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Impacts of feeding dried distillers grains with solubles on aerial emissions when fed to swine

by

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Program of Study Committee:
Robert Burns, Co-Major Professor
Hongwei Xin, Co-Major Professor
Hong Li
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TABLE OF CONTENTS

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CHAPTER 1. GENERAL INTRODUCTION AND LITERATURE REVIEW

Introduction

Iowa is a leader 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 contain high levels of digestible energy and metabolizable energy, digestible amino acids, and available phosphorus (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 then corn (Honeyman et al., 2007). Because of these benefits, animal nutritionists have suggested including up to 20% DDGS in nursery, grow-finish, and lactating sow diets and up to 40% in gestating sow and boar diets (Honeyman et al., 2007). However, the choice to feed DDGS is generally based on economics, and at the current DDGS and corn prices the inclusion of DDGS in swine diets has provided a cost savings over traditional non-DDGS diets.

Aerial emissions from livestock facilities have been a controversial subject. In Iowa, rural residents have concerns with odors and aerial emissions from animal feeding operations and the potential effect these emissions may have on their health, property values, and the environment. Livestock owners are concerned for similar reasons, but also for the health and productivity of their animals (Powers, 2003). Because of this, animal feeding operations are under increased scrutiny for their aerial emissions from the general public, environmental groups, and regulatory organizations.

Expansion of the corn grain ethanol industry has led to increased availability of DDGS, and feeding DDGS to swine has become more common in pork production. With feed being the primary cost in the pork production and increasing interest in air emissions from animal feeding operations, it is important to understand the impacts of DDGS-laden diets on aerial emissions. There is currently a lack of data concerning the impact of DDGS on air emissions at the farm scale. Previous pilot-scale, short-term research indicated that air emissions could be impacted, but long-term effects under production settings have not been examined.

Because feeding DDGS can provide a cost savings, pork producers are likely to continue feeding DDGS. As such, information collected at full-scale finish operations along with suggestions to manage emissions would be of value to pork producers.

Objective

The primary objective of this project was to quantify the impacts on gaseous emissions of feeding DDGS to growing-finishing swine. In order to achieve this objective two co-located wean-to-finish deep-pit swine facilities were monitored simultaneously for two production turns. Animals in one barn received a traditional corn soybean diet while the other received a ration with 22% DDGS inclusion. Constituents monitored and reported from this study were ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4).

Literature Review

It has been hypothesized that the sulfur in DDGS would result in increased H_2S emissions from stored swine manure when pigs are fed rations containing DDGS in full-scale swine production systems. The increased usage of DDGS in swine facilities has led several researchers to examine the effect of DDGS on emissions, odors and manure composition. However, these studies have been conducted at lab or non-commercial scales, and the results have not been consistent. The rest of the chapter is devoted to a review of literature on the subject matter.

Bench-scale Emission Study Results

Spiehs et al. (2000) performed a 10-week trial on 20 barrows receiving either DDGS (at a 20% inclusion rate) or non-DDGS ration. The pigs were housed in two fully-slatted pens within the grow-finish room of a swine research facility based on diet (non-DDGS vs. DDGS). The non-DDGS diet was a typical corn-soybean meal. 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 NH_3 from stored manure as affected by the animal's diet. The stored manure evaluated for emissions was maintained in a container to simulate deep pit storage. Air samples were collected from the head space of the storage containers. Over the 10-week period, this study reported that the DDGS diet did not affect the amount of odor, H_2S, or NH_3 from the stored manure.

Gralapp et al. (2002) performed six, four week trials utilizing a total of 72 finishing pigs. Three diets containing 0, 5, 10% DDGS were fed during the study. 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. Gralapp et al. (2002) observed no significant differences between concentrations of total solids (TS), volatile solids (VS), chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), and phosphorus (TP) content. Additionally, this study compared the effects on odor of each of the different diets and found there were no significant differences.

Xu et al. (2005) performed a study utilizing 40 nursery pigs to evaluate phosphorus excretion from animals receiving DDGS diets. The diets contained 0, 10, 20% DDGS. Results indicated that diets containing 10 and 20 % DDGS had a 15 and 30 % increase in daily manure excretion, respectively, compared to pigs fed the corn-soybean meal diet. Xu et al. (2005) reported the increase was due to a 2.2 and 5.1 % reduction in dry matter digestibility in rations containing 10 and 20 % DDGS, respectively. Reportedly, reduced dry matter digestibility was the result of increased amounts of crude protein and higher fiber levels in the DDGS diet.

Powers et al. (2006 & 2008; non-peer reviewed) completed a study that included 48 barrows in 8 chambers. In the study, the animals received increasing amounts of DDGS in their ration (from 0 –30%) as they progressed through their feeding phases. Corn-based control diets were also included. The diets were formulated to contain similar amounts of lysine and energy. Manure collection pans were placed under the animal pens and were partially cleaned twice weekly to remove manure and prevent overflow. Air samples were collected from within the animal chambers. The reported results indicated that the DDGS ration led to greater NH_3 and H_2S emission rates but reduced CH_4 emissions.

Jarret et al. (2011) investigated the effects of different biofuel co-products (DDGS, SBP, 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 ran on the manure to determine the methane production potential of the difference diet regimens. The DDGS diet was found to excrete the more N, C and dry matter than the other rations. It was also reported that diets with higher fiber contents with higher crude protein (CP) inclusions were had similar ammonia emissions as lower fiber and lower protein diets. Methane production potential was also found to be the lowest in manure when pigs were fed DDGS.

The results of these lab-scale studies cannot be directly compared because of differences in rations, animal housing, manure storage, and analytical methods. However, in general, the studies provide conflicting results. Besides differences in the experimental design of the two studies, the conflicting results might also be attributed to the different scale of the studies. While laboratory and small-scale trials can be quite useful, especially when multiple parameters are being varied, measurement of emissions from full-scale swine production systems with extended period of manure storage would provide data not currently available. Deep-pit systems usually store manure for up to a year before it is applied to the land. It is difficult to simulate these conditions in the laboratory.

Full-scale Emission Study Results

To date, there are no published results from full-scale studies looking at the effects of feeding DDGS to swine. However, there are several studies that have investigated gaseous emissions from full-scale swine finishing production facilities (Dong et al., 2009; Harper et al., 2004; Hoff et al., 2009; Ni et al., 2000; Ni et al., 2008; Sharpe et al., 2000; Zahn et al., 2001). These studies represent a variety of swine production and manure storage systems as well as monitoring style and study duration. Even though these studies aren't all from deep-pit systems in Iowa, they provide a baseline to compare this study's results to. The results reported from the previous field-scale studies are described below by constituent.

Ammonia (NH_3) Emissions

Ammonia is released by the microbiological decay of plant and animal proteins. The primary source of ammonia in deep-pit manure systems is urinary urea and the excretion of undigested and microbial proteins in the feces. Ammonia exists in two forms, a volatile form (NH_3) and a non-volatile form (NH_4^+). At a pH of 7.0 or lower the majority of the released N is in the non-volatile form, NH_4^+(Applegate et al., 2008).

Table 1 summarizes literature data for NH_3 emissions from swine finishing systems. All of these studies were completed on deep-pit manure storage systems with the exception of Harper et al. (2004) which was a flush system that recycled lagoon water weekly. Even though there are arguably more data available for NH_3 emissions than other constituents, the data are relatively variable.

Literature values of NH_3 emissions in g/d-AU (AU = animal unit = 500 kg live body weight) for finishing swine ranged from 14 to 130. It has been shown that NH_3 emission rates from swine finishing facilities increase with increased temperatures (ambient and barn) (Heber et al., 2000). This could account for some of the variability of NH_3 data. The average warm-weather NH_3 emissions rate for available data was 101.8 g/d-AU compared to 25 g/d-AU for colder weather conditions.

There have also been more studies done to determine the best way to mitigate NH_3 emissions than H_2S and greenhouse gas (GHG) emissions. There are two main ways to mitigate emissions: 1. Alter the feed composition (i.e. improve nutrient utilization efficiency within the animal so less undigested nutrients are excreted) 2. Directly applied treatments to the manure or on the exhaust air leaving the facility.

The most common diet modification that has been done to reduce or manipulate NH_3 emission rates was reducing dietary crude protein (CP). It has been shown for each percentage unit of reduction in dietary CP, estimated N excretion and NH_3 emissions were reduced by 8-10% in poultry and swine (Liang et al., 2005; Applegate et al. 2008). Some studies have shown that grow-finish pigs fed diets with 3.5 to 4.5 % lower CP experienced a 40-60% reduction in NH_3 aerial emissions (Powers et al., 2006; Sutton et al., 1999; Prince et al., 2000; and Richert and Sutton., 2006).

Manure treatments have also been successful in reducing NH_3 emissions. Heber et al. (2000) reported reductions of 24% per AU when the two mechanically ventilated deep pits were treated with the pit additive Alliance. Biofiltration of exhaust air could reduce NH_3 emission even more. Hoff et al. (2009) reported 58% NH_3 emissions reduction from a hybrid deep-pit swine finishing facility in Iowa by 58%. This was accomplished by retrofitting the existing system and adding an 88 m^2 biofilter that utilized wood-chips as the main filtration media.

Hydrogen Sulfide (H_2S) Emissions

Hydrogen sulfide is the product of the decomposition of organic compounds containing sulfur to sulfide under anaerobic conditions (Arogo et al., 2000). Sulfides exist in different proportions in aqueous solutions at different pH. For example, the pKa of HS^- is 7 meaning at a pH greater than 7 the majority of sulfides will be present in the form of HS^-, whereas below a pH 7 the majority of sulfides are in the form of H_2S (Figure 1, Snoeyink and Jenkins, 1980). Therefore, when manure storage systems with sulfides present experience a decrease in pH below 7 the potential for H_2S emission increases. In deep-pit swine facilities, the three primary sources of sulfates are excess feed, water, and excreted manure.

There are several studies that have investigated H_2S emissions from deep-pit finish swine facilities. One of the more comprehensive studies was Ni et al. (2001) who measured H_2S emissions from two mechanically ventilated finishing swine barns in central Illinois from June to September 1997. Each barn housed approximately 1,000 pigs and had 2.4 m deep-pits for manure storage. Table 2 shows the results from this study compared to similar studies that measured H_2S emissions from deep-pit swine finishing facilities (Avery et al., 1975; Zhu et al., 2000; Heber et al., 1997; Jacobson et al., 2003).

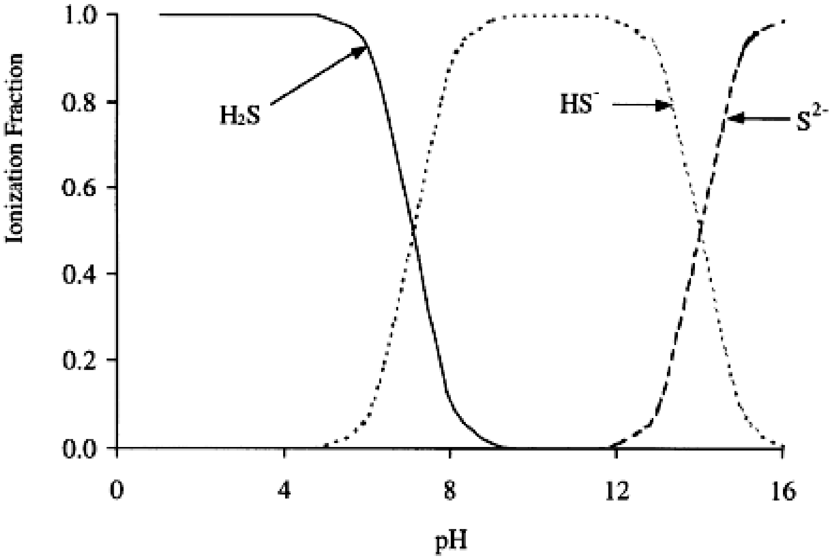

Figure 1: Fraction of sulfides in aqueous solution at 25°C as a function of pH (Snoeyink and Jenkins, 1980)

Based on the results from these studies H_2S emissions are highly variable among facilities and throughout seasons. Ni et al. (2002) and Zhu et al. (2000) showed H_2S emissions tend to increase during summer months. It has also been shown that temperature and ventilation rate have the highest influence on H_2S emissions (Ni et al., 2001).

There are very limited published data (with the exception of Ni et al., 2000, 2002, 2008) on H_2S emission factors for swine finishing facilities. For most of the reported studies, data were collected intermittently for short periods of time.

Mitigation methods considered in literature have focused on diet manipulation. Kendall et al. (2000) were able to reduce in-house H_2S concentrations by 39% by replacing mineral sulfate sources in diets for grow to finish pigs with carbonate, oxide and chloride. Powers et al. (2006) found that by feeding DDGS H_2S concentrations and emissions were increased from the additional sulfur added to the diet by feeding DDGS. Both studies constrained the ventilation systems such that each room received the same flowrate throughout the study.

