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Abstract

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NITROGEN LOSSES FROM LAYING HEN MANURE IN COMMERCIAL HIGH-RISE LAYER FACILITIES

P. Yang, J. C. Lorimor, H. Xin

ABSTRACT. *Nitrogen (N) losses from four high-rise laying hen houses, representing four commercial layer farms in Iowa, were determined from measured performance data of Hy-Line W-36 White Leghorn layers (i.e., manure production, egg production, feed intake, body weight, and mortality). Nitrogen loss was 25, 33, 37, and 41% for Farms A, B, C, and D, respectively, based on the Total Kjeldahl Nitrogen (TKN) in feed. A significant factor contributing to the difference in the N losses was the moisture content (MC, percent on an as-is basis) in manure stored in the ventilated manure storage area of the layer houses. The higher the MC, the higher the ratio of NH_3/TKN_{Manure} in the stored manure, and therefore, the higher the percentage of N loss. Mathematical relationships were developed. Manure handling systems played an important role in N loss by influencing MC of the manure which, in turn, affects rate of manure decomposition. Understanding the factors affecting decomposition and N loss mechanisms of layer manure could provide a means to significantly reduce ammonia emissions to the atmosphere from poultry facilities.*
Keywords. Ammonia, Nitrogen, Ammonia/nitrogen ratio, Moisture content, Manure, Poultry.

Nitrogen (N) is a key element in animal manure, and has been the focus of study in the area of manure management and environmental control for many years. Since N is a nutrient component for crops, ammonia (NH_3) emissions are losses of valuable N fertilizer which should be minimized not only for environmental but also for economic reasons (Hartung, 1991). In addition, ammonia losses contribute to acid rain problems (Fulhage, 1996) and offsite deposition.

The poultry industry plays an important role in Iowa's agriculture. Iowa ranked number four nationally in egg production in 1998 with 5,969 million eggs. The average number of layers on hand during 1998 was 23 million, which was 7.37% of the nation's birds (Iowa Agricultural Statistics, 1999). At the time of this article preparation in March 2000, Iowa's ranking had moved to second place. On the other hand, poultry also produce wastes, especially manure. Ammonia volatilization has become a critical environmental concern of the poultry industry. Approximately 2760 to 5520 metric tons (3,043 to 6,086 English tons) of N from Iowa laying hens were lost to the atmosphere in 1998.

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In Iowa, 80 to 90% of the laying hens are kept in high-rise type houses (Xin, 1999). Manure is generally removed annually for land application. Therefore, identifying N loss rates and developing methods to maintain and stabilize N in layer manure during the storage period has practical importance for modern manure management and environmental control.

Controlling NH_3 loss is especially difficult in poultry manure because the N is more concentrated than other agricultural manure or sewage sludge (Logsdon, 1989). Measuring NH_3 emission from poultry manure stored in confined facilities is difficult. Ventilation rate multiplied by the NH_3 concentration in the exhaust air produces NH_3 emission rate (Oosthoek et al., 1990). But difficulties with this technique involve monitoring ventilation rate and NH_3 concentration in confined facilities continuously and accurately for long periods of time. Strobel et al. (1999) indicated that a lack of continuous air quality data in livestock buildings exists, and that continuous measurement of gas concentrations and temperatures is needed to properly evaluate air quality and animal environments.

The objective of this study was to quantify N losses from layer manure in commercial high-rise houses. N losses from four high-rise laying hen houses, representing four commercial flocks in Iowa (denoted as farms A, B, C, and D), were determined from measured performance data of Hy-Line W-36 layers. Parameters measured included manure production, egg production, feed intake, body weight, mortality, and climate both inside and outside the poultry houses.

LITERATURE REVIEW
BASICS OF N LOSSES

Ammonia is a colorless, irritant gas produced by microbial activity from the nitrogenous fraction of animal wastes (Carlile, 1984). NH_3 emissions result from aerobic
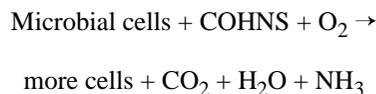
or anaerobic bacterial activities in manure (Zhang et al., 1991; Richard, 1997). Ammonia exists in both the ionized (NH_4^+) and un-ionized (NH_3) forms, with the relative proportions determined by pH and temperature (Richard, 1997). The dominant form of inorganic N in manure is ammonium (NH_4) which is converted to NH_3 as pH increases (Moore, 1998). If the order of abundance of elements in organic matter is represented by C, O, H, N, and S, then the following overall reactions occur during aerobic biological oxidation (Simpson, 1960):

$$\text{Microbial cells} + \text{COHNS} + O_2 \rightarrow$$

$$\text{more cells} + CO_2 + H_2O + NH_3$$

and

$$\text{Nitrifying cells} + NH_3 + O_2 \rightarrow (\text{via } NO_2^-) \rightarrow$$

$$NO_3 + H_2O + \text{more nitrifying cells}$$
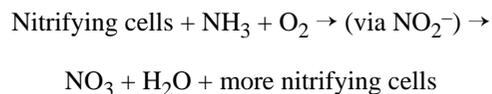
Nitrate nitrogen (NO_3-N), required by plants, is an end product of aerobic treatment (Day and Funk, 1998). Elliott et al. (1992) and Groot Koerkamp (1998) stated that NH_3 is mainly a product of the degradation of uric acid and undigested proteins, which can be simplified as:

$$C_5H_4O_3N_4 + 1.5O_2 + 4H_2O \rightarrow 5CO_2 + 4NH_3$$

$$\text{Undigested proteins} \rightarrow NH_3$$
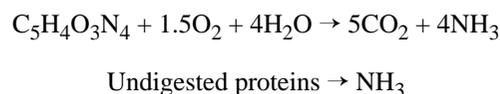
Anaerobic processes of animal manure take place without free oxygen (O_2). Manure in an uncontrolled, open, and anaerobic condition produces objectionable gases and odors such as hydrogen sulfide (H_2S) and NH_3 (Day and Funk, 1998). Koerkamp (1998) indicated that degradation of uric acid by anaerobic microorganisms along other pathways is also possible, but anaerobic processes generally are much slower than aerobic processes.

