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Ammonia, Hydrogen Sulfide, and Greenhouse Gas Emissions from Wean-to-Finish Swine Barns Fed Diets with or without DDGS

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Abstract

In recent years the corn grain ethanol industry has expanded and led to increased availability of dried distillers grains with solubles (DDGS). As a result, feeding DDGS to swine is becoming more common in pork production. With feed being the primary cost in pork production and increasing interest in air emissions from animal feeding operations, it is important to understand the impacts of non-traditional dietary formulations on aerial emissions. The purpose of this study was to evaluate the impacts of feeding DDGS on ammonia (NH_3), hydrogen sulfide (H_2S) and greenhouse gas (GHG) emissions from deep-pit swine wean-to-finish (5.5 – 118 kg) facilities in Iowa, the leading swine producing state in the USA. To attain the study objectives, two commercial, co-located wean-to-finish barns were monitored: one barn received a traditional corn-soybean meal diet (designated as Non-DDGS regimen), while the other received a diet that included 22% DDGS (designated as DDGS regimen). Gaseous concentrations and barn ventilation rate (VR) were monitored or determined semi-continuously, and the corresponding emission rates (ER) were derived from the concentration and VR data. Two turns of production were monitored for this study, covering the period of December 2009 to January 2011. The daily and cumulative emissions are expressed on the basis of per barn, per pig, and per animal unit (AU, 500 kg live body weight). Results from this project indicate that feeding 22% DDGS does not significantly affect aerial emissions of NH_3, H_2S, CO_2, N_2O or CH_4 when compared to the Non-DDGS regimen in a deep-pit wean-to-finish swine facility (p-value = 0.10 for NH_3, 0.13 for H_2S, 0.55 for CO_2, 0.58 for N_2O, and 0.18 for CH_4). ER for the Non-DDGS regimen, in g/d-pig, averaged 7.5 NH_3, 0.37 H_2S, 2127 CO_2 and 72 CH_4. In comparison, ER for the DDGS regimen, in g/d-pig, averaged 8.1 NH_3, 0.4 H_2S, 1849 CO_2, and 48 CH_4. On the basis of kg gas emission per AU marketed, the values were 8.7 NH_3, 0.724 H_2S, 2350 CO_2 and 84 CH_4 for the Non-DDGS regimen; and 12 NH_3, 0.777 H_2S, 2095 CO_2, and 60 CH_4 for the DDGS regimen. Results of this extended field-scale study help filling the knowledge gap of GHG emissions and impact of DDGS on gaseous emissions from modern swine production systems.

Keywords

Ammonia, Hydrogen sulfide, Greenhouse gases, Emissions, Swine

Disciplines

Bioresource and Agricultural Engineering

Comments

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Keywords. *Ammonia, Hydrogen sulfide, Greenhouse gases, Emissions, Swine*

Introduction

Iowa leads the United States in corn and ethanol production. For corn-based ethanol plants, a primary co-product of the process is distillers dried grains with solubles (DDGS). DDGS have been reported to contain equal levels of digestible energy and metabolizable energy and, higher levels of digestible amino acids, and available phosphorus than corn (Shurson et al., 2003; Honeyman et al., 2007). Generally, DDGS have been found to contain 2 to 3.5 times more amino acids, fat, and minerals than corn (Honeyman et al., 2007). Animal nutritionists have suggested including up to 20% DDGS in nursery, grow-finish, and lactating sow diets and up to 40% in gestating sows and boars (Honeyman et al., 2007). However, the decision to feed DDGS is generally based on economics. At the current DDGS and corn prices the inclusion of DDGS in swine diets has provided a substantial cost savings over traditional non-DDGS diets causing some producers to use even higher levels of DDGS in their diets.

It has been hypothesized that sulfur levels in DDGS could result in increased hydrogen sulfide (H_2S) emissions from stored swine manure when pigs are fed rations containing DDGS. However, comparative data from full-scale swine production systems are needed to confirm any impacts on air emissions. The increased usage of DDGS in swine facilities has led several researchers to examine the effect of DDGS on emissions, odors, and manure composition, but these studies were at lab or at non-commercial scale conditions and the data from these studies were inconsistent (Spiehs et al., 2000; Gralapp et al., 2002; Xu et al., 2005; Jarret et al., 2011)

Spiehs et al. (2000) performed a 10-week trial on 20 barrows receiving either a DDGS (at a 20% inclusion rate) or non-DDGS ration. The pigs were housed, based on diet, in two fully-slatted pens within the grow-finish room of a swine research facility. The non-DDGS diet was a typical corn-soybean meal formulation; total phosphorus and total lysine were held constant in both diets within each phase of feeding. The study was conducted to evaluate differences in odor, H_2S, and ammonia (NH_3) levels from stored manure as a result of the pig's diet. The stored manure that was evaluated for emissions was maintained in a container to simulate deep-pit storage. Air samples were collected from the headspace of the storage containers. Over the 10-week period, this study reported that the DDGS diet did not affect odor, H_2S, or NH_3 emissions from the stored manure ($P > 0.10$).

Gralapp et al. (2002) performed six, four week trials utilizing a total of 72 finishing pigs and three diets containing 0, 5 or, 10% DDGS. Manure from the study was collected in a pit below each environmental chamber where the pigs were housed. Samples were collected on day 4 and day 7 of each week and analyzed. Each pit was cleaned weekly. The authors reported no significant differences in concentrations of total solids (TS), volatile solids (VS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), or phosphorus (TP) content ($P > 0.10$). Additionally, this study revealed no significant effects on odor levels between the different diets ($P > 0.10$).

Xu et al. (2006) performed a study utilizing 40 nursery pigs to evaluate phosphorus excretion from animals receiving DDGS diets. Feeding diets containing 10 or 20 % DDGS resulted in a 15 and 30 % increase in daily manure excretion, respectively, compared to pigs fed the corn-soybean meal diet ($P < 0.05$). The authors reported that the increase was due to a 2.2 % and 5.1 % reduction in dry matter digestibility for the respective rations. The reduced dry matter digestibility was speculated to result from increased amounts higher fiber levels in the DDGS diet.

Jarret et al. (2011) investigated the effects of different biofuel co-products (DDGS), sugar beet pulp, and high fat level rapeseed meal on nitrogen (N) and carbon (C) excretion patterns as well as ammonia and methane emissions. Ammonia emissions were measured from a pilot scale system for a period of 16 days using H_2SO_4 ammonia traps. Biochemical methane potentials (BMPs) were then run on the manure to determine the methane production potential of the different diet regimens. Pigs fed the DDGS diet were found to excrete more N, C and dry matter than the other pigs ($P < 0.05$). It was also reported that the diets with higher fiber contents and higher crude protein (CP) inclusions had similar ammonia emissions to lower fiber and lower protein diets. Methane production potential was also found to be the lowest the in the DDGS manure ($P < 0.05$).

The results from these studies were not directly comparable because of the differences in rations, animal housing, manure storage, and analytical methods. In addition to the differences in the experimental design of these studies, the results might also have been affected by the study scale. Moreover, only two of the reported studies investigated the effects of feeding DDGS to swine on aerial emissions, both at small scale.