Carbon Dioxide (CO_2) Emissions

The primary source of CO_2 emissions in livestock production is respiration from the animals. Manure is estimated to contribute only 4% of CO_2 production in livestock facilities (Pedersen and Sallvik, 2002). The third possible source for CO_2 production is the use of heaters during winter months in colder climates. Consequently, CO_2 emissions are not expected to drastically fluctuate on a per pig basis between similar swine production systems.

Ni et al. (2000) measured CO_2 emissions from two mechanically ventilated finishing swine barns with shallow manure flushing systems. Each barn had a capacity of 1,100 pigs. Pigs from both barns entered the facility at 25 kg and were marketed at 123 kg and received identical diets during the study. The average number of pigs in both barns was 1,115 with an average weight of 64 kg. Data were collected continuously from Aug 2002 to June 2003. This study found that the average CO_2 emissions were 15.8 kg/d-AU for both barns.

Dong et al. (2007) compared CO_2 emissions from multiple types of swine production (farrow-to-finish) in China. The finishing facility was naturally ventilated with a partial slatted floor and housed 192 pigs. Solid manure was removed twice a day from this facility. A CO_2 balance was used to estimate the ventilation rate used in the emission rate calculations. Air samples were collected manually at 2-hour intervals for three consecutive days, six times between May 2004 and March 2005. The annual average CO_2 emission for this study was determined to be 16.7 kg/d-AU, comparable to the results from Ni et al. (2000).

Nitrous Oxide (N_2O) Emissions

N_2O is a product of both nitrification and denitrification. N_2O is emitted from manure as an intermediate product of nitrification/denitrification processes under low oxygen conditions (Costa and Guarino, 2009). Nitrification requires aerobic conditions and denitrification requires anaerobic conditions. In swine houses, these conditions occur mainly in deep litter systems but not slurry systems; however emissions can also occur from manure on the floor in swine houses with slatted floors (Philippe et al., 2007).

To date there are only four studies that have monitored N_2O from swine production facilities. Of these studies only one was representative of a full-scale swine operation (Zhang et al., 2007). The other three studies were smaller experimental scale (Costa and Guarino., 2009; Dong et al., 2006; and Osada et al., 1998) (Table 3).

Table 1. Summary of reported ammonia (NH_3) emissions from 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)
		3B	4B	Barn A	Barn B	F-F	F-F	Control
Season	Summer	Spring & Summer		Fall	Fall	Winter	Summer	Summer & Fall
Manure system type	Deep-Pit	Deep-pit	Deep-pit	Deep-pit	Deep-pit	Flush	Flush	Deep-Pit
Average number of pigs	308	785	830	550	400	779	873	297
Average pig weight (kg)	26	73	79	82	109	91	57	59
Ventilation type[a]	M	M	M	M	N	M	M	H
Building ventilation rate (m^3/h)	10,350	[c]	[c]	13,062	30,039	[c]	[c]	61,155
Number days	[c]	92	74	7[b]	7[b]	5	8	168
Concentration (ppm)	27	6.4	7.5	6.5	11	11	10	6
Specific emission ($g\ d^{-1}\ AU^{-1}$)*	128	130	94	14	43	59	18	94

[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 2. Summary of reported hydrogen sulfide (H_2S) emissions from full-scale finishing swine production systems.

Variable	Heber et al. (1997)		Zhu et al. (2000)		Ni et al. (2002)
	Treated	**Control**	**Barn A**	**Barn B**	**3B**
Season	Jan. to March		Sept.	Sept.	June to Sept.
Average number of pigs	[b]	[b]	550	400	887
Average pig weight (kg)	[b]	[b]	82	109	83
Ventilation type[a]	N	N	M	N	M
Building ventilation rate (m^3/h)	[b]	[b]	13,063	30,039	158,202
Number of samples	1,500	1,500	7	7	1,700
Concentration (ppb)	221	180	414	271	173
Specific emission (g d^{-1} AU^{-1})*	0.9	0.84	2.0	3.3	8.3

[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

Zhang et al. (2007) monitored two farrowing operations in southern Manitoba, Canada. Air samples were collected for 19 days in the Fall 2003 and Summer 2004. N_2O exhaust concentrations measured were the same as the background ambient levels (0.4 ppm); therefore there were no emissions of N_2O recorded for this study.

Two of the three experimental scale studies reported similar results for the grams of N_2O emitted on per day per AU basis. Osada et al. (1998) and Dong et al. (2007) reported that finishing swine emit an average of 0.87 g N_2O/ d-AU during a grow-out period. In comparison, Costa and Guarino (2009) results were significantly higher at 3.26 g N_2O/ d-AU. None of the studies was performed in the United States, and nor did any of the facilities use deep-pit manure storage/treatment system. However, Osada et al. (1998) imitated a deep-pit system by storing the manure in the shallow pit for the duration of the eight-week trial and compared this to a system that flushed weekly. It should also be noted that all of reported studies were done abroad. The lack of full-scale studies measurement of N_2O emission data, under the U.S. conditions and the limited data from abroad indicates that there is a need for more research in this area.

Table 3: 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)
	Exp	Ref	G-F	
Season	Fall	Fall	All	Fall and Spring
Location	Denmark		China	Italy
Manure pit type	Partially Slatted		Flush System	Slatted floor
Manure removal	7 d	60 d	Daily	c
Average number of pigs	40	40	66	344
Average pig weight (kg)	59	60	192	c
Ventilation type[a]	M	M	N	M
Building ventilation, m^3/h	2080	2138	c	c
Number of days	56	56	432[b]	70
Concentration, ppm	c	c	0.36	c
Specific emission, $g\ d^{-1}\ AU^{-1}$*	0.88	0.8	0.86	3.3

[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

Methane (CH_4) Emissions

CH_4 production in slurry occurs when anaerobic conditions exist, combined with sufficient availability and degradability of organic compounds. The degree of anaerobic bacterial fermentation and the amount of CH_4 produced depends on the pH, temperature of the manure and the hydraulic retention time of the system (Zeeman, 1991; Huther et al., 1997).

CH_4 production in deep-pit swine production facilities has become more of a concern with increased foaming, flash fires and explosions occurring in recent years (Moody et al., 2009). Unfortunately, there are very few studies that evaluated the CH_4 production from full-scale deep-pit facilities in terms of emission rates. There have been multiple studies that evaluate the CH_4 production potential of deep-pit as a potential energy source (Martin, 2003; Spajic et al., 2010; and Wu-Hann, 2010).

Martin (2003) performed a study to characterize chemical and physical transformations in swine manure accumulated in deep pits under slatted floors and assess the performance of the system with respect to CH_4 emissions. Samples were collected from two groups of feeder pigs finished in a single 1,000 head deep-pit barn from January to October 2002. During this period, three vertically integrated sub-samples were collected and composited every two weeks. Animals were fed a traditional corn-soybean diet. To estimate gaseous CH_4 emissions, Martin (2003) used calculated losses of VS and COD. CH_4 emissions for a 289-day period were estimated to be 20,381 m^3 or 100 g/d-AU. This estimate was comparable to what has been reported in literature as shown in Table 4.

Table 4: 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)
	Exp.	Ref.	1	1		A	B	G-F	1	2	
Season	Fall	Fall	Winter	Summer	All	Summer		All	All	All	Fall and Spring
Manure system type	Flush	Flush	Flush	Flush	[c]	Flush		Flush	Flush	Flush	[c]
Manure removal [a]	7 d	60 d	Daily	Daily	90 d	7 d	7 d	Daily	7 d	7 d	[c]
Average number of pigs	40	40	779	873	54	[c]	[c]		1115	1116	344
Average pig weight (kg)	59	60	91	41	[c]	[c]	[c]	17,280	113	106	77
Ventilation type[b]	M	M	M	M	M	M	M	N	M	M	M
Building ventilation rate (m^3/h)	2080	2138	[c]	[c]	[c]	[c]	[c]	[c]	51,840	52,560	[c]
Number days	56	56	7	7	70	152	152	18	134	131	70
Concentration (ppm)	[c]	[c]	[c]	[c]	[c]	14	20	10	12.7	10.3	[c]
Specific emission (g d^{-1} AU^{-1})**	54	48	34	323	47	184	351	32	36	29	190

[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

Spajic et al. (2010) performed biochemical CH_4 potential assays on swine manure collected from a deep-pit swine finishing operation. The biochemical CH_4 potential assays (BMPs) provide an estimate of potential CH_4 production under optimal anaerobic digestion conditions. The data reported by Spajic et al. (2010) estimated CH_4 production could be up to 254 mL CH_4/g VS. In similar tests performed with manure from a farrow-to-finish shallow-pit system, Wu-Haan (2010) reported potential CH_4 yields of 321 mL CH_4/g VS. It was reported at the time of sampling for both studies animals were receiving a DDGS ration. ASABE Standard D384.2 MAR2005 (R2010) reports that manure from swine finishing operations produce 45 kg VS/pig marketed. Using this factor with the previous study results, CH_4 emission estimates can be made. Table 5 shows the estimates made using data from Spajic et al. (2010) and Wu-Haan (2010). These values are higher than reported literature since BMPs are used as indicators of the highest level of CH_4 production that could be achieved by an anaerobic digestor that has been optimized to produce CH_4.

CH_4 emission rates reported in literature range from 29 to 351 g/d-AU. Similar to NH_3 emission rates, CH_4 emission rates were reported to be higher during summer months. Sharpe et al. (2001) reported the most extreme case of having significantly different emission rates of 34 g/d-AU and 323 g/d-AU for cooler and warmer seasons, respectively.

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Table 5: Methane (CH_4) production potentials from swine finishing manure in Iowa

Reference	CH_4 Production Potential mL CH_4/ g VS	CH_4 Emissions Potential g CH_4/d-AU*
Spajic et al. (2010)	254	225
Wu-Haan et al. (2010)	315	284

*1 AU = 500 kg live body weight

The same swine finishing barn was monitored continuously for 7 days in both spring and winter and it was found that CH_4 emissions were 34 g/d-AU and 323 g/d-AU, for spring and winter, respectively, an 800% increase in CH_4 emission for the warmer months. It was also reported that CH_4 emissions would gradually increase with the growth of the pigs (Osada et al., 1998). Costa and Guarino (2008) reported that CH_4 emission increased when ambient temperatures increased and could be related to the frequency of manure removal from the barn. Both of these studies were supported by findings reported in Haeussermann et al. (2006).

One study reported a reduction of CH_4 emissions per AU by treating the manure with oil (Ni et al., 2008). For this study, the treatment barn was sprayed various oils throughout the growout period and results were compared to a control that was not treated with any suppressant. Oils used in this study were soybean oil, misting of essential oils, and misting of essential oils with water. This was the only full-scale study found that considered mitigation techniques for CH_4.

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CHAPTER 2. AMMONIA, HYDROGEN SULFIDE, AND GREENHOUSE GAS EMSSIONS FROM WEAN-TO-FINISH SWINE BARNS FED TRADITIONAL VS. A DDGS-BASED DIET

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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), and 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 from modern swine production systems.

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 high levels of digestible energy and metabolizable energy, digestible amino acids, and available phosphorus (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 cost savings over traditional non-DDGS 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 from feeding DDGS. The increased usage of DDGS at swine facilities has led several researchers to examine the effect of DDGS on emissions, odors, and manure composition, but these studies have been at lab or at non-commercial scales 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; 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) 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 storage containers. Over the 10-week period, this study reported that DDGS (at a 20% inclusion level) did not affect odor, H_2S, or NH_3 emissions from the stored manure.

Gralapp et al. (2002) performed six, four week trials utilizing a total of 72 finishing pigs. Three diets containing 0, 5, 10% DDGS were fed during the study. 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. Gralapp et al. (2002) observed no significant differences between concentrations of total solids (TS), volatile solids (VS), chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), and phosphorus (TP) content. Additionally, this study compared the effects on odor of each of the different diets and found there were no significant differences.

Xu et al. (2005) performed a study utilizing 40 nursery pigs to evaluate phosphorus excretion from animals receiving DDGS diets. The diets contained 0, 10, 20% DDGS. Results indicated that diets containing 10 and 20 % DDGS had a 15 and 30 % increase in daily manure excretion, respectively, compared to pigs fed the corn-soybean meal diet. Xu et al. (2005) reported the increase was due to a 2.2 and 5.1 % reduction in dry matter digestibility in rations containing 10 and 20 % DDGS, respectively. Reportedly, reduced dry matter digestibility was the result of increased amounts of crude protein and higher fiber levels in the DDGS diet.

Jarret et al. (2011) investigated the effects of different biofuel co-products (DDGS, SBP, 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 ran on the manure to determine the methane production potential of the difference diet regimens. The DDGS diet was found to excrete the more N, C and dry matter than the other rations. It was also reported that diets with higher fiber contents with higher crude protein (CP) inclusions were had similar ammonia emissions as lower fiber and lower protein diets. Methane production potential was also found to be the lowest in manure when pigs were fed DDGS.

