Information and Comments, Recommendations ("FWTAW")

- *to NAEMS Science Advisory Board*
- *by Al Heber, Purdue University*
- *March 15, 2012*

Independent Variables (RH for example)

- ***Function of temperature, "relative"***
- ***Does not directly affect emissions.***
- ***RH is not available information***

For now, use "Simple Sensible Statistical" Prediction

- E' (g/d-m2) = f(LMD, Ti)
  - LMD = # birds x avg wt / area
  - Ti = inside temperature
- So E = A * E'
- So Ti = f(To, LMD, Q', UA, setpoints, etc.)
- Notes:
  - Use hourly data to develop models.
  - Q independent of emissions, per se.
  - Must make physical sense.
- Use data to validate process-based models.

Prediction Models – IN3B (based on HOURLY data)

$$E_{PM_{10}} = -0.162277 + 0.001762 * D + 0.010301 * T + 0.000435 * M$$

where:

E_{PM10} = emission rate in g d^{-1} m^{-2}
D = live mass density, kg m^{-2}
T = barn temperature, °C
M = manure depth, cm

Emission rate	Equations	R^2
NMHC, *kg d^{-1} m^{-2}*	$E_{NMHC} = -0.000030172 + 0.000002162 * D + 0.000008917 * T - 0.000000191 * M$	0.142
H_2S, *g d^{-1} m^{-2}*	$E_{H_2S} = -0.290981 + 0.00523 * D + 0.003924 * T - 0.010019 * M$	0.112
CO_2, kg d^{-1} m^{-2}	$E_{CO_2} = -0.797271 + 0.021896 * D + 0.011926 * T - 0.005058 * M$	0.709
NH_3, kg d^{-1} m^{-2}	$E_{NH_3} = 0.002359 + 0.000061368 * D + 0.000080059 * T$	0.438

D = # animals x average weight / floor area
T = temperature setpoint , default values, thermal model

Sampling times for VOC

- *"Except for times that canisters were received from multiple sites on same day (rare), <u>we transferred the sample from the canister upon arrival</u>. Several samples had to wait 24 h in the lab, and <u>very very few</u> samples waited more than 48 h before transferring, which was an overnight operation. Analysis would start right after the completion of the sample transfer. Almost no samples waited for more than 48 h before transferring, or analysis after transfer."*

Broiler House VOC Sampling

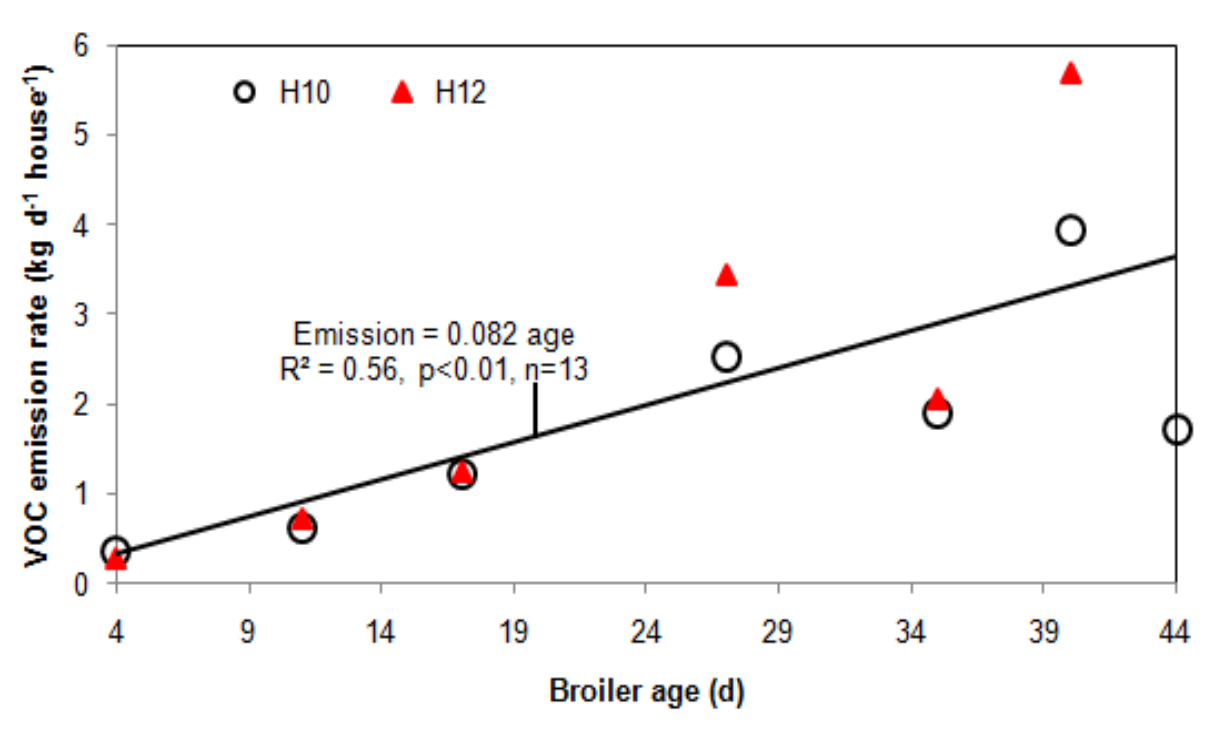
Table 1. Bird and manure age during VOC sampling periods in the broiler houses.

Sample date	Cycle	Bird age, d	Manure age[1], d
7/14/09	1	40	95
8/3/09	2	4	115
8/16/09	2	17	128
8/26/09	2	27	138
9/3/09	2	35	146
9/12/09	2	44	155
10/7/09	3	11	11

[1] Day 1 was the first day of a cycle of birds after all manure was loaded out.

- ***EPA apparently did not use this data and judged the VOC data based on the lack of this information.***

VOC Emission vs. Bird Age



Adjustment of Layer Site VOC Emission to Annual Average

- ***Average VOC emission = 5.42 kg/d. House temperature and airflow showed a strong correlation with VOC emission. A linear regression of VOC emission (V) and ambient temperature (T) resulted in V = 0.46 T – 4.5 (R^2=80%). Using this equation to predict the annual average VOC emission based on the historical mean ambient temperature of 15.0°C resulted in V = 0.46 (15°C) – 4.5 = 2.40 kg/d.***
- ***Similarly, the California VOC was collected during warm weather and should be adjusted downward to annual average T, which would make the average closer to the Kentucky data.***

Two-Year Average Gas Concentrations and Inlet/Outlet Ratios (%)

Site	NH_3			H_2S			CO_2		
	Inlet	Exh.	Ratio	Inlet	Exh.	Ratio	Inlet	Exh.	Ratio
CA1B	0.29	21.8	1.3%	2.10	39.8	5.3%	449	1,556	28.9%
CA2B	1.40	26.6	5.3%	2.40	22.4	10.7%	474	1,030	46.0%
IN2B	0.70	26.1	2.7%	2.00	46.5	4.3%	495	2,290	21.6%
IN2H	1.90	50.4	3.8%	7.00	24.0	29.2%	483	1,780	27.1%
NC2B	0.91	20.8	4.4%	0.87	9.30	9.4%	506	1,657	30.5%
IN3B	0.20	13.3	1.5%	22.0	596	3.7%	495	2,190	22.6%
NC3B	0.25	11.5	2.2%	4.80	176	2.7%	459	1,522	30.2%
NC4B	0.50	5.73	8.7%	6.00	452	1.3%	450	1,694	26.6%
IA4B	0.42	11.7	3.6%	15.0	1,490	1.0%	459	1,648	27.9%
OK4B	0.29	6.13	4.7%	8.00	334	2.4%	479	1,470	32.6%
IN5B	0.14	2.67	5.2%	2.70	27.8	9.7%	459	767	59.8%
WI5B	0.12	1.75	6.6%	5.40	99.6	5.4%	424	872	48.6%
NY5B	0.40	4.25	9.4%	3.00	28.5	10.5%	484	980	49.4%
WA5B	0.90	1.53	58.8%	25.6	30.5	83.9%	657	792	83.0%
CA5B	0.48	0.52	91.3%	18.0	19.0	94.7%	436	450	97.0%
Avg MV	0.58	15.6	4.6%	6.3	257.3	7.4%	470.5	1,496.5	34.8%
Avg NV	0.69	1.0	75.1%	21.8	24.8	89.3%	546.7	621.0	90.0%

Two-Year Average PM Concentrations and Inlet/Outlet Ratios (%)