The primary objective of this study was to quantify the impact on gaseous emissions of feeding DDGS to wean-to-finish pigs in two commercial deep-pit swine barns. The secondary objective was to compare the emission results of this study to similar full-scale emission monitoring studies that have been reported in the literature. To achieve these objectives, concentrations and emissions of NH_3, H_2S and greenhouse gases (GHG) (carbon dioxide – CO_2, nitrous oxide – N_2O, and methane – CH_4) were quantified using a mobile air emissions monitoring unit (MAEMU). The results were further compared with the available literature data.

Methods and Materials

Site Description

Two 12.5 x 57 m (50 x 190 ft) co-located wean-to-finish deep-pit swine barns located in central Iowa, designated as Non-DDGS and DDGS, were monitored for two production turns. Pigs entered the barns at 3 weeks of age and 5.5 kg (12 lbs) body weight and were marketed at approximately 30 weeks of age and 118 kg (260 lbs) body weight. The barns had a rated capacity of 1,200 marketed pigs. Both barns were double-stocked initially, namely, 2,400 pigs were housed in each barn during the wean-to-grow (W-G) phase (occurred first 6 to 10 weeks of the turn). When the pigs reached 27 kg (60 lbs), approximately half of the pigs were moved off-site to another facility for the grow-to-finish (G-F) phase. Each barn had four 0.6 m (24 in.) pit fans, two 0.6 m (24 in.) endwall fans for mechanical ventilation, and sidewall curtains on both sides to provide natural ventilation when needed. The barns were equipped with three space heaters 66 kW (225,000 BTU/h) each, 20 brooder heaters 5 kW (17,000 BTU/h) each and 20 bi-flow ceiling inlets (one per pen).

The diets used in this study were formulated (proprietary information) to meet the pigs' requirements as they grew towards market weight (NRC, 1998); the only difference in ingredients between the Non-DDGS (control) diet and the DDGS (treatment) diet was the inclusion of 22% DDGS for the DDGS regimen. Nutrient levels were kept constant in both feeding programs. Including DDGS resulted in higher levels of crude protein, crude fiber, acid detergent fiber and sulfur compared to the non-DDGS diet. The nursery phase diets for both barns did not include DDGS and they were fed for 10-14 days (body weight of 12 kg) following placement in the barn. Therefore, emissions data for this period were excluded in the evaluation of DDGS effect.

Weekly pig performance data of mortality and average body weight were provided by the cooperative producer throughout the project. A linear regression was performed on the pig performance data to determine daily performance values.

Measurement System

An environmentally- controlled MAEMU was used to continuously collect emissions data from the two deep-pit wean-to-finish swine barns. The monitoring instruments and data acquisition system were housed in the MAEMU. A detailed description of the MAEMU and operation can be found in Moody et al. (2008). Constituents measured during this study were NH_3, CO_2, N_2O, CH_4, and H_2S; monitoring was conducted for two turns of production. The concentrations of NH_3, CO_2, N_2O, and CH_4 gases were measured with a photoacoustic multi-gas analyzer (INNOVA Model 1412, INNOVA AirTech Instruments A/S, Ballerup Denmark). H_2S concentrations were measured using an ultraviolet fluorescence analyzer (Model 101E, Teledyne API, San Diego, CA). The instruments were challenged weekly with calibration gases and recalibrated as needed. All calibration gases were certified grade with ± 2% accuracy (Matheson Tri-gas, Parsippany, NJ).

Air samples were drawn from three composite locations (north pit fans, south pit fans, and endwall fans) in each barn and one outside location to provide ambient background data (Figure 1). Each composite sampling location was chosen to match the fan stages used at the facility. Pit fan sampling points were located below the slats next to each fan. Endwall sample ports were placed approximately 1.0 m (3.28 ft) in front of each endwall fan. Sample locations and placement of sampling ports were chosen to ensure representativeness of the air leaving the barns. Air samples were collected in 30-s cycles for four cycle periods (120 s) at each location. The fourth reading from each sampling cycle was used as the measured constituent concentration, based on that the INNOVA and API analyzers had a T98 and T95 response time of 120 s and 100 s, respectively. Each sampling point had three consecutive dust filters (60, 20, 5 µm) to keep particulate matter from plugging or contaminating the sample lines, the servo valves, or the delicate instruments.

A positive-pressure gas sampling system (P-P GSS) was used in the MAEMU to prevent introduction of unwanted air into the sampling line. The P-P GSS continuously pumped sample air from each sampling location using individual designated pumps. Air samples from each location were analyzed sequentially over the 120 s period via the controlled operation of servo valves of the PP-GSS. It took 14 min to complete one sampling cycle of each barn. It was assumed that any concentration change at a given location between two sampling periods followed a linear relationship. Therefore, linear interpolation was used between sampling points to determine the intermediate concentrations and to line up the concentration with the continuously measured ventilation rate (VR) for the location. A background ambient air sample was collected every two hours for 8 min. Background concentrations were subtracted from the exhaust readings when air emissions rates were calculated for the barns. All pumps and the gas sampling system were checked weekly for leakage to ensure no misrepresentation of the air samples was occurring.

Pit fans at this facility had variable speeds, while the endwall fans had a single speed. All fans were calibrated *in situ* at multiple operation points (RPM and static pressure) to develop a performance or airflow curves for each fan using a fan assessment numeration system (FANS) (Gates et al. 2004). For single-speed fans, airflow was a function of static pressure, whereas for variable-speed fans, airflow was a function of static pressure and fan speed (revolution per minute or RPM). Runtime of each fan was monitored continuously using an inductive current switch (with analog output) attached to the power cord of each fan motor (Muhlbauer et al., 2011). Each current switch's analog output was connected to the data acquisition (DAQ) system (Compact Fieldpoint, National Instruments, Austin, Tex) (Li et al., 2006). Both barns were equipped with static pressure sensors (model 264, Setra, Boxborough, Mass.). Each pit fan's RPM was continuously measured using Hall Effect speed sensors (GS100701, Cherry Corp, Pleasant Prairie, WI). Atmospheric pressure, indoor and outdoor temperature, and relative humidity (RH) were measured with barometric pressure sensor (WE100,Global Water, Gold River, Cal.), temperature sensors (type-T thermocouple, Cole Palmer, Vernon Hills, Ill.), and RH probes (HMW60, Vaisala, Woburn, Mass.). Signals were sampled every second and averaged and recorded on the on-site computer in 30 second intervals.

VR during periods of natural ventilation was determined using a CO_2 balance, an indirect VR determination method. The CO_2 balance method is governed by the principle of indirect animal calorimetry (Xin et al., 2009). Specifically, the metabolic heat production of non-ruminants is related to oxygen (O_2) consumption and CO_2 production of the animals (Brouwer, 1965) (Eq. 1). Using this relationship the VR can be estimated by using the inlet and exhaust CO_2 concentrations and the total heat production (THP) of the animals (Eq. 2 & 3).