The results from these studies cannot be directly compared because of differences in rations, animal housing, manure storage, and analytical methods. Besides differences in the experimental design of these studies, the results may also be affected by scaling issues. Additionally, only two of the studies investigated the effects of feeding DDGS to swine on aerial emissions, both were small scale experimental studies. This has led to deficit of data concerning the impact of DDGS on air emissions at the farm 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 meet these objectives, NH_3, H_2S and greenhouse gases (GHG) (carbon dioxide – CO_2, nitrous oxide – N_2O, and methane – CH_4) concentrations were measured and emission data were collected 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, designated as Non-DDGS and DDGS, located in central Iowa were monitored for two production turns. Pigs entered the barns at 5.5 kg (12 lbs) and were marketed at 118 kg (260 lbs). Each turn was approximately 27 weeks in length with pigs entering the barns at 3 weeks and marketed around 30 weeks of age. The barns had a rated capacity of 1,200 marketed pigs. Both barns were double-stocked initially, meaning during the wean-to-grow (W-G) phase (first 6 to 10 weeks of the turn) both barns held approximately 2,400 pigs. 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 during this study were formulated 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. The ingredients and diet formulations used during this study are proprietary information. 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. Nursery diets were fed until the pigs weighed 12 kg or approximately 10 to 14 days after entering the barn. Therefore, data for the periods when nursery diets were fed were excluded from the analysis.

The producer provided weekly pig performance data, including mortality and average body weight for the duration of the project.

Measurement System

A MAEMU was used to continuously collect emissions data from the two deep-pit wean-to-finish swine barns. The 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. Aerial emissions were monitored for two growout periods. A photoacoustic multi-gas analyzer (INNOVA Model 1412, INNOVA AirTech Instruments A/S, Ballerup Denmark) was used to measure NH_3, CO_2, N_2O, and CH_4 concentrations. H_2S concentrations were measured using an ultraviolet fluorescence H_2S 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.

Air samples were drawn from three composite locations (north pit fans, south pit fans, and endwall fans) in each barn and an 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 pollutant concentration. Use of the fourth reading was due to the fact that the INNOVA and API had 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 consecutively pumped sample air from each sampling location using individual designated pumps. Air samples from each location were collected sequentially over the 120 s period via the controlled operation of servo valves of the PP-GSS. Each barn sampling location was sampled every 14 min. It was assumed with the sequential sampling 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 minutes. 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 leak checked weekly to ensure no contamination 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. The *in situ* calibration of the exhaust fans was conducted with a fan assessment numeration system (FANS) (Gates et al. 2004). For single-speed fans (endwall), 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 principal of indirect animal calorimetry (Xin et al., 2009). More specifically, the metabolic heat production of non-ruminants is related to oxygen (O_2) consumption and CO_2 production of the animals (Brouwer, 1965) (Equation 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 (Equations 2 & 3). For the purpose of this study, finishing pig THP under thermoneutrality (Pedersen and Sallvik, 2002) (Equation 4) and a respiratory quotient (RQ) of 1.14 was 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})

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

$$VR = \frac{CO_2}{CO_{2e} - CO_{2i}} \tag{3}$$

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

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

CO_{2e} = carbon dioxide concentration of exhaust (ppm_v)

CO_{2i} = carbon dioxide concentration of inlet (ppm_v)

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

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

m = mass of animal (kg)

n = daily feed energy intake (expressed as n times the maintenance requirement)

Body mass used in the THP calculation was provided weekly from the producer and linearly interpolated for daily values. The daily feed energy intake was calculated using information provided by the producer about feed composition and the daily maintenance energy requirement (DME, kcal/day) for a finishing swine provided by NRC (1998) (Equation 5). Calculated values for n ranged from 6.9 to 2.9 (with an average of 3.5) for pig weights from 5 -120 kg, respectively.

$$DME = 106 * BW^{0.75} \qquad (5)$$

Where, BW = animal body weight (kg)

In addition to air sampling, manure samples were collected monthly from each barn. Manure samples were collected from each of the four pit pump-out locations and composited for each barn. Samples were cooled and shipped to Midwest Laboratories (Omaha, NE) and were analyzed for 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. A total of eleven manure samples from each barn was collected and analyzed during the monitoring period.

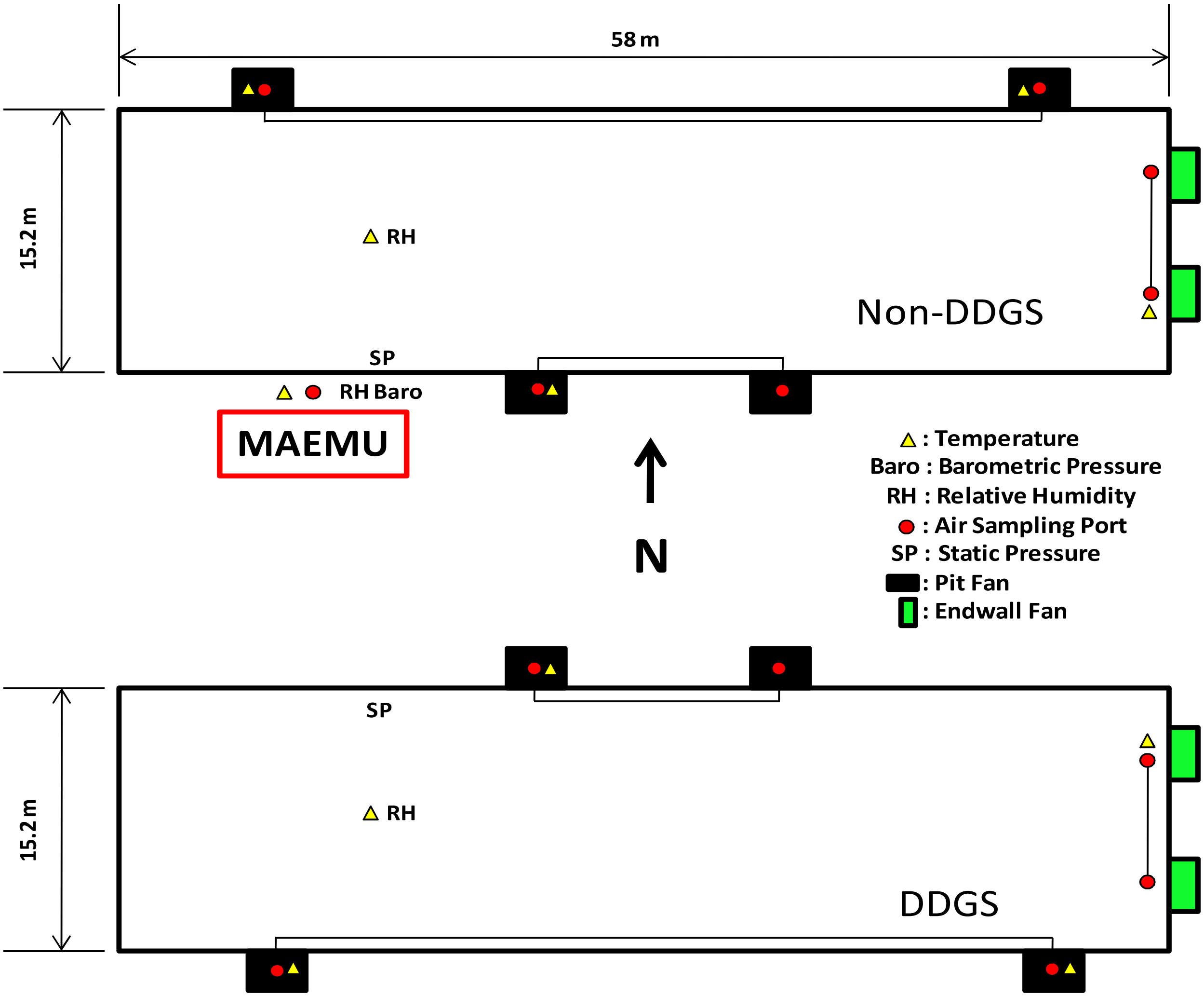

Figure 1: Schematic representation of the monitoring system layout

<u>Gaseous Emission Rate (ER) Determination</u>

Constituent ER was calculated as the mass of the gas emitted from the barn per unit time and expressed in the following form (Equation 6):

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

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℃) 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 emission rates were analyzed with analysis of variance using a proc mixed procedure to determine the effects of diet, turn, temperature, and animal units. Data were analyzed using single factor ANOVA and considering each day as a repeated measure during the period. The dietary effect was considered being significant at P-value $\leq$ 0.05.

Results and Discussion

Manure Sample Analysis Results

Manure samples from each barn were sampled monthly from each barn to determine any differences in manure properties by feeding DDGS. Table 1 shows the average results for both barns over the entire monitoring period along with the standard deviations. There were a total of 11 manure samples collected over the sampling period. The barn fed the DDGS ration tended to have higher for NH_3-N, TN, S, and Z concentrations. Ultimately, manure composition in both barns were similar to each other.

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	4240 (255)	4460 (347)
Organic Nitrogen, ppm	2510 (360)	2610 (366)
Total Nitrogen, ppm	6750 (438)	7070 (386)
Phosphorus, ppm	1984 (814)	1968 (758)
Poatassium, ppm	4385 (496)	4508 (448)
Sulfur, ppm	735 (82)	847 (147)
Calcium, ppm	1430 (157)	1440 (201)
Magnesium, ppm	840 (255)	880 (140)
Sodium, ppm	1030 (82)	1020 (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)
pH	8.2 (.2)	8.1 (.34)

In-House Gaseous Concentrations

Each barn was monitored for two complete turns. Each turn was approximately 29 weeks long. Animal populations were reported for the W-G phase and G-F phase along with corresponding exiting weight (Table 2). The daily average VR for the barns are shown with ambient temperature in Figure 2 for the entire monitoring period. The average VR for the Non-DDGS barn for the monitored period was 61 m^3/hr-pig and 65 m^3/hr-pig for the DDGS barn. There was no significant difference between the two barns VR (p-value = 0.65).

Daily mean concentrations are shown for NH_3 (Figure 3), H_2S (Figure 4), CO_2 (Figure 5), N_2O (Figure 6), and CH_4 (Figure 7) for both turns in the DDGS barn to show dynamic seasonal variations of the concentrations. The concentration means and variations are also reported by fan stage for both barns in Table 3, Table 4, Table 5 and Table 6. Endwall (Stage 3) fan concentrations were typically lower than concentrations measured at both pit (Stage 1 and Stage 2) fan locations.

However, measured concentrations were similar between the two barns with NH_3 and H_2S concentrations trending higher in the DDGS barn and CH_4 concentrations trending higher in the Non-DDGS barn. There were no trending differences for CO_2 or N_2O 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 between barns (p-value = 0.5), 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 diet, especially since the two barns shared the same water source. More investigation is needed to determine if sulfur from feedstuffs is the only influencing factor. The CH_4 concentrations were lower in the DDGS barn than in the Non-DDGS.

Ammonia and Hydrogen Sulfide Emission Rates

Daily ER values calculated using Equation 6 are reported on the basis of per barn, per pig, and per AU. In addition, the cumulative emissions are reported per pig marketed and per AU marketed. A statistical analysis was completed to determine if difference in emission rates between the two barns was significant.

The daily average ERs and cumulative emissions for NH_3 and H_2S are shown for both barns in Figure 8 and Figure 9, respectively. Average NH_3 and H_2S ER for each turn are shown in Table 7 for Non-DDGS barn and Table 8 for the DDGS barn. 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. There was no statistical difference detected between the diets for either NH_3 (p-value = .10) or H_2S (p-value = 0.13). However, judging from the borderline p-value, significant difference may have been detected had there been more replications monitored for NH_3 and H_2S emissions. There was a difference between turns 1 and 2 for H_2S emissions in both barns (p-value=0.04), indicating there is seasonal variation in H_2S emissions from deep-pit swine facilities. On average, H_2S ER increased from .27 – 1.28

kg/barn for winter and summer seasons, respectively, for both barns. Ni et al. (2002) and Zhu et al. (2000) also found that H_2S emissions tended to increase during summer months. Similar to H_2S, NH_3 also exhibited some seasonal variation in each barn, the Non-DDGS barn experienced in an increase from 9 to 12.6 kg/barn and the DDGS barn was similar with an increase from 10.5 to 12.6 kg/barn (p-value = 0.06).

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 ambient and barn temperatures, accounting for the wide range of the previously reported values. The average warm weather NH_3 ER for the available data was 102 g/d-AU, as compared to 25 g/d-AU for colder weather conditions. NH_3 ERs measured during this study for both the DDGS and Non-DDGS barns were within the range of reported NH_3 ER (Table 13). However, when seasonal ER values were compared to those reported in literature, results from this study were higher for both cool and warm weather. Table 11 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.

