Title: Influence of corn co-products on air emissions and nutrient excretionsfrom grow-finish swine - **NPB #05-111**

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Date Received: 12/12/2006

Abstract:
Four diets were fed to growing swine in order to compare corn (C) to corn co-products and the impact on swine performance and air emissions. The corn co-product diets contained increasing levels of the co-product; from 5 to 30% over the course of six feeding phases. Co-products used included distillers dried grains with solubles (DDGs), corn germ meal (CGM), and dehulled, degermed corn (DDC).

Feeding the corn co-product diets did not alter animal performance compared to corn diets when co-products were fed at increasing amounts over the life-cycle. Ammonia emissions from animal housing were consistently increased as a result of DDGs inclusion in the diet (increasing inclusion from 5 to 30% of the diet as pigs progressed through 6 feeding phases). Although the DDGs diet contained more N in the diet, adjusting the emissions data for N intake did not impact the increased ammonia emissions as a result of this treatment suggesting the N utilization was poorer in the DDGs diets. In general, hydrogen sulfide emission rate and daily mass of hydrogen sulfide emitted from housing were increased as a result of DDGs inclusion in the diet (increasing inclusion from 5 to 30% of the diet as pigs progressed through 6 feeding phases) but adjusting data for bodyweight and sulfur intakes, accounted for the differences observed. No treatment or phase effects were observed for non-methane total hydrocarbon (NMTHC) emission variables. The DDGs treatment produced less methane than the other treatments. Corn diets were intermediate in methane production and the CGM and DDC diets resulted in the greatest methane production. In addition to evaluating dietary treatment impacts, this study provided valuable baseline data on emissions from swine facilities.

II. Introduction:

Air emissions continue to draw attention at both the state and federal levels. Practices to reduce emissions from animal feeding operations (AFOs) are therefore of great importance to producers as they look down the road to how future regulations might impact their operations. Inclusion of fiber in non-ruminant diets has effectively reduced ammonia (NH_3) emissions (Canh et al., 1998) Increased fiber, hemicellulose, has been shown to encourage an increase the abundance of bacteria able to ferment hemicellulose in the pig hind-gut that results in an increase in the proportion of microbial nitrogen excretion relative to urinary nitrogen excretion (Younes et al., 1995; Groeneveld et al., 2000). This increase in microbial nitrogen has been suggested to stabilize stored manure nitrogen such that it is not volatilized into the environment after excretion relative to urinary nitrogen excretion (largely urea). In addition, manure from pigs fed fibrous ingredients often results in manure with lower pH which also reduces the emission of NH_3 from manure.

The U.S. continues to expand its ethanol production, generating an increasing available supply of distillers dried grains plus solubles (DDGS), a co-product that contains more fiber than corn. Dehulled, degermed corn (DDC), a product of corn milling is more digestible than corn because the fibrous hull is removed (negative control). Removal of the germ has the added benefit of reduced phosphorus content. Corn germ meal (CGM), another product of corn milling contains highly digestible amino acids. While there has been some recent work (Muley et al., 2004, Kendall et al., 2003) evaluating swine performance when fed corn co-products, in general, research is limited and has not addressed impacts on gaseous emissions.

III. Objectives:

The objective of this study was to evaluate the impact of feeding corn and corn co-products to swine throughout the grow-finish phase and to quantify gaseous emissions, nutrient excretions, and animal performance. Specific objectives were to:

1. Evaluate the effects of dietary hemicellulose concentration on growing-finishing pig performance.
2. Evaluate the impact of dietary hemicellulose content on dry matter, nitrogen, sulfur, and carbon excretion; and quantify the generation of malodorous compounds (ammonia, hydrogen sulfide, volatile fatty acids, volatile sulfurs, and volatile phenols).
3. Quantify long-term emissions from manure generated by pigs fed diets varying in hemicellulose content.

IV. Materials & Methods:

Animals and Housing

All animal procedures were approved by the Iowa State University Committee on Animal Care and Use. Crossbred barrows (six per chamber at the start of the project; initial BW = 20.1 kg) were housed in eight indirect calorimeters at the Air Emissions Laboratory at Iowa State University. Pigs were allocated to each chamber by weight in order to minimize body weight differences within each chamber. The pigs were penned in a 3.05 m × 1.52 m raised deck with Tenderfoot® flooring. Swinging nipple waters were located above the middle of the pen and a two-hole Smidley feeder (Marting Manufacturing, Britt, IA) was located at one end of each pen. Chamber temperatures (18.3°C to 25.6°C) were adjusted weekly based on the average body weight within the chamber so as to remain in the thermoneutral zone of the animal. Fluorescent lighting was programmed to come on at 07:00 h and go off at 18:00 h.

Dietary Treatments

Six feeding phases followed: Starter Phase (S1; beginning at 18 kg BW), Grower Phase 1 (G1; 27 kg BW), Grower Phase 2 (G2; 41 kg BW), Finisher Phase 1 (F1; 58 kg BW), Finisher Phase 2 (F2; 78 kg BW) and Finisher Phase 3 (F3; 101 kg BW). Pigs were offered one of mash diets during each phase: a control corn diet (C), a diet with increasing amounts of dehulled, degermed corn (DDC), a diet with increasing amounts of dried distillers grains with solubles (DDGs) and a diet with increasing amounts of corn germ meal (CGM). Co-product content increased from 0% to 30% as pigs progressed through the feeding phases. Table 1 illustrates the formulated diet composition and analyzed CP, lysine, and energy contents that were present in each diet. Diets were formulated to contain similar lysine and energy content. Each diet was offered in two of the eight chambers during the six feeding periods and pigs in each chamber were fed the same treatment throughout the study.

Barrows were provided ad libitum access to feed and water. New feed was offered daily between 06:00 and 09:00 h. Feed data were recorded daily and remaining feed was removed and weighed from the feeders at the end of each feeding phase from which average daily intake was calculated. Diets were assigned, randomly, to groups in each of the eight chambers at the start of each feeding phase. Diets were sampled weekly and pooled together at the end of the feeding phase for proximate and amino acid analyses. At the end of F1, one pig was removed from each chamber such that five pigs remained in each pen for the remaining finisher phases (F2 and F3).

Measurements and Analytical Procedures

Continuous measurement of housing emissions

Through software (LabVIEW Ver. 7.0, National Instruments; Austin, TX) control H_2S, NH_3, methane, and non-methane total hydrocarbon concentration (NMTHC) monitoring of the chambers occurred in a sequential manner, beginning first with incoming air, then sampling exhaust air from each of the eight chambers. The incoming air line was allowed to purge for 14.5 min and bucket sample lines are allowed to purge for 9.5 min before the start of data collection. Following purging, data was collected for 5.5 min. All gases are measured simultaneously within a sample stream. Samples from the chambers were pulled to a sampling manifold using a Cole-Parmer vacuum pump (Cole-Parmer Instrument Company, Vernon Hills, IL) at a rate of 30 L/min, through Teflon tubing (5 m long with an outer diameter of 0.95 cm) placed 5 cm into the exhaust line of each chamber. From the manifold the air stream was diverted into three gas analyzers: a TEI 17C NH_3 Analyzer (Thermo Electron Corporation; Franklin, MA) that determined and NH_3 concentration, a TEI 450C (Thermo Electron Corporation; Franklin, MA) measuring H_2S concentration and a VIG Model 200/1 analyzer (VIG Industries; Anaheim, CA) for measuring methane and non-methane total hydrocarbons. Airflow rates into and out of each chamber was measured continuously, allowing for calculation of gas emission rates.

