and then decreased for the tom flocks except flock 3; but PM_{10} ER increased with bird age throughout the third flock for the toms and all four flocks for the hens. The cumulative PM_{10} emission (mean ± SE) was 29.0 ± 3.7 g/bird for the toms over the 15-wk grow-out period, and 4.4 ± 1.7 g/bird for the hens over the 7-wk grow-out period (fig. 13). However, the barn also emitted certain amount PM_{10} during the downtime (from litter tilling). The cumulative PM_{10} emission for the hen barn over 7-wk period increased to 5 ± 2.6 g/bird when the downtime emission was included. In comparison, the cumulative PM_{10} emission for the toms over the same 7-wk period was 9.6 ± 2.2 g/bird. Expressed on the basis of emission per kg of body weight gain, the annual PM_{10} emissions averaged 1.7 g per kg weight gain (0.77 g per lb weight gain) for the toms and 0.9 g per kg weight gain (0.41 g per lb weight gain) for the hens.

The daily $PM_{2.5}$ ER for the tom barn varied from 0.01 to 0.61 kg/d-house. The $PM_{2.5}$ ER had similar patterns during the three monitored flocks. On a per-bird basis, the $PM_{2.5}$ ER varied from 0.002 to 0.137 g/d-bird. The cumulative PM_{25} ER over the 15-wk grow-out period for the three tom flocks was 3.8 ± 0.8 g/bird (mean ± SE) (fig. 14). Expressed on the basis of emission per kg of body weight gain, the annual $PM_{2.5}$ emission averages 0.22 g per kg weight gain (0.1 g per lb weight gain) for the tom turkeys.

Summary and Conclusions

Air emissions (NH_3, PM_{10}, and $PM_{2.5}$) from a tom turkey barn in Iowa and a hen turkey barn in Minnesota were continuously monitored for 16 and 10 consecutive months, covering three grow-out flocks for each gender. Stocking density of the birds averaged 3.0 birds/m^2 for the toms and 4.8 bird/m^2 for the hens; and the monitoring period covered the bird age of 6-20 weeks (i.e., 15-week monitoring) for the toms and 6-12 weeks (i.e., 7-week monitoring) for the hens. The following preliminary observations and conclusions were made.

- The cumulative NH_3 emission (mean ± SE) was 144 ± 11 g/bird marketed for the toms, and 104 ± 3.8 g/bird marketed for the hens, both including downtime emissions. The annual mean NH_3 emission per unit body weight gain (BWG) was 8.5 g per kg BWG (3.8 g per lb BWG) for the toms and 18.8 g per kg BWG (8.5 g per lb BWG) for the hens.
- The cumulative PM_{10} emission (mean ± SE) was 29 ± 3.7 g/bird marketed for the toms, and 5 ± 2.6 g/bird marketed for the hens. The annual mean PM_{10} emission per unit body weight gain (BWG) was 1.7 g per kg BWG (0.77 g per lb BWG) for the toms and 0.9 g per kg BWG (0.41 g per lb BWG) for the hens.
- The cumulative $PM_{2.5}$ emission was 3.8 ± 0.8 g/bird marketed (mean ± SE) for the toms, or 0.22 g per kg BWG (0.1 g per lb BWG).

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Table 1. Data of the four flocks of tom turkeys monitored for air emissions in Iowa

Flock #	Flock dates	Bird age, d	Bird weight, kg	Marketed bird	Density, bird/m^2
1	05/02/07–08/23/07	32 – 145	1.3-19.7	3985	2.2
2	08/31/07–12/17/07	35 – 143	0.9-17.0	6059	3.3
3	01/07/08–04/28/08	38 – 150	1.4-19.5	5550	3.0
4	05/09/08–08/26/08	35 – 144	1.4-17.9	5124	2.8

Table 2. Data of the four flocks of hen turkeys monitored for air emissions in Minnesota

Flock #	Flock dates	Bird age, d	Bird weight, kg	Marketed bird	Density, bird/m^2
1	10/10/07–11/28/07	35 – 84	1.7-7.2	808	4.8
2	12/18/07–02/05/08	35 – 84	1.3-6.7	837	5.0
3	03/12/08–04/17/08	42 – 84	2.1-6.5	792	4.8
4	05/29/08–07/20/08	35 – 86	1.5-7.2	812	4.8

Table 3. Daily mean temperature and relative humidity (RH) during the monitoring of air emissions from tom and hen turkey barns in Iowa and Minnesota.