Site	PM10, µg/m^3			PM2.5, µg/m^3			TSP, µg/m^3		
	Inlet	Exh.	Ratio	Inlet	Exh.	Ratio	Inlet	Exh.	Ratio
CA1B	58.5	956	6.1%	21.8	104	20.9%	71.2	2,237	3.2%
IN2B	123	663	18.6%	45.0	108	41.6%	350	1,432	24.4%
IN2H	101	556	18.2%	19.0	53.5	35.5%	77.0	1,297	5.9%
NC2B	36.0	464	7.8%	23.0	40.0	57.5%	41.0	885	4.6%
CA2B	58.0	302	19.2%	28.6	53.9	53.1%	56.1	707	7.9%
IN3B	22.0	260	8.5%	13.2	19.3	68.4%	28.0	1,024	2.7%
NC3B	19.2	283	6.8%	11.6	26.2	44.3%	24.4	757	3.2%
IA4B	20.0	324	6.2%	9.0	43.7	20.6%	20.0	753	2.7%
OK4B	29.0	267	10.8%	9.0	30.7	29.3%	27.0	505	5.3%
NC4B	13.0	285	4.6%	1.2	31.3	3.8%	18.0	472	3.8%
IN5B	21.0	24.0	87.5%	13.8	14.5	95.2%	22.0	46.0	47.8%
WI5B	17.7	42.0	42.3%	9.8	19.4	50.5%	21.7	81.3	26.6%
NY5B	13.0	38.5	33.8%	9.3	14.8	63.1%	19.0	65.0	29.2%
WA5B	96.0	182	52.9%	22.8	39.3	58.1%	191	608	31.4%
CA5B	48.0	47.5	101.1%	11.8	6.1	193.4%	65.0	119	54.9%
Avg MV	40.9	343.3	20.8%	16.5	43.0	44.9%	59.6	789.4	12.9%
Avg NV	72.0	114.5	77.0%	17.3	22.7	125.8%	128.0	363.3	43.1%

PM Completeness

- *PM10 first priority*
  - *Interrupted only by TSP and PM2.5*
  - *364/609 = 60%*
- *TSP second priority*
  - *Measured 1/8 of the time. 17*7=119 d*
    - *Completeness = 38/91 = 42%*
- *PM2.5 third priority*
  - *2 weeks winter, 2 weeks summer*
    - *Completeness = 48/28 = 171%*

Table 1. Emissions data completeness (days with >75% valid emission data collection).

Location	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
H10	467	592	352	53	37
H12	466	590	376	43	39

Missing Ammonia Data

Approximately 144 d of NH3 concentration data were lost or invalidated due to INNOVA-related issues.

Gas concentrations were invalidated between 9/27/08 and 11/9/08, because of a leak in the GSS and high analyte concentrations detected during zero gas checks

See Table of Major Data Invalidations for other losses.

Short term negative emission

- Emission calculations are “noisy” due to:
  - Analyzer noise
  - Wind caused variations in inlet concentrations.
  - Localized activities (mowing, man. hauling, gravel rds, etc.)
  - Location-shared and nonsimultaneous sequential sampling
- Subtracting inlet introduces some negative emissions when inlet concentration > outlet concentrations
  - Low emissions
  - Imperfect representation of inlet air (e.g. 1200 ft of eave inlet).
  - Interpolation of inlet air readings coupled with interpolation of outlet.
- Also introduces unnoticed high biases of emissions.
- Actual negative emissions could result from:
  - Dry scrubbing.
  - PM settling in barn.
  - Ammonia wet deposition and adsorption

Feed samples

- 44 samples (22 each house) were taken. Data resubmitted to EPA today.
- Missing from 2010 EPA Report.
- Meant to submit on 8-2-11.
- N content, solids content
  - 2.2 to 4.4% TKN

CO2 Data

- Concentrations submitted early 2010.
- Daily and hourly emissions submitted a few days ago.

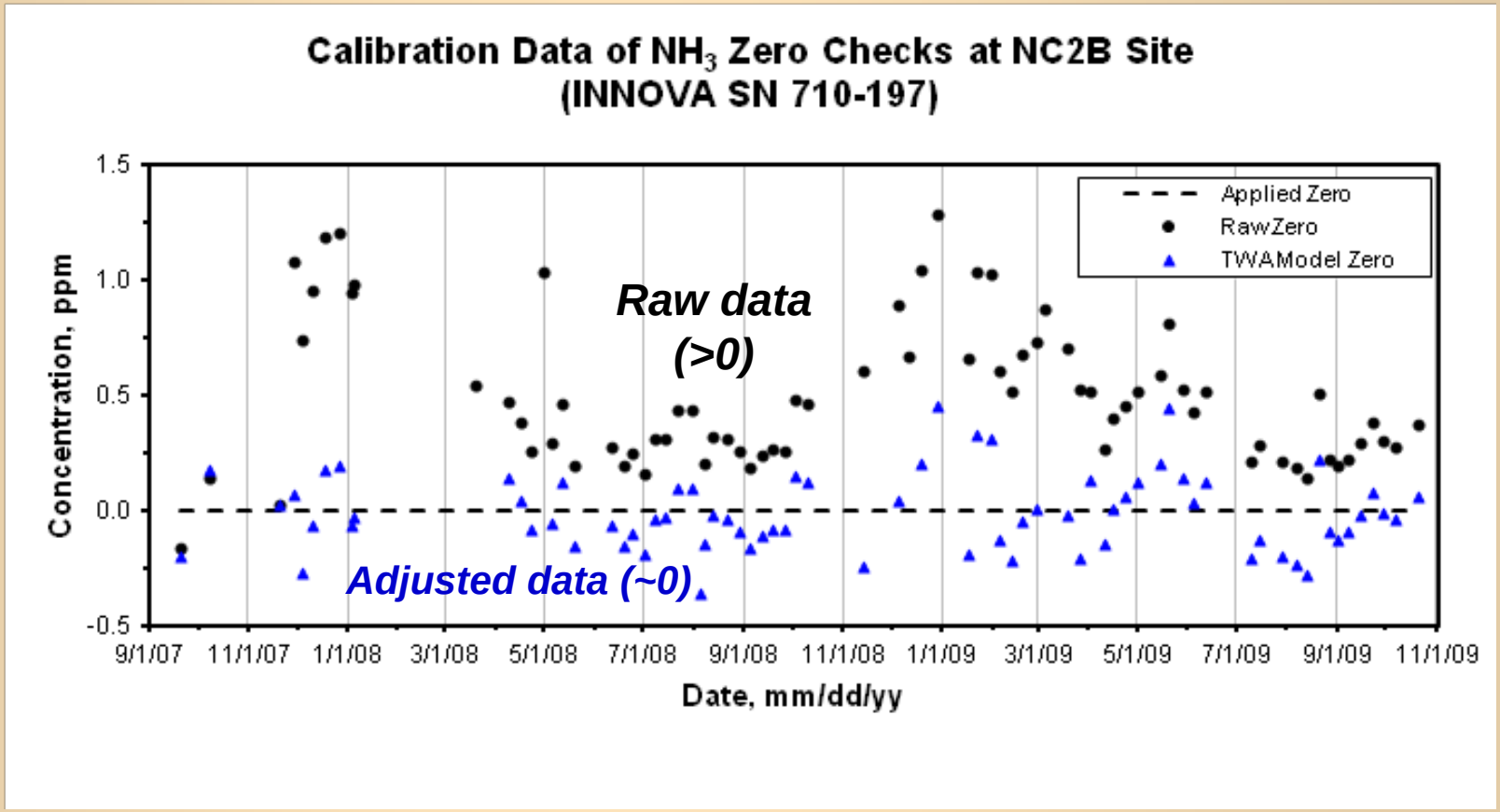
Broiler Site Publications

- Lin, X-.J., E.L. Cortus, R. Zhang, S. Jiang, and A.J. Heber. 2011. Ventilation monitoring of broiler houses in California. Transactions of ASABE 54(3):1059-1068.
- Lin, X.J., E.L. Cortus, R. Zhang, S. Jiang, and A.J. Heber. (Accepted 2/29/12 pending acceptable revision.). Air emissions from broiler buildings in California. Transactions of ASABE.

Are negative concentrations are bad data?

1. ***Gas analyzers have noise – random up and down variation, even when measuring zero.***
2. ***Slightly negative gas concentrations occur with zero or very low concentrations. Negative gas concentrations in the NAEMS were <u>slight</u>.***
3. ***Similar but unnoticed noise occurs at high gas levels.***
4. ***EPA advised Purdue not to delete noise-related negatives for the emission calculations. "Report the validated data and indicate the MDL rather than arbitrarily modifying the data".***
5. ***Slight to large negative PM concentrations can occur at short time scales (minute, hour) due to moisture, but disappear at longer time scales (day, month, year)***
   1. ***Negative PM2.5 more frequent than PM10 and TSP.***
6. ***Changing the treatment of readings<MDL would require Purdue to recalculate all the data submitted to EPA.***

Calibration Adjustment Zero Checks for NH3 analyzer



Seven (7) adjustment models (NH3 NC2B) (2, 1, 7, 2, 2, 4 and 2 months)

Start/end dates	# of checks		Linear model	Accuracy, % of span			
				Bias		Precision	
	Zero	Span		z	s	z	s
9/20/07-11/19/07	3	3	y = 1.14x – 0.06	0.0	0.0	1.0	3.3
11/28/07-1/4/08	7	7	y = 1.10x – 1.15	0.0	0.0	0.2	3.1
3/19/08-10/10/08	26	26	y = 1.05x – 0.39	0.0	0.0	0.2	2.4
11/13/08-1/16/09	6	5	y = 1.04x – 0.87	0.0	0.0	0.3	0.6
1/22/09-3/26/09	8	9	y = 1.04x – 0.78	0.0	0.1	0.3	0.8
4/02/09-8/13/09	15	15	y = 1.09x – 0.44	0.0	0.3	0.5	2.6
8/20/09-10/20/09	9	9	y = 1.11x – 0.34	0.0	0.0	0.3	0.7

Effect of Ventilation

- MV barns can represent NV barns.
- Can’t measure NV barns reliably.
- Everything else is the same in the barn.
- Temperature affects emissions more than ventilation type.