Gas concentrations were recorded every 30 sec during the last 5.5 min of sampling in each chamber. The recorded values were exported to a spreadsheet, adjusted to standard temperature and pressure, and averaged. All averaged incoming air gas concentrations were subtracted from the chamber gas concentrations before chamber averages were calculated. Averages were calculated to determine the emissions during the 2 h and 20 m time that it took to sample a chamber again.

Excreta composition

Galvanized steel manure collection pans (3.05 m × 1.52 m × 7.5 cm-deep) were placed underneath the Tenderfoot® flooring of each pen to collect urine, feces and wasted feed and water. Manure pans were partially cleaned twice weekly to remove some manure and prevent overflow. The weight of each manure volume removed from the pan was recorded and a sub-sample collected and frozen for future compositional analyses. One day after the start of each new feeding phase, the manure pans were cleaned completely, the mass of manure removed from the pan was recorded and a homogenous sub-sample was frozen. Following each feeding phase, samples were removed from the freezer and allowed to thaw in a refrigerator. Once thawed, 4N hydrochloric acid was added to each sample bag to obtain a pH between 1 and 3 before blending each individual sample in a blender. A portion of the blended sample, equal to the proportion removed from the manure pan at each sampling, was combined to form a single sample for each feeding phase that represented the manure collected from each chamber. The sample was remixed and a sub-sample was oven-dried at 100°C to determine total solids. Ammonium-nitrogen (NH_4^+-N) and total Kjeldahl nitrogen (TKN) analyses were performed on the remixed homogenous liquid sub-sample according to AOAC (1990) procedures.

Long-term emission measures

Composite samples of excreta removed from the pans were added to 18 L buckets to determine long-term emissions. Manure additions were made daily such that volume increased as the feeding trial progressed, mimicking a commercial swine facility. Through software (LabVIEW Ver. 7.0, National Instruments; Austin, TX) control H_2S, NH_3, methane, and NMTHC concentration monitoring of the buckets (one bucket per chamber) occurred in a sequential manner, beginning first with incoming air, then sampling exhaust air from each of the eight buckets. The incoming air line is allowed to purge for 14.5 min and bucket sample lines are allowed to purge for 9.5 min before the start of data collection. Following purging, data was collected for 5.5 min. All gases are measured simultaneously within a sample stream. Samples from the buckets were pulled to a sampling manifold using a Cole-Parmer vacuum pump (Cole-Parmer Instrument Company, Vernon Hills, IL) at a rate of 30 L/min, through Teflon tubing (5 m long with an outer diameter of 0.95 cm) placed 5 cm into the top of each bucket. From the manifold the air stream was diverted into three gas analyzers: a TEI 17C NH_3 Analyzer (Thermo Electron Corporation; Franklin, MA) that determined and NH_3 concentration, a TEI 450C (Thermo Electron Corporation; Franklin, MA) measuring H_2S concentration and a VIG Model 200/1 analyzer (VIG Industries; Anaheim, CA) for measuring methane and NMTHC.

Gas concentrations were recorded every 30 sec during the last 5.5 min of sampling in each chamber. The recorded values were exported to a spreadsheet, adjusted to standard temperature and pressure, and averaged. All averaged incoming air gas concentrations were subtracted from the bucket gas concentrations before bucket averages were calculated. Averages were calculated to determine the emissions during the 2 h and 20 m time that it took to sample a chamber again.

Airflow rates into and out of each bucket were measured daily, allowing for calculation of gas emission rates. Flow was provided across bucket surfaces continuously, regardless of whether or not sampling of the bucket was occurring at that time.

Statistical Analyses

Data were analyzed using the statistical procedures of SAS v. 8.1 (SAS Institute, Cary, NC). Animal performance data and manure production data were analyzed using a general linear model whereby diet, phase and the interaction of diet and phase served as fixed effects. Emissions data were analyzed as a mixed model with diet, phase and the interaction of diet and phase treated as fixed terms. Date served as the random effect. Significance was declared at $P<0.05$.

VI. Results:

1. Evaluate the effects of dietary hemicellulose concentration on growing-finishing pig performance.

Dietary treatment had no significant effect on feed consumption, weight gain, or feed conversion (G:F; Table 1). Diet formulations are depicted in Tables 2 and 3. Pigs consumed more feed as they aged resulting in a significant phase effect for feed intake. Performance measures were similar to that reported by others (Carr et al., 2005; Dean et al., 2005). Pigs were less efficient converters of feed to weight gain as they aged (Table 1). Corn co-product diets did not alter animal performance compared to corn diets when co-products were fed at increasing amounts over the life-cycle.

Table 1. Pen performance, over 6 feeding phases, for pigs fed 4 dietary treatments.

Dietary treatment[a]	*Feeding phase*[b]	*Phase weight gain, kg*[c]	*Phase feed consumption, kg*	*G:F*
C	S1	43.2	88.6	0.49
	G1	77.0	213.0	0.36
	G2	113.0	278.3	0.41
	F1	58.0	304.2	0.20
	F2	94.5	300.4	0.31
	F3	64.8	228.2	0.29
DDGs	S1	35.9	82.0	0.44
	G1	106.6	204.9	0.52
	G2	121.6	270.2	0.45
	F1	43.6	300.2	0.18
	F2	95.5	296.2	0.32
	F3	49.5	234.9	0.21
DDC	S1	42.3	83.2	0.51
	G1	94.5	211.8	0.45
	G2	122.3	295.6	0.41
	F1	42.5	349.7	0.19
	F2	94.8	345.4	0.27
	F3	67.3	234.4	0.29
CGM	S1	44.1	87.8	0.51
	G1	79.3	187.5	0.42

	G2	111.1	256.5	0.44
	F1	51.6	300.9	0.17
	F2	88.9	300.4	0.30
	F3	55.0	235.1	0.24
[d]SEM		12.21	31.66	0.06
Cumulative over all phases				
C		468.4	1412.6	0.33
DDGs		440.7	1388.2	0.32
DDC		464.5	1519.8	0.31
CGM		436.1	1360.5	0.33
Source of variation				
Diet		0.52	0.06	0.98
Phase		<0.01	<0.01	<0.01
Diet × Phase		0.67	0.86	0.83

[a]C - corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[b]Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg, Finisher phase 1: duration = 21 d, average initial bodyweight = 58 kg; Finisher phase 2: duration = 21 d, average initial bodyweight = 78 kg; Finisher phase 3: duration = 14 d, average initial bodyweight = 101 kg.
[c]6 pigs per pen in S through F1 phases, 5 pigs per pen in F2 and F3 phases; 1 pen per chamber; 2-3 chambers per treatment.
[d]SEM - standard error of the mean.

Table 2. Composition of dietary treatments during starter and grower swine feeding phases [a].