For the purpose of this study, finishing pig THP under thermoneutrality (Pedersen and Sallvik, 2002) (Eq. 4) and a respiratory quotient (RQ) of 1.14 were used.

$$THP = 16.18 * O_2 + 5.02 * CO_2 \tag{1}$$

Where, THP = total heat production rate of the animals (W)

O_2 = oxygen consumption rate of the animals (mL s^{-1})

CO_2 = carbon dioxide production rate of the animals (mL s^{-1})

$$CO_2 = \frac{THP}{16.18/RQ + 5.02} \quad where, \quad RQ = \frac{CO_2}{O_2} \tag{2}$$

$$VR = \frac{CO_2}{CO_{2_e} - CO_{2_i}} \tag{3}$$

Where, VR = building ventilation rate (m^3 s^{-1})

$CO_{2\,e}$ = carbon dioxide concentration of exhaust air (ppm_v)

$CO_{2\,i}$ = carbon dioxide concentration of inlet air (ppm_v)

$$THP = 5.09m^{.75} + [1-(0.47+.003m)][n*5.09m^{.75} - 5.09m^{.75}] \tag{4}$$

Where, THP = total heat production rate of animals (W)

m = body mass of the animal (kg)

n = daily feed energy intake as times of the maintenance energy requirement

$$DME = 106 * m^{0.75} \tag{5}$$

Where, m = body mass of the animal (kg)

Daily body mass of the pigs (m) was linearly interpolated from the two consecutive weekly values provided by the producer. Daily feed energy intake was calculated based on the metabolizable energy content of the feed and feed intake data provided by the producer and the daily maintenance energy requirement (DME, kcal/day) for finishing swine (NRC, 1998; Eq. 5). The calculated n values ranged from 5.7 to 2.9 (with an average of 3.4) for pig weights from 5 - 120 kg, respectively, shown in Figure 2. The n values calculated were similar to those reported by Pedersen and Sallvik (2002).

In addition to air sampling, monthly manure and water samples were collected monthly. The manure samples were collected from the four pit pump-out locations and composited for each barn. The samples were cooled and shipped to Midwest Laboratories (Omaha, NE) for analysis of total solids (TS), total nitrogen (TN), ammoniacal nitrogen (NH_3-N), total phosphorus (TP), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), manganese (Mn), copper (Cu), zinc (Z), and pH. The water samples were collected from water line inside each barn and analyzed for Total Sulfur. A total of eleven manure and water samples per barn were analyzed during the monitoring period.