Elliott et al. (1982) studied total ammoniacal N which includes both the uncharged soluble NH_3 and the ammonium ion NH_4^+. An equilibrium will be established between soluble NH_3 in the manure and the gaseous NH_3 in the manure airspace since NH_3 is a volatile base:

$$NH_4^+ \Leftrightarrow NH_3 + H^+$$
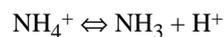
Regarding the NH_3 volatilization, Koerkamp (1998) further indicated that the ammonium-ammonia equilibrium in manure before being released to the air is influenced by temperature and pH:

$$NH_4^+(l) \Leftrightarrow NH_3(l) + H^+$$
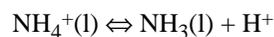
where (l) represents the liquid. The volatilization equilibrium of liquid NH_3 to the gas phase:

$$NH_3(l) \Leftrightarrow NH_3(g)$$
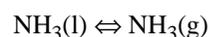
is affected by the partial pressure of gaseous NH_3, where (g) represents gas; and the volatilization of NH_3 from manure to air:

$$NH_3 (g, \text{manure}) \Leftrightarrow NH_3 (g, \text{air})$$
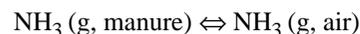
is defined as the mass flux which is generally defined as the product of the difference in partial pressure between two media and a mass transfer coefficient.

FATE OF N LOSS

Ammonia nitrogen (NH_3-N) represents one of the most important sources of manure N losses to the atmosphere. The NH_3 volatilization from livestock management has been recognized as an increasing problem in many countries during recent years (Svensson, 1993). High NH_3 concentrations in animal houses may cause decreased production rates and chronic health problems in both animals and human workers (Stombaugh et al., 1969; Drummond et al., 1980; Donham et al., 1982). Human eyes can detect NH_3 with a concentration of 25 ppm or less, while the maximum concentration that humans can withstand is 100 ppm for 8 h (Moum et al., 1969). The Health and Safety Executive of England sets a Threshold Limit Value of 25 ppm NH_3 for an 8 h exposure or 35 ppm for exposure up to 15 min (Carlile, 1984). Valentine (1964) observed NH_3 levels in the range of 60 to 70 ppm in the air of poultry houses; whereas, Anderson et al. (1964b) found that NH_3 concentrations were often as high as 100 ppm in the atmosphere of commercial poultry houses. Poultry can display a variety of disorders when exposed for extended periods to levels as low as 20 ppm (Anderson et al., 1964a). In layers, NH_3 also has an effect on laying capacity and egg quality (Carlile, 1984). The NH_3 generated by animal manure, especially by poultry manure, has now been linked to acid rain in Europe and "the ammonia that comes down with rain is converted to nitrate in the soil" (Logsdon, 1989). A soluble anion in the soil, NO_3 and can be transported to streams through runoff, thus, endangering the supply of drinking water (Ibrahim and Scott, 1990). Excessive NO_3 from manure may lead to high levels of NO_3 in groundwater and potentially in wells (Brinton, 1989).

QUANTITY OF N LOSS

Numerous articles have reported N losses or NH_3 emissions from the poultry manure. Based on the sum of N determined from manure, eggs, and carcasses, approximately 40% of feed N input was lost to the atmosphere as NH_3 (Patterson and Lorenz, 1996). Typical N losses between excretion and land application for poultry manure stored in deep pits are 25 to 50% (MWPS, 1985). Sims and Wolf (1994) stated that more than 50% of the total N in poultry manure may be lost via NH_3 volatilization; whereas, Hartung (1990) reported that 37% of all N losses are in the form of NH_3. Hartung (1990) indicated that it is important to remove manure and urine as soon as possible because fresh urine in the manure is a considerable source of NH_3 as a result of urease from feces. Kroodsma et al. (1988) reported that average NH_3 concentration was reduced by removing the manure by means of a manure belt system under the cages twice a week in comparison to a stair-step laying hen cage system. Moore (1998) indicated a majority of NH_3 loss from broiler litter and laying hen manure probably occurs when the litter or manure is still in the houses, since uric acid conversion to NH_3 is a quick process. Zhang et al. (1994)
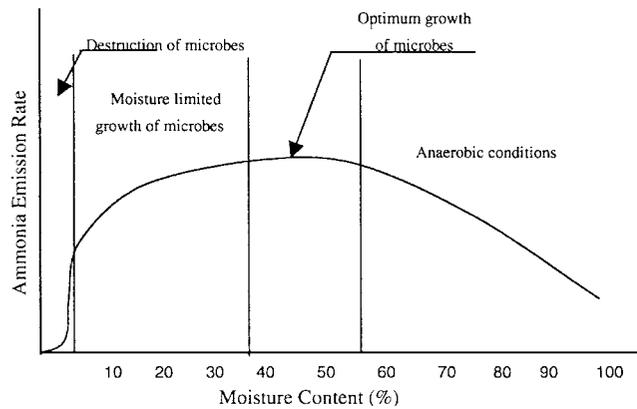
Figure 1–Schematic representation of dependence of ammonia release on litter moisture content (from Groot Koerkamp, 1998).

reported that NH_3 released from manure pits is increased with increasing ambient temperature and air velocities over the manure surface. Valli et al. (1990) reported that specific NH_3 emission per bird proved extremely high in the case of a composting plant (0.951 to 1.628 g/hen-d) although it was considerably lower in a ventilated deep pit plant (0.176 g/hen-d). AWMFH-1 (1992) stated that the percentage of original N of poultry manure retained by manure stored in pits beneath a slatted floor is 80 to 90%. Hansen et al. (1989) calculated mean N reduction from seven composting tests was 28.74%. Surbrook et al. (1971) reported protein and N losses of up to 25% would result during high temperature drying of manure. Groot KoerKamp (1998) shows the relationship between moisture and ammonia emissions in figure 1.

MATERIALS AND METHODS

This field study was conducted at four commercial high-rise laying hen houses in different geographical locations in Iowa. In high rise houses the layer cage are located in the upper level, referred to as the layer space. The manure either drops directly, or is scraped periodically, into the lower level, referred to as the manure space. The birds in all four farms were Hy-Line W-36 White Leghorns.

LAYING HEN FACILITIES

The structural, ventilation and production characteristics of the four high-rise houses monitored in this study are summarized in table 1. Cross-sections of houses A, B, C

and D are shown in figures 2, 3, and 4, respectively. All houses were equipped with automatic auger or screw-trough feeder, nipple or cup drinker, and egg collection systems

Farms A and B had similar manure handling systems. Layer manure dropped onto boards below the cages. It was periodically scraped mechanically through a slot opening between adjacent boards into the storage area below. A small portion of the manure was intercepted by manure shields placed on the back of the cages. On Farm A, the manure scraper system was normally operated two times a day (four times a day during the molting period). On Farm B the scraper was operated four to five times a day.