Table 11: 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

There is limited published data available on H_2S ER for deep-pit swine finishing facilities. Previous studies have reported ER ranging from .84 to 8.3 g/d-AU from monitored deep-pit swine facilities for H_2S (Avery et al., 1975; Heber et al., 1997; Ni et al., 2002; Zhu et a., 2000). Based on the results from these studies H_2S emissions are highly variable between facilities and seasons. Ni et al. (2002) and Zhu et al. (2000) showed H_2S emissions tended to increase during summer months. The majority of these studies collected data intermittently for short periods of time.

Similar H_2S ER was observed for both dietary regimens in this study (Table 14). The average colder weather H_2S ER was 1.7 and 2.4 g/d-AU for Non-DDGS and DDGS barns, respectively. There was a drastic increase in H_2S ER during warmer periods of the year for both regimens (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 NH_3 and H_2S are reported in Table 12 for both barns. The average of NH_3 emissions for both turns in the DDGS barn was 1,499 g/pig marketed with only 9 g difference between turns 1 and 2. The Non-DDGS barn had a similar average of 1,420 g/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 were:

8.7 kg NH_3 and 724 g H_2S for the Non-DDGS regimen; and 12.2 kg NH_3 and 777 g H_2S for the DDGS diet.

Greenhouse Gas (GHG) Emission Rates

The daily ER and cumulative emissions of CO_2, N_2O and CH_4 for both dietary regimens are compared in Figures 10, 11, and 12, respectively. The daily average ERs of CO_2, N_2O and CH_4 are shown in Table 9 for the Non-DDGS barn and in Table 10 for the Non-DDGS barn. The average,ER (±SD) in g/d-pig barn was 1847 (±768) CO_2, 0.11 (±.41) N_2O and 48 (±35) CH_4 for the DDGS, as compared to 2,127 (±817) CO_2, 0.10 (±.60) N_2O and 72 (±65) CH_4 for the Non-DDGS barn. N2O 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. The average daily ER per pig were 0.30 and 0.39 g for the Non-DDGS and DDGS diets, respectively. There was no statistical difference detected between the diets for any of the GHG (CO_2 p-value = 0.46, N_2O p-value = 0.58, and CH_4 p-value = 0.18).

CO_2 emissions increased with pig weight, caused by increased metabolic rate (thus respiratory CO_2 production), as shown in Figure 10. Two previous studies have reported CO_2 emissions from finishing swine facilities. Results from both studies were similar with Ni et al. (2000) reporting 15.8 kg/d-AU and 16.7 kg/d-AU reported by Dong et al. (2006). Both of these studies monitored a grow-to-finish phase of a shallow pit operation where manure was removed weekly for Ni et al. (2000) and daily for Dong et al. (2006). Results from this study were higher than both previously reported studies likely due to the difference in pig age between this study and the other two studies. The CO_2 ER for the Non-DDGS pigs was 19.5 kg/d-AU for turn 1 and 23.6 kg/d-AU for turn 2; whereas it was 18.5 and 23 kg/d-AU for turn 1 and turn 2, respectively, for the DDGS pigs.

N_2O ERs were determined for the second half of turn 2 for the previously stated reason, with the Non-DDGS barn averaging 1.2 g/d-AU and the DDGS barn having an average of 3.1 g/d-AU. These results were comparable to the three studies in 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 15).

With high variability of the CH_4 emissions between barns there was no statistical difference detected between the dietary regimens; however there was a significant difference (p-value = 0.04) between turns 1 and 2. This indicates CH_4 emission tends to increase with ambient temperature and accumulation of manure in the deep-pit storage.

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 16). In comparison, CH_4

ER from the current study ranged from 325 to 1327 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 a full-scale deep-pit swine finishing operations made it difficult to compare the result from the current study.

Cumulative emissions of CO_2, N_2O and CH_4 are shown in Table 12. The average CO_2 emission per pig marketed was 337 kg for the DDGS regimen and 398 kg for the Non-DDGS regimen. Since there were no N_2O emission data for turn 1 and part of turn 2, the cumulative emissions were based on part of turn 2 with both barns emitting similar amounts of 79 g (Non-DDGS) and 75 g (DDGS) per pig marketed. Average CH_4 emissions per pig marketed were 14 kg and 9.0 kg for the Non-DDGS and DDGS regimens, respectively. The CH_4 emissions between turns 1 and turns 2 increased by 13 kg/pig for the Non-DDGS barn and 4 kg/pig for the DDGS barn. GHG emissions per AU marketed were: 2350 kg CO_2 and 84 kg CH_4 for the Non-DDGS regimen; and 2095 kg CO_2 and 60 kg CH_4 for the DDGS regimen.

Conclusions

Results from this project indicate that feeding 22% DDGS to wean-to-finish pigs in a deep-pit facility does not seem to affect aerial emissions of NH_3, H_2S, CO_2, N_2O and CH_4 gases when compared to a traditional corn-soybean ration (NH_3 p-value = 0.10, H_2S p-value = 0.13, CO_2 p-value = 0.55, N_2O p-value = 0.58, and CH_4 p-value = 0.18). 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 seasonal variations in H_2S and CH_4 emissions (H_2S p-value = 0.02, CH_4 p-value = 0.04).

On average the wean-to-finish pigs fed the traditional corn-soybean diet emitted 7.5 ± 4.0 g/d-pig of NH_3, 0.37 ± .59 g/d-pig of H_2S, 2,127 ± 817 g/d-pig of CO_2 and 72 ± 65 g/d-pig of CH_4. The W-F pigs fed a 22% DDGS ration emitted 8.1 ± 4.6 g/d-pig of NH_3, 0.40 ± .51 g/d-pig of H_2S, 1,847 ± 768 g/d-pig of CO_2, and 48 ± 35 g/d-pig of CH_4. On the basis of per AU marketed, the gaseous emissions for the two dietary regimens were: 8.6 kg NH_3, 724 g H_2S, 2,350 kg CO_2 and 84 kg CH_4 for the Non-DDGS diet; and 12.2 kg NH_3, 777 g H_2S, 2,095 kg CO_2, and 60 kg CH_4 for the DDGS diet.

There were no noticeable differences in manure compositions between the DDGS and Non-DDGS regimens.

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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

		Growout Days		# pigs		Avg. Pig Wt., kg	
		W-G	G-F	W-G	G-F	W-G*	G-F*
Non-DDGS	Turn 1	59	126	2574	1236	7.4, 40	40, 109
	Turn 2	49	155	2614	1289	7.2, 27	27, 123
DDGS	Turn 1	52	139	2375	1121	7.3, 30	30, 116
	Turn 2	76	110	2403	1235	6.8, 37	37, 123

* incoming wt, exiting wt

Table 3. Daily ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations for each ventilation stage for the Non-DDGS barn

		NH_3, ppm			H_2S, ppb		
		Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Turn 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	1170	1210	650
	Min	7.28	4.10	2.91	90.2	34.0	26.2
	SEM	0.52	0.53	0.30	14.5	13.7	7.47
Turn 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	5139	6570	3680
	Min	4.08	4.41	1.46	69.3	24.2	21.6
	SEM	0.60	0.58	0.56	45.3	50.7	33.0
Average	Mean	18.9	15.0	10.4	450	347	228
	SD	7.85	7.64	6.28	477	533	343
	Max	42.1	52.1	43.2	5139	6570	3680
	Min	2.92	2.09	1.22	69.3	24.2	21.6
	SEM	0.41	0.40	0.33	25.0	27.9	17.9

***Stages 1 and 2 are pit fans, and Stage 3 are endwall fans.**

Table 4. Daily ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations for each ventilation stage for the DDGS barn

		NH_3, ppm			H_2S, ppb		
		Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Turn 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	1641	1080	1032
	Min	3.92	4.42	3.42	48.8	106	22.2
	SEM	0.56	0.48	0.41	25.5	17.1	12.1
Turn 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	3977	6198	3303
	Min	5.07	2.16	1.63	3.18	2.94	0.33
	SEM	0.78	0.81	0.85	53.5	55.0	32.6
Average	Mean	20.3	20.6	14.3	580	655	332
	SD	9.89	9.48	9.33	617	611	357
	Max	48.1	56.3	49.3	3977	6198	3303
	Min	2.79	1.70	1.31	3.18	2.94	0.33
	SEM	0.52	0.49	0.49	32.3	55.0	18.7

***Stages 1 and 2 are pit fans, and Stage 3 are endwall fans.**

Table 5. Greenhouse gas (CO_2, N_2O, and CH_4) concentrations for each ventilation stage for the Non-DDGS Barn

		CO_2, ppm			N_2O, ppb			CH_4, ppm		
		Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Turn 1	Mean	3026	2915	3138	211	217	203	148	116	68.4
	SD	1301	1353	1527	104	106	111	67.8	72.5	33.4
	Max	5540	5364	5688	484	479	487	489	497	249
	Min	552	553	484	13.9	18.1	6.52	51.2	26.0	21.9
	SEM	100	104	117	8.17	8.36	8.78	5.23	5.596	2.57
Turn 2	Mean	1941	1834	2027	800	785	824	234	201	151
	SD	1259	1132	1313	544	497	568	155	106	81.4
	Max	6300	5348	6428	2293	1912	2907	1475	710	450
	Min	509	524	452	193	189	188	27.7	44.6	20.9
	SEM	91.6	82.3	95.5	39.7	36.2	41.4	11.4	7.805	5.97
Average	Mean	2398	2290	2490	523	518	533	190	157	109
	SD	1404	1368	1539	493	460	517	129	101	75.4
	Max	6300	5364	6428	2293	1912	2907	1475	710	450
	Min	509	486	452	13.9	18.1	6.52	27.7	26.0	20.9
	SEM	73.1	71.2	80.1	25.9	24.2	27.2	6.74	5.287	3.95

*** Stages 1 and 2 are pit fans, and Stage 3 are endwall fans.**

Table 6. Greenhouse gas (CO_2, N_2O, and CH_4) concentrations for each ventilation stage for the DDGS Barn

		CO_2, ppm			N_2O, ppb			CH_4, ppm		
		Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Turn 1	Mean	2807	2745	3253	236	250	211	124	106	76.6
	SD	1124	1209	1547	86	85	109	53.5	38.6	30.8
	Max	4667	4917	6080	474	484	507	251	191	177
	Min	517	507	499	60.0	70.0	5.2	26.4	27.6	15.8
	SEM	86.5	93.0	119	6.76	6.66	8.60	4.13	2.98	2.38
Turn 2	Mean	1840	1832	1981	791	796	809	148	192	122
	SD	1099	1105	1285	500	514	515	64.9	167	71.9
	Max	4895	5024	5506	1903	2024	2007	341	1486	289
	Min	490	458	443	205	203	165	32.2	20.2	15.4
	SEM	80.0	80.4	93.5	36.5	37.5	37.6	4.76	12.2	5.27
Average	Mean	2244	2211	2519	530	539	528	134	148	98.7
	SD	1230	1258	1567	456	462	480	61.2	130	60.9
	Max	4895	5024	6080	1903	2024	2007	341	1486	289
	Min	479	455	443	60.0	70.0	5.2	26.4	20.2	15.4
	SEM	64.0	65.5	81.6	24.0	24.3	25.2	3.20	6.81	3.19

*** Stages 1 and 2 are pit fans, and Stage 3 are endwall fans.**

Table 7. Daily ammonia (NH_3) and hydrogen sulfide (H_2S) emission rates for each turn from the Non-DDGS barn

		VR	kg d^{-1} barn^{-1}		g d^{-1} pig^{-1}		g d^{-1} AU^{-1}	
		(m^3 h^{-1} pig^{-1})	NH_3	H_2S	NH_3	H_2S	NH_3	H_2S
Turn 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
	SEM	4.20	0.34	0.01	0.33	0.01	1.41	0.13
Turn 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
	SEM	6.00	0.51	0.13	0.31	0.06	7.37	2.79
Average	Mean	61.3	10.5	0.74	7.50	0.37	80.5	8.36
	SD	70.1	5.94	1.12	4.08	0.59	73.7	26.2
	Max	363	39.8	8.89	28.2	5.06	551	241
	Min	5.80	0.69	0.01	0.65	0.00	14.1	0.00
	SEM	3.90	0.33	0.06	0.23	0.03	4.15	1.48

Table 8. Daily ammonia (NH_3) and hydrogen sulfide (H_2S) emission rates for each turn from the DDGS barn

		VR	kg d^{-1} barn^{-1}		g d^{-1} pig^{-1}		g d^{-1} AU^{-1}	
		(m^3 h^{-1} pig^{-1})	NH_3	H_2S	NH_3	H_2S	NH_3	H_2S
Turn 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
	SEM	3.93	0.47	0.01	0.47	0.01	2.26	0.16
Turn 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
	SEM	4.82	0.59	0.13	0.23	0.06	8.13	2.43
Average	Mean	49.4	10.7	0.73	8.10	0.40	93.2	12.0
	SD	53.5	6.47	1.12	4.64	0.51	69.3	35.8
	Max	263	36.9	8.89	32.9	3.65	513	336
	Min	4.02	0.80	0.00	1.31	0.01	19.4	0.08
	SEM	3.18	0.36	0.06	0.28	0.03	4.11	2.09