Item	*Starter phase 1*				*Grower phase 1*				*Grower phase 2*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Ingredient, % (as-fed basis)												
Corn	55.50	51.00		52.71	69.50	60.85		61.14	74.74	62.00		66.00
DDGs		5.00				10.00				15.00		
DDC			53.50				67.17				72.40	
CGM				5.00				10.00				15.00
Soybean meal	33.80	33.41	35.79	33.56	26.17	25.00	28.50	24.65	21.20	19.19	23.55	15.15
Whey, dried	5.00	5.00	5.00	3.00								
Vegetable oil	1.60	1.60	1.60	1.60	0.30	0.30	0.30	0.20	0.30	0.30	0.30	
Dicalcium phosphate	1.59	1.40	1.60	1.58	1.38	1.04	1.42	1.34	1.10	0.59	1.13	1.05
Limestone	0.80	0.88	0.80	0.84	0.89	1.05	0.85	0.91	0.90	1.16	0.86	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin mix	0.30	0.30	0.30	0.30	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral mix	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
L-Lysine/HCl					0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20
Celite[c]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Analyzed composition (dry matter basis)												
Crude protein, %	22.51	23.91	21.33	23.48	19.77	21.14	19.46	21.03	16.98	19.25	17.90	17.46
Lysine, %	1.35	1.38	1.36	1.41	1.21	1.27	1.14	1.26	1.08	1.13	0.94	1.07
Sulfur, %	0.16	0.18	0.16	0.16	0.14	0.19	0.16	0.16	0.13	0.19	0.14	0.14

[a]Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg.
[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[c]Celite – indigestible marker (World Minerals Corp; Lompoc, CA).
[d]ME - metabolizable energy.

Table 3. Composition of dietary treatments during swine finisher feeding phases [a].

Item	*Finisher phase 1*				*Finisher phase 2*				*Finisher phase 3*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Ingredient, % (as-fed basis)of complete diet												
Corn	79.15	59.50		65.98	82.19	60.07		60.90	86.20	58.65		60.91
DDGs		20.00				25.00				30.00		
DDC			76.64				79.70				83.66	
CGM				20.00				25.00				30.00
Soybean meal	17.00	17.17	19.50	10.37	13.40	12.00	15.88	10.80	9.76	8.50	12.30	6.00
Whey, dried												
Vegetable oil	0.30	0.20	0.30		1.00		1.00		0.80		0.80	
Dicalcium phosphate	0.90	0.22	0.95	0.85	0.76		0.79	0.65	0.59		0.62	0.43
Limestone	0.90	1.25	0.86	0.97	0.90	1.28	0.88	1.00	0.90	1.20	0.87	1.01
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin/trace	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral mix	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-Lysine/HCl	0.10		0.10	0.18	0.10		0.10		0.10		0.10	
Celite[c]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Analyzed composition (dry matter basis)												
Crude protein, %	16.20	19.62	15.88	16.24	14.65	18.29	14.29	16.46	11.90	18.35	12.93	15.32
Lysine, %	0.89	1.02	0.84	0.93	0.81	0.88	0.73	0.83	0.70	0.77	0.66	0.68
Sulfur, %	0.12	0.20	0.12	0.13	0.11	0.11	0.11	0.15	0.10	0.21	0.11	0.13

[a]Finisher phase 1: duration = 21 d, average initial bodyweight = 58 kg; Finisher phase 2: duration = 21 d, average initial bodyweight = 78 kg; Finisher phase 3: duration = 14 d, average initial bodyweight = 101 kg.
[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[c]Celite – indigestible marker (World Minerals Corp; Lompoc, CA).
[d]ME - metabolizable energy.

2. Evaluate the impact of dietary hemicellulose content on dry matter, nitrogen, sulfur, and carbon excretion; and quantify the generation of malodorous compounds (ammonia, hydrogen sulfide, volatile fatty acids, volatile sulfurs, and volatile phenols.

Excreta composition
No diet effects were observed for wet weight of manure and wastewater generated nor for total nitrogen (TKN) content of the manure and wastewater. However, ammonium nitrogen was greater from pigs fed the DDC and DDGs diets than from pigs offered the corn and CGM diets suggesting that nitrogen excretion resulting from those treatments might have been more susceptible to volatilization. In looking at the ammonia emission data (Table 6, 7) this was the case for the DDGs treatment.

Concentration of volatile organic compounds
Concentrations (ppm) of measured volatile organic compounds (VOCs) are presented in Table 5. In general, for those compounds where a diet effect was observed the effect was largely attributable to concentrations being greater in rooms where the CGM diet was offered. This suggests that either the feed itself or the fermentation of the feed, *in vivo*, varied from the other treatments. Diet effects were observed for select volatile fatty acids and select phenols but not for indoles or alkanes, supporting that the effect was due to fermentation patterns in the hindgut or perhaps due to feed processing itself. No samples were collected from headspaces above the isolated feeds so the options can not be narrowed. Phase effects were observed, with concentrations increasing as pigs aged.

While VOCs are not currently regulated, per se, from swine operations the value of including these measures in this study was that it provides baseline concentrations as the topic becomes more prominent, following California's lead. Unfortunately there is little data available for comparison or to assist in interpreting the findings of this study.

Continuous measurement of housing emissions
Average daily ammonia concentration (Table 6, 7) was less from manure where pigs had been fed the corn diets compared to the other three treatments. However, when adjusted for airflow, ammonia emission rate from manure generated by pigs fed the DDGs treatment were greater than emissions resulting from the remaining three dietary treatments (Table 6, 7). Mass of ammonia emitted per day was less in the CGM and C treatments than the DDGs and DDC treatments. Daily mass of ammonia emitted was less in the DDC treatment than in the DDGs treatment. When emissions were adjusted for animal liveweight and nitrogen consumption, ammonia emissions were less in the CGM treatment, intermediate in the C and DDC treatments, and greatest in the DDGs treatment. In general, ammonia emissions were consistently increased as a result of DDGs inclusion in the diet (increasing inclusion from 5 to 30% of the diet as pigs progressed through 6 feeding phases). Although the

DDGs diet contained more N in the diet, adjusting the emissions data for N intake did not impact the increased ammonia emissions as a result of this treatment. Phase effects on ammonia emissions were significant and are depicted in Table 6 and 7. In general, emissions increased as the pigs grew and manure accumulated.

Average daily hydrogen sulfide concentration (Table 8, 9) were lowest from manure where pigs had been fed the corn diets, intermediate in the DDC and DDGs treatment, and greatest in the CGM treatment. However, when adjusted for airflow, hydrogen sulfide emission rate from manure generated by pigs fed the DDGs treatment were greater than emissions resulting from the remaining three dietary treatments (Table 8, 9). Mass of hydrogen sulfide emitted per day was less in the CGM, DDC and C treatments than the DDGs treatment. However, when emissions were adjusted for animal liveweight and sulfur consumption, hydrogen sulfide emissions were not different as a result of treatment. In general, hydrogen sulfide emission rate and daily mass of hydrogen sulfide emitted were increased as a result of DDGs inclusion in the diet (increasing inclusion from 5 to 30% of the diet as pigs progressed through 6 feeding phases) but adjusting data for bodyweight and sulfur intakes, accounted for the differences observed. Phase effects on hydrogen sulfide concentration were significant; however emission variables were not influenced by feeding phase (Tables 8, 9).

Non-methane total hydrocarbon (NMTHC) concentration varied as a result of dietary treatment (Table 10) with the DDC diet resulting in the greatest concentration of NMTHC. No treatment or phase effects were observed for NMTHC emission variables. In addition to evaluating dietary treatment impacts on NMTHC, this study provided valuable baseline swine data.