Variable	Iowa		Minnesota	
	$T_{outside}$, °C	$RH_{outside}$, %	$T_{outside}$, °C	$RH_{outside}$, %
Mean	8.8	68	3.8	68
S.D.	5.0	14	12.6	14
Max	27.8	100	25.5	95
Min	-22.4	40	-23.0	34

Table 4. Ventilation rate (VR), concentrations and emission rates of NH_3, PM_{10} and $PM_{2.5}$ of the tom turkey barn during grow-out period of 6-20 weeks (1 m^3/hr = 0.59 cfm).

IA		V.R., m^3/hr-bird	Concentration			ER, kg/d-house			ER, g/d-bird		
			NH_3, ppm	PM_{10}, μg/m^3	$PM_{2.5}$, μg/m^3	NH_3	PM_{10}	$PM_{2.5}$	NH_3	PM_{10}	$PM_{2.5}$
Flock 1*	Mean	47.6	3.1	767	67	7.5	2.3	0.19	1.9	0.58	0.05
	S.D.	21.3	1.6	416	26	5.9	1.3	0.11	1.5	0.34	0.03
	Max	75	8.4	2558	176	25.2	6.2	0.43	6.4	1.6	0.11
	Min	2.9	0.59	174	25	0.15	0.18	0.01	0.04	0.04	0
Flock 2	Mean	9.7	11.7	1355	175	8	1.2	0.12	1.3	0.2	0.02
	S.D.	7.3	5.9	661	130	4.6	0.44	0.08	0.77	0.07	0.01
	Max	39.3	28.7	3207	500	20.5	2.4	0.3	3.4	0.39	0.05
	Min	1.9	1.81	173	18	1.18	0.27	0.01	0.2	0.04	0
Flock 3	Mean	9.7	12.8	1722	245	6.1	1.6	0.23	1.4	0.37	0.05
	S.D.	9.2	11.5	591	130	3.7	0.95	0.16	0.85	0.22	0.04
	Max	53.7	44.7	3384	637	16.6	3.6	0.61	3.8	0.82	0.14
	Min	1.5	1.34	200	50	0.7	0.17	0.01	0.16	0.04	0
Flock 4	Mean	39.5	2.4	548	57.7	7.6	1.5	0.20	1.5	0.29	0.04
	S.D.	17.3	1.3	491	20.6	4.3	0.6	0.10	0.8	0.12	0.02
	Max	70.3	6.2	2688	117	17.9	3.0	0.48	3.5	0.58	0.09
	Min	3.0	0.60	144	19.5	0.5	0.0	0.0	0.1	0.0	0.0
Flock 2-4	Mean	19.6	9.0	1208	159	7.2	1.4	0.2	1.3	0.3	0.03
	S.D.	18.5	10.5	762	132	4.3	0.1	9.5	0.8	0.2	0.1
	Max	70.3	44.7	3384	637	20.5	3.6	0.61	3.5	0.65	0.11
	Min	1.5	0.6	144	18	0.5	0.0	0.0	0.1	0.0	0.0
All flocks	Mean	26.6	7.50	1098	136	7.3	1.65	0.19	1.52	0.36	0.04
	S.D.	22.8	9.58	719	124	4.8	0.98	0.12	1.04	0.15	0.25
	Max	75.0	44.7	3384	637	25.2	6.2	0.6	6.4	1.6	0.14
	Min	1.5	0.6	144	18.0	0.2	0.0	0.0	0.0	0.0	0.0

* The flock had unusual low stocking density.

Table 5. Ventilation rate (VR), concentrations and emission rates of NH_3 and PM_{10} of the hen turkey barn during grow-out period of 6 to 12 weeks (1 m^3/hr = 0.59 cfm).