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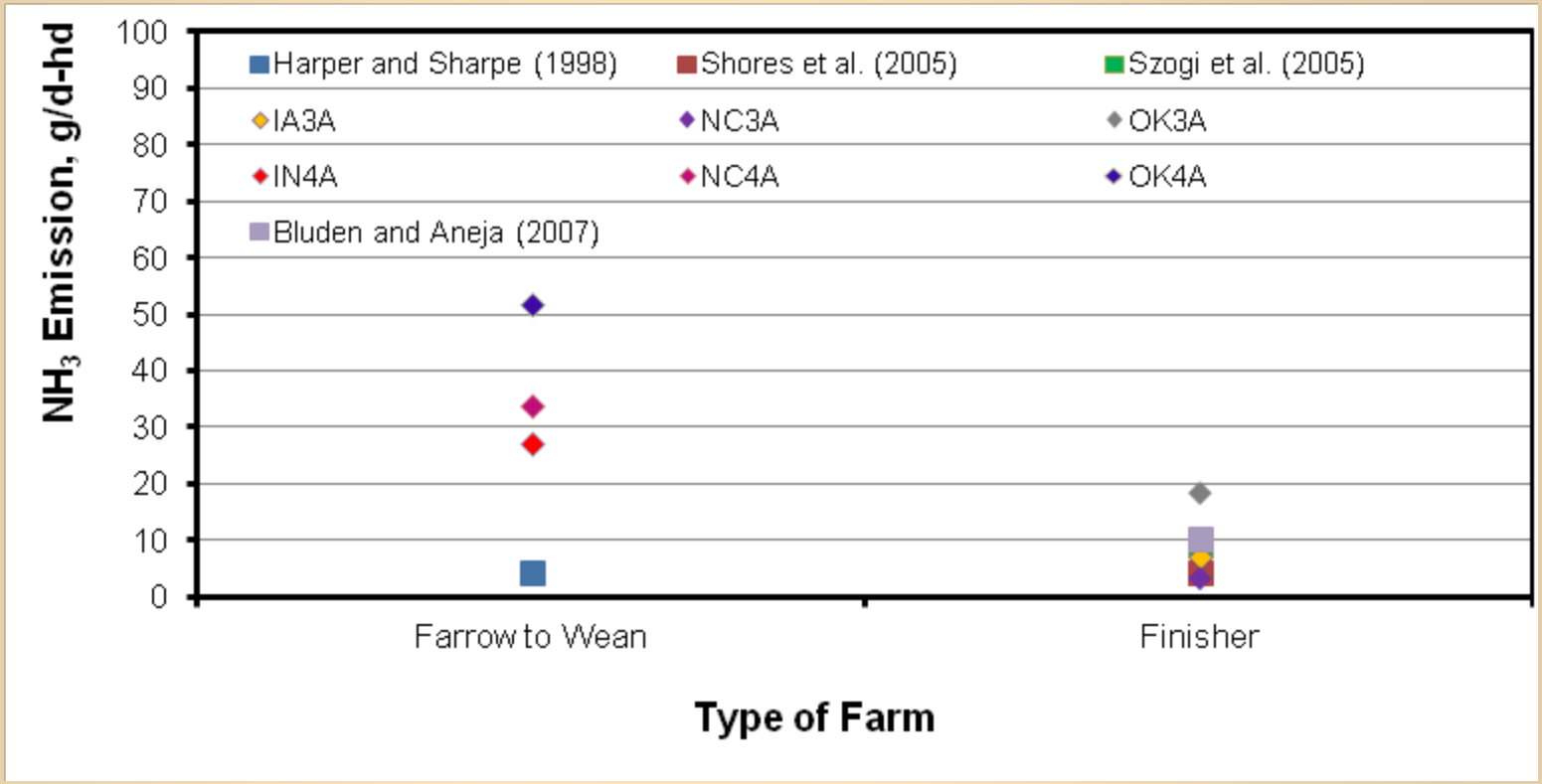
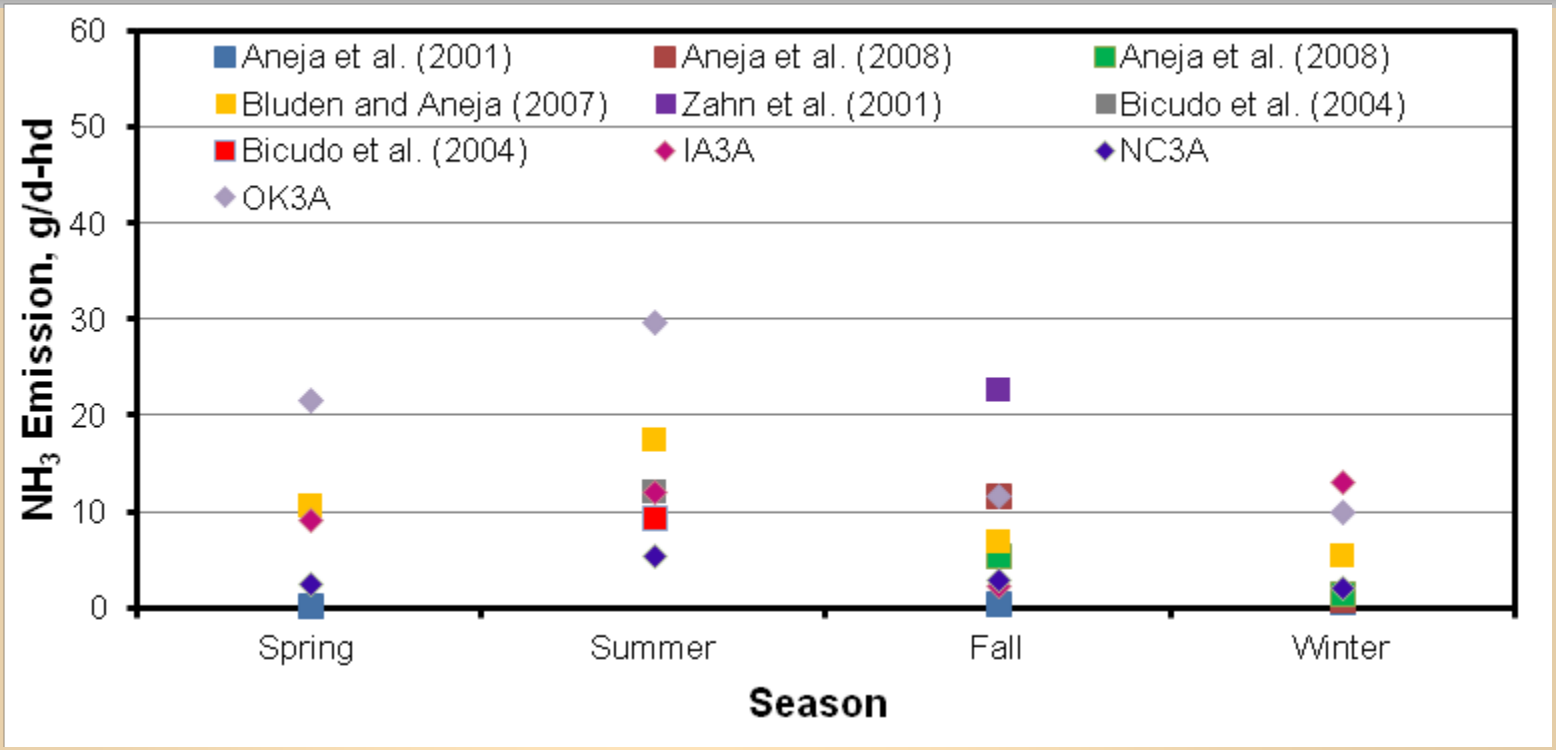
Loading Rates, Pork

	IA3A	IN4A	NC3A	NC4A	OK3A	OK4A
Sow Capacity		1400		2000		2784
Average Sow Weight, lbs		475		433		490
Finisher Capacity	3840		8000		3000	
Average Finisher Weight, lbs	150		135		170	
Piglet Capacity		1960		2800		3898
Average Piglet Weight, lbs		11		11		11
Calculated Animal Units	524	624	982	815	464	1279
Source Surface Area, m^2	2350	12009	18878	22641	11139	21381
Source Capacity, m^3	5768	40208	46003	60779	28663	84453
Mean Source Depth, m	2.5	3.3	2.4	2.7	2.6	3.9
Guideline Volumetric VS Loading Rate						
lbs/d-1000 ft^3	3.5	3.8	4.5	4.5	4.2	4.2
kg/d	324	2453	3323	4390	1932	5694
lbs/d-acre	1200	1200	1200	1200	1200	1200
kg/d	317	1619	2544	3052	1501	2882
Calculated VS Loading Rate, kg/d	2244	1440	4205	1886	1987	2950
kg/d-AU	4.28	2.31	4.28	2.31	4.29	2.31
Ratio of Calculated to Guideline Volumetric VS Loading Rate	6.92	0.59	1.27	0.43	1.03	0.52
Ratio of Calculated to Guideline Area-Based VS Loading Rate	7.08	0.89	1.65	0.62	1.32	1.02