Dietary treatment affected all methane variables. In general, the DDGs treatment produced less methane than the other treatments. Corn diets were intermediate in methane production and the CGM and DDC diets resulted in the greatest methane production. Phase effects were significant for concentration and methane emissions per unit of feed intake, generally increasing as pigs grew. Similar to NMTHC, the data are valuable in that limited methane data currently exists.

3. Quantify long-term emissions from manure generated by pigs fed diets varying in hemicellulose content.

Figures 1 through 4 illustrate the average daily mass of emitted ammonia and methane (Figures 1, 3, respectively) and the cumulative emission mass of ammonia and methane (Figures 2, 4, respectively) from the long-term emission study. Only data for these two compounds are shown because diet effects were only observed for cumulative mass of both ammonia ($P<0.0001$) and methane ($P<0.0001$) and average daily mass of methane emissions ($P<0.0001$). Spikes in ammonia emissions (Figure 1) reflect new additions of manure at the end of each feeding phase. Note also that in addition to no spikes observed for methane, emissions were minimal until a suitable anaerobic environment had been established in the buckets.

Table 4. Excreta mass and composition of swine manure from pigs fed diets containing corn or corn co-products[a].

	Mass, kg wet				Total N, % (wet basis)				Ammonium N, % (wet basis)			
Phase[b]	Corn	DDC	CGM	DDGs	Corn	DDC	CGM	DDGs	Corn	DDC	CGM	DDGs
Starter	483	268	364	295	0.28	0.35	0.27	0.29	0.16	0.20	0.14	0.16
Grower 1	830	606	714	667	0.28	0.43	0.27	0.32	0.16	0.23	0.14	0.20
Grower 2	985	962	859	932	0.28	0.34	0.29	0.37	0.18	0.21	0.18	0.24
Finisher 1	692	966	744	980	0.49	0.42	0.46	0.43	0.29	0.24	0.25	0.29
Finisher 2	428	588	638	857	0.65	0.66	0.60	0.52	0.36	0.36	0.35	0.35
Finisher 3	259	298	307	351	0.59	0.62	0.76	0.69	0.33	0.38	0.40	0.45
Cumulative	3678	3687	3625	4082	0.36	0.42	0.38	0.44	0.21	0.24	0.21	0.29

	Mass, kg wet weight	Total N, % (wet basis)	Ammonium N, % (wet basis)
Corn	613	0.43	0.25[a]
DDC	615	0.47	0.27[b]
CGM	604	0.44	.24[a]
DDGs	680	0.44	.28[b]
P =			
Diet	0.2339	0.2194	0.0089
Phase	<0.0001	<0.0001	<0.0001
Diet × Phase	0.5409	0.0928	0.0928

[a] Corn – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.

[b] Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg. Finisher phase 1: duration = 21 d, average initial bodyweight = 58 kg; Finisher phase 2: duration = 21 d, average initial bodyweight = 78 kg; Finisher phase 3: duration = 14 d, average initial bodyweight = 101 kg.

Table 5. Concentrations of volatile organic compounds in chambers as a result of feeding swine diets containing corn or corn co-products[a].

	Concentration, ppm				P-value		
Compound[b]	Corn	DDC	CGM	DDGs	Diet	Phase	Diet x Phase
Acetate	9.94	7.86	14.50	6.47	0.0014	<0.0001	0.0810
Propionate	2.91	1.46	6.05	2.75	<0.0001	<0.0001	<0.0001
Iso-Butyrate	0.00	0.03	0.00	0.05	0.4982	0.4747	0.5631
Butyrate	1.34	1.44	1.92	1.28	0.6342	<0.0001	0.8474
Iso-Valerate	0.00[c]	0.00	0.03	0.00	0.5229	0.4827	0.5624
Valerate	0.37	0.11	0.47	0.19	<0.0001	<0.0001	<0.0001
Phenol	0.03	0.00	0.03	0.01	0.0202	<0.0001	0.0006
4-Methylphenol	0.12	0.13	0.19	0.11	0.4982	0.4720	0.5635
4-Ethylphenol	0.00	0.01	0.00	0.00	<0.0001	<0.0001	0.0003
2,6-*bis*-Tertbutylphenol	0.00	0.00	0.00	0.00	0.2031	<0.0001	0.3705
3-Methylindole	0.01	0.01	0.01	0.01	0.1376	0.0003	0.3588
2-Methylindole	0.00	0.00	0.00	0.00	0.1315	<0.0001	0.1903
Undecane	0.08	0.06	0.11	0.20	0.4982	0.4747	0.5631
Dodecane	0.27	0.26	0.32	0.53	0.1112	0.0004	0.3426
Nonane	0.31	0.34	0.32	0.27	0.8812	<0.0001	0.4864
Tridecane	0.14	0.15	0.27	0.34	0.6618	0.1414	0.8435
Tetradecane	1.32	1.46	1.14	1.73	0.4021	<0.0001	0.9409

[a]Corn – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[b]Additional compounds were capable of being quantified but were not observed in samples.
[c]Compound observed but at concentrations less than reportable significant figures.

Table 6. Least squares means of ammonia emissions from swine fed diets containing corn or corn co-products during the starter and grower phases.

Item	*Starter phase 1*[a]				*Grower phase 1*				*Grower phase 2*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Average daily concentration, ppm	2.093	2.099	3.185	2.375	2.226	2.438	3.102	2.894	2.052	2.541	2.618	2.118
Average daily emission rate, mg min^{-1}	6.307	6.501	7.752	5.614	10.624	12.446	11.185	9.140	13.708	19.598	16.922	10.710
Cumulative average daily emission mass, mg d^{-1}	8.964	9.184	10.966	7.952	13.724	15.663	14.374	11.743	18.540	26.628	23.227	14.567
Daily emissions, mg kg^{-1} BW	59.225	63.869	75.444	54.512	63.938	72.649	69.929	60.106	68.236	85.153	74.978	49.489
Daily emissions, mg g^{-1} N consumed	6.350	6.457	8.682	5.800	7.685	8.529	8.342	7.307	9.479	12.174	10.456	7.680

	Average daily concentration, ppm	Average daily emission rate, mg min^{-1}	Cumulative average daily emission mass, mg d^{-1}	Daily emissions, mg kg^{-1} BW	Daily emissions, mg g^{-1} N consumed
SEM[c]	0.254	1.368	2.007	5.351	0.907
Main effect means					
Diet					
C	2.244	13.079	17.869	55.564	9.985
DDGs	2.896	19.326	26.438	75.201	11.986
DDC	2.849	13.962	19.159	59.682	9.991
CGM	2.833	12.005	16.498	50.462	8.777
Phase					
Starter phase 1	2.438	6.544	9.266	63.262	6.822
Grower phase 1	2.665	10.852	13.882	66.668	7.967
Grower phase 1	2.332	15.235	20.740	69.464	9.947
Source of variation					
Diet	0.0004	<0.0001	<0.0001	0.0256	<0.0001
Phase	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Diet × Phase	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a]Feeding phases: Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg.
[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[c]SEM – standard error of the mean.

Table 7. Least squares means of ammonia emissions from finishing swine fed diets containing corn or corn co-products.