Table 9. Greenhouse gas (CO_2, N_2O, and CH_4) emission rates for each turn from the Non-DDGS Barn

		VR	kg d^{-1} $barn^{-1}$			g d^{-1} pig^{-1}			g d^{-1} AU^{-1}		
		(m^3 h^{-1} pig^{-1})	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
Turn 1	Mean	38.6	3174	--	57.9	2173	--	42.6	19542	--	342
	SD	52.2	1058	--	20.3	818	--	20.1	10353	--	110
	Max	293	8147	--	115	4415	--	101	64541	--	719
	Min	5.80	781	--	18.4	684	--	7.10	2791	--	125
	SEM	4.20	85.3	--	1.70	65.9	--	1.60	834	--	8.96
Turn 2	Mean	82.4	3067	0.40	149	2085	0.30	98.6	23695	1.20	1287
	SD	77.8	984	0.80	114	816	0.60	79.0	19251	5.60	1294
	Max	363	5078	3.00	758	3931	2.20	535	177950	15.9	8942
	Min	6.50	780	--	12.1	74.4	--	10.3	4469	--	86.2
	SEM	6.00	76.4	0.10	8.8	63.4	0.00	6.10	1508	0.40	102
Average	Mean	61.3	2999	--	102	2127	--	72.0	21746	--	833
	SD	70.1	1155	--	94.5	817	--	65.2	15668	--	1047
	Max	363	8147	--	758	4415	--	535	177950	--	8942
	Min	5.80	62.6	--	12.1	74.4	--	7.10	2791	--	86.2
	SEM	3.90	63.2	--	5.20	45.7	--	3.70	881	--	59.3

Table 10. Greenhouse gas (CO_2, N_2O, and CH_4) emission rates for each turn from the DDGS Barn

		VR	kg d^{-1} $barn^{-1}$			g d^{-1} pig^{-1}			g d^{-1} AU^{-1}		
		(m^3 h^{-1} pig^{-1})	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
Turn 1	Mean	36.1	2336	--	46.0	1809	--	38.26	18258	--	320
	SD	48.5	622	--	23.9	757	--	24.2	6333	--	111
	Max	263	4079	--	119	3497	--	105.8	42439	--	615
	Min	4.02	1114	--	9.86	468	--	4.02	6470	--	140
	SEM	3.93	50.5	--	1.95	61.4	--	1.97	514	--	9.02
Turn 2	Mean	65.0	2884	0.46	98.0	1895	0.39	59.2	23499	3.18	815
	SD	55.2	1016	0.77	79.6	783	0.55	42.1	8961	5.85	627
	Max	213	5788	2.37	434	3762	1.85	306	73476	18.4	2680
	Min	10.7	573	--	11.8	265	--	4.82	6989	--	135
	SEM	4.82	88.8	0.07	6.95	68.4	0.05	3.68	783	0.51	54.7
Average	Mean	49.4	2363	--	65.2	1847	--	48.0	20663	--	550
	SD	53.5	1079	--	61.3	768	--	35.2	8077	--	499
	Max	263	5788	--	434	3762	--	306	73476	--	2680
	Min	4.02	21.5	--	3.59	265	--	4.02	6470	--	135
	SEM	3.18	60.8	--	3.46	45.6	--	2.09	479	--	29.6

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

			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)	Turn 1	W-G	83.7	1.05	5.17	64.8	53.3	668	--	--	0.65	8.21
		G-F	1023	4.68	21.9	100	316	1449	--	--	6.39	29.2
	Turn 2	W-G	319	5.89	56.4	1044	58.2	1077	--	--	3.15	58.4
		G-F	1373	5.59	53.5	218	363	1481	77.1	314	17.0	69.3
DDGS (pigs present)	Turn 1	W-G	103	7.62	6.53	108	33.6	556	--	--	0.31	5.19
		G-F	1317	6.02	25.2	115	275	1256	--	--	6.09	27.9
	Turn 2	W-G	568	6.92	79.0	1059	95.7	1282	--	--	4.33	58.0
		G-F	903	3.67	44.5	181	259	1056	73.1	297	6.60	26.9
Non-DDGS (downtime)	Turn 1		24.4	0.09	4.74	19.4	1.26	5.82	--	--	0.27	1.11
	Turn 2		15.9	0.06	0.34	1.43	4.89	19.9	1.89	7.75	0.24	0.99
DDGS (downtime)	Turn 1		83.0	0.03	0.02	90.7	5.26	21.5	--	--	0.476	1.95
	Turn 2		23.3	0.09	0.0001	0.76	4.72	19.3	1.63	0.62	0.151	0.621
Non-DDGS (total)	Turn 1		1131	5.82	31.8	184	371	2123	--	--	7.31	38.5
	Turn 2		1708	11.5	110	1263	426	2578	79.0	322	20.4	129
	Average		1420	8.68	71.0	724	398	2350	--	--	13.9	83.6
DDGS (total)	Turn 1		1503	13.67	31.8	314	314	1834	--	--	6.88	35.0
	Turn 2		1494	10.7	124	1241	359	2357	74.7	298	11.1	85.5
	Average		1499	12.2	77.6	777	337	2095	--	--	8.98	60.3

*** 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

Table 13. Summary of reported ammonia (NH_3) emissions from 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	1928	1783
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 14. 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	1928	1783
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

Table 15: 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)	
	Exp	Ref	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	1928	1783
Average pig weight (kg)	59	60	192	[c]	61	63
Ventilation type[a]	M	M	N	M	H	H
Building ventilation, m^3/h	2080	2138	[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 16: 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]		1115	1116	344	1928	1783
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)	2080	2138	[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

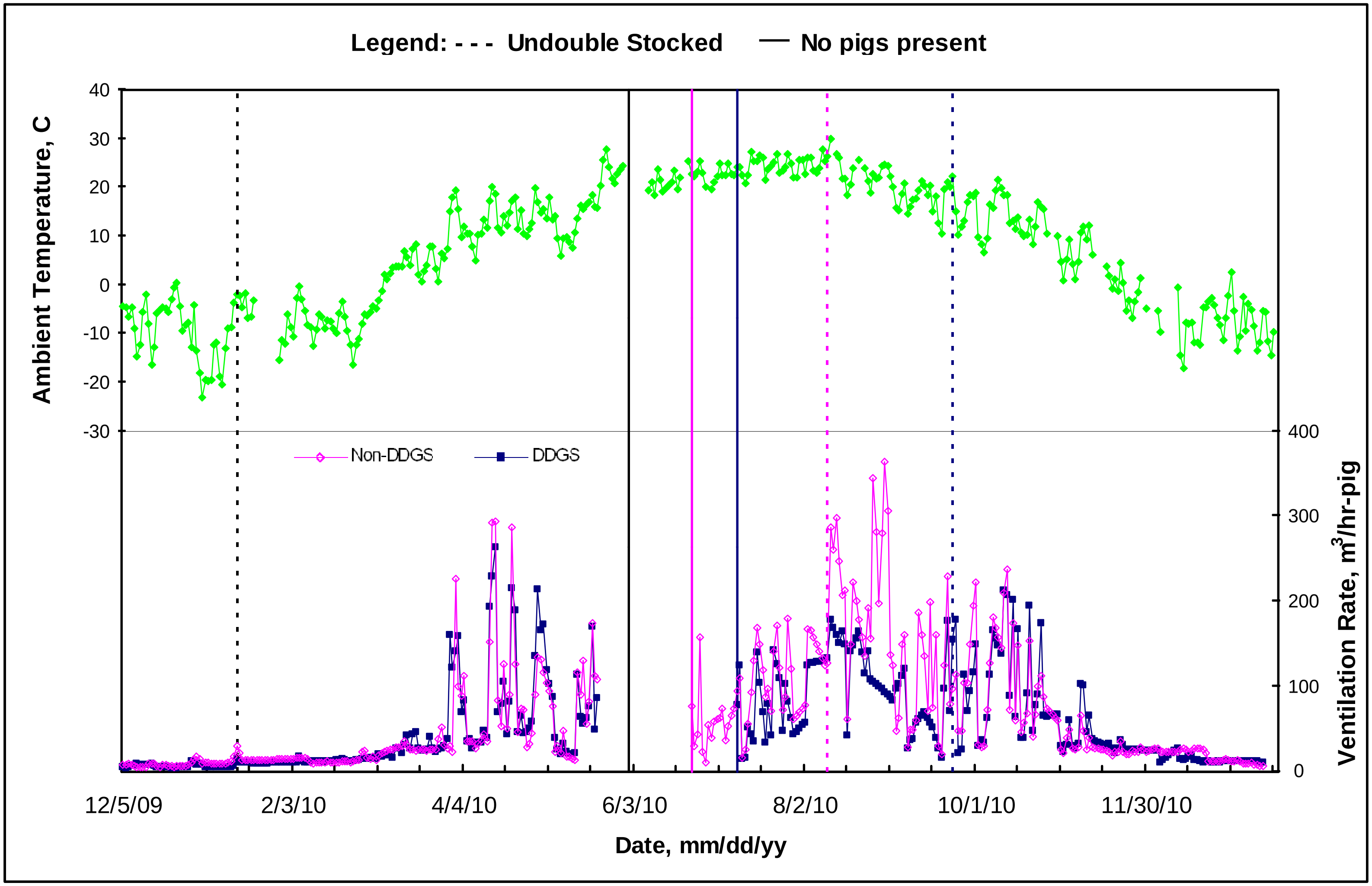

Figure 2. Average ventilation rate (m^3 hr^{-1} pig^{-1}) for each barn and ambient temperature.

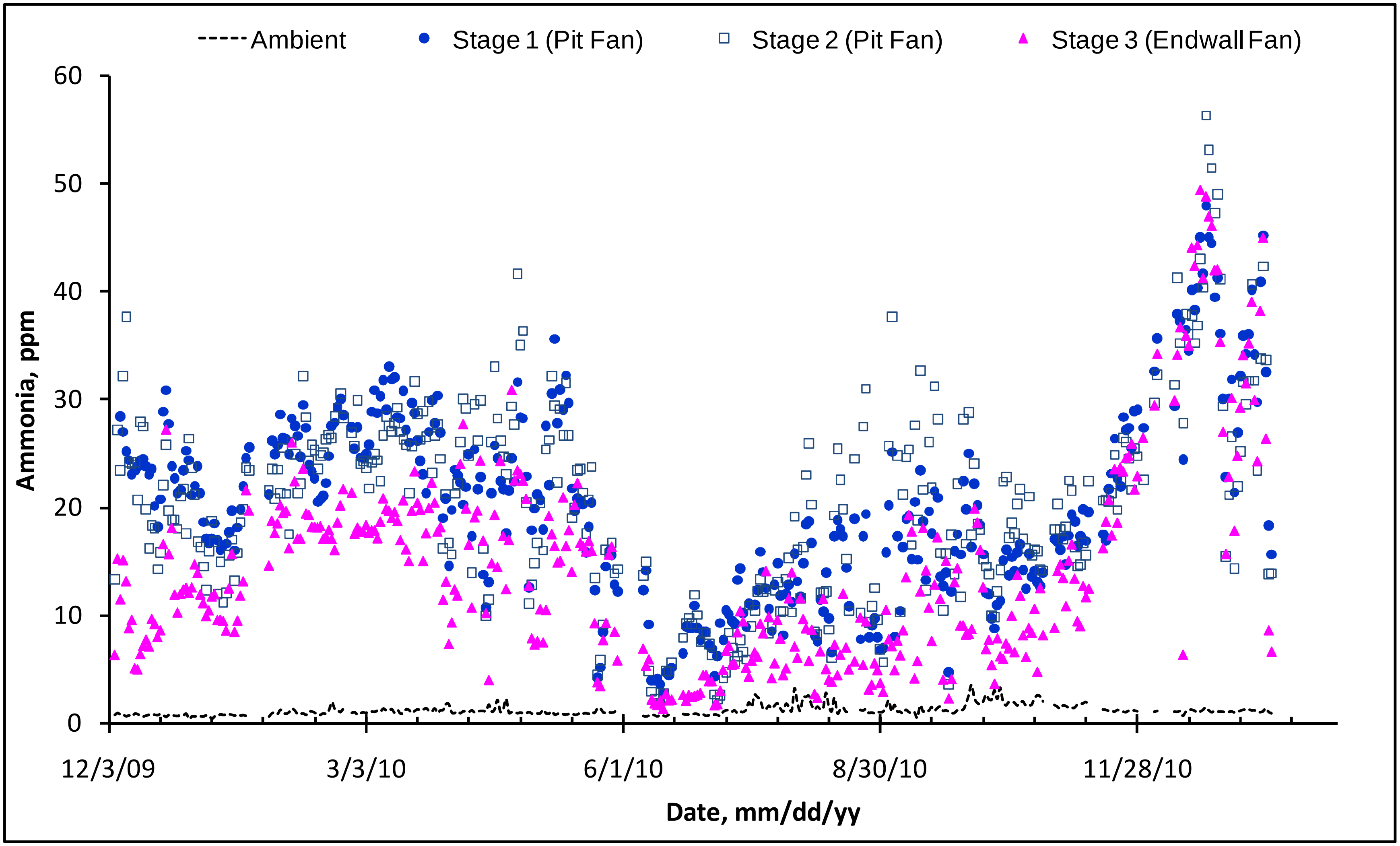

Figure 3. Daily average ammonia concentrations for the DDGS barn for the monitoring period.