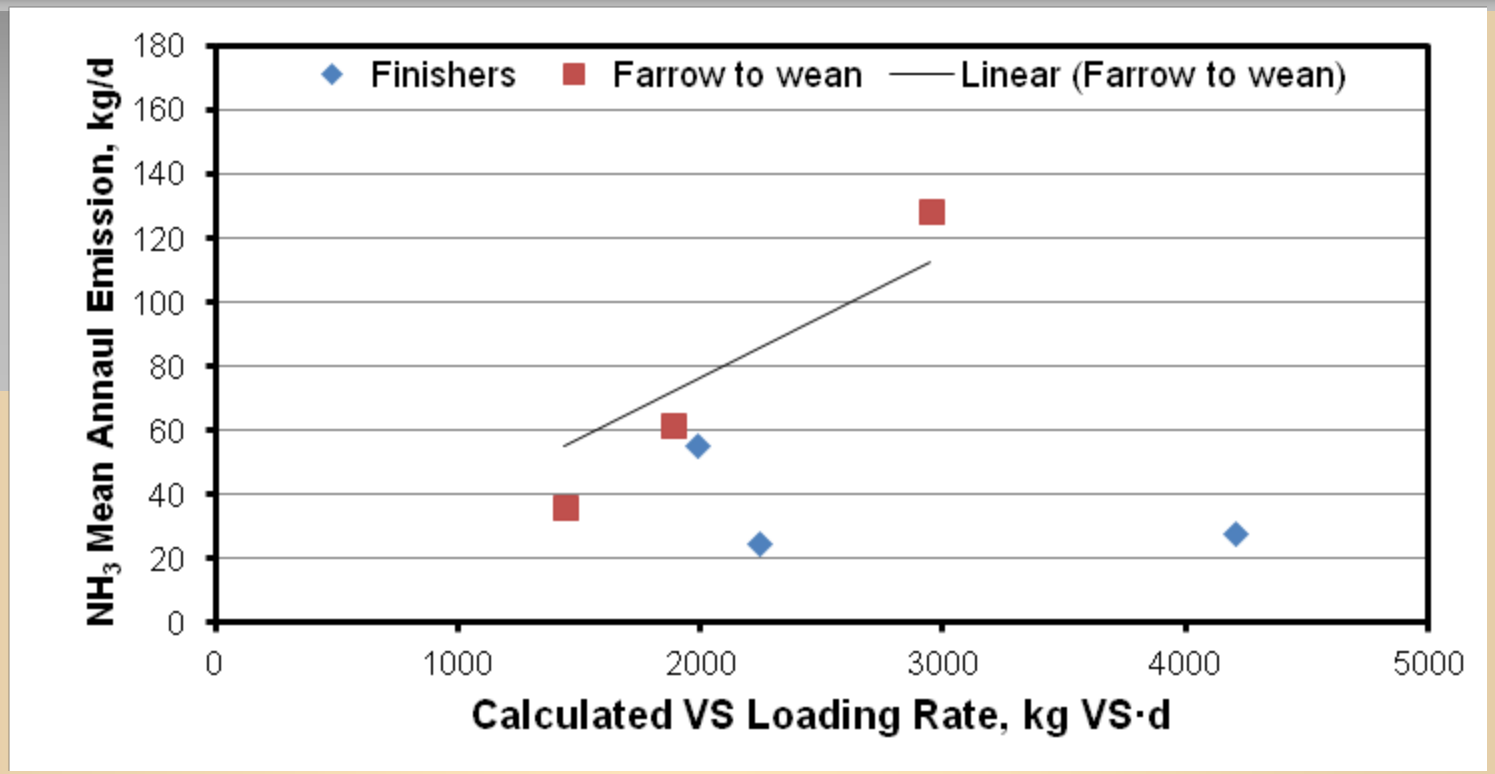
Pork Open Source Ammonia Emissions



Seasonal Variation Open Source Pork



Comparison between mean annual NH_3 emissions and VS loading rates (based on farm capacity). Regression (forced through 0): y=0.0382x (R^2=0.84).



Pork Open Sources

Farm	Type	Manure Handling	Animal Capacity	VS Loading (lb/d)
IA3A	Finisher	Pull plug, basin	3840	4936
IN4A	Farrow to wean	Deep pits, lagoon	1400 sows / 1960 piglets	3169
NC3A	Finisher	Pull plug with recharge, lagoon	8000	9251
NC4A	Farrow to wean	Pit recharge, lagoon	2000 sows / 2800 piglets	4149
OK3A	Finisher	Pull plug with recharge, lagoon	3000	4372
OK4A	Farrow to wean	Pull plug with recharge, lagoon	2784 sows / 3898 piglets	6490

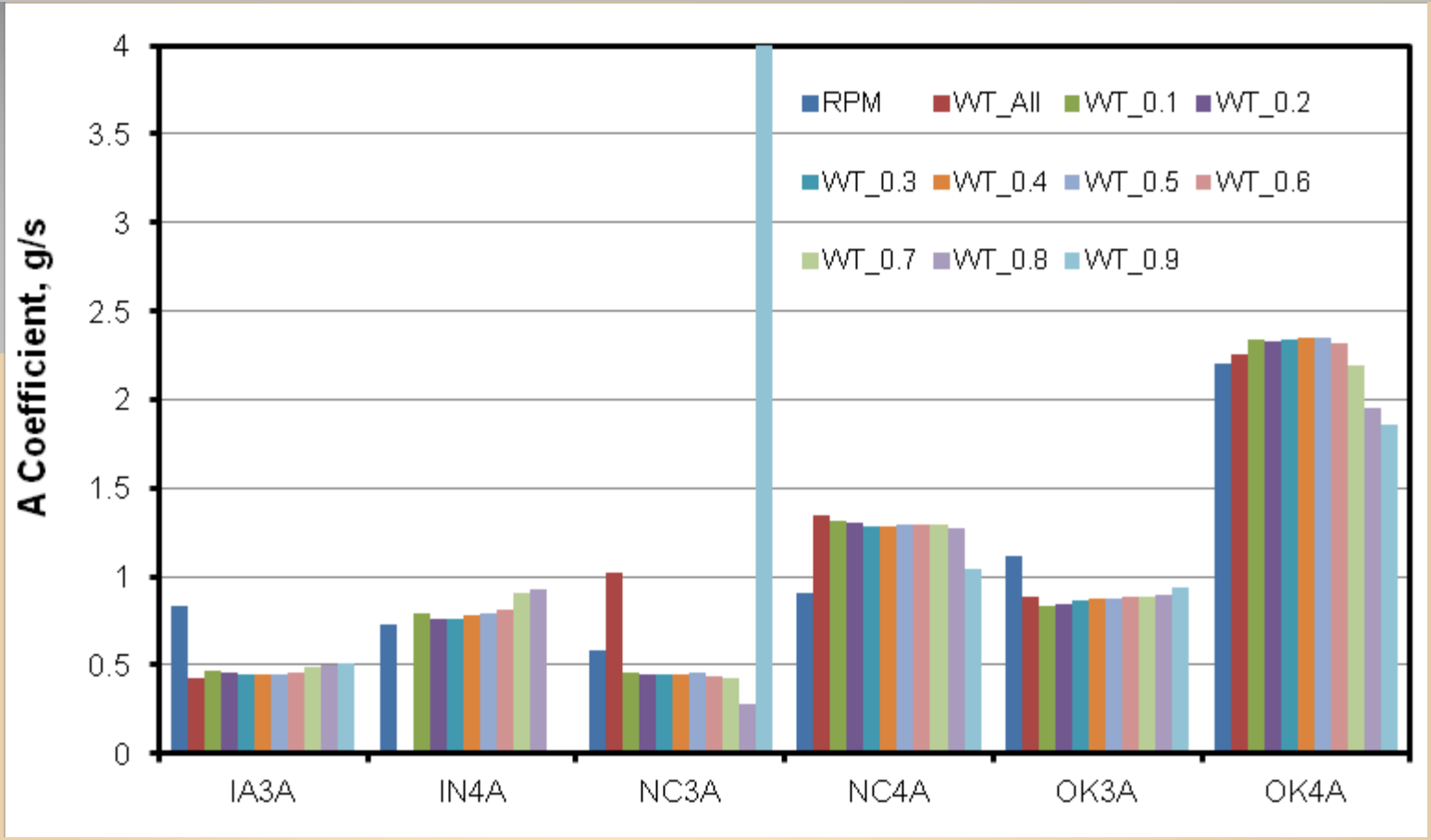
Pork Lagoon Emission Model

The 30-min NH_3 emissions data were compared with a variety of other variables, including, primarily, wind speed, air temperature, and lagoon temperature. The emission rate was found to have the closest relationship with air temperature, with some relationship to lagoon temperature and virtually no relationship to wind speed. The temperature dependence is in agreement with the Henry's law temperature dependence of the solubility of NH_3 in water. The emissions data were fit to the following equation:

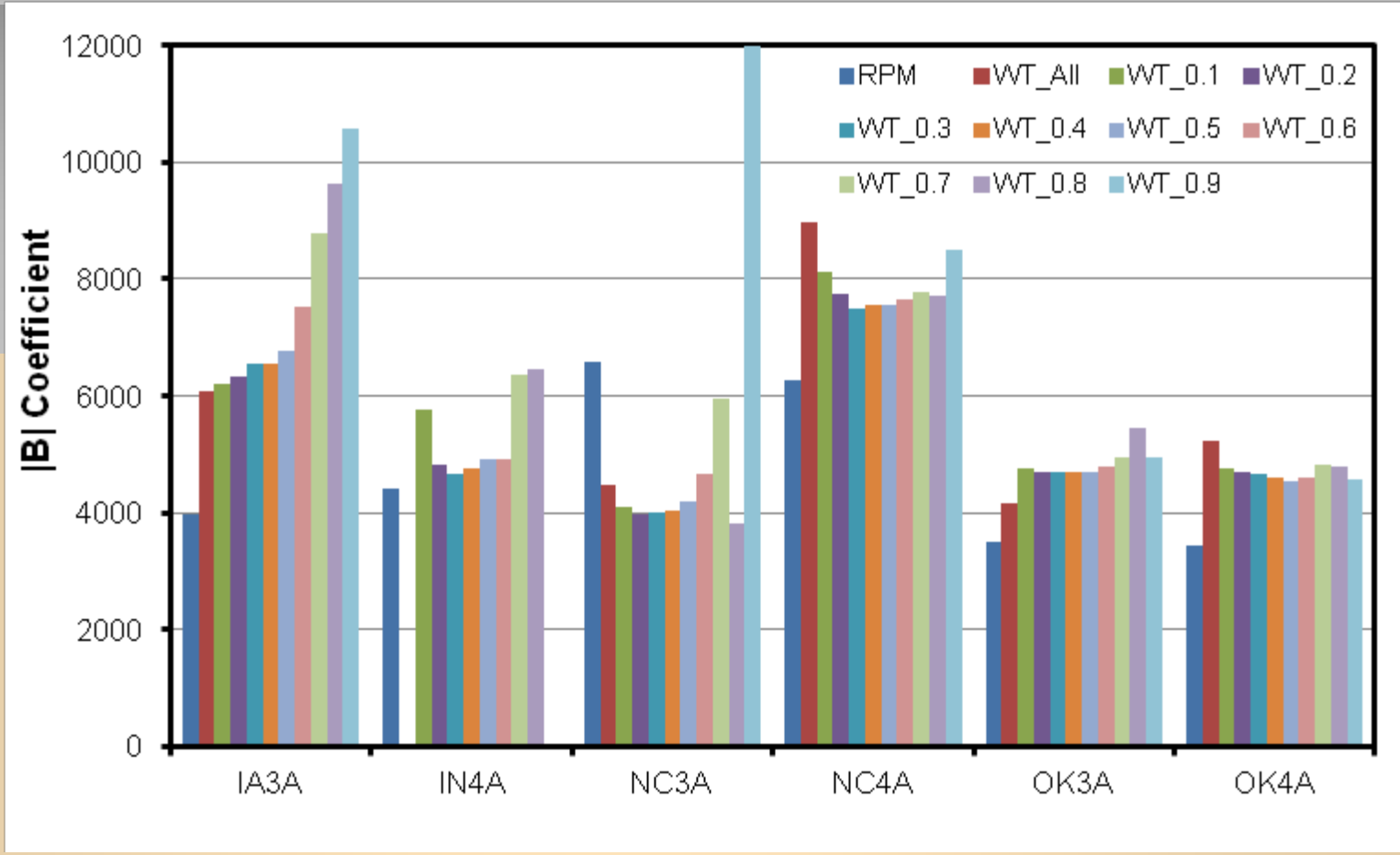
$$NH_3\ Emission_{30-min} = Ae^{-B\left(\frac{1}{T_{air}} - \frac{1}{298}\right)}$$

In this equation, A represents the emission rate at 298 K and B is the coefficient for the exponential dependence on temperature. The equation has the same form as Henry's Law, in which the value of B for NH_3 in pure water is about -4200.

A Coefficient



B Coefficient



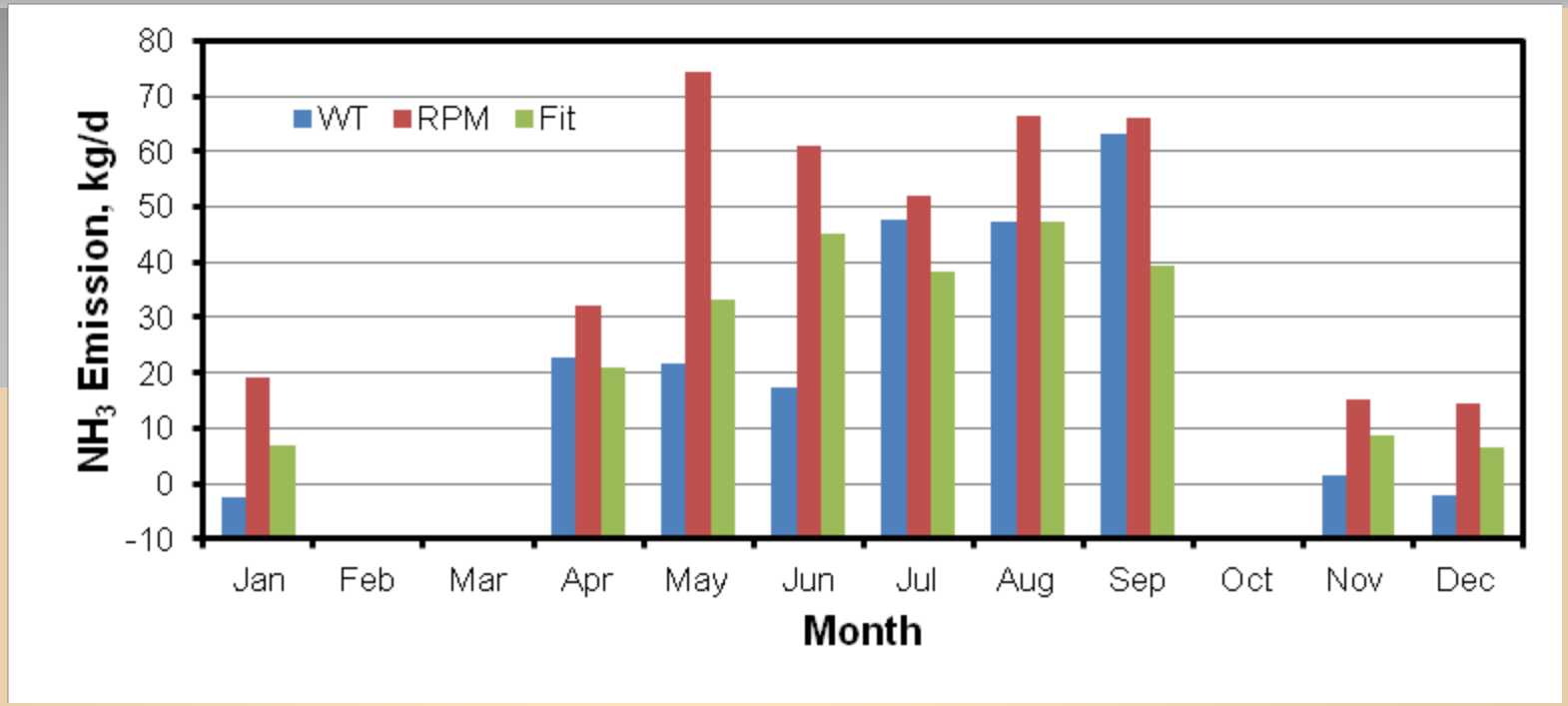
Fit Coefficients for East Site

Site	Average Fit		WindTrax Model Fit				Radial Plume Model Fit			
	A (g/s)	B	Count	A (g/s)	B	R^2	Count	A (g/s)	B	R^2
IA3A	0.65	-5748	1363	0.46	-7513	0.37	1059	0.84	-3983	0.41
IN4A	0.77	-4674	276	0.81	-4932	0.41	340	0.73	-4416	0.26
NC3A	0.51	-5630	1389	0.44	-4669	0.17	1132	0.58	-6591	0.38
NC4A	1.10	-6958	1676	1.29	-7658	0.57	1182	0.91	-6259	0.54
OK3A	1.00	-4158	2799	0.88	-4805	0.50	1620	1.11	-3510	0.33
OK4A	2.26	-4022	2776	2.32	-4594	0.55	2307	2.21	-3450	0.42