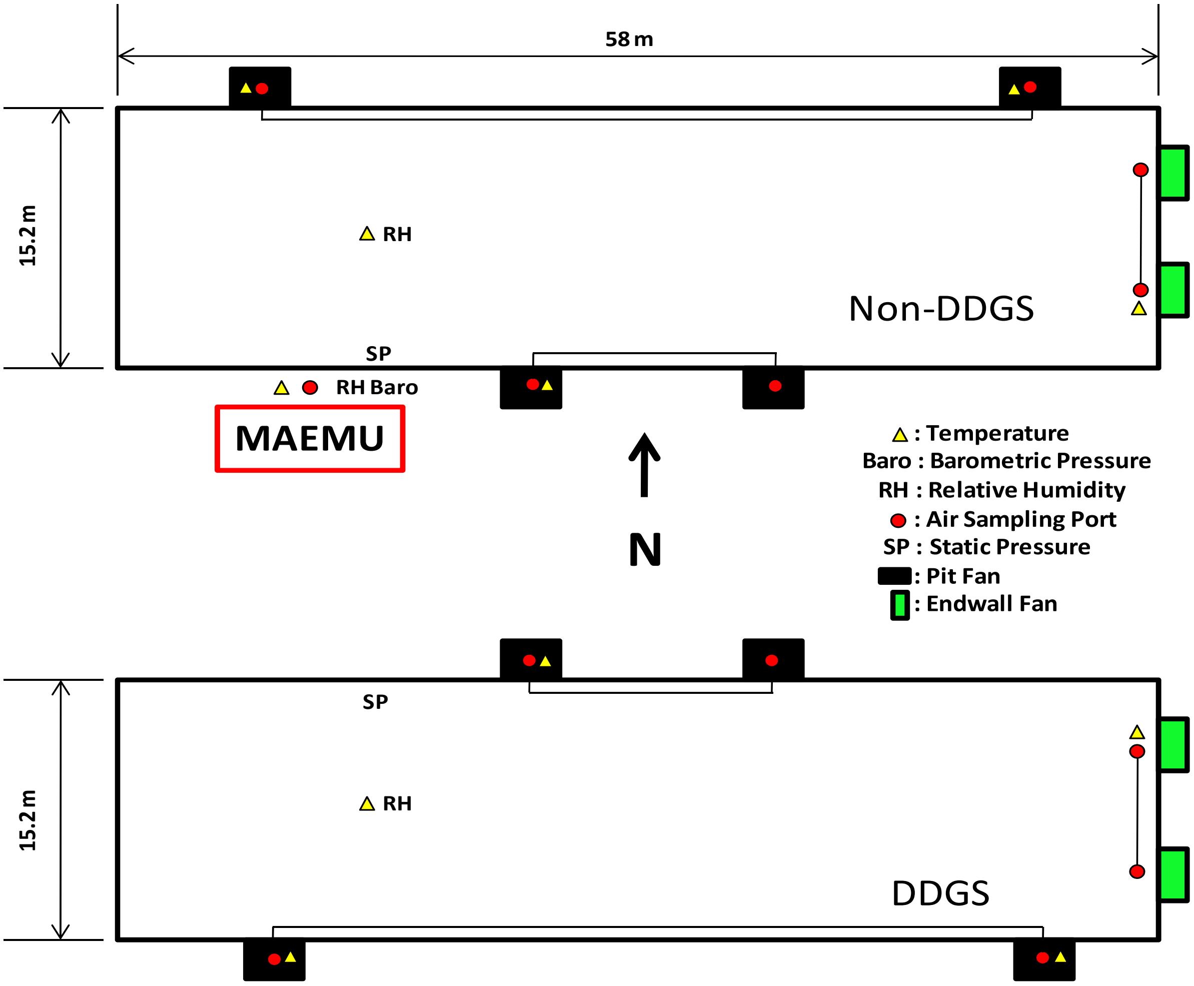

Figure 1. Schematic representation of the monitoring system layout

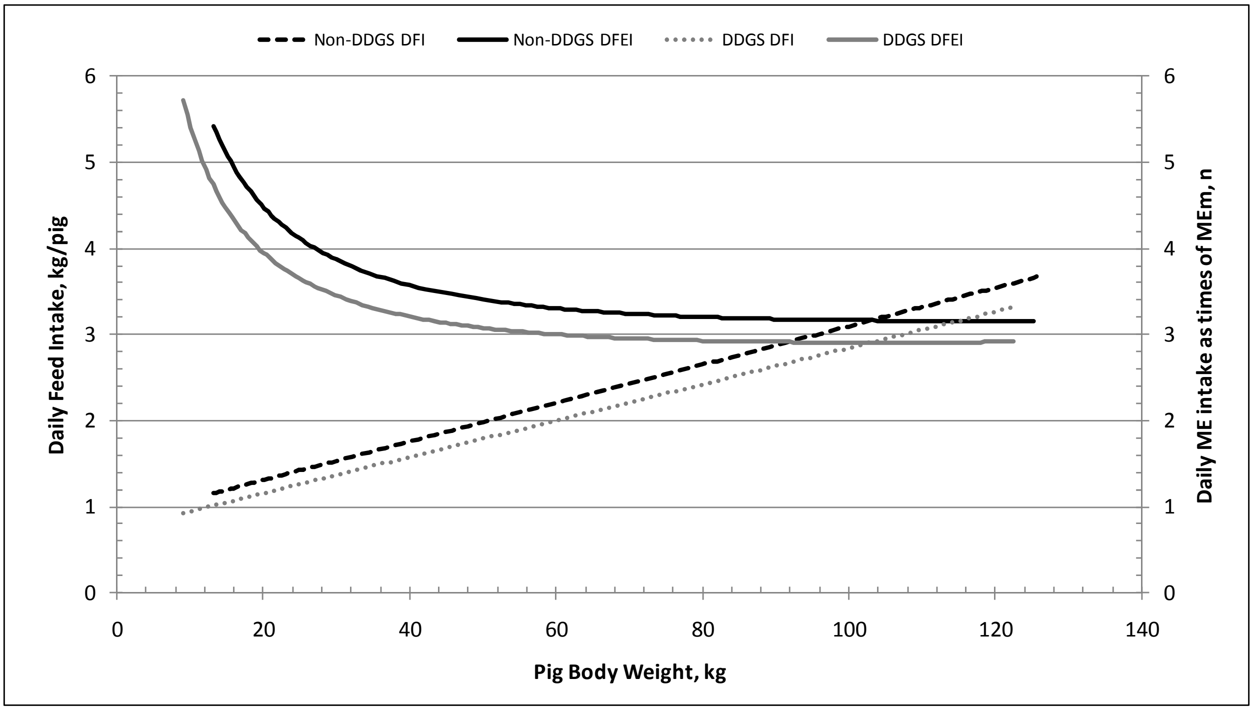

Figure 2. Daily feed intake and daily feed energy intake values for both DDGS and Non-DDGS diets. (ME – Metabolizable Energy, MEm – Maintenance Energy)

Gaseous Emission Rate (ER) Determination

Constituent ER was calculated as the mass emitted from the barn per unit time and expressed in the following form:

$$ER = \sum Q_e * (G_e - \frac{\rho_e}{\rho_i} * G_i) * 10^{-6} * \frac{T_{std}}{T_a} * \frac{P_a}{P_{std}} * \frac{w}{v} \quad (6)$$

Where ER = Gas emission rate for the house, g hr^{-1} $barn^{-1}$

Q_e = Exhaust ventilation rate of the barn at field temperature and barometric pressure, respectively, m^3 hr^{-1} $barn^{-1}$

$[G]_i$,$[G]_e$ = Gas concentration of incoming and exhaust ventilation air, respectively, ppm_v

w_m = molar weight of the gas, g $mole^{-1}$ (e.g., 17.031 for NH_3)

V_m = molar volume of gas at standard temperature (0°C) and pressure (101.325 kPa) or STP, 0.022414 m^3 $mole^{-1}$

T_{std} = standard temperature, 273.15 K

T_a = ambient air temperature, K

ρ_i, ρ_e = density of incoming and exhaust air, respectively, g/cm^3

P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure at the monitoring site, kPa

The data collection period for this study was December 2009 through January 2011. Statistical analysis was performed using SAS 9.2 (SAS Institute Inc., Cary, NC). Daily ER was analyzed with analysis of variance (ANOVA) using a proc mixed procedure to determine the effects of diet, turn, temperature, and animal units (1 AU=500 kg), each day as a repeated measure during the period. The dietary effect was considered significant at P-value ≤ 0.05.

Results and Discussion

Manure Sample Analysis Results

Table 1 shows the average results for both barns over the entire monitoring period. Manure from the DDGS barn tended to have higher NH_3-N, TN, S, and Z contents, although no statistical differences were detected between the two dietary regimens.

Table 1. Mean (SD) manure analysis results for Non-DDGS and DDGS barns reported for the duration of monitoring period (n=11).

Sample ID	Non-DDGS	DDGS
Ammonium Nitrogen, ppm	4,240 (255)	4,460 (347)
Organic Nitrogen, ppm	2,510 (360)	2,610 (366)
Total Nitrogen, ppm	6,750 (438)	7,070 (386)
Phosphorus, ppm	1,984 (814)	1,968 (758)
Potassium, ppm	4,385 (496)	4,508 (448)
Sulfur, ppm	735 (82)	847 (147)
Calcium, ppm	1,430 (157)	1,440 (201)
Magnesium, ppm	840 (255)	880 (140)
Sodium, ppm	1,030 (82)	1,020 (122)
Copper, ppm	40 (7)	41 (9)
Iron, ppm	132 (15.4)	128 (17.5)
Manganese, ppm	27 (6.3)	24 (4.7)
Zinc, ppm	203 (40)	222 (52)
Total Solids, %	6.4 (.9)	6.7 (.9)
Volatile Solids, %	4.5 (.6)	5.0 (.8)
pH	8.2 (.2)	8.1 (.34)

In-House Gaseous Concentrations

Each barn was monitored for two complete turns and each turn lasted for approximately 29 weeks. Animal population and body weight were reported for the W-G phase and G-F phase (Table 2). Daily average VR of the barns are shown with ambient temperature in Figure 3 for the entire monitoring period. The average VR for the monitored period was 61 m^3 /hr-pig for the Non-DDGS barn and 65 m^3 /hr-pig for the DDGS barn (P = 0.65).

Daily mean concentrations and variations are shown for noxious gases (NH_3 and H_2S) in Table 3 and GHG (CO_2, N_2O, and CH_4) in Table 4 for both turns of the DDGS barn to depict seasonal variations of the concentrations. Concentrations at the endwall (Stage 3) fan location were typically lower than those at the pit (Stage 1 and Stage 2) fan locations.

Table 2. Pig populations and average weight for Non-DDGS and DDGS barns during each growing phase for turns 1 and 2 for the monitoring period.

	Turn	Growout Days		# pigs		Avg. Pig Wt., kg	
		W-G	G-F	W-G	G-F	W-G*	G-F*
Non-DDGS	1	59	126	2,574	1,236	7.4, 40	40, 109
	2	49	155	2,614	1,289	7.2, 27	27, 123
DDGS	1	52	139	2,375	1,121	7.3, 30	30, 116
	2	76	110	2,403	1,235	6.8, 37	37, 123

* incoming wt, exiting wt

Measured NH_3 concentrations for the DDGS diet regimen were significantly higher than those for the Non-DDGS diet ($P = 0.03$) and differences in H_2S concentrations were nearly significant between the two barns with H_2S ($P = 0.12$). CH_4 ($P = 0.3$) concentrations trended higher (though not significant) in the Non-DDGS barn. There were no trending differences for CO_2 ($P > 0.5$) or N_2O ($P > 0.5$) between the barns. The average NH_3, H_2S, CO_2, N_2O, and CH_4 concentrations (±SD) in the DDGS barn were, respectively, 18.4 (±9.5) ppm, 522 (±528) ppb, 2,324 (±1,351) ppm, 532 (±466) ppb, and 127 (±84) ppm. The average gas concentrations (±SD) in the Non-DDGS barn were, respectively, 14.7 (±7) ppm NH_3, 341 (±451) ppb H_2S, 2,392 (±1437) ppm CO_2, 524 (±490) ppb N_2O, and 152 (±102) ppm CH_4.

