EFFECTS OF MEASUREMENT INTERVALS ON ESTIMATION OF AMMONIA EMISSIONS FROM LAYER HOUSES

Y. Liang, H. Xin, H. Li, R. S. Gates, E. F. Wheeler, K. D. Casey

ABSTRACT. *Continuous quantification of aerial emissions from animal feeding operations over an extended time period is labor and resource intensive. Strategically reducing measurement time to achieve comparable emission results is thus highly desirable. This article delineates the effects of measurement intervals on estimation of annual mean and maximum daily ammonia emission rate (ER) of high-rise (HR) and manure-belt (MB) layer houses. The full dataset consisted of 318 daily ER values of four HR houses from weekly 48 h continuous measurement and 112 daily ER values of two MB houses from bi-weekly 48 h continuous measurements over one-year period. Each full dataset was sampled to yield subsets of daily ER at different intervals, i.e., one week (HR houses only), two weeks, one month, two months, or three months. The corresponding estimates of annual ammonia ER from the subsets were computed and compared with that of the full dataset. The results indicate that the annual mean daily ER values derived from the subsets progressively deviated from that of the full dataset by 3% to 37% for the HR houses and by 6% to 41% for the MB houses. The augmented measurement intervals (i.e., greater than bi-weekly for the HR houses and greater than monthly for the MB houses) led to considerable underestimation of the daily maximum ER values, and thus are not recommended when daily maximum emission values are to be assessed.*

Keywords. *Air quality, Animal feeding operation, Measurement uncertainty, Sampling frequency.*

Continuous measurement of gaseous emissions from animal feeding operations (AFOs) is a complex and resource-intensive task. Strategic, periodic sampling over an extended period may significantly reduce such resource needs, and yet yield reasonably sound data on annual emissions. Techniques of nonparametric estimation of statistical error, such as jackknife estimation (Efron and Gong, 1983), have been used to investigate temporal variability of carbon dioxide flux from soil (Parkin and Kaspar, 2004) or volatile organic compounds in contaminated groundwater (Varljen et al., 1999). Information concerning requirement of measurement intervals and the resultant measurement uncertainty for AFO air emissions is rather meager. Vranken et al. (2004) developed a method for predicting annual ammonia emissions based on a statistical model, derived from 345 days of emission measurements on a commercial Belgian pig farm. The model related intermittent measurements of ammonia emission to building ventilation rate and animal body weight.

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The objective of this article was to delineate the effect of measurement intervals on estimation of annual mean and maximum daily ammonia ER for commercial high-rise (HR) or manure-belt (MB) laying hen houses. Results of this study may provide insight into sampling protocols for future monitoring of AFO air emissions.

MATERIALS AND METHODS

Ammonia emission rate (ER) from four high-rise (HR) and two manure-belt (MB) commercial layer houses were monitored for a full year (Li et al., 2005; Liang et al., 2005). The HR houses featured in-house manure storage for one year, while the MB houses featured daily manure removal. The field measurements were performed for two consecutive days per measurement episode, which was done every week for the HR houses and every two weeks for the MB houses. For each 48 h measurement episode, ammonia concentrations of the exhaust air and building ventilation rates were collected at 30 min intervals. Liang et al. (2005) provided the details of the measurement techniques. As such, the full dataset consisted of 318 daily ammonia ER values (15,264 thirty-minute data points) for the HR houses and 112 daily ammonia ER values (5,376 thirty-minute data points) for the MB houses. Annual mean daily ER values determined from the full dataset for each house (Liang et al., 2005) were used as the references for evaluation of the measurement interval effect. The full dataset was then sampled to generate subsets. Specifically, one-day continuous measurements were sampled at weekly (HR houses only), bi-weekly, monthly, bi-monthly, or tri-monthly intervals (table 1). For instance, all the first daily measurements of each month constituted a subset with a monthly measure-

Table 1. Number of sunsets and daily NH_3 ER per subset for different measurement intervals.