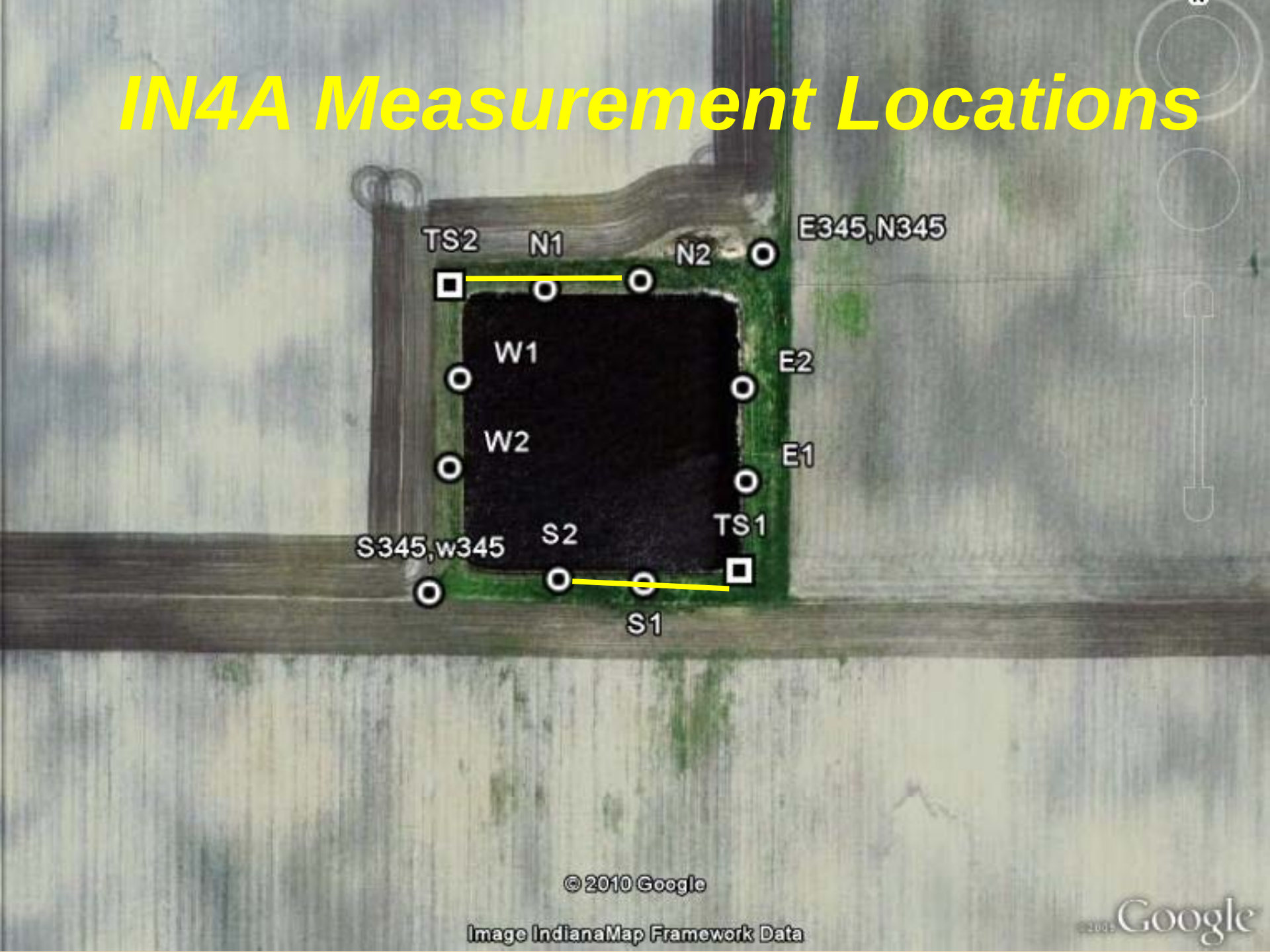
IA3A

- *3840 Finishers*
- *524 Animal Units*
- *Pull plug, basin*

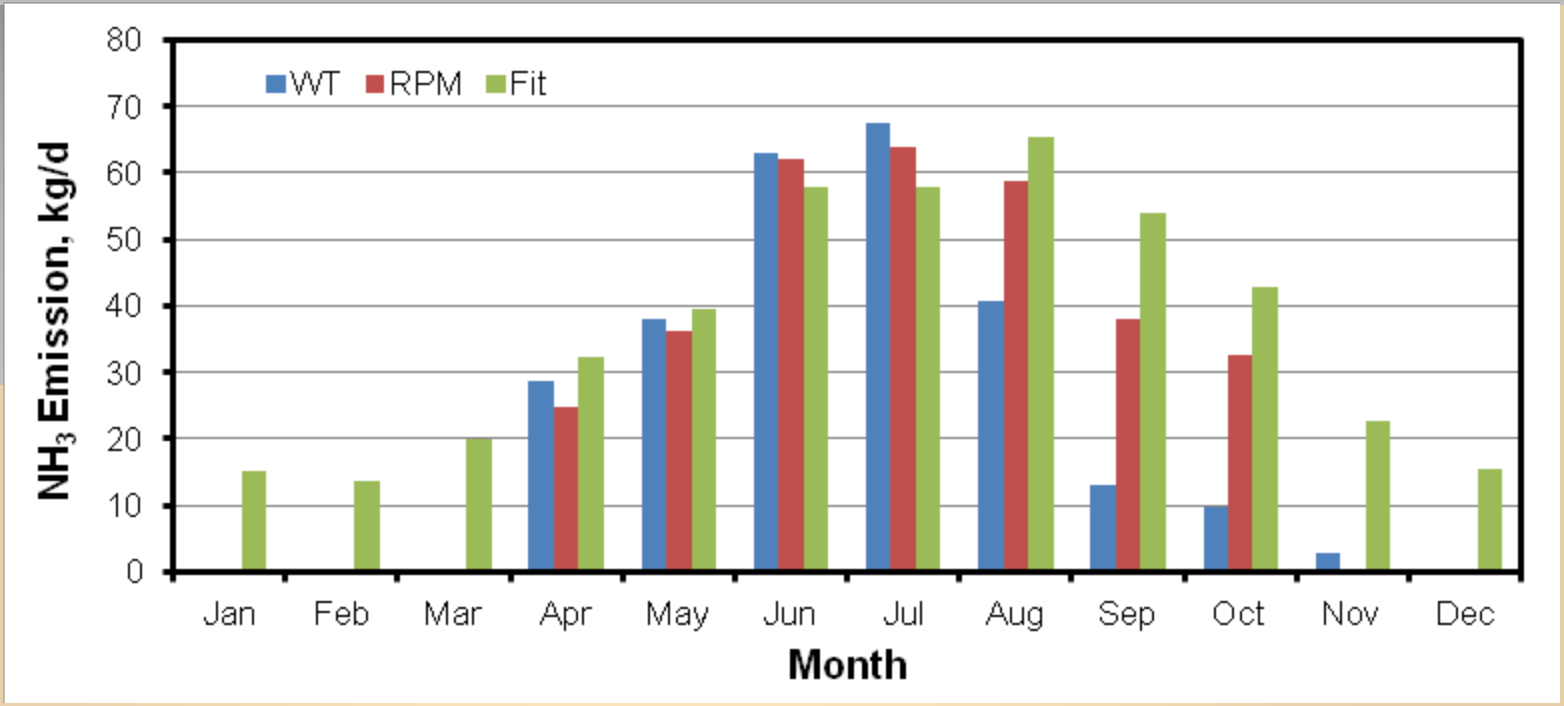
IA3A NH3


80
70
60
50
40
30
20
10
0
-10
WT
RPM
Fit
NH3 Emission, kg/d
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

IN4A Measurement Locations



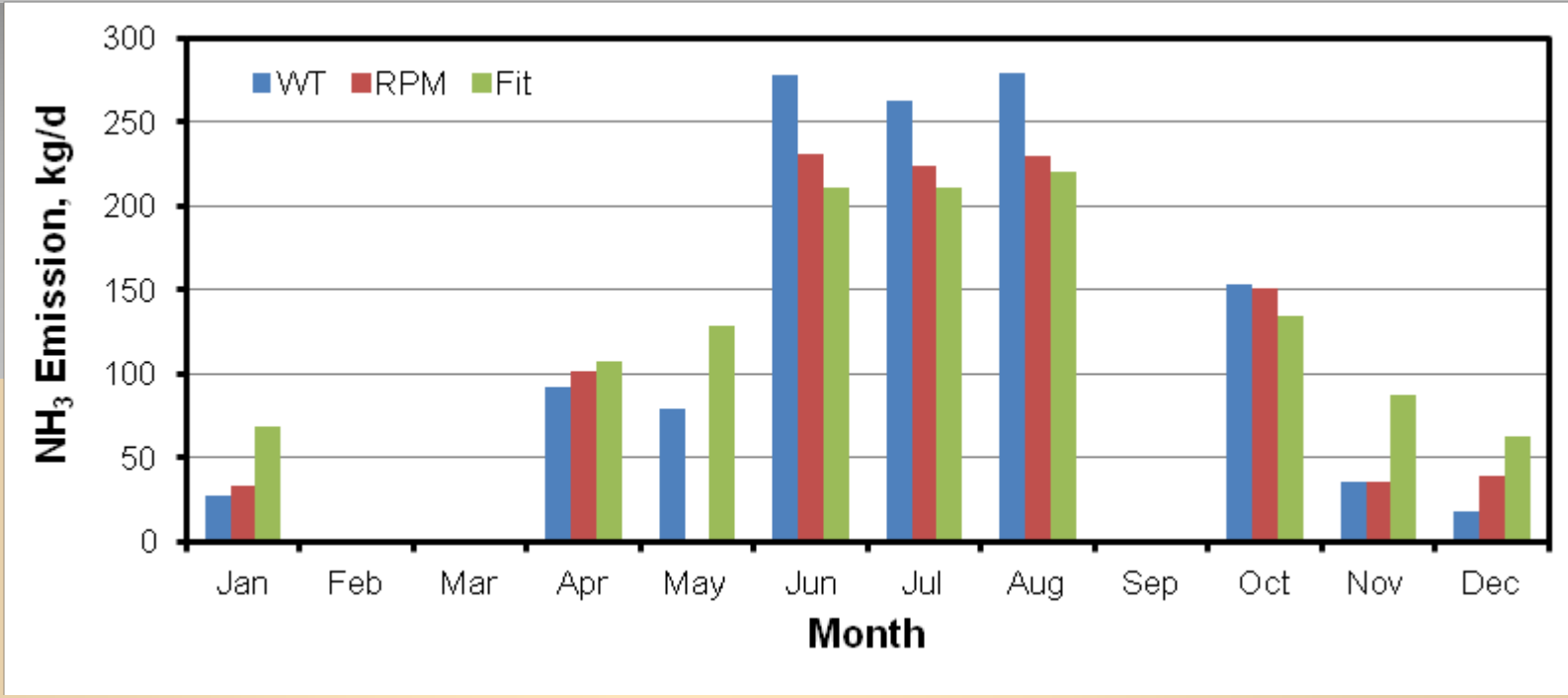
IN4A – NH3


WT
RPM
Fit
NH_3 Emission, kg/d
0
10
20
30
40
50
60
70
80
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