Item	*Finisher phase 1*[a]				*Finisher phase 2*				*Finisher phase 3*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Average daily concentration, ppm	2.354	2.973	2.163	2.386	1.979	3.097	2.957	3.464	2.775	4.131	3.217	3.697
Average daily emission rate, mg min^{-1}	17.382	24.410	13.794	12.659	13.073	21.221	16.552	16.608	17.556	31.292	17.461	17.736
Cumulative average daily emission mass, mg d^{-1}	23.785	33.900	19.026	17.464	18.757	30.300	23.638	18.757	23.722	42.247	23.577	24.186
Daily emissions, mg kg^{-1} BW	58.618	81.400	45.669	43.225	40.304	66.918	51.686	50.737	42.353	78.344	43.031	45.786
Daily emissions, mg g^{-1} N consumed	11.581	13.989	8.170	8.597	10.273	13.455	11.253	11.532	14.649	16.622	13.755	11.571

	Average daily concentration, ppm	Average daily emission rate, mg min^{-1}	Cumulative average daily emission mass, mg d^{-1}	Daily emissions, mg kg^{-1} BW	Daily emissions, mg g^{-1} N consumed
SEM[c]	0.254	1.368	2.007	5.351	0.907
Main effect means					
Diet					
C	2.244	13.079	17.869	55.564	9.985
DDGs	2.896	19.326	26.438	75.201	11.986
DDC	2.849	13.962	19.159	59.682	9.991
CGM	2.833	12.005	16.498	50.462	8.777
Phase					
Finisher phase 1	2.469	17.061	23.544	57.228	10.584
Finisher phase 2	2.874	16.864	24.095	52.411	11.628
Finisher phase 3	3.455	21.003	28.419	52.330	14.160
Source of variation					
Diet	0.0004	<0.0001	<0.0001	0.0256	<0.0001
Phase	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Diet × Phase	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a]Feeding phases: Finisher phase 1: duration = 21 d, average initial BW = 58 kg; Finisher phase 2: duration = 21 d, average initial BW = 78 kg; Finisher phase 3: duration = 14 d, average initial BW = 101 kg.

[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.

[c]SEM – standard error of the mean.

Table 8. Least squares means of hydrogen sulfide emissions from swine fed diets containing corn or corn co-products during the starter and grower phases.

Item	*Starter phase 1*[a]				*Grower phase 1*				*Grower phase 2*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Average daily concentration, ppm	.0022	.0021	.0026	.0029	.0065	.0060	.0053	.0102	.0089	.0068	.0072	.0088
Average daily emission rate, mg min^{-1}	.0382	.0365	.0317	.0395	.1360	.1312	.0816	.1520	.3023	.2365	.3023	.2140
Cumulative average daily emission mass, mg d^{-1}	55.079	51.969	45.373	55.909	189.65	180.21	108.58	201.36	439.65	344.79	300.02	300.68
Daily emissions, mg kg^{-1} BW	0.3429	0.3308	0.3097	0.3687	0.8587	0.7802	0.4932	0.9133	1.6588	1.0304	0.9393	1.0593
Daily emissions, mg g^{-1} S consumed	5.1958	4.4994	4.5385	5.7398	14.7671	10.4843	7.5253	15.0516	29.9.80	15.7594	17.4700	21.4141

	Average daily concentration, ppm	Average daily emission rate, mg min^{-1}	Cumulative average daily emission mass, mg d^{-1}	Daily emissions, mg kg^{-1} BW	Daily emissions, mg g^{-1} S intake
SEM[c]	.0023	.0781	106.22	0.3371	6.4417
Main effect means					
Diet					
C	.0064	0.1765	249.41	0.7944	18.1965
DDGs	.0080	0.2305	324.35	0.8483	16.8085
DDC	.0078	0.1851	259.60	0.6957	15.8228
CGM	.0098	0.1800	247.34	0.7202	15.9850
Phase					
Starter phase 1	.0026	0.0383	54.712	0.3417	5.0315
Grower phase 1	.0070	0.1248	169.31	0.7589	11.9104
Grower phase 1	.0079	0.2415	346.28	1.1794	21.1454
Source of variation					
Diet	0.0255	0.0169	0.0222	0.1749	0.0624
Phase	0.0004	0.0652	0.0920	0.5481	0.8908
Diet × Phase	<0.0001	<0.0001	<0.0001	0.0008	<0.0001

[a]Feeding phases: Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg.
[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[c]SEM – standard error of the mean.

Table 9. Least squares means of hydrogen sulfide emissions from finishing swine fed diets containing corn or corn co-products.

Item	*Finisher phase 1*[a]				*Finisher phase 2*				*Finisher phase 3*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Average daily concentration, ppm	.0107	.0096	.0166	.0091	.0051	.0111	.0070	.0143	.0049	.0128	.0074	.0133
Average daily emission rate, mg min^{-1}	.3327	.3293	.4778	.2093	.1283	.3204	.1523	.2772	.0606	.3358	.1058	.2076
Cumulative average daily emission mass, mg d^{-1}	465.27	463.42	678.67	288.02	185.74	458.86	217.57	394.69	74.724	453.18	141.64	274.490
Daily emissions, mg kg^{-1} BW	1.1301	1.1178	1.6333	0.7200	0.3992	0.9991	0.4714	0.8297	0.1225	0.8276	0.2458	0.5146
Daily emissions, mg g^{-1} S consumed	31.2117	19.6109	38.7029	18.1725	13.9887	36.0470	12.9576	21.7963	8.7160	15.8965	12.4859	15.6206

	Average daily concentration, ppm	Average daily emission rate, mg min^{-1}	Cumulative average daily emission mass, mg d^{-1}	Daily emissions, mg kg^{-1} BW	Daily emissions, mg g^{-1} S consumed
SEM[c]	.0023	.0781	106.22	0.3371	6.4417
Main effect means					
Diet					
C	.0064	0.1765	249.41	0.7944	18.1965
DDGs	.0080	0.2305	324.35	0.8483	16.8085
DDC	.0078	0.1851	259.60	0.6957	15.8228
CGM	.0098	0.1800	247.34	0.7202	15.9850
Phase					
Finisher phase 1	.0115	0.3373	473.84	1.1503	26.8120
Finisher phase 2	.0094	0.2232	319.45	0.6859	21.5532
Finisher phase 3	.0096	0.1933	257.46	0.4715	13.7666
Source of variation					
Diet	0.0255	0.0169	0.0222	0.1749	0.0624
Phase	0.0004	0.0652	0.0920	0.5481	0.8908
Diet × Phase	<0.0001	<0.0001	<0.0001	0.0008	<0.0001

[a]Feeding phases: Finisher phase 1: duration = 21 d, average initial BW = 58 kg; Finisher phase 2: duration = 21 d, average initial BW = 78 kg; Finisher phase 3: duration = 14 d, average initial BW = 101 kg.
[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[c]SEM – standard error of the mean.

Table 10. Least squares means of methane and non-methane hydrocarbon emissions from swine fed diets containing corn or corn co-products during the starter and grower phases.