MN		V.R., m^3/hr-bird	Concentration		ER, kg/d-house		ER, g/d-bird	
			NH_3, ppm	PM_{10}, μg/m^3	NH_3	PM_{10}	NH_3	PM_{10}
Flock 1	Mean	8.5	14.9	246	1.02	0.03	1.24	0.04
	S.D.	4.5	13.0	124	0.66	0.03	0.93	0.03
	Max	50.5	45.9	552	3.02	0.11	3.67	0.14
	Min	2.5	0.06	113	0.00	0.00	0.00	0.01
Flock 2	Mean	3.3	19.8	315	1.13	0.02	1.32	0.02
	S.D.	2.4	15.2	200	1.75	0.02	2.09	0.03
	Max	11.1	83.2	885	12.74	0.16	15.2	0.19
	Min	2.1	1.35	22	0.05	0.00	0.00	0.00
Flock 3	Mean	11.2	6.9	307	0.37	0.05	0.46	0.06
	S.D.	5.7	6.5	226	0.24	0.05	0.30	0.07
	Max	29.7	36.6	853	1.10	0.22	1.38	0.28
	Min	2.2	0.81	97	0.01	0.00	0.02	0.00
Flock 4	Mean	42.7	1.6	201	1.06	0.15	1.28	0.18
	S.D.	12.7	0.9	38	0.72	0.05	0.88	0.06
	Max	50.5	4.3	336	2.71	0.26	3.26	0.33
	Min	11.1	0.33	143	0.06	0.04	0.07	0.05
Flocks 1,2 & 4	Mean	18.2	12.1	254	1.1	0.07	1.3	0.08
	S.D.	19.8	14.2	152	1.2	0.12	1.5	0.08
	Max	50.5	83.2	885	12.7	0.3	15.2	0.33
	Min	2.1	0.1	22.1	0.0	0.0	0.0	0.0
All flocks	Mean	7.7	10.8	267	0.89	0.06	1.07	0.08
	S.D.	18.2	12.8	177	1.11	0.13	1.32	0.07
	Max	50.5	0.0	0.0	0.0	0.0	15.2	0.33
	Min	2.1	0.0	0.0	0.0	0.0	0.00	0.00

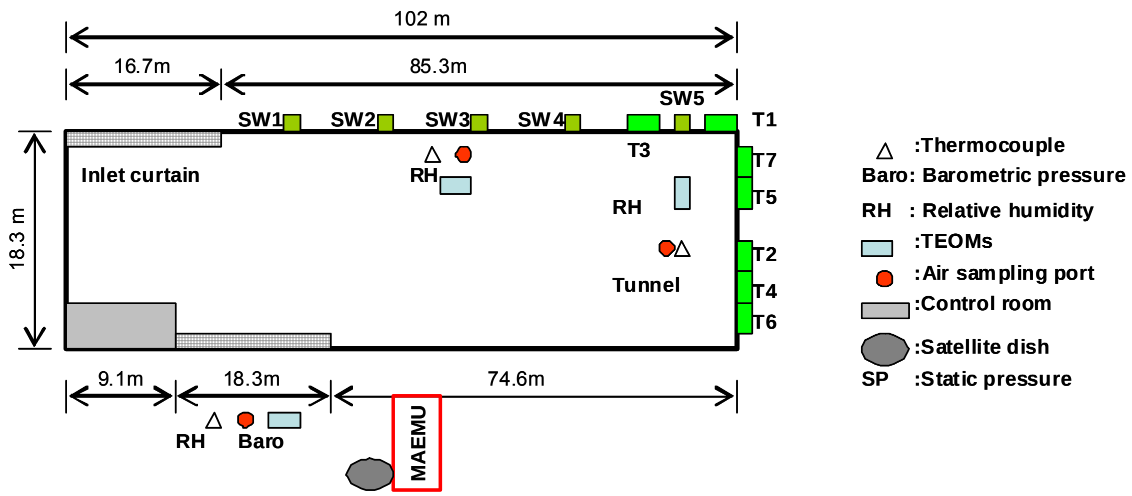

Figure 1. Schematic layout of the mechanically ventilated tom turkey barn monitored at the Iowa site.