Since the VR were similar for both barns ($P = 0.5$), the higher NH_3 concentrations in the DDGS regimen could be caused by the increase of ammoniacal nitrogen excreted when pigs are fed more dietary protein (Kerr et al. 2006), as is the case when feeding DDGS. The increase in H_2S concentrations could be attributed to the addition of sulfur contained in the DDGS, especially as both the barns shared the same water source (ground water source, Concentration ± SD, 21 ± .3 mg/L Total Sulfur).

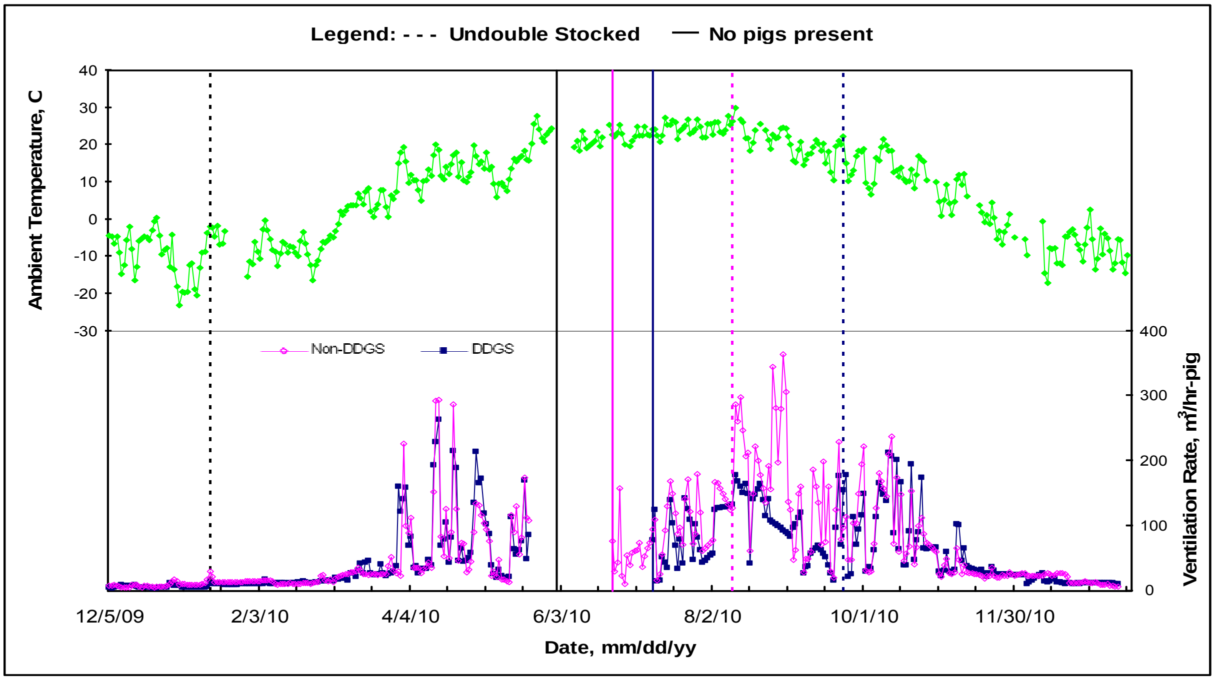

Figure 3. Average ventilation rate (m^3 hr^{-1} pig^{-1}) for each barn and ambient temperature.

Table 3. Daily ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations for each ventilation stage for both the Non-DDGS barn and DDGS barn December 2009 through January 2011.

	Turn	*Fan Stage	NH_3, ppm			H_2S, ppb		
			1	2	3	1	2	3
Non-DDGS	1	Mean	20.4	15.4	9.78	337	203	139
		SD	6.69	6.89	3.87	186	176	96.0
		Max	42.1	43.0	25.1	1,170	1,210	650
		Min	7.28	4.10	2.91	90.2	34.0	26.2
	2	Mean	18.2	15.3	11.4	539	478	304
		SD	8.25	8.02	7.66	623	697	453
		Max	41.7	52.1	43.2	5,139	6,570	3,680
		Min	4.08	4.41	1.46	69.3	24.2	21.6
DDGS	1	Mean	23.9	22.6	15.4	400	420	217
		SD	7.27	6.20	5.30	327	219	155
		Max	41.8	41.7	30.8	1,641	1,080	1,032
		Min	3.92	4.42	3.42	48.8	106	22.2
	2	Mean	17.9	19.8	14.0	684	843	423
		SD	10.8	11.1	11.7	735	755	448
		Max	48.1	56.3	49.3	3,977	6,198	3,303
		Min	5.07	2.16	1.63	3.18	2.94	0.33

*Stage 1: North Pit Fans, Stage 2: South Pit Fans, Stage 3: Endwall Fans

Table 4. Greenhouse gas (CO_2, N_2O, and CH_4) concentrations for each ventilation stage for the Non-DDGS barn and DDGS barn December 2009 through January 2011.

	Turn	*Fan Stage	CO_2, ppm			N_2O, ppb			CH_4, ppm		
			1	2	3	1	2	3	1	2	3
Non-DDGS	1	Mean	3,026	2,915	3,138	211	217	203	148	116	68.4
		SD	1,301	1,353	1,527	104	106	111	67.8	72.5	33.4
		Max	5,540	5,364	5,688	484	479	487	489	497	249
		Min	552	553	484	13.9	18.1	6.52	51.2	26.0	21.9
	2	Mean	1,941	1,834	2,027	800	785	824	234	201	151
		SD	1,259	1,132	1,313	544	497	568	155	106	81.4
		Max	6,300	5,348	6,428	2,293	1,912	2,907	1,475	710	450
		Min	509	524	452	193	189	188	27.7	44.6	20.9
DDGS	1	Mean	2,807	2,745	3,253	236	250	211	124	106	76.6
		SD	1,124	1,209	1,547	85.7	84.5	109	53.5	38.6	30.8
		Max	4,667	4,917	6,080	474	484	507	251	191	177
		Min	517	507	499	60.0	70.0	5.2	26.4	27.6	15.8
	2	Mean	1,840	1,832	1,981	791	796	809	148	192	122
		SD	1,099	1,105	1,285	500	514	515	64.9	167	71.9
		Max	4,895	5,024	5,506	1,903	2,024	2,007	341	1,486	289
		Min	490	458	443	205	203	165	32.2	20.2	15.4

*Stage 1: North Pit Fans, Stage 2: South Pit Fans, Stage 3: Endwall Fans

Ammonia and Hydrogen Sulfide Emission Rates

The daily average ERs for NH_3 and H_2S are shown for both barns in Table 5. The average NH_3 and H_2S ER (±SD) in g/d-pig for the DDGS barn was 8.1 (±4.6) and 0.4 (±0.51), respectively. These are comparable to the ER for the Non-DDGS ration, 7.5 (±4.1) g/d-pig of NH_3 and 0.37

(±0.59) g/d-pig of H_2S. No statistical difference was detected between the diets for either NH_3 (P = 0.10) or H_2S emissions (P = 0.13). However, judging from the borderline p-value, significant difference may have been detected had there been more replications. There was a difference between turns 1 and 2 in H_2S emissions for both barns (P = 0.04), indicating the significant impact of the season variation on the gaseous emissions from the deep-pit swine facilities. On average, H_2S daily ER increased from 0.27 – 1.28 kg/barn for winter and summer seasons, respectively, for both barns. Ni et al. (2002) and Zhu et al. (2000) also reported that H_2S emissions tended to increase during summer months. Similar to H_2S emission, NH_3 daily emissions also exhibited seasonal variations that ranged from 9 to 12.6 kg/barn for the Non-DDGS barn and from 10.5 to 12.6 kg/barn (P = 0.06) for the DDGS barn.