	Average daily concentration, ppm		*Average daily emission rate, mg min⁻¹*		*Cumulative average daily emission mass, mg d⁻¹*		*Daily emissions, mg kg⁻¹ BW*		*Daily emissions, mg kg⁻¹ feed intake*	
Main effect means	Methane	NMTHC	Methane	NMTHC	Methane	NMTHC	Methane	NMTHC	Methane	NMTHC
Diet[a]										
C	2.445	0.229	5.072	3.670	6702.12	4555.45	20.678	12.008	511.98	311.28
DDGs	2.383	0.223	4.890	3.431	6455.67	4313.30	20.195	9.677	517.82	286.45
DDC	2.691	0.245	5.509	2.824	7336.01	3411.92	23.031	7.674	551.53	219.04
CGM	2.850	0.222	5.493	2.974	7292.95	3702.82	24.225	9.985	621.84	273.96
Phase[b]										
Starter phase 1	1.852	0.089	2.603	0.242	3279.38	419.40	20.936	1.942	459.81	39.47
Grower phase 1	2.627	0.082	3.372	0.593	4704.31	821.51	22.285	3.618	482.88	79.87
Grower phase 2	2.549	0.161	5.897	2.781	8310.96	4063.02	27.303	12.672	630.30	293.47
Finisher phase 1	2.972	0.548	6.418	2.723	8128.03	3060.71	20.711	8.048	517.88	198.17
Finisher phase 2[d]	--	--	--	--	--	--	--	--	--	--
Finisher phase 3	2.961	0.268	7.914	6.802	10311.00	8038.25	18.927	15.005	663.08	519.22
Source of variation										
Diet	<0.0001	0.0002	<0.0001	0.1114	<0.0001	0.2636	0.0002	0.7140	0.0006	0.3555
Phase	<0.0001	0.6350	0.0739	0.8181	0.0606	0.9020	0.0015	0.9086	0.0008	0.8401
Diet × Phase	<0.0001	0.3130	<0.0001	0.9739	<0.0001	0.9765	<0.0001	0.9531	<0.0001	0.9546

[a]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[b]Feeding phases: Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg.
[c]NMTHC – non-methane total hydrocarbon.
[d]No data available due to analyzer malfunction.

Figure 1. Average daily ammonia emissions (mg) from buckets containing manure from pigs fed one of four dietary treatments.

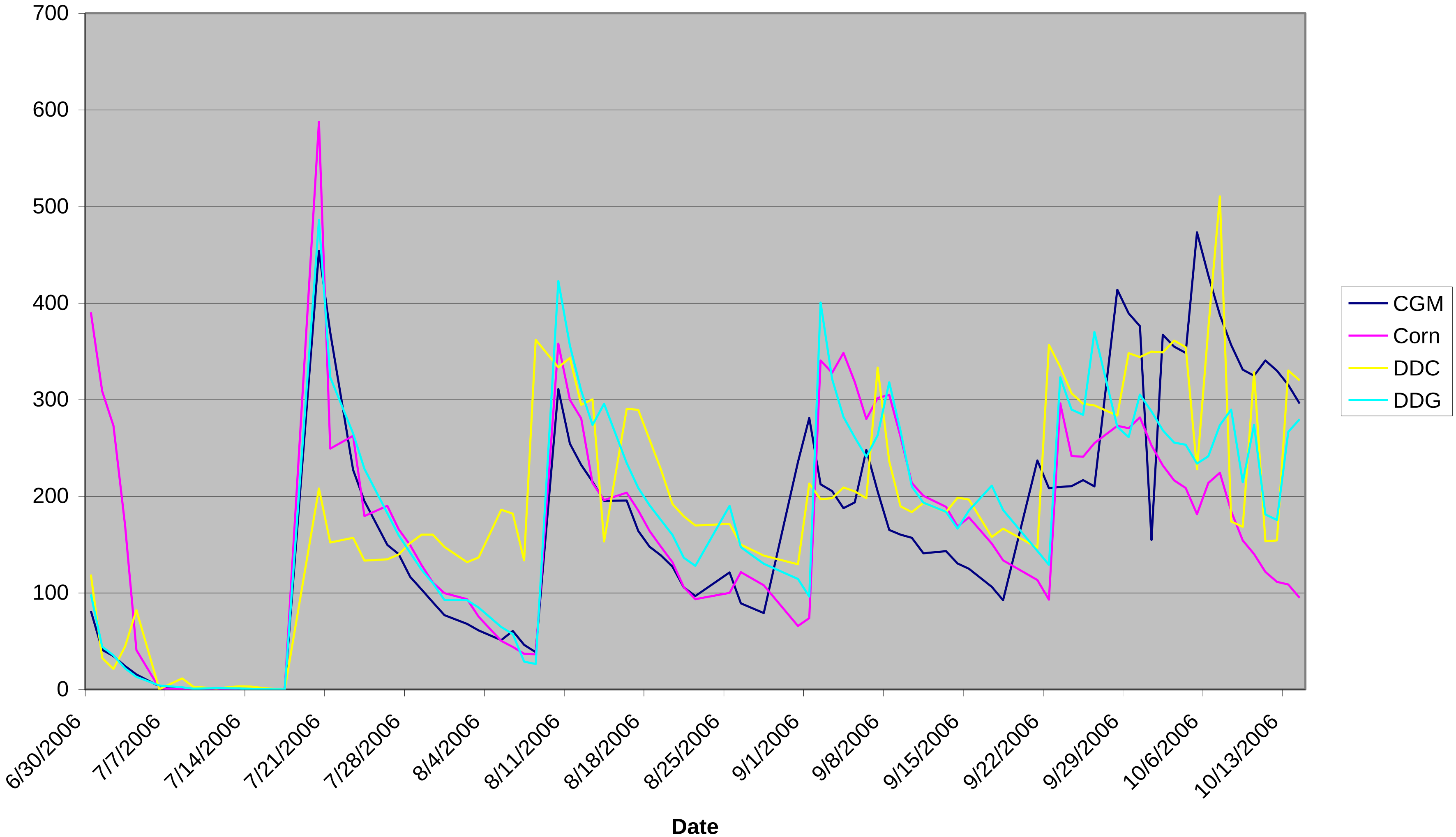


Figure 2. Cumulative ammonia emissions (mg) from buckets containing manure from pigs fed one of four dietary treatments (daily value is the sum of all previous days).