Measurement Interval (month)	No. of Subsets		No. of Daily ER per Subset
	HR	MB	
0.25	8	--	48
0.5	16	4	24
1	32	8	12
2	64	16	6
3	96	24	4

ment interval, while all the second daily measurements of each month constituted another subset with a monthly measurement interval. This monthly sub-sampling resulted in eight one-day subsets per month per house. The longer the sampling intervals, the greater numbers of subsets generated. The annual mean daily ERs of the houses were computed from the subsets and were compared with that from the respective full dataset, i.e., the reference ER.

Deviation between the annual mean daily ammonia ERs derived from the subsets and the full set was quantified using the following standard deviation equation:

$$s = \sqrt{\frac{\sum_{j=1}^{n} (Relative\ Deviation_j)^2}{n-1}} = \sqrt{\frac{\sum_{j=1}^{n} \left[\frac{ER_{j,mean} - ER_{full,mean}}{ER_{full,mean}} \times 100 \right]^2}{n-1}} \quad (1)$$

where

ER_j = annual mean daily NH_3 ER computed from subset j (g d^{-1} hen^{-1})

ER_{full} = annual mean daily NH_3 ER based on the full set (g d^{-1} hen^{-1})

n = number of subsets.

In addition to estimation of the annual mean daily ER, annual maximum daily ammonia ERs were also determined from the subsets and compared to that of the full set. Knowledge of daily maximum ER may be useful for evaluation of potential emission reporting requirements.

Results and Discussion

Annual mean daily NH_3 ERs determined from the full dataset and from the various subsets for houses HR-1 and MB-1 are plotted in figures 1 and 2. The relative deviations of subset-based ERs from the reference for the four HR houses and the two MB houses are plotted in figures 3 and 4. Standard deviations of the relative deviations shown in figures 3 and 4 are presented in table 2. Deviation of the subset-based annual ERs from the reference was positively related to the measurement interval. Specifically, ERs measured at 3-month intervals could deviate from the reference value by −37% to 30% for the HR houses and by −41% to 33% for the MB houses. In comparison, deviations of ERs of the HR houses measured at 0.5-month intervals and of the MB houses measured at 1-month intervals would be within 10%. Vranken et al. (2004) reported that strategic sampling of eight days throughout the year was sufficient to model the specific relationship between ammonia emission

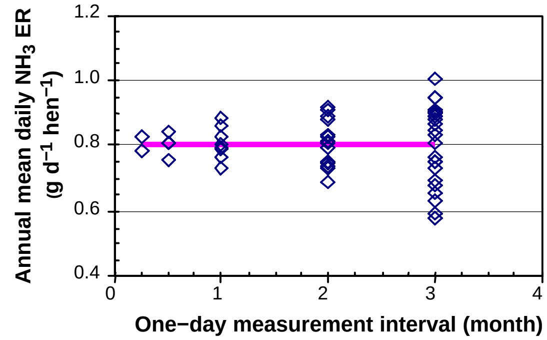

Figure 1. Annual mean daily ammonia emission rate (ER) from subsets at different one-day measurement intervals for a high-rise layer house. Straight line represents the reference ER from the full dataset.

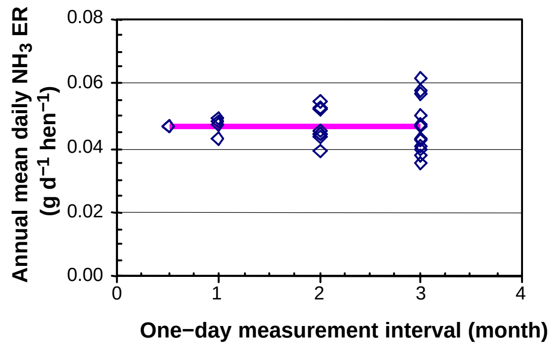

Figure 2. Annual mean daily ammonia emission rate (ER) from subsets at different one-day measurement intervals for a manure-belt layer house. Straight line represents the reference ER from the full dataset.