The house at Farm D was similar to that at Farm C, with the exception that the Farm C house had six cage rows and the Farm D house had five cage rows. The floor opening under each cage row had the same overall width as the cages, so manure dropped directly into the storage space. A small part of the manure was intercepted by manure shields placed at the back of cages, and then dropped into the storage.

MEASUREMENT OF VARIABLES AND DATA ACQUISITION

Hourly dry-bulb temperature and relative humidity (RH) were monitored for both inside the manure space and outside the facility at each site. StowAway™ electronic temperature and RH data loggers (Onset Computer Corporation, Pocasset, Massachusetts) were installed in the middle of the manure space just below the intermediate floor, and outside the layer house. At each site, one waterproof temperature sensor (Onset Computer Corporation) was buried in the core of the middle manure pile at a central location to measure manure temperature. The logged data were retrieved with a portable PC using the companion LogBook software, and then imported to Excel spreadsheet for further analysis and plotting.

Weekly feed samples were collected by company personnel at each site during feed unloading, and were subsequently analyzed for nutritional composition (TKN and P level) at Iowa State University. Bird performance data including feed and water consumption, egg production, mortality, and body weight were also collected from the farm's weekly record. Monthly manure samples were collected by the investigators during regular farm visits.

As described by Lorimor and Xin (1999), manure production volume in each house was measured monthly by reading an array of vertical steel rods placed 0.15 m (6 in.) apart, across a central row of manure (fig. 5). The

Table 1. Commercial high-rise layer houses, general information

Farm	Location in Iowa	House Dimension Overall*	M.S.H†	Type	Fan No.	Fan Size (m)	Inlet Type	Manure Handling Type	Scraping Times/d	Start-ing No	Age Range	Molt-ing Age	Drinker Type
A	N.W.	124×14.6×5.79	2.59	Neg. pres.	26	1.22	CCSI‡	Board/Scraper	2 (4§)	84,280	60-99 (wk)	69 (wk)	Nipple
B	Central	178×17.4×5.64	2.90	Pos. pres.	80	0.91	CCSI	Board/Scraper	4 to 5	126,144	30-81(wk)	70 (wk)	Cup
C	N.	171×17.7×5.18	2.44	Neg. pres.	36	1.22	CPSI‖	Direct drop	N/A	120,960	44-78 (wk)	69 (wk)	Nipple
D	S.W.	215×14.9×4.88	2.19	Neg. pres.	42	1.22	CPSI	Direct drop	N/A	126,795	52-106 (wk)	71(wk)	Nipple

* Length of cage row × width of the house interior × height of sidewall or ceiling height from the ground floor in m × m × m.
† Manure space height in m.
‡ Continuous ceiling slot inlet.
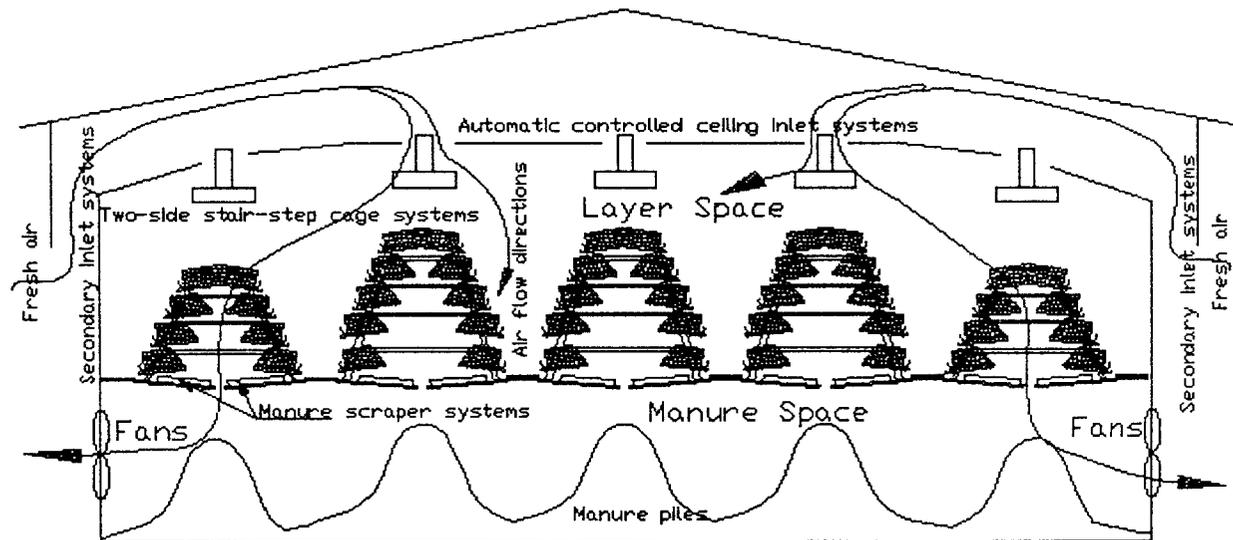§ Scraping times during molting period.
‖ Continuous perimeter slot inlet.

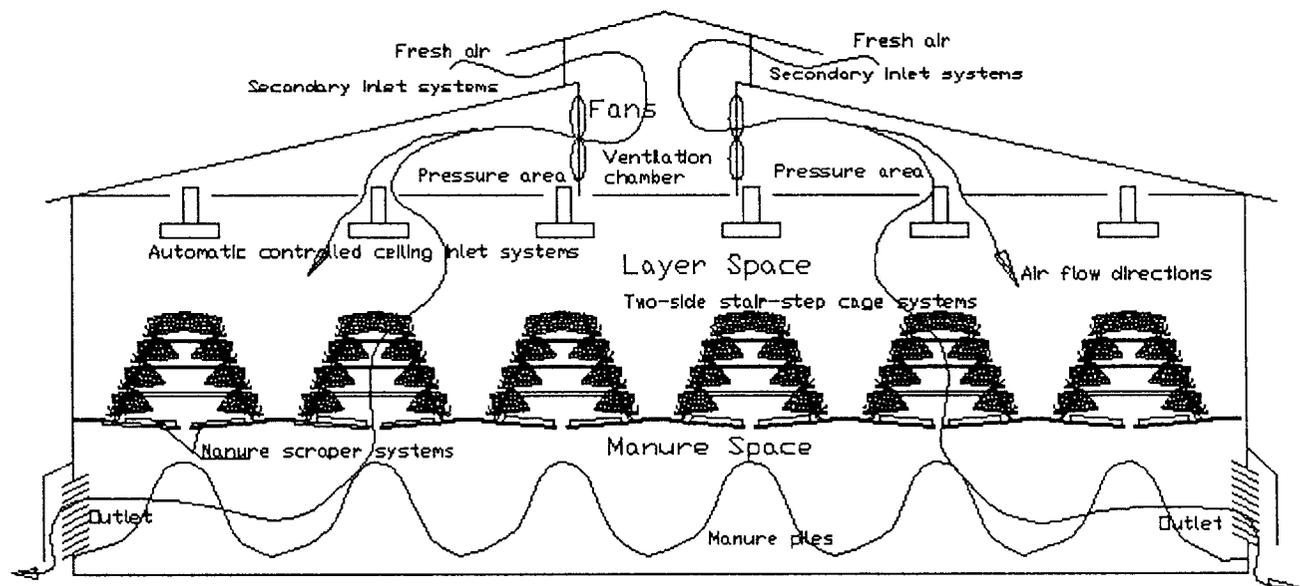**Figure 2–Schematic of the high-rise laying hen house in Farm A.**