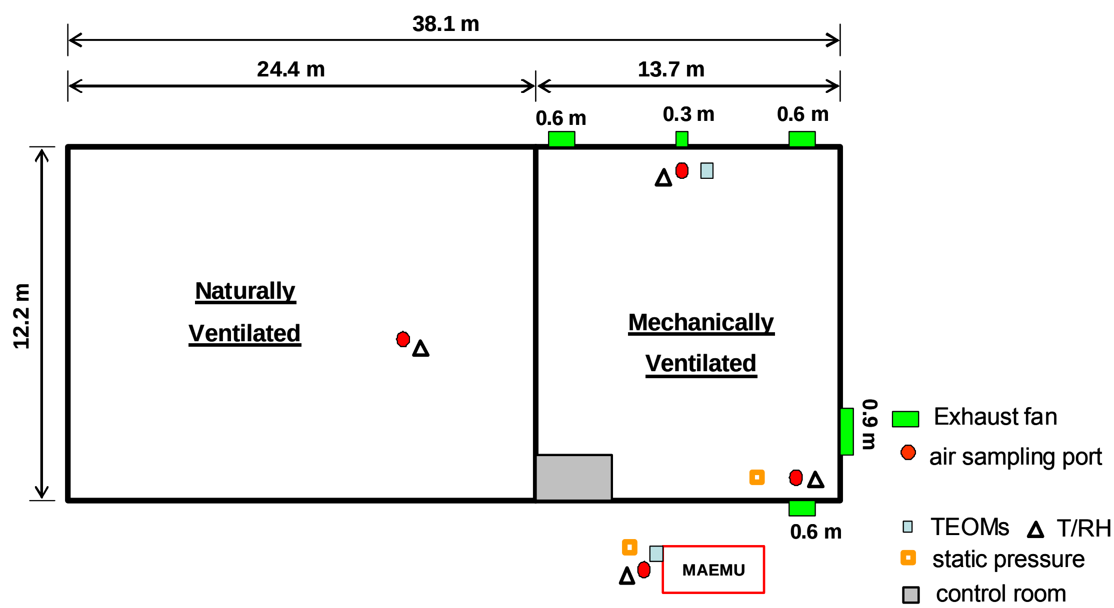

Figure 2. Schematic layout of the hen turkey barn monitored at the Minnesota site.

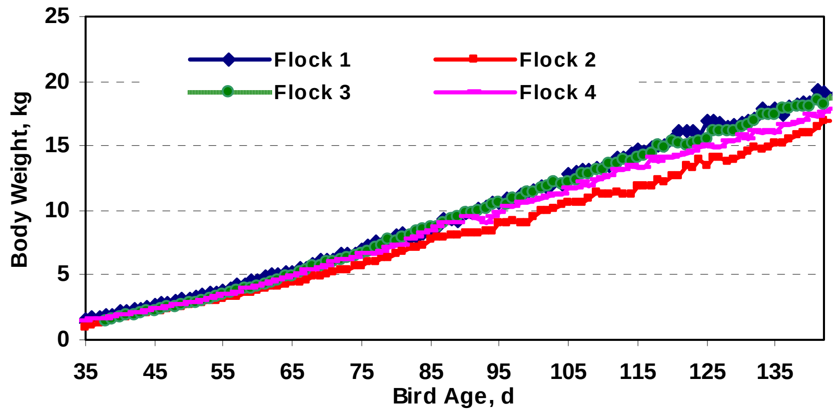

Figure 3. Growth curves of Hybrid tom turkey during four flocks of air emissions monitoring.

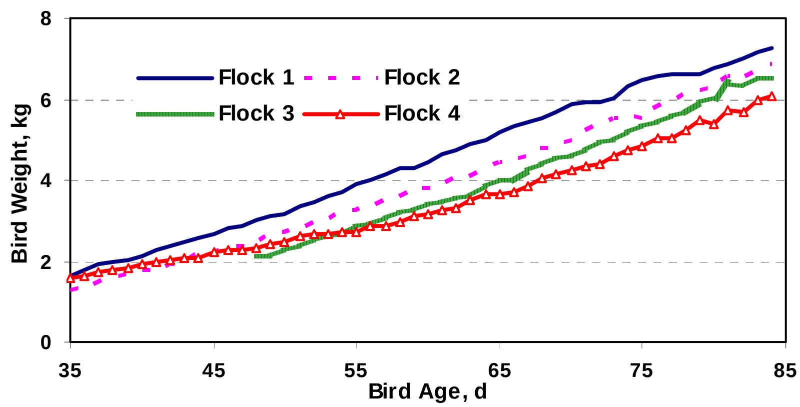

Figure 4. Growth curves of Hybrid hen turkey during four flocks of air emissions monitoring.