There have been several studies that quantify NH_3 ER from deep-pit swine finishing facilities (Demmers et al., 1999; Heber et al., 2000; Zhu et al., 2000; Harper et al., 2004; Hoff et al., 2009). These studies reported an ER range of 14 – 130 g/d-AU. It was also shown that NH_3 ER tends to increase with temperatures, accounting for the wide range of the previously reported values. The average warm weather NH_3 ER from published data was 102 g/d-AU, compared to 25 g/d-AU for colder weather conditions. NH_3 ERs obtained during this study for both the DDGS and Non-DDGS barns were within the range of reported NH_3 ER (Table 6). However, when seasonal ER values were compared to those reported in literature, the average ERs from this study were higher for both cool and warm weather. Table 7 shows the average NH_3 ER values from turns 1 (colder weather) and turn 2 (warmer weather) for this study compared to literature in g/d-AU.

Limited published data were available on H_2S ER for deep-pit swine finishing facilities. Previous studies have reported H_2S ER ranging from 0.84 to 8.3 g/d-AU for deep-pit swine facilities (Avery et al., 1975; Heber et al., 1997; Ni et al., 2002; Zhu et a., 2000), similar H_2S ERs were observed for both dietary regimens in this study (Table 8). The majority of these previous studies collected data intermittently for short periods of time. There was a drastic increase, compared to literature, in H_2S ER during warmer periods of the year for both regimens (up to 15 g/d-AU). The difference between this study and the previously reported data could have been due to the data collection method (i.e. continuous for long-time periods vs. intermittent for short-time periods).

Cumulative emissions for all gases, including NH_3 and H_2S, are reported in Table 12. The average NH_3 emission for both turns in the DDGS barn was 1,499 g per pig marketed with only 9 g difference between turns 1 and 2. The Non-DDGS barn had a similar average of 1,420 g per pig marketed but with a much larger difference of 577 g between turns 1 and 2. H_2S emissions per pig marketed for each barn was comparable with 32 g for both dietary regimens in the first turn, and 110 g and 124 g for the Non-DDGS barn and DDGS barn, respectively, in the second turn. On the basis of per AU marketed, the gaseous emissions for the two dietary regimens (mean ± SE) were: 6.07 ±0.88 kg NH_3 and 297 ±151 g H_2S for the Non-DDGS regimen; and 6.28 ±0.20 kg NH_3 and 321 ±183 g H_2S for the DDGS diet.

Table 5. Daily ammonia (NH_3) and hydrogen sulfide (H_2S) emission rates for each turn from the Non-DDGS barn and the DDGS barn December 2009 through January 2011.

	Turn		VR (m^3 h^{-1} pig^{-1})	kg d^{-1} $barn^{-1}$		g d^{-1} pig^{-1}		g d^{-1} AU^{-1}	
				NH_3	H_2S	NH_3	H_2S	NH_3	H_2S
Non-DDGS	1	Mean	38.6	9.01	0.27	6.70	0.16	51.7	1.61
		SD	52.2	4.18	0.13	4.07	0.13	17.5	1.60
		Max	293	24.4	0.60	21.4	0.97	100	9.44
		Min	5.80	3.48	0.06	1.35	0.00	22.3	0.00
	2	Mean	82.4	12.6	1.30	8.25	0.55	108	14.8
		SD	77.8	6.51	1.53	3.97	0.76	93.7	35.5
		Max	363	39.8	8.89	28.2	5.06	551	241
		Min	77.8	0.69	0.01	0.65	0.00	14.1	0.06
DDGS	1	Mean	36.1	10.5	0.27	8.50	0.19	74.5	2.39
		SD	48.5	5.76	0.13	5.81	0.08	27.8	1.95
		Max	263	36.9	0.60	32.9	0.48	187	8.72
		Min	4.02	3.12	0.06	1.31	0.05	23.8	0.43
	2	Mean	65.0	12.6	1.26	7.63	0.65	115	15.0
		SD	55.2	6.72	1.54	2.67	0.67	93.1	27.9
		Max	213	36.3	8.89	15.1	3.65	513	219
		Min	10.7	2.46	0.01	1.39	0.01	19.4	0.08

Table 6. Summary of reported ammonia (NH_3) emissions from deep-pit full-scale finishing swine production systems.

Variable	**Demmers et al. (1999)**	**Heber et al. (2000)**		**Zhu et al. (2000)**		**Harper et al. (2004)**		**Hoff et al. (2009)**	**This Study (2011)**	
		3B	**4B**	**Barn A**	**Barn B**	**F-F**	**F-F**	**Control**	**Non-DDGS**	**DDGS**
Season	Summer	Spring & Summer		Fall	Fall	Winter	Summer	Summer & Fall	All	All
Manure system type	Deep-Pit	Deep-pit	Deep-pit	Deep-pit	Deep-pit	Flush	Flush	Deep-Pit	Deep-pit	Deep-pit
Average number of pigs	308	785	830	550	400	779	873	297	1,928	1,783
Average pig weight (kg)	26	73	79	82	109	91	57	59	61	63
Ventilation type[a]	M	M	M	M	N	M	M	H	H	H
Building ventilation rate (m^3/h)	10,350	[c]	[c]	13,062	30,039	[c]	[c]	61,155	96,575	84,166
Number days	[c]	92	74	7[b]	7[b]	5	8	168	384	384
Concentration (ppm)	27	6.4	7.5	6.5	11	11	10	6	341	522
Specific emission ($g\ d^{-1}\ AU^{-1}$)*	128	130	94	14	43	59	18	94	81	93

[a] M = mechanical ventilation N = natural ventilation H = hybrid barn with mechanical and natural ventilation

[b] 7 samples collected every 2 hours during a 12 hour period

[c] information not provided in article

* AU = 500 kg live body weight

Table 7: Comparison of ammonia (NH_3) emission rates (g/d-AU) from published literature and this study.

Weather	Published Literature	This Study	
		DDGS	Non-DDGS
Colder	25	74	52
Warmer	102	114	108

Table 8. Summary of reported hydrogen sulfide (H_2S) emissions from deep-pit full-scale finishing swine production systems.