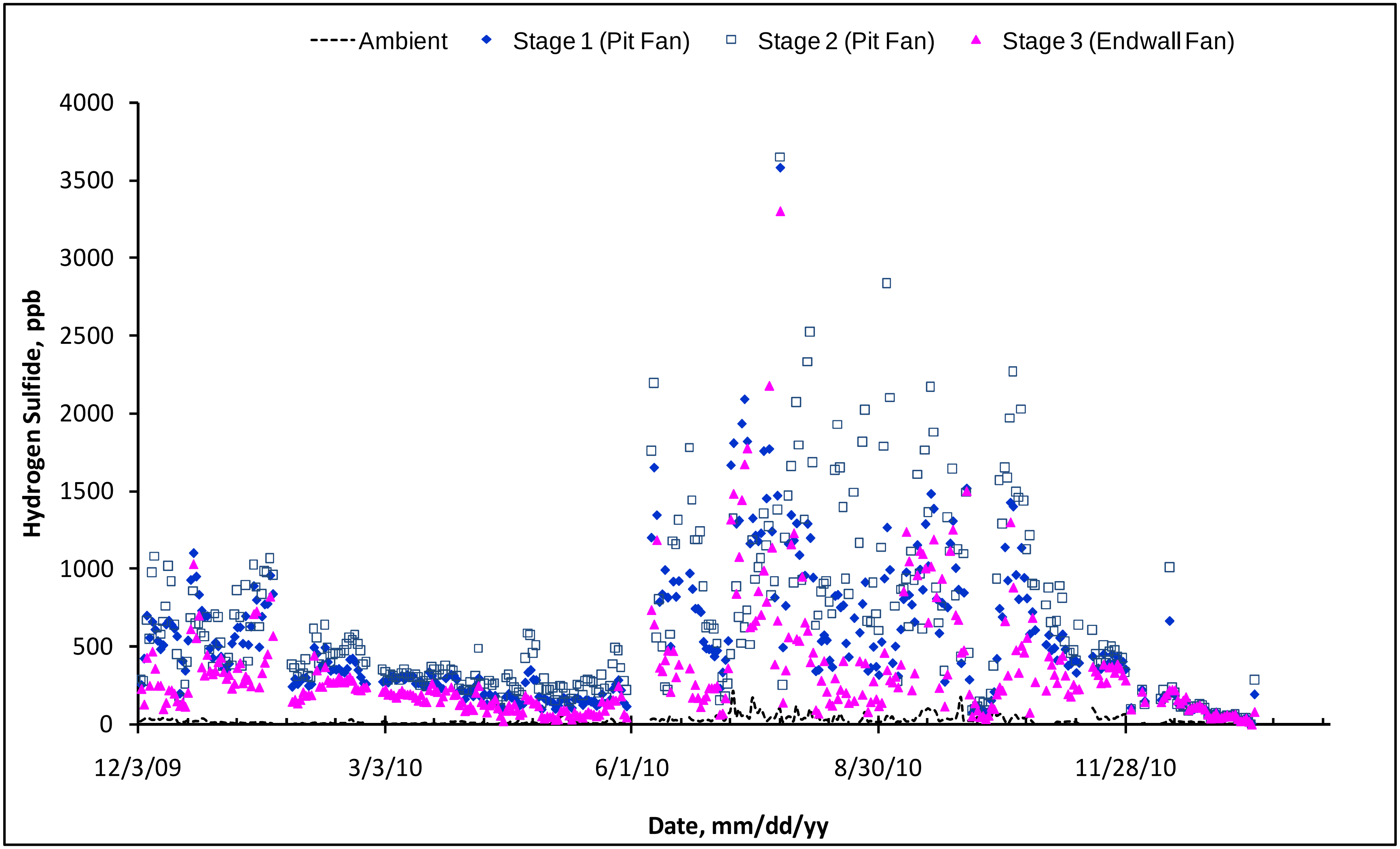

Figure 4. Daily average hydrogen sulfide concentrations for the DDGS barn for the monitoring period.

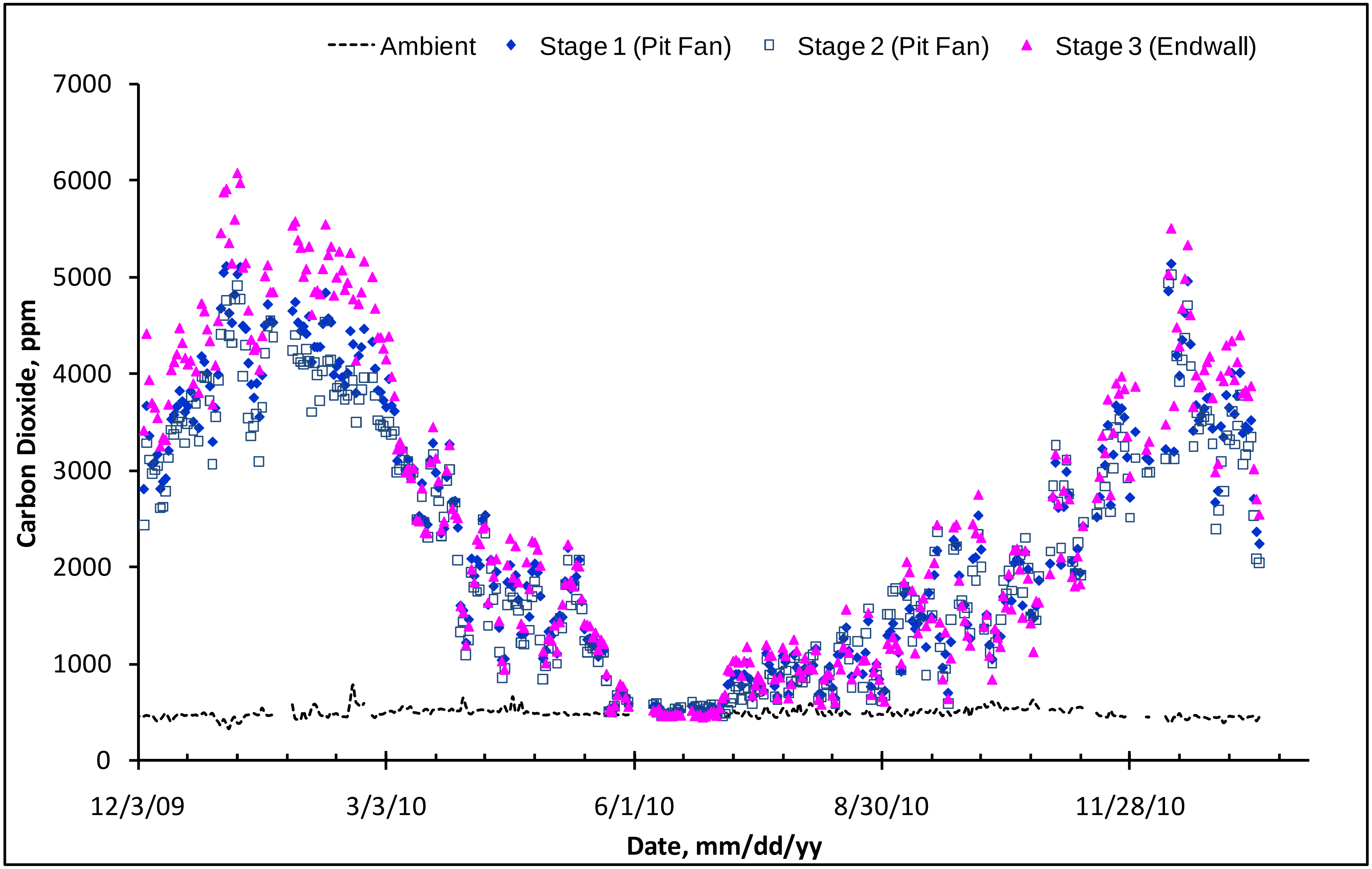

Figure 5. Daily average carbon dioxide concentrations for the DDGS barn for the monitoring period.

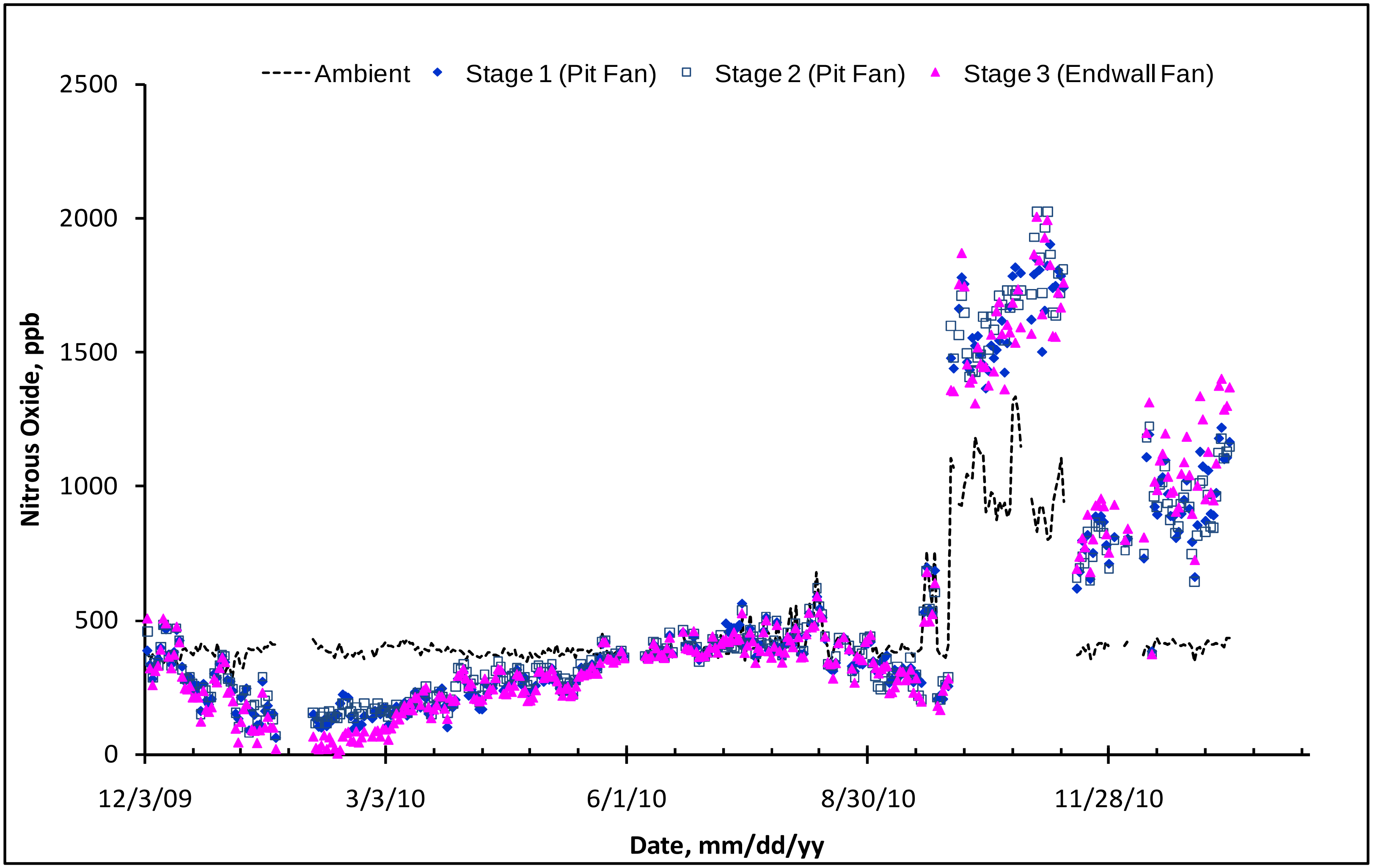

Figure 6. Daily average nitrous oxide concentrations for the DDGS barn for the monitoring period.