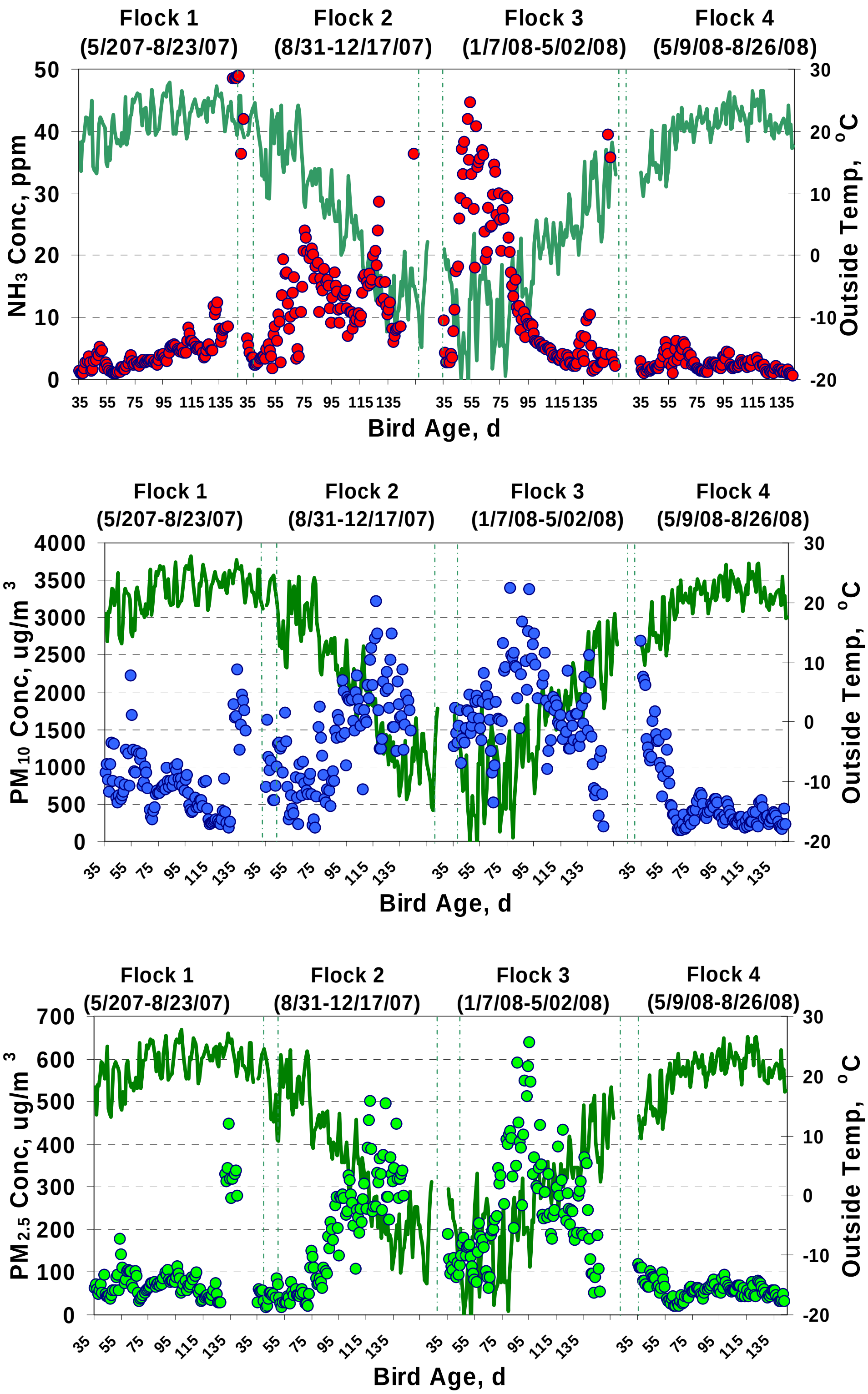

Figure 5. Daily mean NH_3, PM_{10} and $PM_{2.5}$ concentrations of a tom turkey barn, along with outside air temperature, over the 16-month monitoring period at the Iowa site.