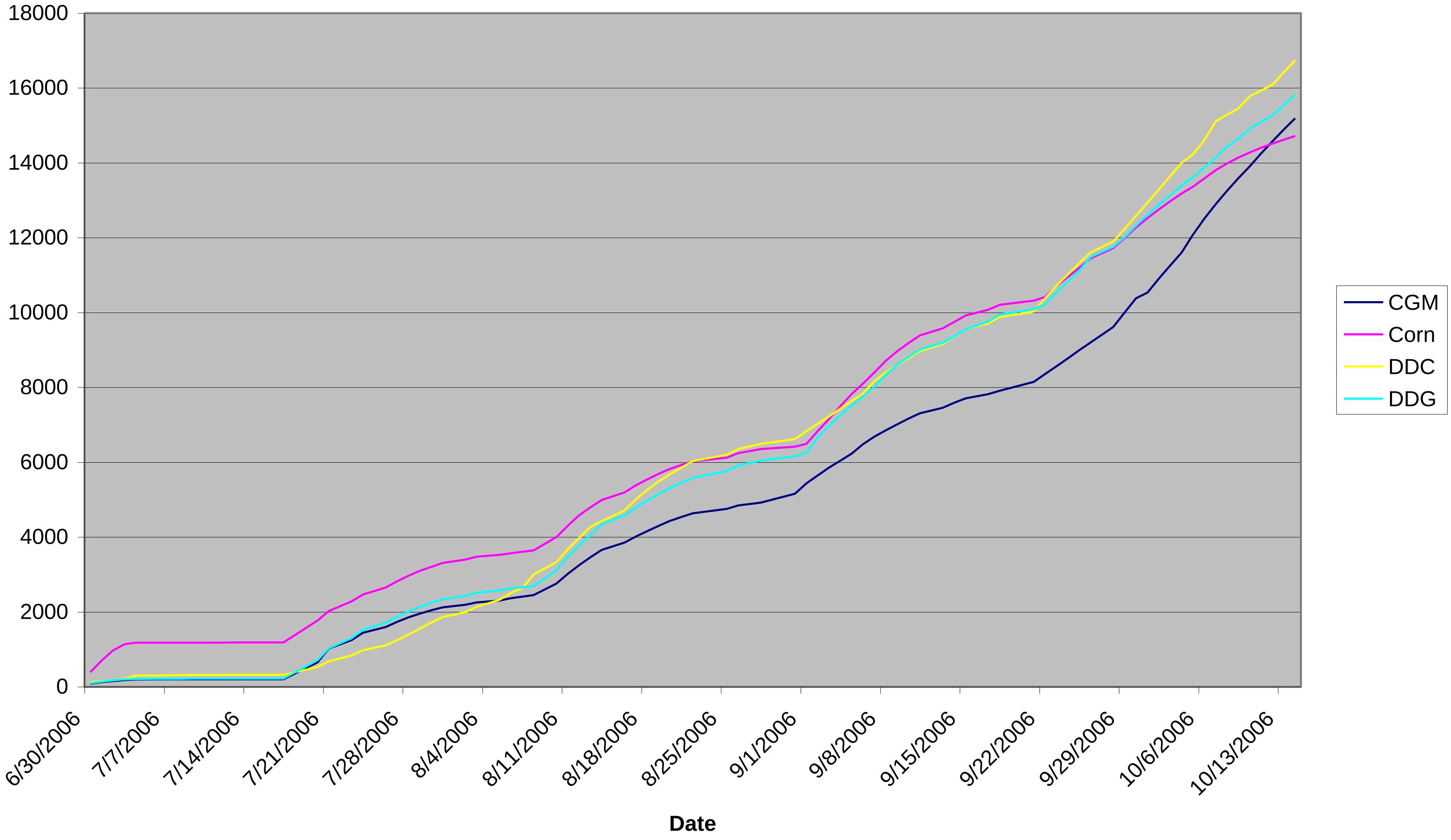


Figure 3. Average daily methane emissions (mg) from buckets containing manure from pigs fed one of four dietary treatments.

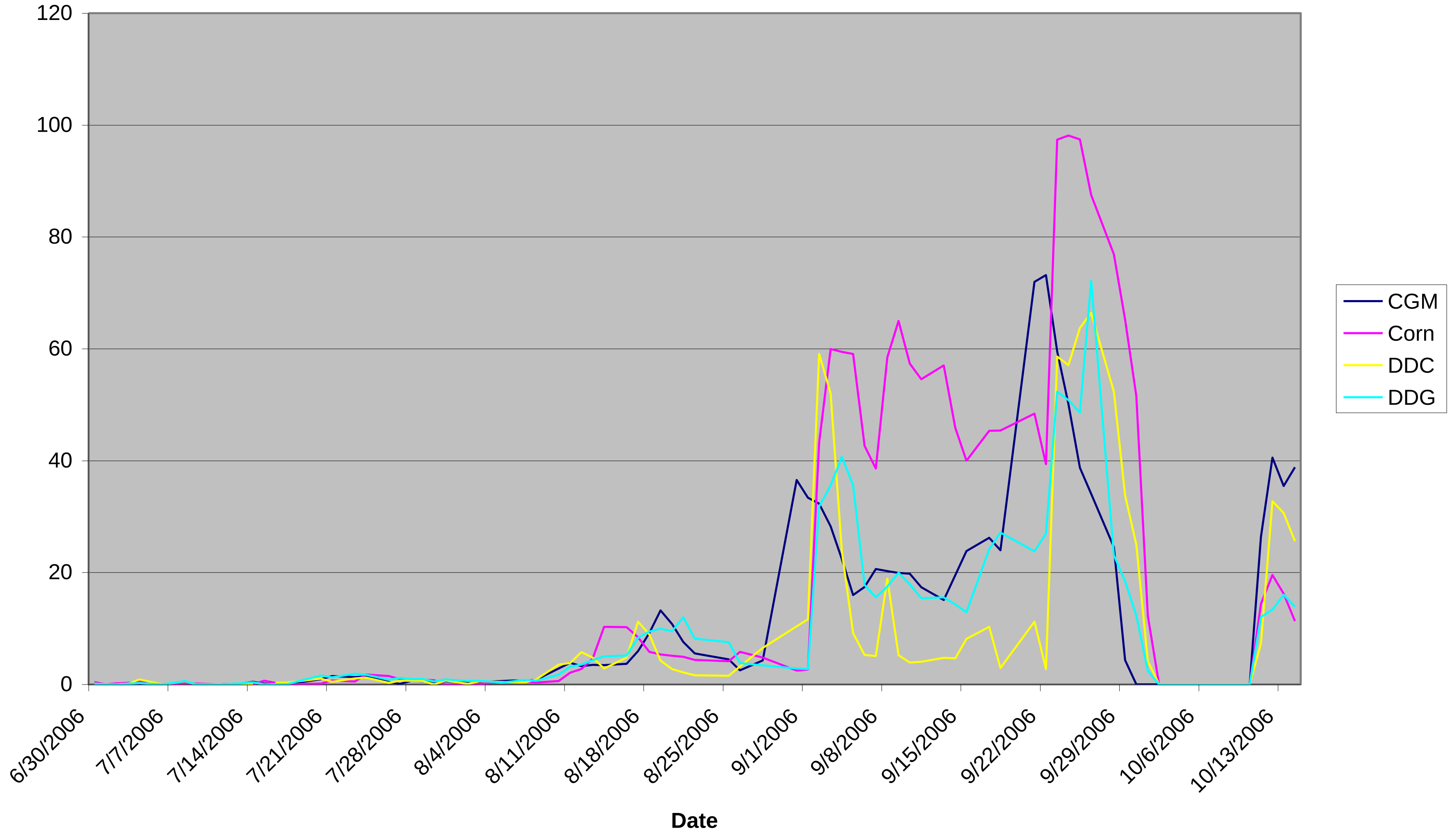
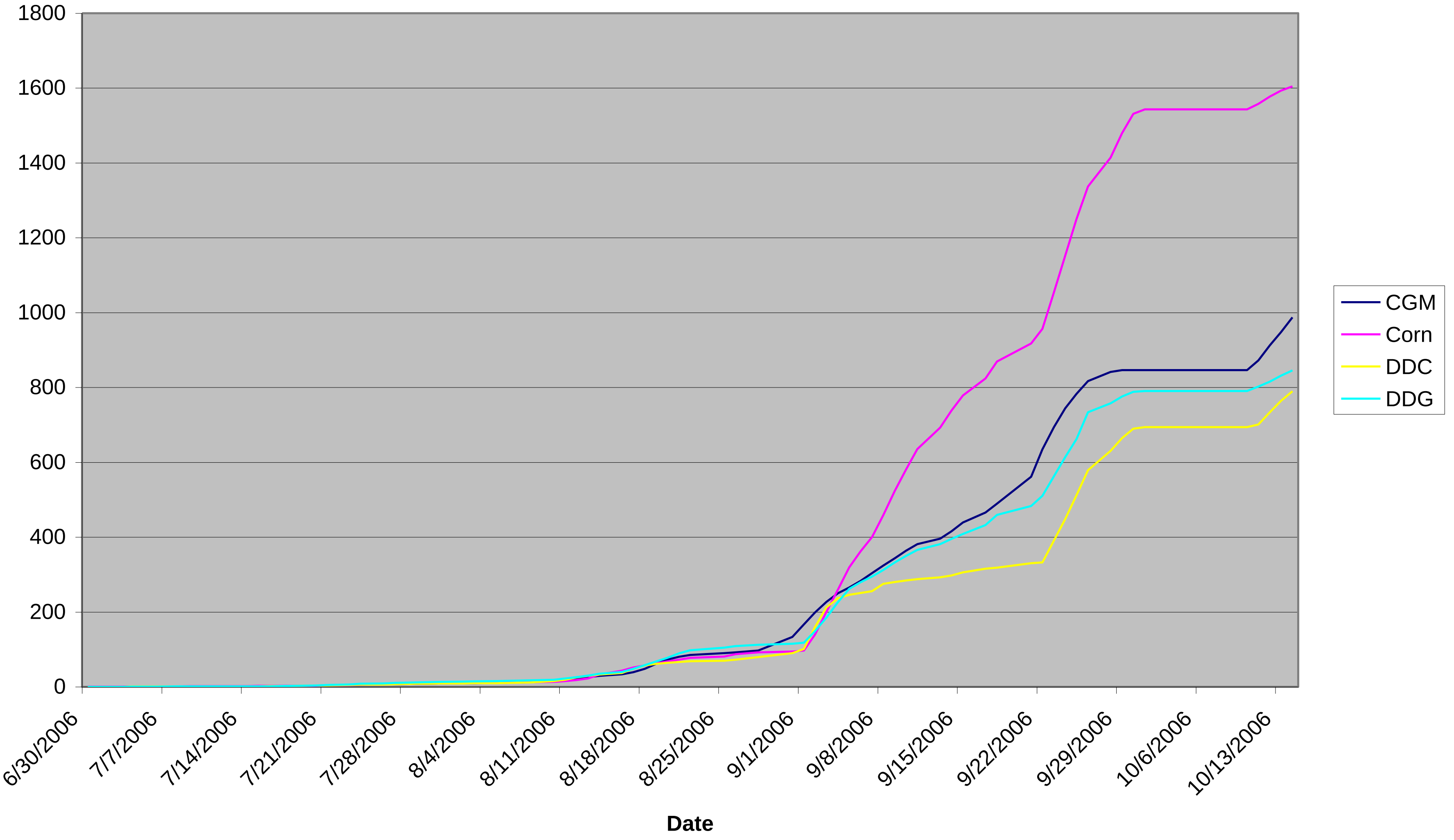