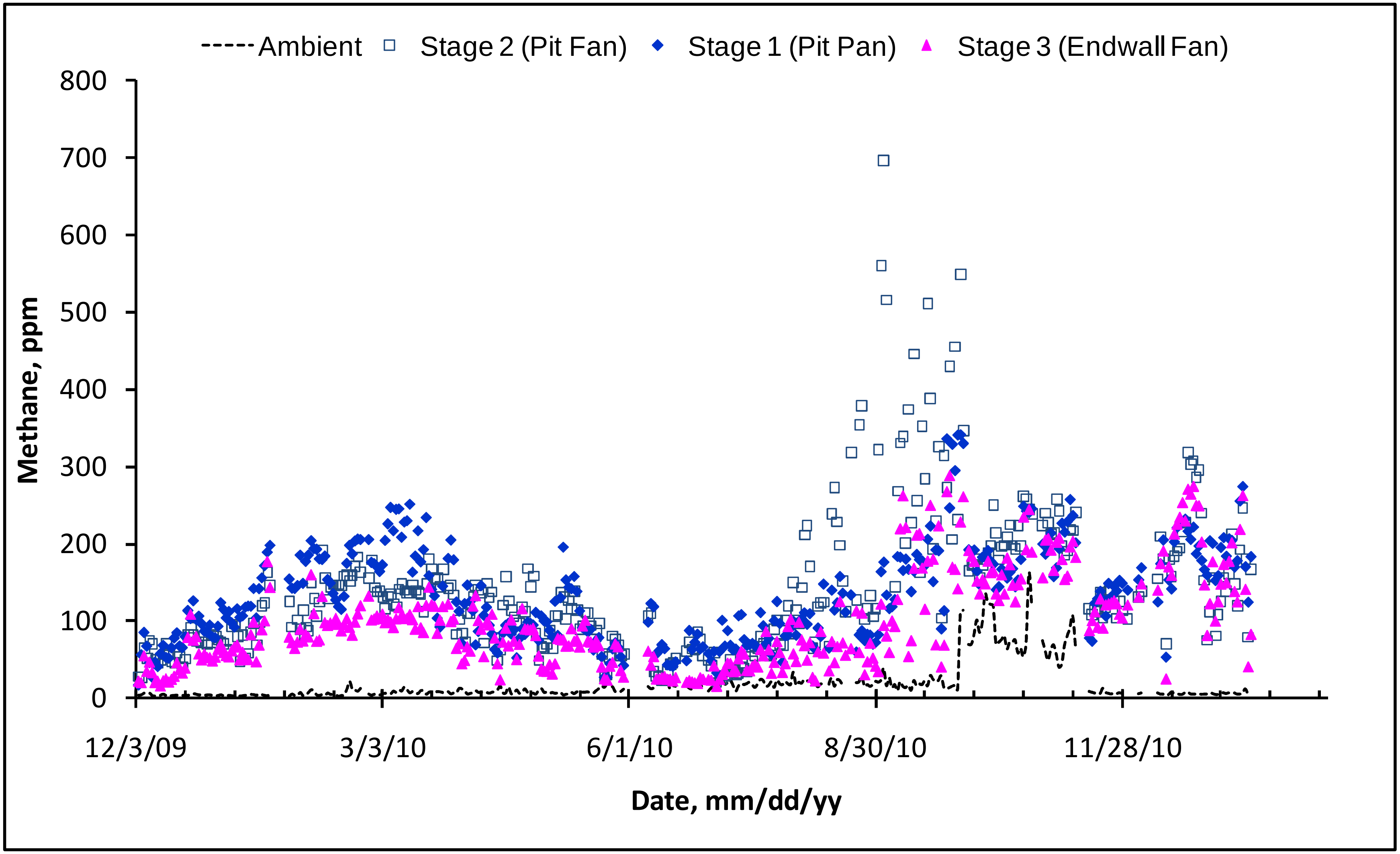

Figure 7. Daily average methane concentrations for the DDGS barn for the monitoring period.

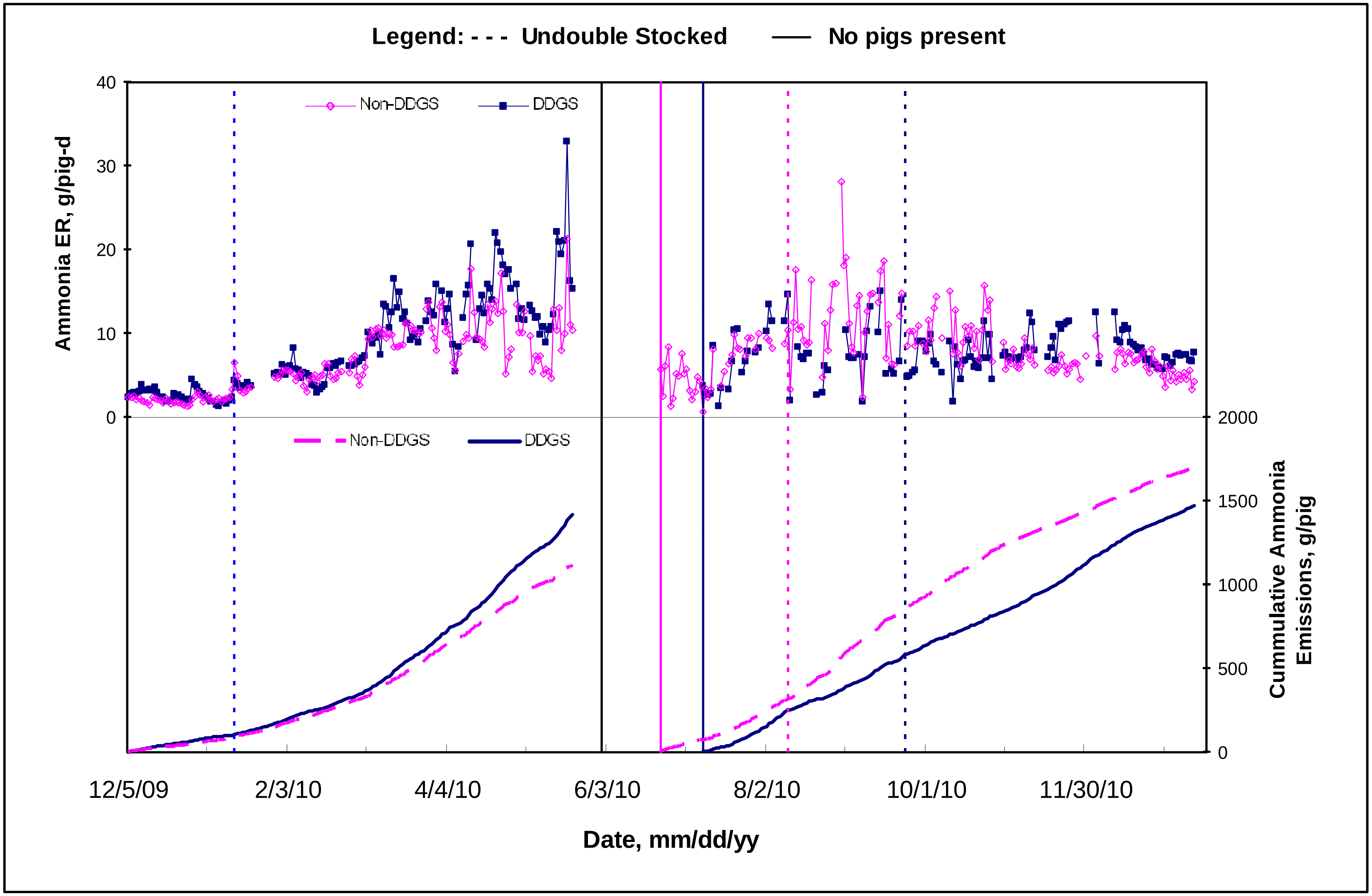

Figure 8. Daily ammonia emissions (g d^{-1} pig^{-1}) and cumulative emission (g pig^{-1}) for each turn in the DDGS barn and the Non-DDGS barn for the monitored period.

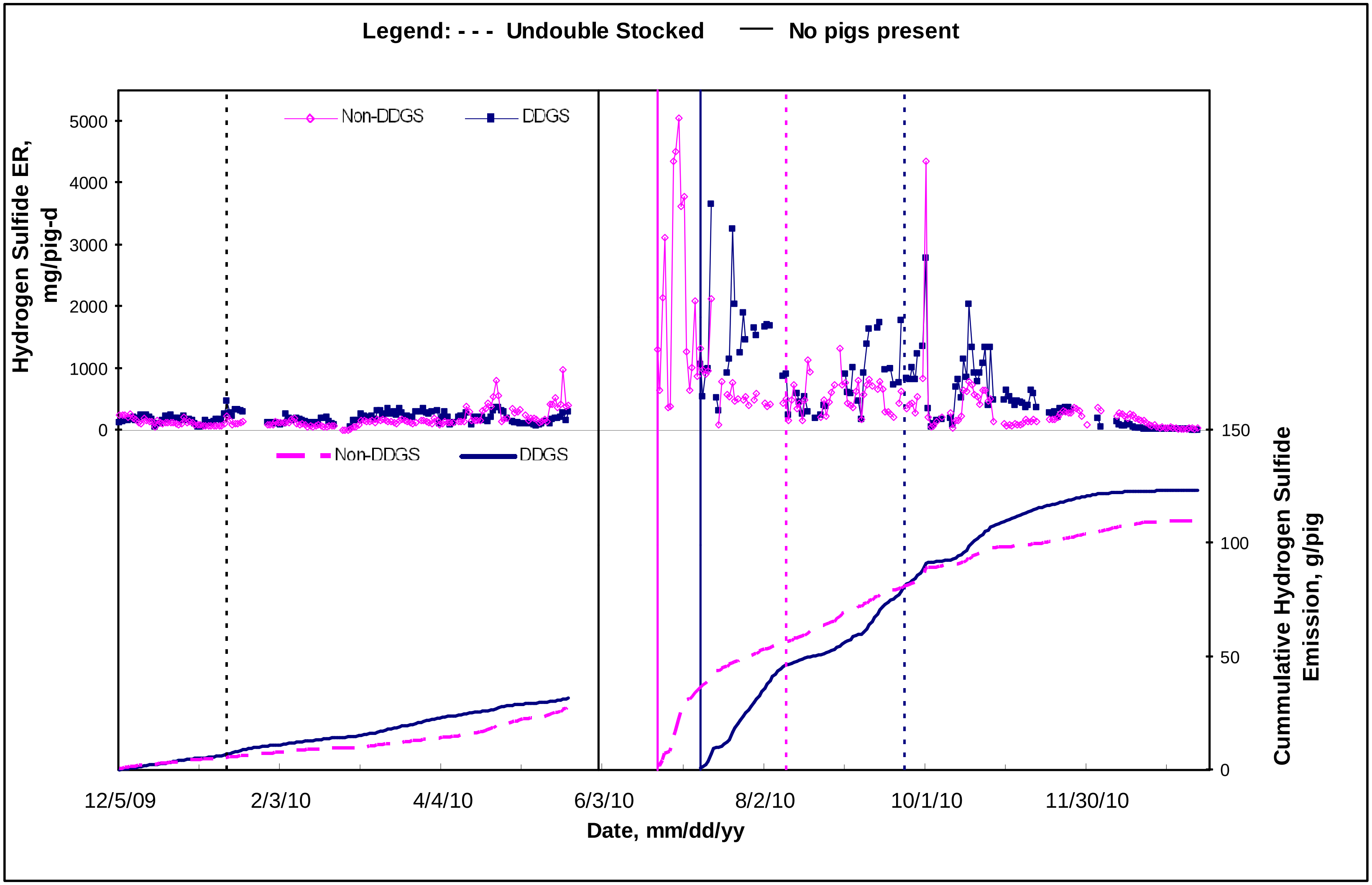

Figure 9. Daily hydrogen sulfide emissions (mg d^{-1} pig^{-1}) and cumulative emission (g pig^{-1}) for each turn in the DDGS barn and the Non-DDGS barn for the monitored period.