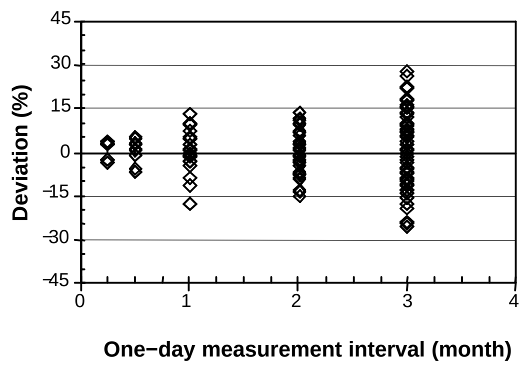

Figure 3. Relative deviation of ammonia emission rate based on the subsets of different one-day measurement intervals from the reference ER of the full dataset for four high-rise layer houses.

Table 2. Standard deviation (%) of relative deviation of subset-based mean daily NH_3 emission rates from that of the full dataset.

Measurement Interval (month)	High-rise	Manure-belt
0.25	3.9	
0.5	4.8	3.8
1	6.6	5.9
2	7.7	12.3
3	15.3	20.5

vs. ventilation rate and average pig weight, thereby predicting annual ammonia emissions from Belgian pig houses.

Frequency distributions of the ER deviations associated with the different measurement intervals for the HR and MB

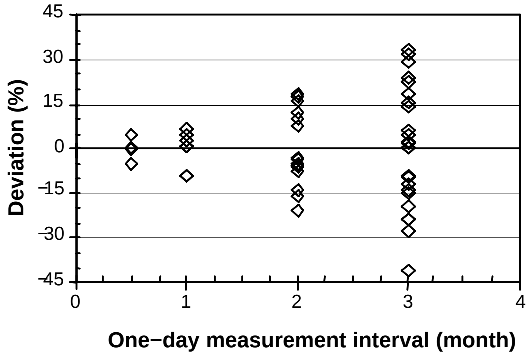

Figure 4. Relative deviation of ammonia emission rate based on the subsets of different one-day measurement intervals from the reference ER of the full dataset for two manure-belt houses.

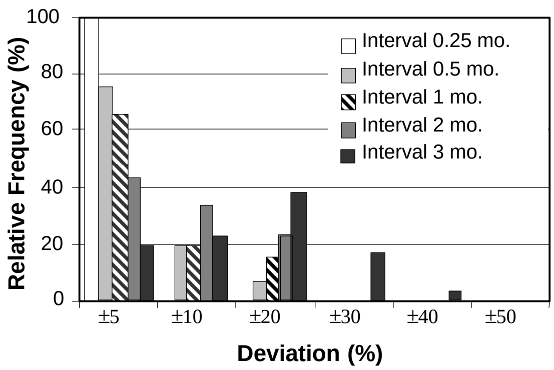

Figure 5. Frequency distributions of ammonia emission rate deviations from the reference value at different one-day measurement intervals for the high-rise layer houses.

houses are illustrated in figures 5 and 6, respectively. These distribution patterns allow for a comparative observation of where the most deviations would fall for a given measurement interval. For instance, 100% of the daily ER estimates at the weekly measurement interval were within ±5% of the reference ER for the HR houses. In comparison, most of the daily ER estimates derived from the 3-month measurement interval will be expected to have 20% deviation from the references for both housing types.

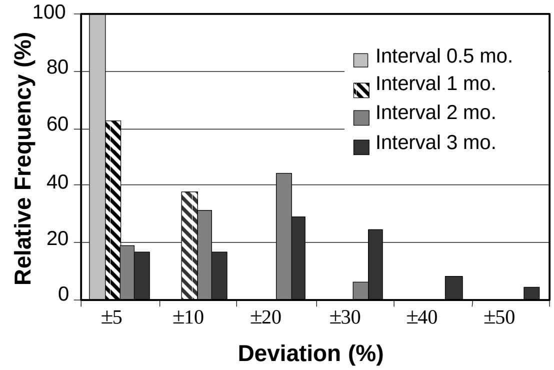

Figure 6. Frequency distributions of ammonia emission rate deviations from the reference value at different one-day measurement intervals for the manure belt houses.

The maximum daily ER values of the HR houses obtained with the subsets measured at bi-weekly, monthly, bi-monthly, and tri-monthly intervals were within 73%, 67%, 58%, and 46%, respectively, of the reference maximum daily ER with the full dataset (table 3). Similarly, the maximum daily ER values of the MB houses obtained with the subsets measured at monthly, bi-monthly, and tri-monthly intervals were within 56%, 33%, and 30%, respectively, of the reference maximum daily ER with the full dataset (table 4). Hence, augmented measurement intervals would fall short in identifying the maximum daily emissions.