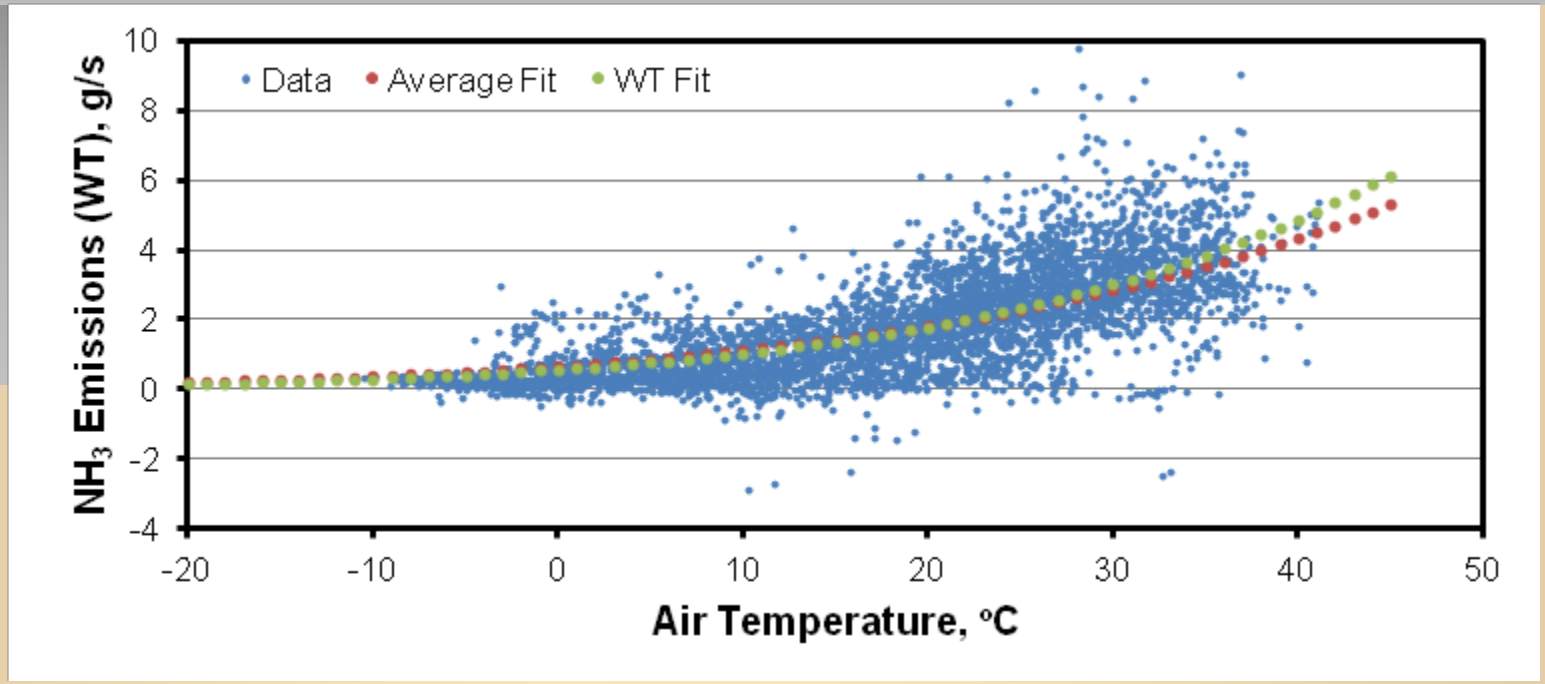
OK4A

- *2784 Sows*
- *3898 piglets*
- *1279 Animal Units*
- *Pull plug with recharge, lagoon*

OK4A NH3


WT
RPM
Fit
300
250
200
150
100
50
0
NH3 Emission, kg/d
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Influence of Temperature OK4A NH3

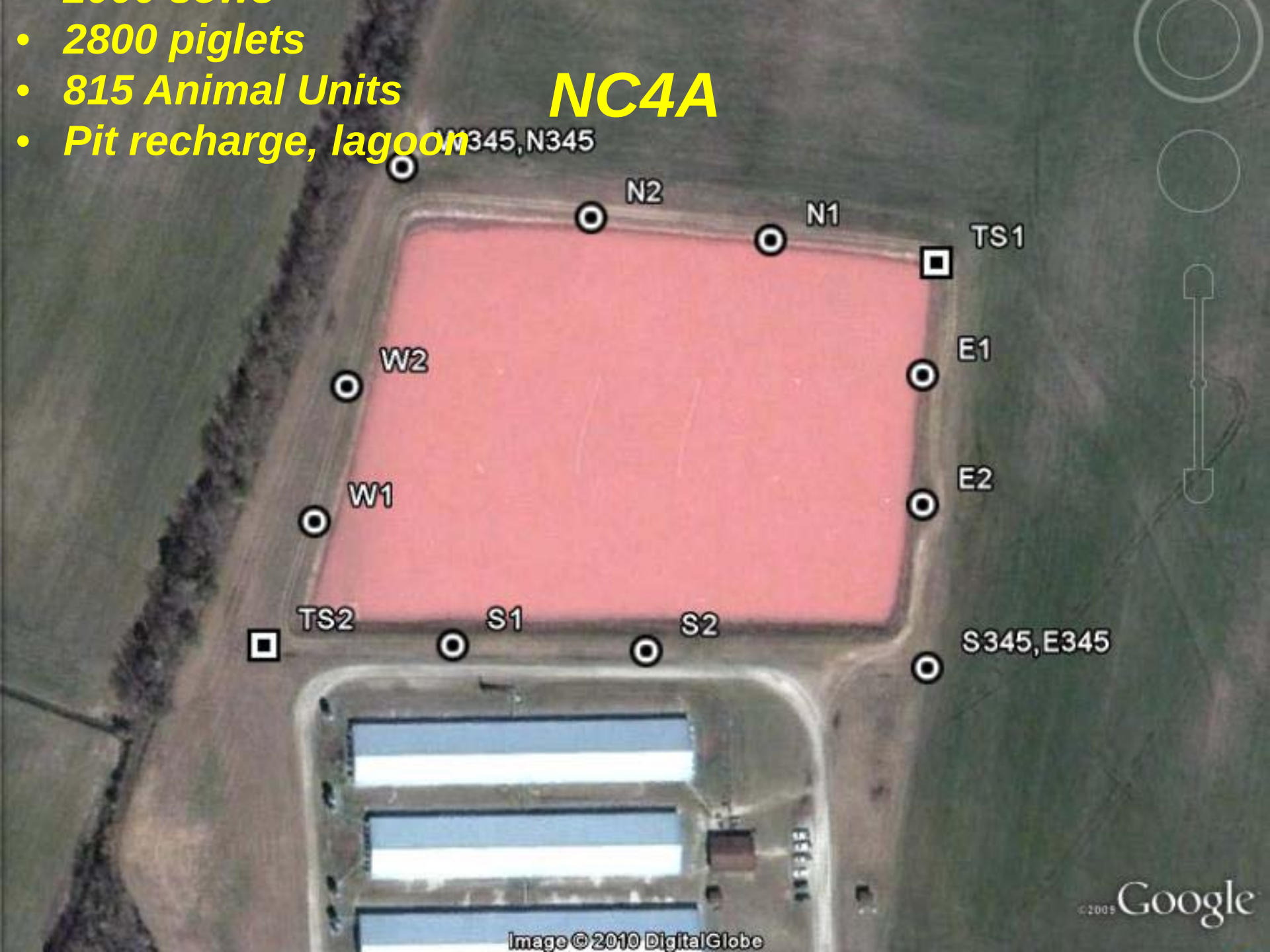


NC3A

- *8000 Finishers*
- *982 Animal Units*
- *Pull plug with recharge, lagoon*

- *2800 piglets*
- *815 Animal Units*
- *Pit recharge, lagoon*

NC4A



OK3A

- *3000 Finishers*
- *464 Animal Units*
- *Pull plug with recharge, lagoon*

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- *by Al Heber, Purdue University*
- *March 16, 2012*

Open Source Lagoons

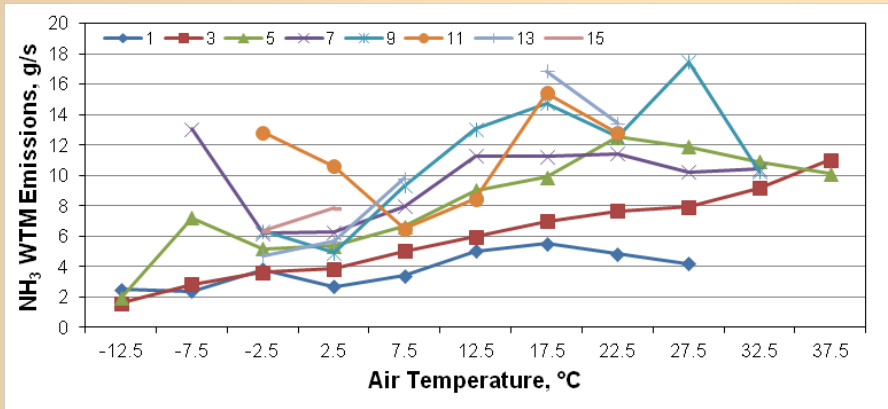
Open Source Q/A

- Follow on reports have been prepared by Dr. Rich Grant:
  - Pork: Submitted to NPB but is not yet publicly available.
  - Dairy: Final report under final formatting.