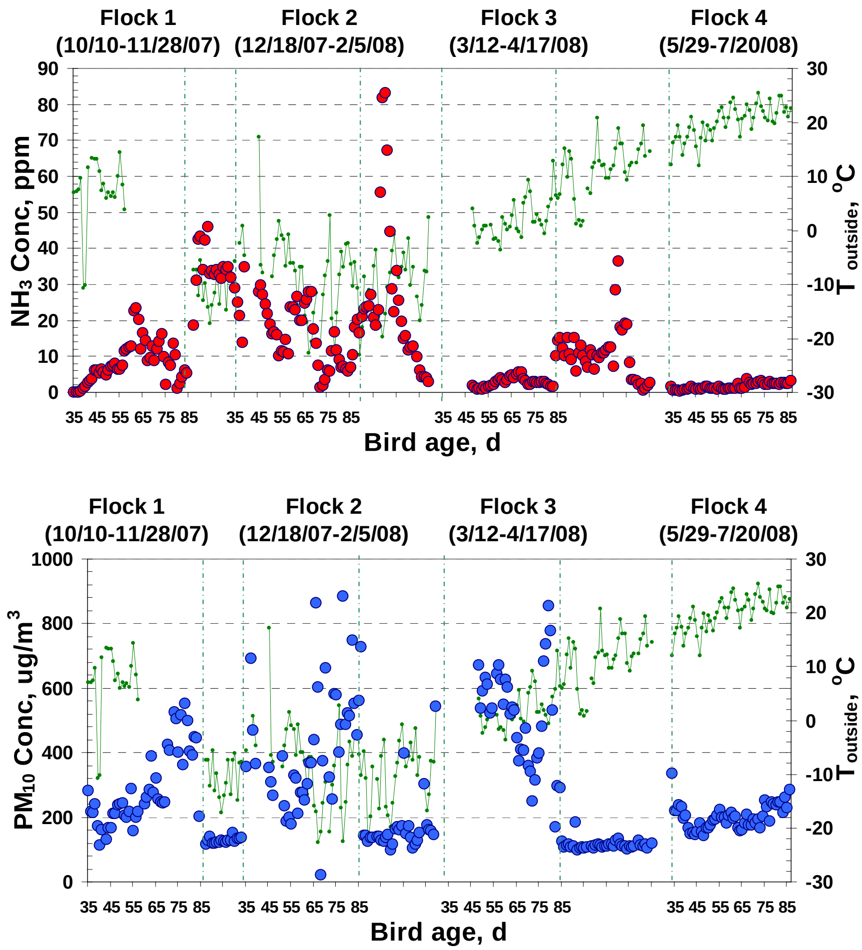

Figure 6. Daily mean NH_3, PM_{10} and $PM_{2.5}$ concentrations of a hen turkey barn, along with outside air temperature, during the 10-month monitoring at the Minnesota site.

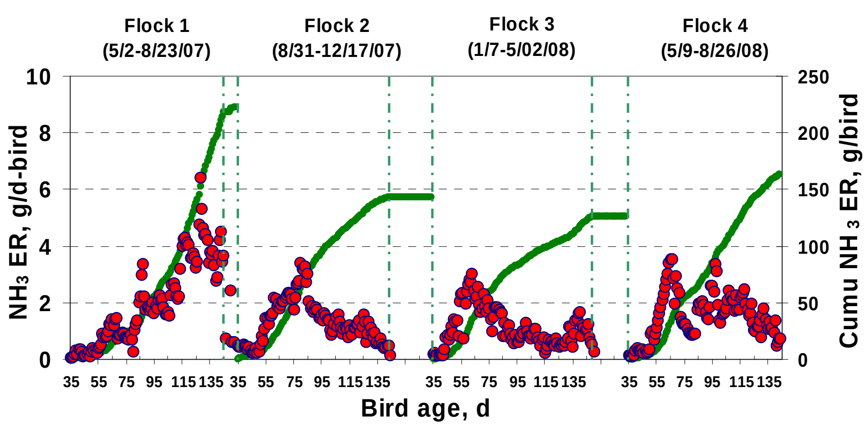

Figure 7. NH_3 emission rate (ER) during the four-flock monitoring of air emissions from a tom turkey barn in Iowa.

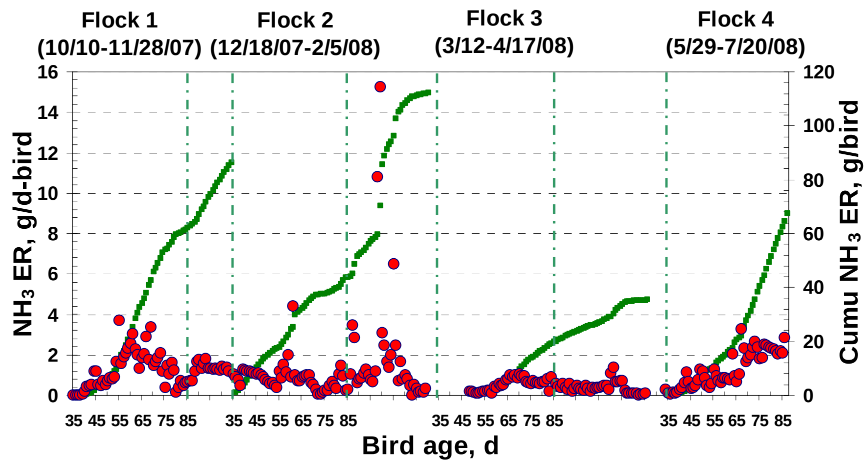

Figure 8. NH_3 emission rate (ER) during the four-flock monitoring of air emissions from a hen turkey barn in Minnesota.