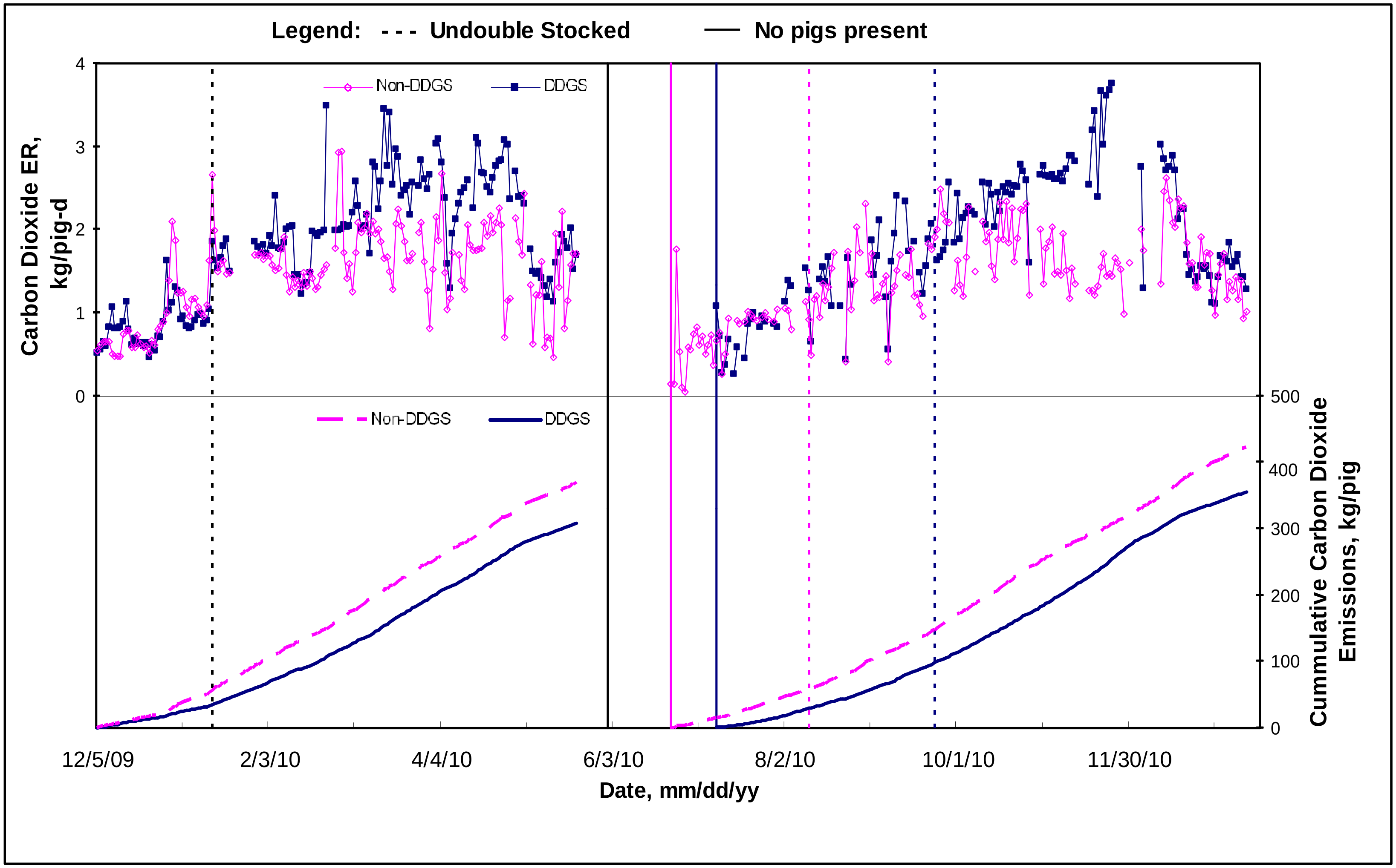

Figure 10. Daily carbon dioxide emissions (kg d^{-1} pig^{-1}) and cumulative emission (kg pig^{-1}) for each turn in the DDGS barn and the Non-DDGS barn for the monitored period.

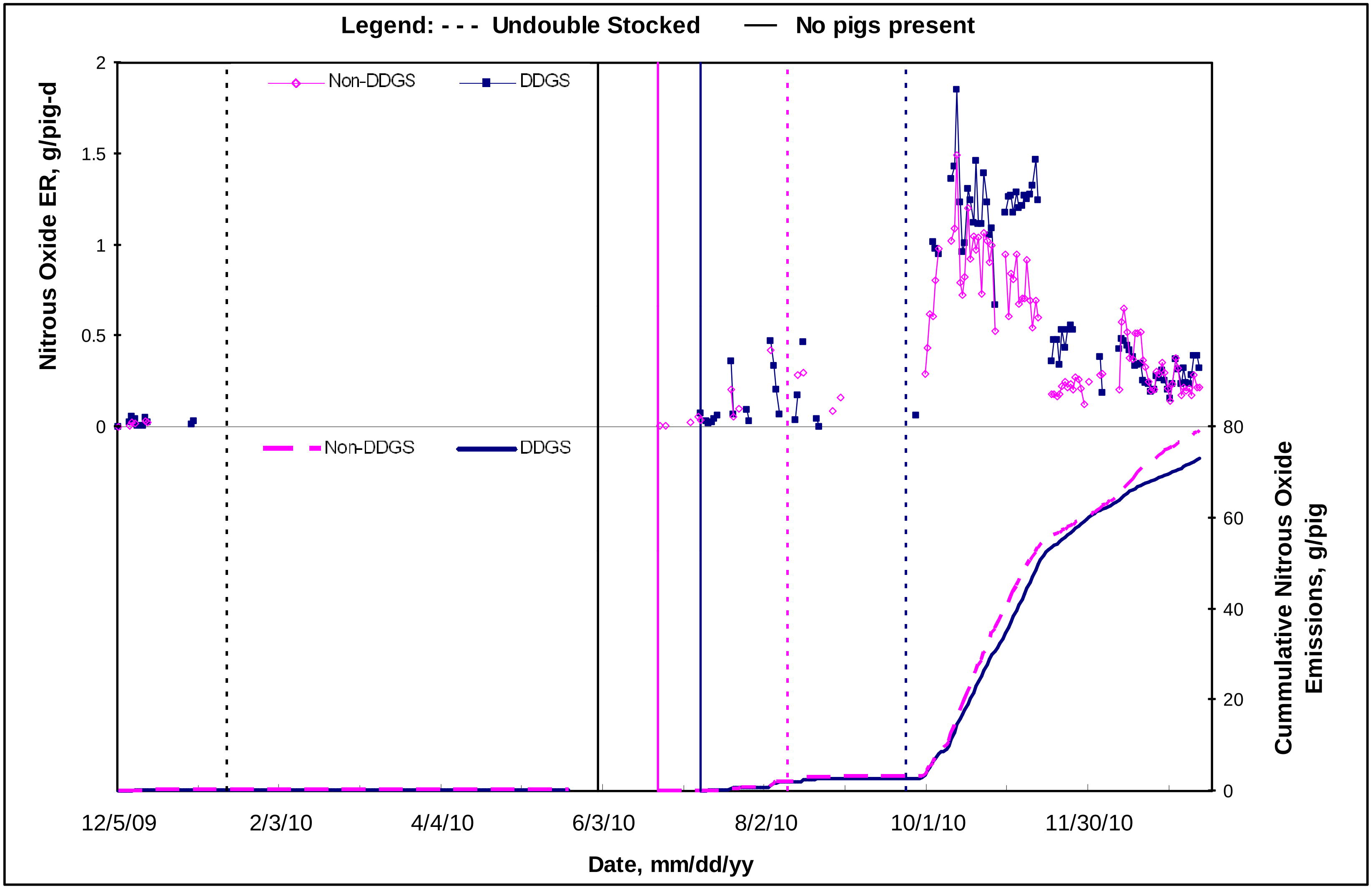

Figure 11. Daily nitrous oxide emissions (g d^{-1} pig^{-1}) and cumulative emission (g pig^{-1}) for each turn in the DDGS barn and the Non-DDGS barn for the monitored period.

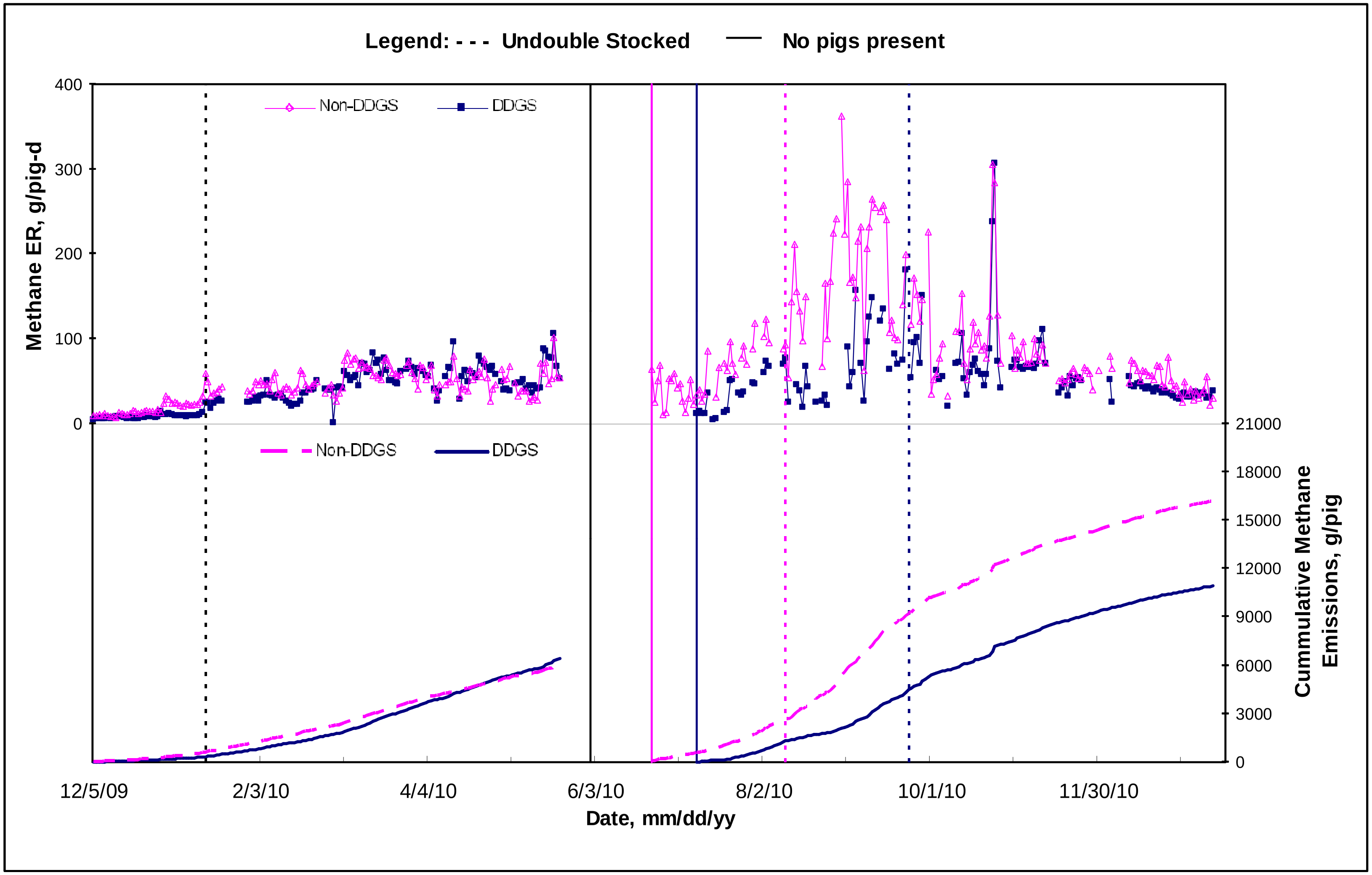

Figure 12. Daily methane emissions (g d^{-1} pig^{-1}) and cumulative emission (g pig^{-1}) for each turn in the DDGS barn and the Non-DDGS barn for the monitored period

CHAPTER 3. GENERAL CONCLUSIONS

Feeding 22% corn DDGS to growing-finishing swine in a full-slat and deep-pit housing system did not seem to affect aerial emissions of ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), nitrous oxide (N_2O), or methane (CH_4) when compared to a traditional corn-soybean ration (NH_3 p-value = 0.10, H_2S p-value = 0.13, CO_2 p-value = 0.55, N_2O p-value = 0.58, and CH_4 p-value = 0.18). There were no noticeable differences in manure compositions between the DDGS and the traditional rations. The lack of statistical significance could have resulted from the insufficient replications of the treatments. It was also found that both barns experienced considerable seasonal variations in H_2S and CH_4 emissions (H_2S p-value = 0.02, CH_4 p-value = 0.07).

On average the wean-to-finish pigs fed the traditional corn-soybean diet emitted 7.5 ± 4.0 g/d-pig of NH_3, 0.37 ± .59 g/d-pig of H_2S, 2,127 ± 817 g/d-pig of CO_2 and 72 ± 65 g/d-pig of CH_4. The W-F pigs fed a 22% DDGS ration emitted 8.1 ± 4.6 g/d-pig of NH_3, 0.40 ± .51 g/d-pig of H_2S, 1,847 ± 768 g/d-pig of CO_2, and 48 ± 35 g/d-pig of CH_4. These emission rates, except for CH_4, were comparable to those reported by a few other studies that had monitored full-scale deep-pit swine finishing barns in the US and abroad. There were no comparable studies for CH_4 emissions from deep-pit swine facilities.

Gaseous emissions per pig marketed were 1,420 g NH_3, 71 g H_2S, 398 kg CO_2, and 14 kg CH_4, respectively for the traditional corn-soybean ration and 1,499 g NH_3, 78 g H_2S, 337 kg CO_2, and 9.0 kg CH_4, respectively for the 22% DDGS ration.

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.

These data will help swine producers to estimate emissions from their facilities when feeding a traditional corn-soybean ration or a ration containing 22% corn DDGS.

Future Research Recommendations

1. It is clear from the amount of published data available that more studies are needed to look at GHG and H_2S emissions from full-scale swine growing-finishing operations.
2. If possible, more replications should be considered to further determine the impact of feeding corn DDGS on aerial emissions from finishing swine facilities through long-term field-scale monitoring.
3. With the price of corn continuing to increase there is also a need to determine the impact of higher inclusion rates of corn DDGS on aerial emission from full-scale swine operations.