Figure 3–Schematic of the high-rise laying hen house in Farm B.

array was located near the middle of the manure row and was set perpendicular to the row. Each rod was marked at 2.54 cm (1 in.) increments throughout its length so that the monthly depth across the manure row could be read without disturbing the manure row. Those readings were then used to determine the cross-section area of the manure row. Multiplying the cross-section area by the length of the manure (cage) row equaled the cumulative manure volume for that cage row. For some manure piles, the cumulative manure volume was adjusted according to layer numbers in the cages. Multiplying the row volume by the number of rows in the house, and adjusting for the number of birds in the rows, gave the total manure volume for the house. Monthly manure production was calculated as the difference in volume between the current month and the previous month.

Bulk densities of the manure were determined two times during the experimental period at each site by excavating a uniform cross-section of the pile 0.30 to 0.38 m thick (12 to 15 in.) and weighing the material excavated (fig. 6). At the end of the monitoring period, a final density was determined by weighing a known length of the manure row from 6.1 to 9.1 m (20 to 30 ft) long. The manure production values were converted to kilograms per 1000 kg (pounds/1000 lb) live body weight (BW) per day.

Farm visits were conducted at an approximately four-week interval throughout the experiment period. On each farm visitation day, a total of nine manure samples were collected from three locations along the length of the middle manure row at one-eighth, one-fourth, and three-eighths of the total length, respectively. At each location, three samples were collected, i.e., near the bottom, at the center, and near the top of the manure pile, by inserting a sharpened 5 cm (2 in.) galvanized tube. These nine samples were composited into one and placed in a plastic container. The samples were sent immediately to Iowa Testing
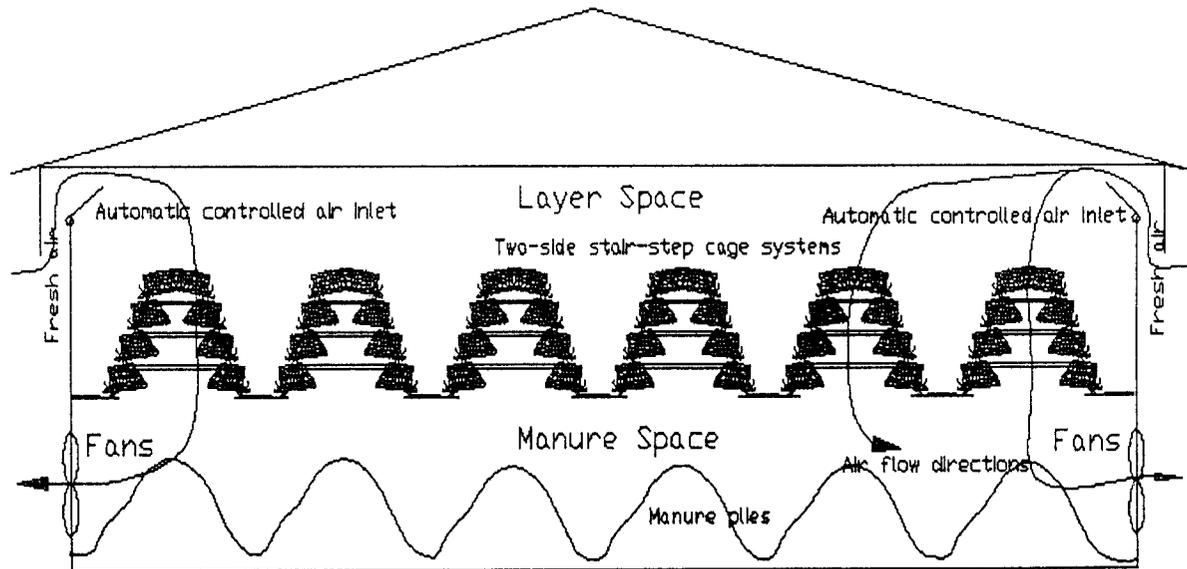
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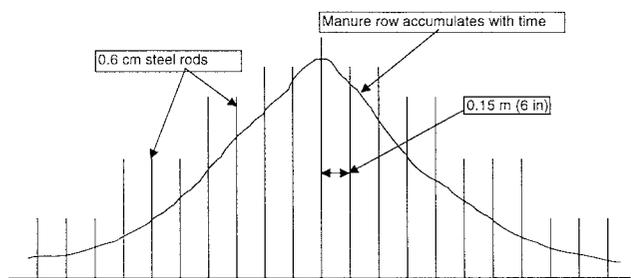
Figure 4–Schematic of the high-rise laying hen house in Farms C and D.

Figure 5–Manure volume measuring device.

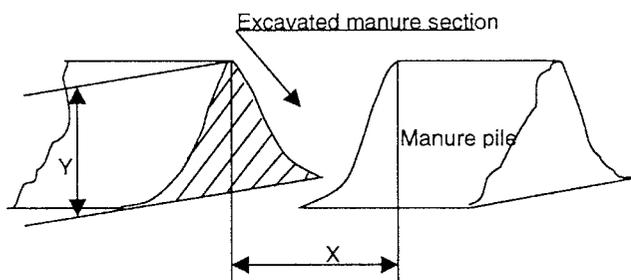**Figure 6–Excavation of manure section for bulk density determination.**

Laboratories, Eagle Grove, Iowa, where they were analyzed for the chemical properties listed in table 2.