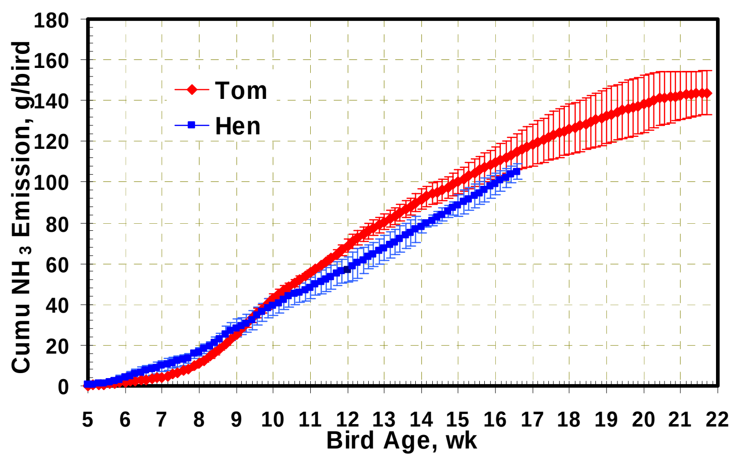

Figure 9. Cumulative NH_3 emissions of tom and hen turkey barns (mean ± SE).

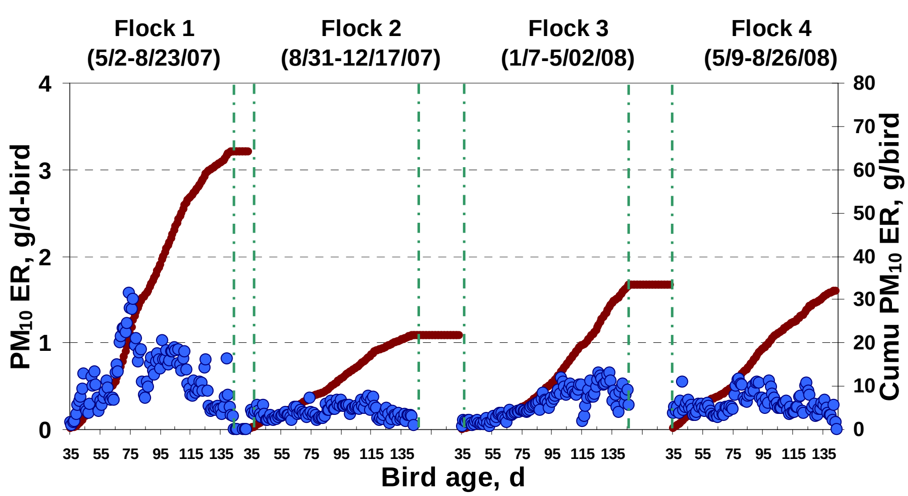

Figure 10. PM_{10} emission rate (ER) during the four-flock monitoring of air emissions from a tom turkey barn in Iowa.

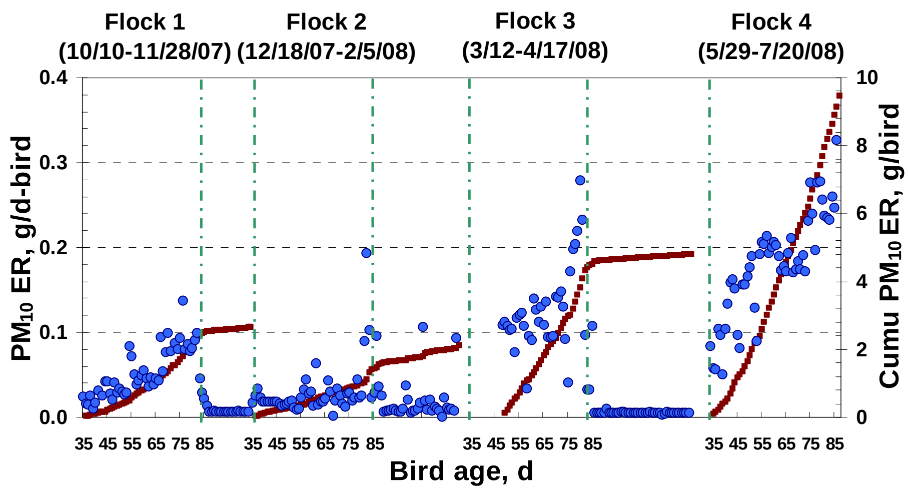

Figure 11. PM_{10} emission rate (ER) during the four-flock monitoring of air emissions from a hen turkey barn in Minnesota.