CONCLUSIONS

Measurement uncertainty in annual mean and maximum daily ammonia emission rate (ER) associated with periodic sampling was investigated for high-rise (HR) and manure-belt (MB) laying hen houses. Using ER values derived from 2-day continuous measurements conducted weekly for the HR houses and bi-weekly for the MB houses as the reference values, the analysis revealed the following:

- Annual mean daily ammonia ER estimated from 24 h continuous measurements conducted bi-weekly for the HR houses or monthly for the MB houses would be within 10% of the reference ER values. Longer mea−

Table 3. Annual mean and maximum daily NH_3 emission rates (ER, g d^{-1} hen^{-1}) from the full dataset (ER_{full}) and the ranges of annual maximum daily NH_3 ER from subsets (ER_{sub}) of high-rise (HR) layer houses at four measurement intervals.

HR House		ER_{full}	ER_{sub} at Different One-day Measurement Intervals: Bi-weekly Mean	Bi-weekly Range[a]	Monthly Mean	Monthly Range[a]	Bi-monthly Mean	Bi-monthly Range[a]	Tri-monthly Mean	Tri-monthly Range[a]
1	Mean	0.84	0.84		0.84		0.84		0.83	
	Max	1.48	1.31	1.23-1.48 (83%-100%)	1.23	1.05-1.48 (71%-100%)	1.23	1.05-1.48 (71%-100%)	1.06	0.69-1.48 (46%-100%)
2	Mean	0.95	0.95		0.95		0.96		0.95	
	Max	1.74	1.42	1.26-1.74 (73%-100%)	1.35	1.16-1.74 (67%-100%)	1.31	1.01-1.74 (58%-100%)	1.21	0.87-1.74 (50%-100%)
3	Mean	0.81	0.81		0.81		0.81		0.81	
	Max	1.35	1.17	1.02-1.35 (76%-100%)	1.12	0.92-1.35 (68%-100%)	1.11	0.94-1.35 (69%-100%)	1.04	0.75-1.35 (55%-100%)
4	Mean	0.80	0.80		0.80		0.81		0.80	
	Max	1.33	1.19	1.13-1.33 (85%-100%)	1.11	1.01-1.33 (76 %-100%)	1.10	0.84-1.33 (63%-100%)	1.02	0.81-1.33 (61%-100%)

[a] Values in parentheses are percentages of maximum ER estimates by the subset in reference to the full dataset.

Table 4. Annual mean and maximum daily NH_3 emission rates (ER, g d^{-1} hen^{-1}) from the full dataset (ER_{full}) and the ranges of annual maximum daily NH_3 ER from subsets (ER_{sub}) of manure-belt (MB) layer houses at three measurement intervals.

MB House		ER_{full}	ER_{sub} at Different One-day Measurement Intervals: Monthly Mean	Monthly Range[a]	Bi-monthly Mean	Bi-monthly Range[a]	Tri-monthly Mean	Tri-monthly Range[a]
1	Mean	0.047	0.047		0.047		0.047	
	Max	0.100	0.079	0.066-0.100 (66%-100%)	0.070	0.055-0.100 (55%-100%)	0.064	0.044-0.100 (44%-100%)
2	Mean	0.063	0.063		0.064		0.064	
	Max	0.172	0.126	0.095-0.172 (56%-100%)	0.096	0.056-0.172 (33%-100%)	0.091	0.052-0.172 (30%-100%)

[a] Values in parentheses are percentages of maximum ER estimates by the subset in reference to the full dataset.

surement intervals would lead to deviations of the mean ER from the reference value by 15% to 37% for the HR houses and by 20% to 41% for the MB houses.

- The augmented measurement intervals (i.e., greater than bi-weekly for the HR houses and monthly for the MB houses) led to considerable underestimation of the daily maximum ER values, and thus would not be recommended when daily maximum emission values are to be assessed.

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