DATA ANALYSIS

N losses from the four commercial high-rise laying hen houses were determined by combining bird performance data with the manure and feed chemical analysis data. Nitrogen contents in feed, manure, fresh eggs, live hens, dead hens, and NH_3-N in the manure were calculated. Average feed N, denoted as N_{Feed}, over the experimental period was used to compute the N intake by the birds. Nitrogen content of live hens (including feathers), denoted as $N_{LiveHen}$, was calculated using data from Haque et al.

Table 2. Chemical properties tested in layer manure samples

Moisture	Calcium	Zinc
Total Kjeldahl nitrogen	Magnesium	Manganese
Ammonia nitrogen	pH	Copper
Phosphorus	Sulfur	Iron
Potassium	Sodium	Cobalt

(1991). Haque et al. did three experiments studying extrusion processing of broiler starter diets containing ground spent hens, poultry by-product meal, feather meal, or ground feathers. The ground hens were collected from a commercial layer operation with a bird age of 78 weeks. In this study, we used dry matter content of 39.5% and crude protein of 54.0% on dry basis for spent hens to calculate N content in the live hens, as used by Haque et al. (1991). N content of dead birds, denoted as $N_{DeadHen}$, was similarly calculated.

Protein content of fresh whole egg on as-is basis varies from 11.96% to 12.00% (Carter, 1968; Cook and Briggs, 1973; Sell, 1999). In this study, protein content of 12% was used to calculate N content of eggs, denoted as N_{Egg}. Nitrogen content was calculated as protein/6.25. Nitrogen content in stored manure, denoted as N_{Manure}, was computed based on the chemical analysis results of the manure samples. Nitrogen loss was calculated as the difference between N input in the feed and N output as follows:

$$N_{Loss} = N_{Feed} - (N_{Manure} + N_{Egg} + N_{LiveHen} + N_{DeadHen})$$

Nitrogen losses were assumed to occur through ammonia nitrogen volatilization into the ventilation air.

RESULTS AND DISCUSSION

The average flock size, weekly mortality rate, bird age, and body weight for the four sites studied are summarized in table 3. The birds consumed an average of 58.61 kg feed and 112.1 kg H_2O/1000 kg live body weight per day (or 58.61 lb feed and 13.44 gal H_2O/1,000 lb live body weight

Table 3. Flock size and layer performance during the period of this study

Farm	Average No. of Birds	Mortality* (%)	Bird Age (wks)	Av. BW kg(lb)/bird	Feed Intake kg/10³kgBW/d	Water Intake kg/10³kgBW/d	Egg Prod.† (Eggs/Bird/Y)	Egg Weight g/Egg (lb/Egg)	Manure Produced‡ as-is basis	Manure Produced‡ dry basis	Manure BD§ kg/m³ (lb/ft³)	Manure MC‖ (% as-is)
A	77,142	0.214	60-99	1.578(3.477)	60.14(60.14)#	117.6(14.09)**	240	60.7(0.1337)	20.38	14.77	501.1(31.28)	27.5
B	121,951	0.095	30-81	1.569(3.453)	58.67(58.67)	120.7(14.47)	274	60.2(0.1326)	16.20	10.74	546.5(34.11)	33.7
C	109,232	0.126	44-78	1.511(3.330)	60.42(60.42)	107.2(12.85)	257	61.4(0.1353)	16.49	9.22	518.6(32.38)	44.1
D	115,475	0.162	52-106	1.701(3.750)	55.20(55.20)	103.0(12.35)	253	62.0(0.1367)	17.74	9.08	646.0(40.32)	48.8
Ave.	105,950	0.149		1.590(3.503)	58.61(58.61)	112.1(13.44)	256	61.1(0.1346)	17.70	10.95	553.1(34.52)	38.5
SD	19,895	0.051		0.080(0.177)	2.398(2.398)	8.39(1.006)	14	0.68(0.0016)	1.904	2.655	64.67(4.04)	9.69

* Average weekly mortality was the average percentage of dead birds per week relative to the average flock size of the layer house.
† All flocks had one molting time during this study.
‡ Data from Lorimor and Xin (1999), kg/1000 kg BW/d or lb/1000 lb BW/d.

Table 4. Partitioning of N intake; N retained in manure, egg, and bird body; and lost through volatilization per 1,000 kg live body weight per year

| Farm	N_{Feed} (kg)	N_{Manure} (kg)	N_{Egg} (kg)	$N_{LiveHen}$ (kg)	$N_{DeadHen}$ (kg)	NH_3-N_{Manure} (kg)	N_{Loss} (kg)	N_{Loss}/N_{Feed} (%)	NH_3-N_{Manure}/N_{Manure} (%)	MC (%)
A	561.93	207.51	176.59	34.13	3.78	26.03	139.92	25	12.54	27.5
B	569.66	143.72	201.40	34.13	1.70	23.06	188.71	33	16.05	33.7
C	505.02	79.44	199.86	34.13	2.33	19.26	189.27	37	24.24	44.1
D	495.64	80.29	176.48	34.13	2.68	23.96	202.07	41	29.84	48.8
Mean	533.06	127.74	188.58	34.13	2.62	23.08	179.99	34	20.67	38.5
SD	38.12	61.11	13.93	0.00	0.87	2.83	27.42	6.87	7.84	9.7

per day) and produced an average of 256 eggs/bird per year (table 3).

As shown in table 4, N loss was 25, 33, 37, and 41% of the N intake from feed for Farms A, B, C, and D, respectively. Nitrogen loss for Farm D was 1.64 times of that for Farm A although NH_3 concentration in the manure of the two farms was quite similar. Table 5 lists the manure production, N and NH_3 in manure, and N loss on the basis of 100 lb feed consumed, one dozen eggs produced, or one hen housed per year.

Table 5. Manure production, N and NH_3 in manure, and N loss based on 100 lb of feed consumed, one dozen eggs produced, and one hen housed per year

Farm	Manure Producd (lb, wet basis) 100 lb feed	Manure Producd (lb, wet basis) 1 dozen egg	Manure Producd (lb, wet basis) 1 hen-year	N_{Manure} (lb) 100 lb feed	N_{Manure} (lb) 1 dozen egg	N_{Manure} (lb) 1 hen-year	$NH_{3Manure}$ (lb) 100 lb feed	$NH_{3Manure}$ (lb) 1 dozen egg	$NH_{3Manure}$ (lb) 1 hen-year	N_{Loss} (lb)* 100 lb feed	N_{Loss} (lb)* 1 dozen egg	N_{Loss} (lb)* 1 hen-year
A	33.87	1.292	25.86	0.94	0.036	0.72	0.119	0.0045	0.091	0.637	0.0243	0.4865
B	27.62	0.895	20.42	0.67	0.022	0.50	0.108	0.0035	0.080	0.881	0.0286	0.6517
C	27.28	0.936	20.04	0.36	0.012	0.26	0.087	0.0030	0.064	0.858	0.0294	0.6303
D	32.14	1.152	24.28	0.40	0.014	0.30	0.119	0.0043	0.090	0.913	0.0327	0.6900
Average	30.23	1.069	22.65	0.59	0.021	0.45	0.108	0.0038	0.081	0.822	0.0288	0.6146
SD	3.287	0.187	2.872	0.272	0.011	0.210	0.015	0.001	0.012	0.126	0.0035	0.0889