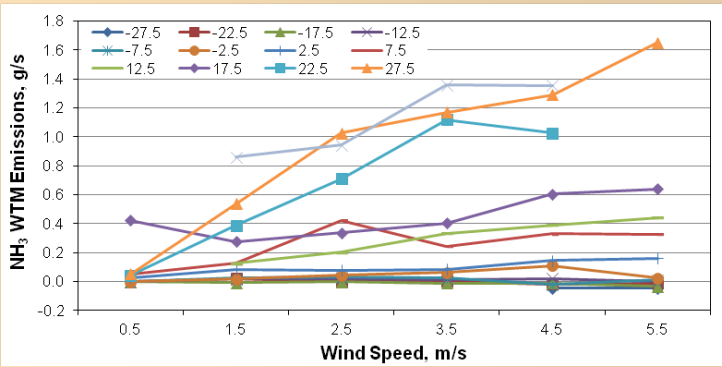
Effect of Wind Speed

- *RG: "The correlation that exists between air temp and wind speed in a diurnal cycle masks the individual ½ h period influences."*
- *Clear effects of wind speed observed at higher temperatures, see below.*
- *H2S was correlated with wind speed, but not temperature so well.*

NH3 TX5A



NH3 WI5A



Source of Negative Values

- *"Negative emissions are noise in measurements associated with the sequential measurements considered simultaneous (some associated with upwind but mostly not). Also variation in wind conditions within the ½ h period."*

Effect of Lagoon Temperature vs. Air Temperature

- ***"As lagoon temperatures were at 0.3 m, it is hardly a surface measurement. Furthermore records for lagoon temp were limited while air temperature was continuous. Comparisons were made between the two showing the expected lags and damping."***

Lack of Valid WA5A Data

- *RG: "The regular slope/valley winds mean most days there are light turning winds for a substantial part of the day (night). Reducing criteria can give more data but produce highly questionable data."*
- *The concentration requirements for RPM are more restrictive. In particular, the bLS requires at least one valid downwind concentration, while RPM requires all 5 (or 10, depending on wind direction) of the downwind concentrations to be valid. Thus, having even a single invalid downwind path prevents \calculation using RPM, while bLS can still calculate emissions. Missing downwind paths were caused by moisture in retro-reflector boxes due to rain or heavy dew. Moisture was more often a problem at night.*
- *The wind requirements for WTM were that $u^*>0.15$ m/s (u^* is friction velocity, a measure of turbulence strength) and that $|L|>2$ m (L is the Monin-Obukov length, a measure of atmospheric stability), while the requirement for RPM is wind speed greater than 1 m/s (QAPP; Grant, 2006). For both emissions models, the wind criteria were violated most frequently at night when winds were generally much lighter than during the day. Significant fractions of the variability in the ½-h emissions calculations were a result of limited representations of the lagoon/basin in upwind.*

To reduce variance, new QA was applied. For NH3:

Site	NH_3 WindTrax Completeness			
	Reported in Final Report		New QA	
	Valid 1/2 hrs	Complete Days	Valid 1/2 hrs	Complete Days
IN5A	7,462	73	6,733	61
TX5A (Corral only, including 1032 on NE corner)	4,909	66	4,618	59
TX5A (Corral only, excluding 1032 on NE corner)	4,415	58	4,189	53
TX5A (Entire farm, including 1032 on NE corner)			4,575	57
TX5A (Entire farm, excluding 1032 on NE corner)			4,150	51
WA5A	749	1	375	0
WI5A (including 1031)	2,488	22	2,059	17
WI5A (excluding 1031)	1,633	12	1,323	10

Site	H_2S WindTrax Completeness			
	Reported in Final Report		New QA	
	Valid 1/2 hrs	Complete Days	Valid 1/2 hrs	Complete Days
IN5A	5,149	24	4,667	17
TX5A (Corral only)	3,180	34	2,983	28
TX5A (Entire farm)	-	-	2,979	28
WA5A	586	0	374	0
WI5A	1,305	6	1,143	4

Where did the 75% criteria come from?

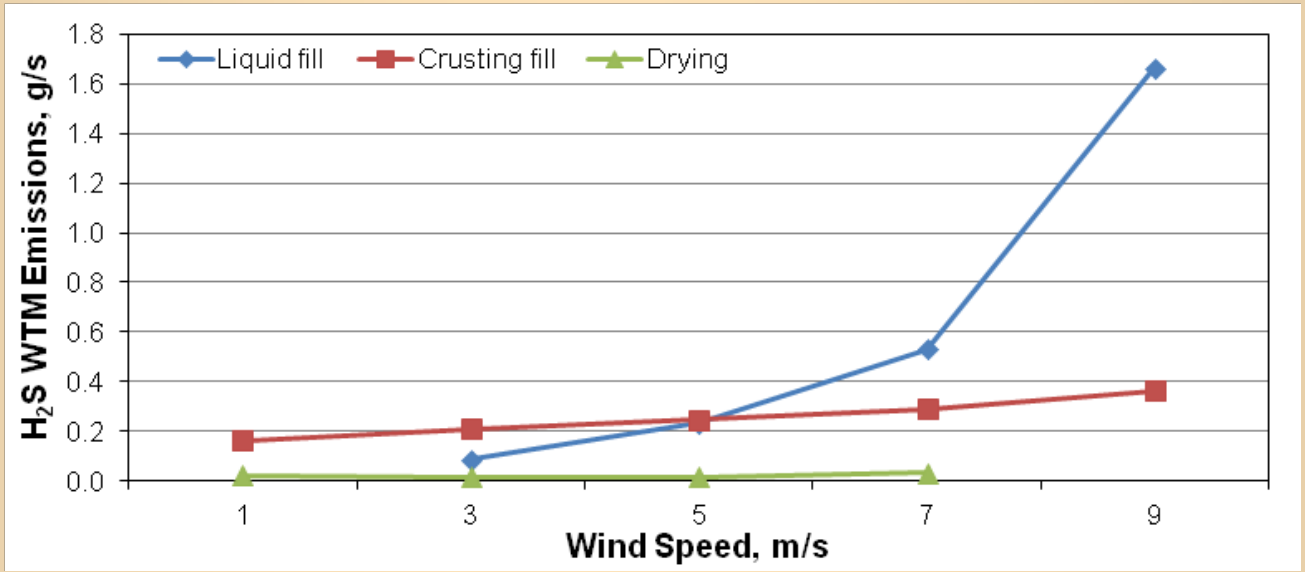
- ***AG "The questions tie to the fact that there was no analysis in the final reports and the acceptance criteria were based on the QAPP. Thresholds for 75% come from state AQ standards and EPA AQ Q/A criteria."***
- ***AG "This was taken care of in the follow-on pork and dairy reports"***

Why are H2S emissions from IN5A zero for bLs method?

- "Frozen lagoon?"
- From follow-on report:

Site	H_2S WindTrax Completeness			
	Reported in Final Report		New QA	
	Valid 1/2 hrs	Complete Days	Valid 1/2 hrs	Complete Days
IN5A	5,149	24	4,667	17
TX5A (Corral only)	3,180	34	2,983	28
TX5A (Entire farm)	-	-	2,979	28
WA5A	586	0	374	0
WI5A	1,305	6	1,143	4

WA5A



Need to see when the missing data occurs. Do gap filling to get a better set of data ... to create a more robust data set.

- ***This was taken care of in the follow-on reports***

Can fill gaps like you did for the year. This is acceptable. Additional stringency on number of sequential hours of empty data.

- ***This was addressed in the pork and dairy reports.***

Did you try to correlate emissions to the N content in the lagoons?

- ***"Very little data. Was looked at and useless."***

Were tracer tests done beyond the tracer tests of the UVDOAS?

- ***"No."***
- ***Smoke visualization tests were conducted. (this comment added later, not presented to the panel).***

Content of Follow-On Reports Part 1

- Thorough comparison of H2S and NH3 emissions with literature.
  - Manure storage and treatment units
  - Whole farm
- Extrapolation of data to whole farms.
- Discussion of the results
- Application of stricter QA to data
  - Demonstrated influence on valid data.

Content of Follow-On Reports Part 2

- Influence of changing source area on NH3 emission at corral site.
- Variation of emissions by air T for range of wind speed.
- Variation of emissions by wind speed for range of air temperatures.
- Mean emissions for 3-h intervals of day in each month.
- # of RPM data for 3-h int for each mon.

Content of Follow-On Reports Part 3

- Normalization to cwt produced
- Normalization to AU, hd, m^2, etc.

Questions?