Variable	**Heber et al. (1997)**		**Zhu et al. (2000)**		**Ni et al. (2002)**	**This Study (2011)**	
	Treated	**Control**	**Barn A**	**Barn B**	**3B**	**Non-DDGS**	**DDGS**
Season	Jan. to March		Sept.	Sept.	June to Sept.	All	All
Average number of pigs	[b]	[b]	550	400	887	1,928	1,783
Average pig weight (kg)	[b]	[b]	82	109	83	61	63
Ventilation type[a]	N	N	M	N	M	H	H
Building ventilation rate (m^3/h)	[b]	[b]	13,063	30,039	158,202	96,575	84,166
Number of samples	1,500	1,500	7	7	1,700	Cont. (384d)	Cont. (384d)
Concentration (ppb)	221	180	414	271	173	341	522
Specific emission ($g\ d^{-1}\ AU^{-1}$)*	0.9	0.84	2.0	3.3	8.3	10.3	8.2

[a] M = mechanical ventilation N = natural ventilation H = hybrid barn with mechanical and natural ventilation

[b] information not provided in article

* AU = 500 kg live body weight

Greenhouse Gas (GHG) Emission Rates

The daily ER of CO_2, N_2O and CH_4 for both dietary regimens are compared in Table 9. The average,ER (±SD) in g/d-pig was 1,847 (±768) CO_2, 0.11 (±.41) N_2O and 48 (±35) CH_4 for the DDGS barn, as compared to 2,127 (±817) CO_2, 0.10 (±.60) N_2O and 72 (±65) CH_4 for the Non-DDGS barn. N_2O ER was determined during part of turn 2 for both barns due to concentrations falling below the instrument detection limit (0.5 ppm) during the rest of the monitoring period. No statistical difference was detected between the diets for any of the GHG ($P = 0.46$ for CO_2, $P = 0.58$ for N_2O, and $P = 0.18$ for CH_4).

CO_2 emissions increased with pig weight, results of increasing metabolic rate and thus respiratory CO_2 production. Two previous studies have reported CO_2 emissions from finishing swine facilities, with similar CO_2 emission values of 15.8 kg/d-AU (Ni et al., 2000) and 16.7 kg/d-AU (Dong et al., 2006). Both studies monitored a grow-to-finish phase of a shallow pit operation where manure was removed weekly (Ni et al., 2000) and daily (Dong et al., 2006). Results from the current study (18.5 – 23.6 kg/d-AU) were higher than both previously reported studies, which was likely due to the longer monitoring period in the current study (i.e. monitoring the W-G phase in addition to G-F) than in the other two studies.

The partial results of N_2O ER (1.2 g/d-AU for Non-DDGS and 3.1 g/d-AU for DDGS) were comparable to the three studies reported in the literature that reported N_2O emissions from swine finish facilities ranging from 0.8 to 3.3 g/d-AU (Costa and Guarino, 2009; Dong et al., 2006; Osada et al., 1998) (Table 10).

The high variability in CH_4 emissions between the barns led to no statistical difference between the dietary regimens. However there was a significant difference ($P = 0.04$) between turns 1 and 2. This indicates CH_4 emission increases with ambient temperature and manure accumulation in the deep-pit. Even though there was no statistical in CH_4 emissions difference between the barns the Non-DDGS barn tended to have higher methane emission. This outcome is possibly due a decrease of methane production in the manure when DDGS are fed to pigs. The additional heat DDGS are exposed to during the drying process at the ethanol plant makes the DDGS less digestible compared to regular corn, Jarret et al. (2011) found similar results during their study.

To date there have been no full-scale emission studies on CH_4 emission from deep-pit swine finishing operations over a long period of time. There have been a few small-scale studies with systems that were manipulated to reflect a deep-pit system where manure was stored below slats for the duration of the monitoring period. The majority of studies reporting CH_4 ER were for shallow-pit systems. These studies reported results ranging from 29 to 351 g/d-AU CH_4 (Costa and Guarino, 2009; Dong et al., 2006; Heussermann et al., 2006; Ni et al., 2008; Osada et al., 1998; Sharpe et al., 2001; Zhang et al., 2007) (Table 11). In comparison, CH_4 ER from the current study ranged from 325 to 1,327 g/d-AU for the Non-DDGS regimen and 314 g/d-AU to 792 g/d-AU for the DDGS regimen. The lack of published CH_4 ER data for full-scale deep-pit swine finishing operations made it difficult to comparatively assess the result from the current study.

Cumulative GHG (CO_2, N_2O and CH_4) emissions are shown in Table 12. GHG emissions per AU marketed (mean ± SE) were: 1,717 ±15 kg CO_2 and 58.2 ±24.7 kg CH_4 for the Non-DDGS regimen; and 1,406 ±53 kg CO_2 and 37.4 ±7.7 for the DDGS regimen.

Table 9. Greenhouse gas (CO_2, N_2O, and CH_4) emission rates for each turn from the Non-DDGS barn and the DDGS Barn December 2009 through January 2011.

Turn			VR (m^3 h^{-1} pig^{-1})	kg d^{-1} $barn^{-1}$			g d^{-1} pig^{-1}			g d^{-1} AU^{-1}		
				CO_2	N_2O	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
Non-DDGS	1	Mean	38.6	3,174	--	57.9	2,173	--	42.6	19,542	--	342
		SD	52.2	1,058	--	20.3	818	--	20.1	10,353	--	110
		Max	293	8,147	--	115	4,415	--	101	64,541	--	719
		Min	5.80	781	--	18.4	684	--	7.10	2,791	--	125
	2	Mean	82.4	3,067	0.40	149	2,085	0.30	98.6	23,695	1.20	1,287
		SD	77.8	984	0.80	114	816	0.60	79.0	19,251	5.60	1,294
		Max	363	5,078	3.00	758	3,931	2.20	535	177,950	15.9	8,942
		Min	6.50	780	--	12.1	74.4	--	10.3	4,469	--	86.2
DDGS	1	Mean	36.1	2,336	--	46.0	1,809	--	38.26	18,258	--	320
		SD	48.5	622	--	23.9	757	--	24.2	6,333	--	111
		Max	263	4,079	--	119	3,497	--	105.8	42,439	--	615
		Min	4.02	1,114	--	9.86	468	--	4.02	6,470	--	140
	2	Mean	65.0	2,884	0.46	98.0	1,895	0.39	59.2	23,499	3.18	815
		SD	55.2	1,016	0.77	79.6	783	0.55	42.1	8,961	5.85	627
		Max	213	5,788	2.37	434	3,762	1.85	306	73,476	18.4	2,680
		Min	10.7	573	--	11.8	265	--	4.82	6,989	--	135

Table 10. Summary of nitrous oxide (N_2O) emission rate from experimental-scale finishing swine.