Figure 4. Cumulative methane emissions (mg) from buckets containing manure from pigs fed one of four dietary treatments (daily value is the sum of all previous days).



V. Discussion:

Housing emissions and point concentrations

The hypothesis of this project was that increasing fiber content in the diet would shift the site of hindgut fermentation resulting in more fecal nitrogen (N) and less urinary N. Urinary N is more readily volatilized than fecal. Therefore, when fermentation resulted in a greater proportion of fecal nitrogen as a result of dietary fiber, we would observe less ammonia volatilization. The DDGs diet contained more dietary fiber than the corn diet, while the DDC diet contained less fiber. However, our work showed greater ammonia emissions as a result of feeding DDGs with no difference in ammonia emissions between corn and DDC diets. This contradicts our hypothesis. The DDGs treatment contained more dietary N than did the other treatments because DDGs was fed as an energy diet and less synthetic lysine was included in that treatment as pigs aged. However, adjusting emissions data for N intake was not sufficient to account for the differences in ammonia emissions. Excess dietary N is typically excreted in urine. We suspect the additional N in the DDGs diets was sufficiently large to mask any emissions benefit that might have occurred as a result of increased dietary fiber.

Hydrogen sulfide emissions were increased as a result of DDGs inclusion at 25 or 30%. Unlike N and ammonia emissions, the increased sulfur content of the DDGs diets accounted for the increased hydrogen sulfide emissions. Sulfur is a nutrient that may be able to be reduced in diets even when high levels of DDGs are included; mineral sources could be selected to reduce the S contribution from minerals. For example, iron oxide could be fed rather than iron sulfate. So while S emissions did increase in this study, there are options available to producers to minimize the potential for increases.

Differences in methane emissions are likely attributable to some change in microbial fermentation in the hindgut. The mechanism is difficult to discern and not the intent of this study. However, in the event that interest in methane production from swine increases from a regulatory sense, there is merit in determining the underlying cause for the DDC and CGM diet impacts on methane production.

Excreta composition and long-term emissions

In spite of ammonia emission differences, manure nitrogen differences were not observed suggesting that any additional nitrogen in the manures from pigs fed the DDGs diet was rapidly volatilized and not reflected in the manure nitrogen due to the sampling procedures (animals were not in metabolism crates). Hemicellulose content did not result in differences in manure mass although such an observation would not have been unexpected. However, the implication of the findings is that additional manure storage volume is not necessary, based on our findings, to accommodate high fiber feeds.

Long-term emissions were influenced by diet, but differently than emissions from animal housing. Reasons for this are unclear but suggest different fermentation patterns during manure decomposition. While housing emissions demonstrated that the DDGs diet resulted in greater emissions, the long-term storage work featured the corn diet as having greater methane emissions and the CGM diet producing reduced ammonia emissions over time. The implication is that emissions change with storage time, including how diet impacts emissions.

VIII. Lay Interpretation:

Corn co-products are an increasingly important alternative to corn in swine diets. While there has been some research to evaluate how these co-products affect pig performance, the effect on air emissions was poorly documented. As a result, a study was conducted to see how feeding distillers dried grains with solubles (DDGs), corn germ meal (CGM), and dehulled, degermed corn (DDC) would alter air emissions as compared to a traditional corn diet (C).

Generally, ammonia and hydrogen sulfide emissions increased as a result of feeding the DDGs diets, relative to the corn diets in the animal housing area. Corn and DDGs diets produced less methane emissions than the DDC and CGM diets. No diet effects were observed for non-methane total hydrocarbon emissions.

When emissions from the manure, alone were considered the findings were contrary to that observed in the animal housing areas. The corn diet produced greater methane emissions while the CGM diet resulted in less ammonia emissions that the other treatments. This suggests that manures from pigs fed different diets metabolize differently over time producing emissions that may be unlike that observed during a period when the manure is in the animal housing area for a short time period.

Within this study no performance differences were observed when corn co-products were fed at increasing levels of the diet (from 5 to 30% as pigs aged over the course of six feeding phases) suggesting that there may be value in considering greater inclusions than is currently practiced if there are also no negative carcass quality effects. It is imperative that as producers include DDGs in their diet formulations, they consider the added N and S and account for those nutrients in the formulation rather than feeding DDGs solely as an energy source.