* Nitrogen loss calculated from N intake minus N retained in hens, eggs, and stored manure.

$$N_{loss} = 0.8276(NH_3\text{-}N/TKN_{manure}) + 16.962$$
$$R^2 = 0.892$$
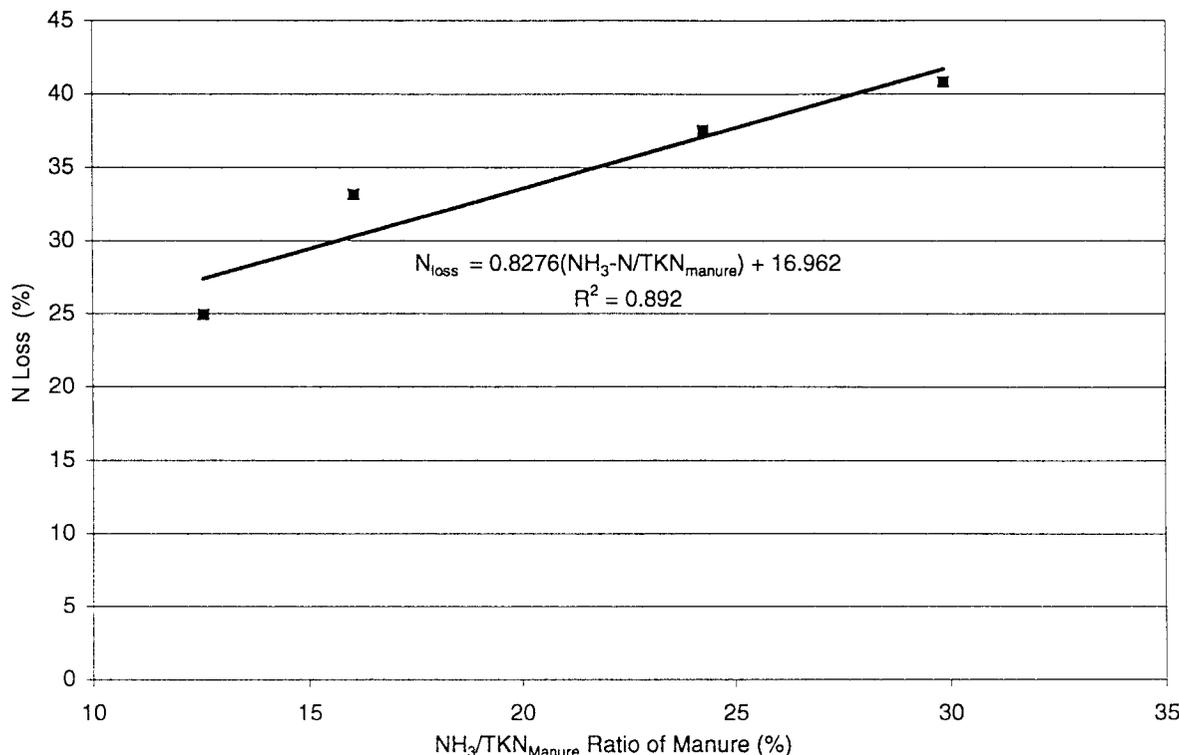
Figure 7–Relationship of N loss vs. NH_3/TKN_{Manure} ratio.

Higher NH_3/TKN_{Manure} ratios were associated with higher N losses from the manure (fig. 7). The relationship had the following form:

$$N_{Loss}, \% = 0.8276 \, NH_3/TKN_{Manure} + 16.96$$

$$(R^2 = 0.89) \tag{1}$$

Higher moisture content (MC, %) corresponded to higher NH_3/TKN_{Manure} ratio for the stored manure, and consequently, higher N loss (fig. 8). The relationships had the following forms:

$$N_{Loss}, \% = 0.6874 \, MC + 7.59 \quad (R^2 = 0.94) \tag{2}$$

and

$$NH_3/TKN_{Manure}, \% = 0.803 \, MC - 10.27$$

$$(R^2 = 0.98) \tag{3}$$

Farms A and B had lower MC, NH_3/TKN_{Manure}, and N losses compared with Farms C and D. Manure at Farms A and B first fell onto manure dropping boards under the cages, and then was removed by a scraper to the manure storage area several times a day. The thin layer of manure on the boards had more exposed surface area and contact time with the ventilation air. The manure was turned and mixed when scraped down to the manure storage area, which also may have increased the manure drying ability. Farm A operated the manure scraper systems twice a day, resulting in a drier manure than that of Farm B. Farm B operated the manure scraper system four to five times a day. By comparison, manure at Farms C and D fell directly into the storage as soon as the birds excreted it. The manure in Farms C and D had less surface area exposed to ventilation air, resulting in relatively higher MC.

Figure 9 shows individual sample data from all four houses and the relationship between NH_3/TKN_{Manure} and MC:

$$NH_3/TKN_{Manure} (\%) = 0.7372 \, MC - 5.0$$

$$(R^2 = 0.56) \tag{4}$$

The relationship observed in this study agreed with the report by Lorimor (1998) that higher solids content or lower MC of the manure corresponds to lower NH_3 as a fraction of TKN in the manure. Moisture in the layer manure was critical to retaining N (Koerkamp, 1998), as verified by this study. The MC of manure at Farm C and D, 44.1% and 48.8%, respectively, was in the range for optimum growth of microbes.

Table 6 shows environmental measurements for the manure storage space, the outside air, and the manure for each house. Average temperatures, and relative humidity or MC are shown, along with standard deviations, over the entire experimental period.

Heights of the manure piles formed in the four houses were affected by MC of the manure, as shown in figure 10. Higher MC of the manure resulted in lower height of the manure pile.