Variable	**Osada et al. (1998)**		**Dong et al. (2007)**	**Costa and Guarino (2009)**	**This Study (2011)**	
	Experimental	**Reference**	**G-F**		**Non-DDGS**	**DDGS**
Season	Fall	Fall	All	Fall and Spring	All	All
Location	Denmark		China	Italy	US	US
Manure pit type	Partially Slatted		Flush System	Slatted floor	Slatted Floor	Slatted Floor
Manure removal	7 d	60 d	Daily	[c]	Annual	Annual
Average number of pigs	40	40	66	344	1,928	1,783
Average pig weight (kg)	59	60	192	[c]	61	63
Ventilation type[a]	M	M	N	M	H	H
Building ventilation, m^3/h	2,080	2,138	[c]	[c]	96,575	84,166
Number of days	56	56	432[b]	70	384	384
Concentration, ppm	[c]	[c]	0.36	[c]	0.52	0.53
Specific emission, g d^{-1} AU^{-1}*	0.88	0.8	0.86	3.3	1.2	3.2

[a] M = mechanical ventilation N = natural ventilation

[b] 12 sample per day for 3 day during six different months

[c] information not provided in article

* 1 AU = 500 kg live body weight

Table 11: Summary of reported methane (CH_4) emissions from experimental and full-scale swine production systems.

Variable	**Osada et al. (1998)**		**Sharpe et al. (2001)***		**Haeussermann et al. 2006)**	**Zhang et al. (2007)***		**Dong et al. (2007)**	**Ni et al. (2008)***		**Costa and Guarino (2009)**	**This Study (2011)**	
	Exp.	**Ref.**	**1**	**1**		**A**	**B**	**G-F**	**1**	**2**		**Non-DDGS**	**DDGS**
Season	Fall	Fall	Winter	Summer	All	Summer		All	All	All	Fall and Spring	All	All
Manure system type	Flush	Flush	Flush	Flush	^{c}	Flush		Flush	Flush	Flush	^{c}	Deep-pit	Deep-pit
Manure removal ^{a}	7 d	60 d	Daily	Daily	90 d	7 d	7 d	Daily	7 d	7 d	^{c}	Annual	Annual
Average number of pigs	40	40	779	873	54	^{c}	^{c}		1,115	1,116	344	1,928	1,783
Average pig weight (kg)	59	60	91	41	^{c}	^{c}	^{c}	17,280	113	106	77	61	63
Ventilation type^{b}	M	M	M	M	M	M	M	N	M	M	M	H	H
Building ventilation rate (m^3/h)	2,080	2,138	^{c}	^{c}	^{c}	^{c}	^{c}	^{c}	51,840	52,560	^{c}	96,575	84,166
Number days	56	56	7	7	70	152	152	18	134	131	70	384	384
Concentration (ppm)	^{c}	^{c}	^{c}	^{c}	^{c}	14	20	10	12.7	10.3	^{c}	341	522
Specific emission (g d^{-1} AU^{-1})**	54	48	34	323	47	184	351	32	36	29	190	833	550

[a] Estimated pigs numbers but not weight were reported assume market weight of 118 kg

[b] M = mechanical ventilation N = natural ventilation H = hybrid barn with mechanical and natural ventilation

[c] information not provided in article

* Full scale studies (others are all experimetnal scale)

** AU = 500 kg live body weight

Table 12. Cumulative gas emission per pig and per AU marketed for deep-pit wean-to-finish swine fed Non-DDGS and DDGS December 2009 through January 2011.

	Turn		NH_3		H_2S		CO_2		N_2O*		CH_4	
			g pig^{-1}	kg AU^{-1}	g pig^{-1}	g AU^{-1}	kg pig^{-1}	kg AU^{-1}	g pig^{-1}	g AU^{-1}	kg pig^{-1}	kg AU^{-1}
Non-DDGS (pigs present)	1	W-G	83.7		5.17		53.3		--	--	0.65	
		G-F	1,023		21.9		316		--	--	6.39	
	2	W-G	319		56.4		58.2		--	--	3.15	
		G-F	1,373		53.5		363		77.1	314	17.0	
DDGS (pigs present)	1	W-G	103		6.53		33.6		--	--	0.31	
		G-F	1,317		25.2		275		--	--	6.09	
	2	W-G	568		79.0		95.7		--	--	4.33	
		G-F	903		44.5		259		73.1	297	6.60	
Non-DDGS (downtime)	1		24.4		4.74		1.26		--	--	0.27	
	2		15.9		0.34		4.89		1.89	7.75	0.24	
DDGS (downtime)	1		83.0		0.02		5.26		--	--	0.476	
	2		23.3		0.0001		4.72		1.63	0.62	0.151	
Non-DDGS (total)	1		1,131	5.19	31.8	146	371	1,702	--	--	7.31	33.5
	2		1,708	6.94	110	447	426	1,732	79.0	322	20.4	82.9
DDGS (total)	1		1,503	6.48	31.8	137	314	1,353	--	--	6.88	29.7
	2		1,494	6.07	124	504	359	1,459	74.7	298	11.1	45.1
Mean ± SE (Non-DDGS)			1,420± 289	6.07± 0.88	70.9± 39.1	297± 151	399± 27.5	1,717± 15	--	--	13.9± 6.55	58.2± 24.7
Mean ± SE (DDGS)			1,499± 4.50	6.28± 0.20	77.9± 46.1	321± 183	337± 22.5	1406± 53	--	--	8.99± 2.11	37.4± 7.7

* Reported for 104 days only due to concentration readings below instrument detection limit the rest of the time
See Table 2 for corresponding phase and market weights for each barn and turn

Conclusions

The impact of feeding 22% corn DDGS to growing-finishing (G-F) swine on NH_3, H_2S and greenhouse gas (GHG – CO_2, N_2O and CH_4) production was investigated using two side-by-side commercial deep-pit swine barns (1200 G-F pigs per barn). The field monitoring was performed continually for one year, involving two turns of animal production. The following findings were observed and conclusions drawn.

- Feeding 22% DDGS to G-F pigs in a deep-pit facility does not seem to affect the aerial emissions of NH_3, H_2S, CO_2, N_2O and CH_4 gases when compared to a traditional corn-soybean ration ($p = 0.10$ for NH_3, 0.13 for H_2S, 0.55 for CO_2, 0.58 for N_2O, and 0.18 for CH_4). The borderline p-values for the differences between the dietary regimens in NH_3 and H_2S emissions imply that statistical significance may have occurred if more replications had been involved.
- There were considerable/significant seasonal variations in H_2S and CH_4 emissions, hence the need to conduct measurements that cover the full production seasons to maximize data representativeness.
- Daily emissions (mean ± SD), in g/d-pig, were 7.5 ± 4.0 NH_3, 0.37 ± .59 H_2S, 2,127 ± 817 CO_2 and 72 ± 65 CH_4 for the Non-DDGS (control) diet; and 8.1 ± 4.6 NH_3, 0.40 ± .51 H_2S, 1,847 ± 768 CO_2, and 48 ± 35 CH_4 for the DDGS (treatment) diet. On the basis of kg emission per AU marketed, the values were: 8.6 NH_3, 0.724 H_2S, 2,350 CO_2 and 84 CH_4 for the Non-DDGS diet; and 12.2 NH_3, 0.777 H_2S, 2,095 CO_2, and 60 CH_4 for the DDGS diet.
- There were no noticeable differences in manure properties between the DDGS and Non-DDGS regimens.

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