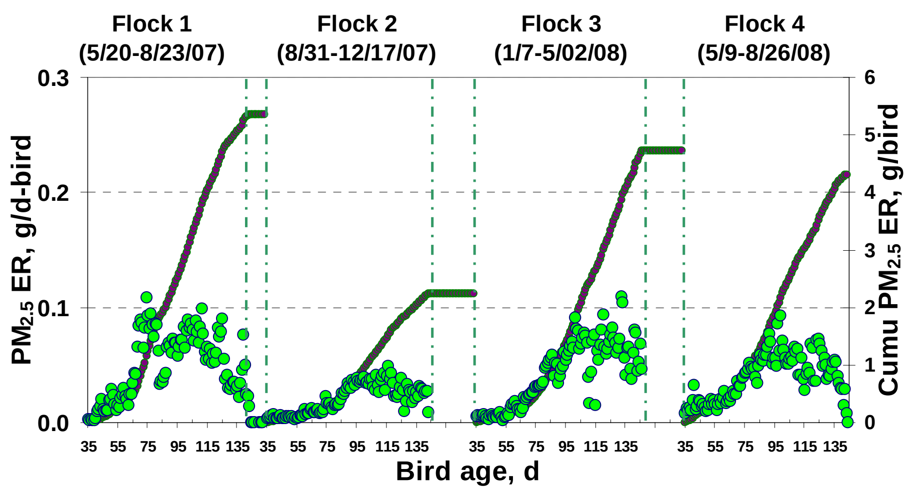

Figure 12. $PM_{2.5}$ emission rate (ER) and air temperature during the four-flock monitoring of air emissions from a turkey barn in Iowa.

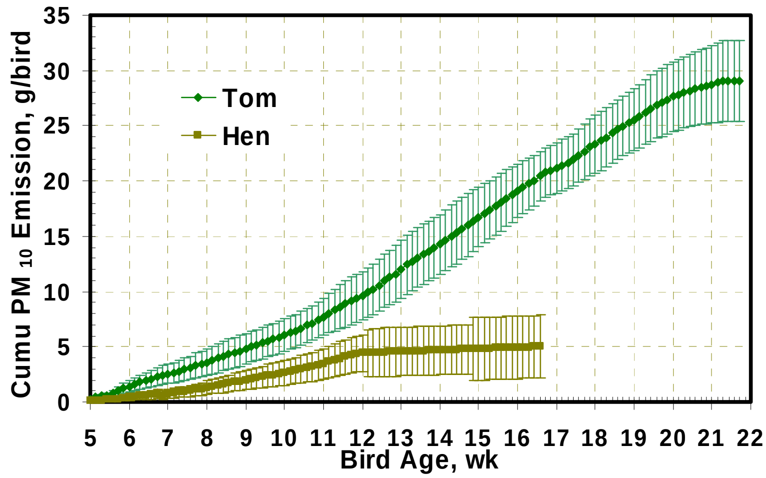

Figure 13. Cumulative PM_{10} emissions of tom and hen turkey barns (mean ± SE).

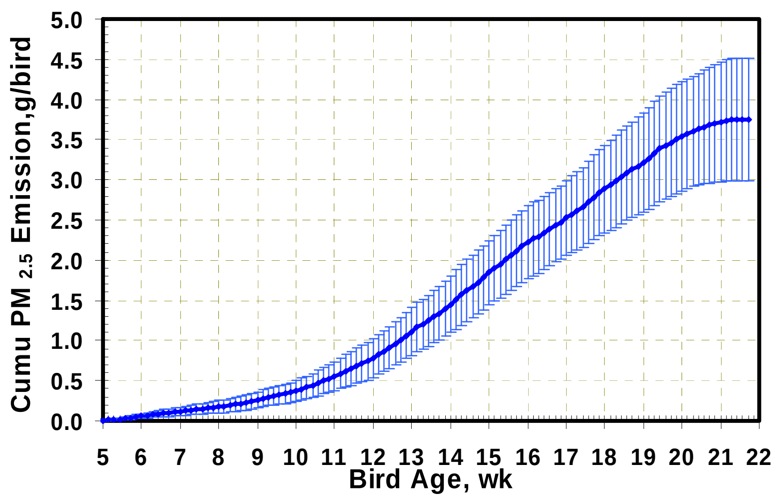

Figure 14. Cumulative $PM_{2.5}$ emissions of a tom turkey barn (mean ± SE).