Figure 11 shows the temperature in the core of the manure piles in the four high-rise houses. The highest average temperature was 39.0°C (102°F) with the
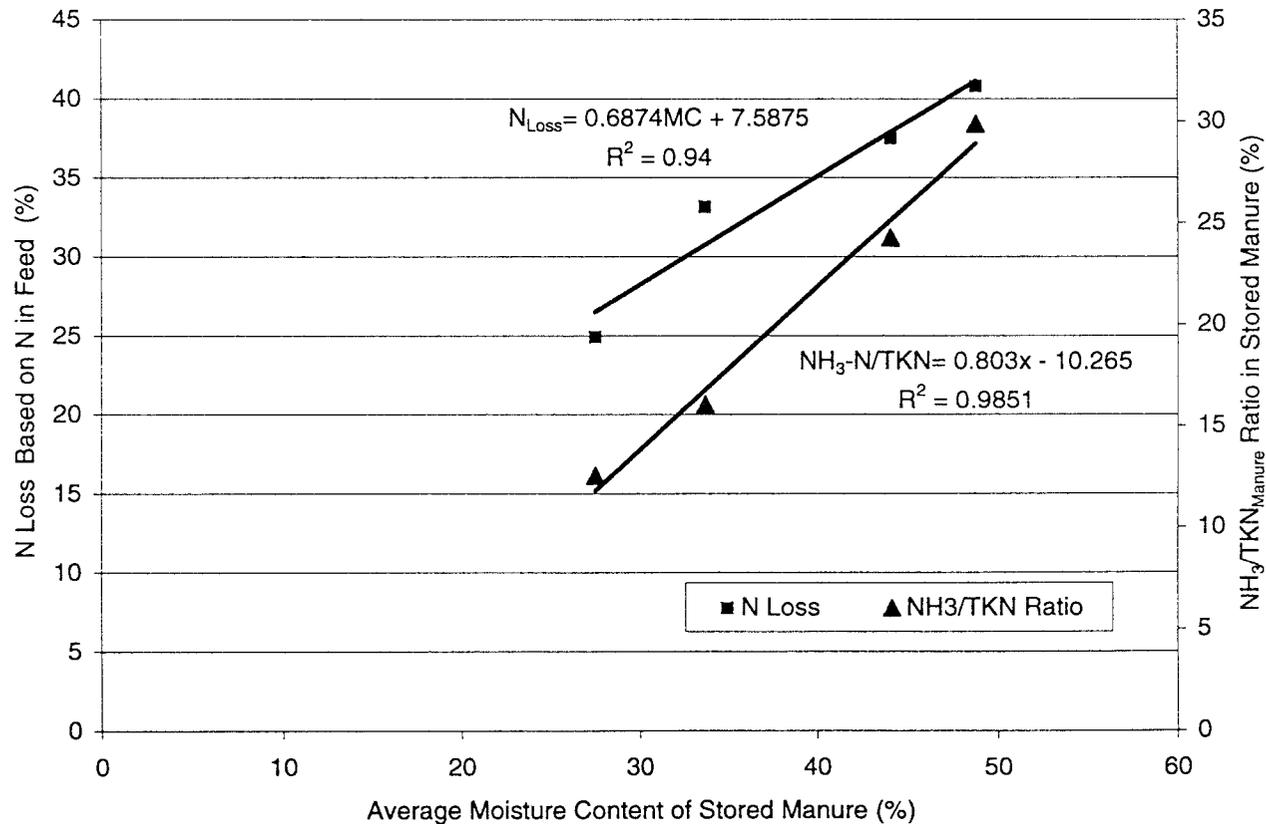

Figure 8–Nitrogen loss and NH_3/TKN_{Manure} ratio (%) in stored manure versus manure MC.
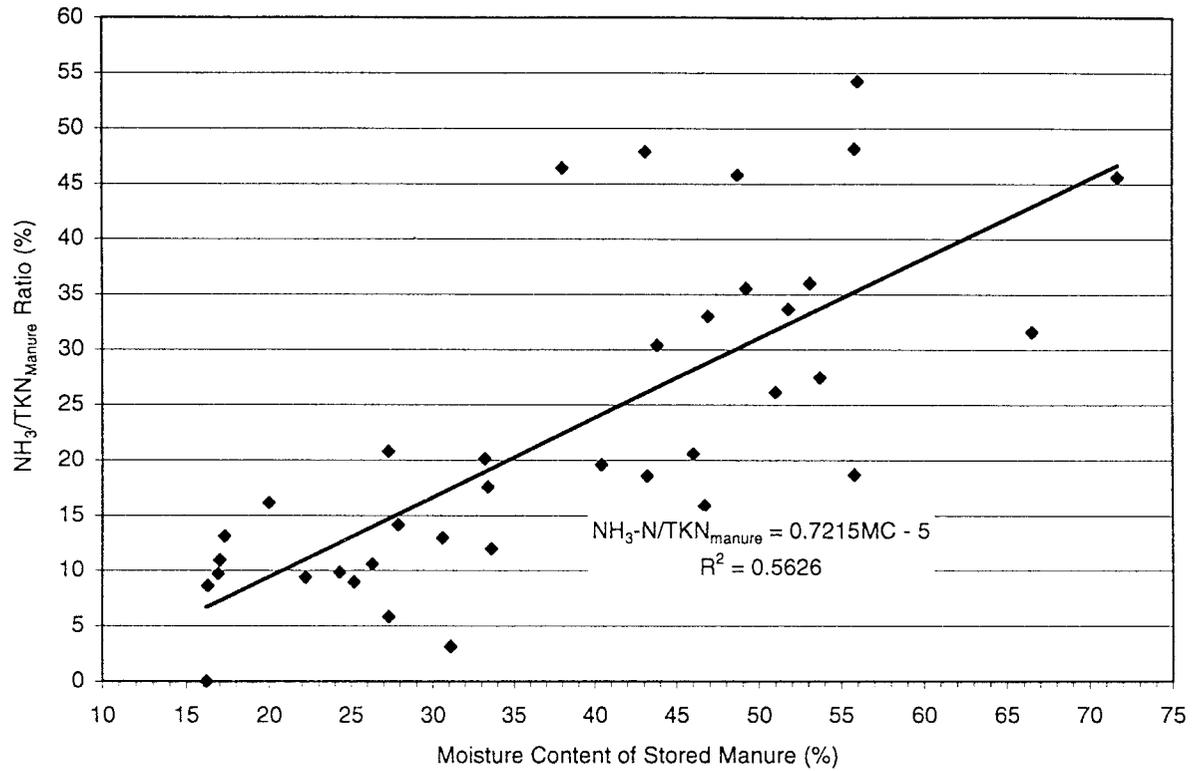
Figure 9–NH$_3$/TKN$_{Manure}$ ratio of stored manure versus MC.

$$NH_3\text{-}N/TKN_{manure} = 0.7215MC - 5$$
$$R^2 = 0.5626$$

Table 6. Average temperature, RH, and MC over the experimental period

Farm		Manure Storage Space		Outside Poultry House		Manure	
		RHinside (%)	Tinside, °C (°F)	RHoutside (%)	Toutside, °C (°F)	MC (% as-is)	Tmanure, °C (°F)
A	Mean	68	23 (73)	75	12 (53)	27.5	33.1 (92)
	SD	8	3	11	12	13.3	1.8
B	Mean	64	22 (72)	82	9 (48)	33.7	37.2 (99)
	SD	9	3	11	11	13.9	2.8
C	Mean	59	23 (73)	73	14 (57)	44.1	33.8 (93)
	SD	10	3	16	10	11.1	1.7
D	Mean	59	23 (73)	82	10 (50)	48.8	39.0 (102)
	SD	9	3	10	11	12.4	3.6
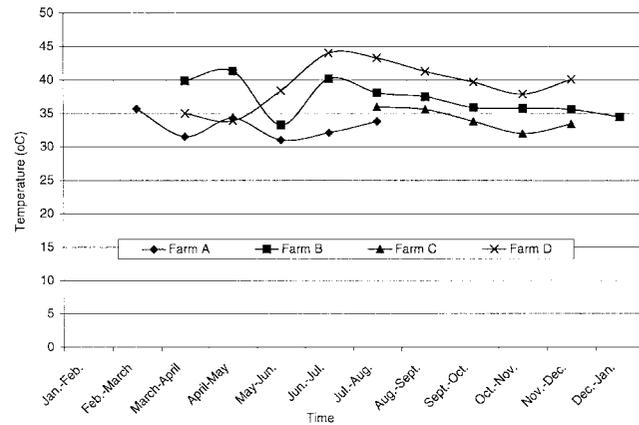
Figure 11–Temperature in the manure pile cores.

MC FARM A = 27.5%
MC FARM B = 33.7%
MC FARM C = 44.1%
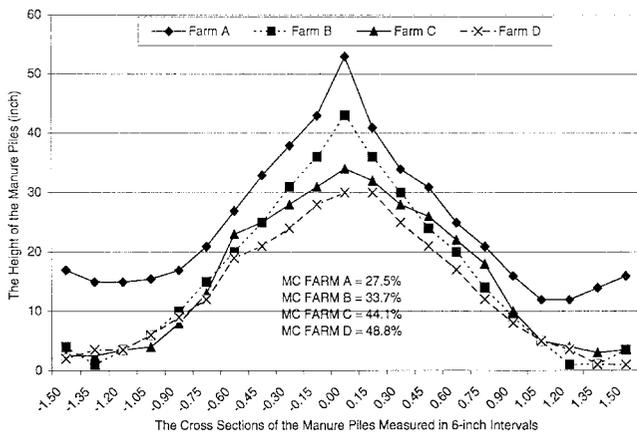MC FARM D = 48.8%

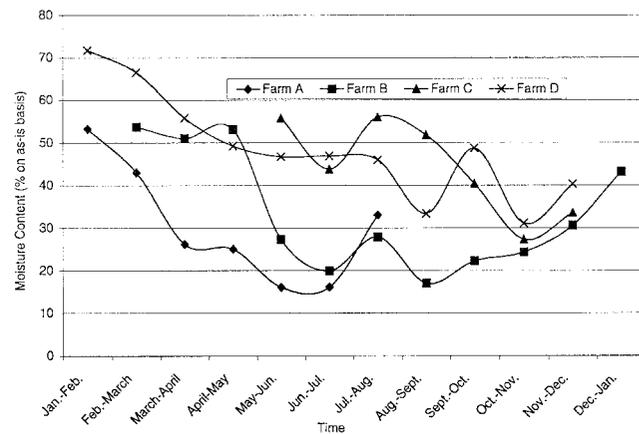Figure 10–Eight months accumulation height and MC of manure piles.

Figure 12–Moisture content of the manure.

Table 7. The N and NH₃-N retained in laying hen manure per 1000 kg live body weight per year for four high-rise houses as compared with ASAE estimates of fresh excreta

	As Excreted*	Farm A	Farm B	Farm C	Farm D
MC (% as-is)	75.0	27.5	33.7	44.1	48.8
N (kg)	306.6	207.51	143.72	79.44	80.30
NH₃-N (kg)	76.7	26.03	23.06	19.26	23.94
Diff. of N (kg)†		99.09	162.88	227.16	226.30
Diff. of NH₃-N (kg)†		50.62	53.59	57.39	52.71

* Values from *ASAE Standards* (1998).

† Differences between N or NH₃-N estimates for manure as excreted and measured values in storage.

concomitant average MC of 48.8% for Farm D. The lowest average temperature was 33.1°C (91.6°C) with the concomitant average MC of 27.5% for Farm A (table 6). The MC of the manure generally tended to decrease with additional storage time as shown in figure 12.

Comparison of TKN_{Manure} and NH_3 in the manure measured in this study and those cited in ASAE (1997) is shown in table 7. Both TKN_{Manure} and NH_3 in the stored manure for the four farms were significantly lower than the fresh excreted manure. This means that both TKN_{Manure} and NH_3 were lost during manure storage.

SUMMARY

A study was conducted to determine N loss from accumulated manure in four commercial high-rise laying hen houses in Iowa. Nitrogen loss from the stored manure varied from 25 to 41% of the TKN intake of the hens. The losses resulted in different TKN concentrations in the stored manure.

The NH_3/TKN ratio in the layer manure was directly proportional to the manure moisture content (MC). Higher NH_3/TKN ratio resulted in higher N loss from the manure by ammonia volatilization. Therefore, moisture in layer manure, which tended to decrease with storage time, was an important factor in N retention of the manure. The height of manure pile was inversely related to MC of the manure.

Both TKN and NH_3 in the stored manure as measured in the study were markedly lower than the published values for excreted raw manure (ASAE, 1997), attributable to N degradation followed by volatilization.

The highest average temperature was 39.0°C (102.2°F) in the manure with an average MC of 48.8%, The lowest was 33.1°C (91.6°F) with average MC of 27.5%.

CONCLUSION

Manure handling systems and manure drying by the ventilation air played an important role in determining high rise layer manure MC, and thus manure decomposition. Use of manure board and scraper system led to drier manure and lower N loss as compared to systems that allowed the excreta to drop directly into the manure storage area.

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