RESEARCH REPORT
ENVIRONMENT

Title: Effects of inclusion of corn distillers dried grains with solubles in the diet of finishing pigs and gestating sows on nutrient excretion and gaseous emissions – **NPB** #09-124

Investigator: Scott Carter, Associate Professor, scott.carter@okstate.edu.

Institution: Oklahoma State University

Co-Investigators: Hae Jin Kim, Ph.D. Candidate
Doug Hamilton, Associate Professor

Industry Summary

Three experiments were conducted to determine the effects of DDGS on nutrient excretion and gaseous emissions by swine. In Exp. 1, a total of 80 pigs initially weighing 36.8 kg were blocked by weight and allotted to four dietary treatments. Dietary treatments were randomly allotted to four rooms with 2 pens per room (20 pigs/room). Each room was housed within the same building with each room receiving the same incoming air. Each room was equipped with a shallow pit, pull-plug manure system. Thus, each room served as the experimental unit. All pigs within a room were fed one of four diets.

The four dietary treatments included a fortified corn-soybean meal diet (control) or a corn-soybean meal diet with the addition of 10, 20, or 40% distillers dried grains with solubles (DDGS). The corn DDGS was purchased from a new generation ethanol plant. The DDGS diets were formulated to a similar standardized ileal digestible (SID) Lys content and digestible P content as the control diet. Thus, all diets contained similar levels of DM, SID Lys, and digestible P. However, CP and S concentrations increased with increasing DDGS levels. Also, macro- and micro-mineral concentrations varied among diets due to the contribution from DDGS.

Each week, the pigs were removed from each room and weighed. At this time, the feeders were weighed to calculate feed intake and a feed sample was collected from each feeder. Nutrient concentration of the slurry was multiplied by total pit volume to achieve total nutrient output by phase. Airflow from each fan was continuously measured and ammonia and hydrogen sulfide concentrations in the exhaust air were measured. The generation and emission rates of each gas were calculated. The emission rates for each room were based on the mean gas concentration in the exhaust air of each room and the total airflow rate for each sampling cycle.

Daily gain tended to decrease with increasing DDGS. Increasing DDGS did not affect ADFI. However, G:F ratio decreased with increasing DDGS. The daily intake of DM was similar among dietary treatments. However, N and S intakes increased with increasing DDGS. The intake of P tended to decrease with increasing DDGS.

Slurry volume tended to increase for pigs fed increasing DDGS. Pigs fed 40% DDGS had a 15% greater slurry volume compared with pigs fed 0% DDGS. However, slurry pH was reduced for pigs fed increasing DDGS. Nutrient concentration of the slurry was multiplied by total volume of the slurry and divided by the number of pigs and days on test to calculate excretion on a g/pig/d basis. The excretion of DM, N, Mg, Na, and S were increased markedly for pigs fed increasing DDGS. The excretion of P, Ca, Cu, and Zn also tended to be increased for pigs fed DDGS.

Airflow was similar for all rooms. Increasing DDGS increased the concentration of NH_3, H_2S, CO_2, CH_4, and N_2O in the exhaust air. The emission rates (mg/min) of these gases were also increased with increasing DDGS. When calculated on a per pig basis, the emissions of these gases were increased for pigs fed increasing DDGS.

In Exp. 2, pigs were fed either a control diet or the control diet with 25% DDGS for the entire finishing period. The DDGS diet was formulated to a similar SID Lys content and digestible P content as the control diet. Crystalline Lys, Thr, and Trp were added as needed to the DDGS diet in order to equalize CP similar to that in the control diet. Digestible P was allowed to decrease with age in the control diet, but it remained higher in the DDGS diet due to the contribution from DDGS. In addition, phytase was added to each diet. Thus, both diets contained similar levels of DM, CP, and SID Lys. Digestible P and S content were greater in the DDGS diet. Also, macro- and micro-mineral concentration varied between diets due to the contribution from DDGS. .

The addition of 25% DDSG tended to slightly reduce ADG resulting in a slight reduction in final weight. Addition of 25% DDGS did not affect feed intake or G:F ratio. The daily intakes of DM and N were similar for both dietary treatments. However, S intake increased with the addition of DDGS. The intake of P tended to increase with DDGS.

Slurry volume was increased by 16% for pigs fed DDGS; however, this difference was not significant. Slurry pH was reduced for pigs fed 25% DDGS. The excretion of DM, Na, and S were increased markedly for pigs fed 25% DDGS. Cumulative excretion of DM and S per pig for the entire finishing period was increased for pigs fed DDGS.

Airflow was similar for all rooms. Unlike Exp. 1, the concentration and emission of NH_3 was similar for pigs fed both diets most likely due to the equalization of protein content in the diets. However, H_2S concentration and emission rate was increased for pigs fed DDGS. Also, the emission of CH_4 per pig was increased with DDGS. The concentration and emissions of CO_2 and N_2O were not affected by diet.

In Exp. 3, two similar gestation barns, each housing 44 sows, were used to determine the effect of DDGS inclusion in gestation diets on nutrient excretion. Sow parity and gestation stage (early, mid, late gestation) were equalized between barns. Two dietary treatments consisting of a fortified corn-soybean meal diet and an experimental diet with 40% DDGS inclusion in a corn-soybean meal diet were compared during a 2-phase crossover design. Each period consisted of a 2-week adaptation period, followed by a 4-week collection period. Following the 2-week adjustment where sows were fed their respective dietary treatment, a 4-week collection period began. Following this 1st period, dietary treatments were switched between barns and the 2nd six-week period commenced. The daily intakes of DM and P were similar; however, N and S intakes increased for sows fed DDGS. Pit characteristics, pH, and temperature were similar for sows fed both diets. However, volume was increased by 12% for sows fed DDGS. The daily excretion of DM, Mg, and S were increased for sows fed DDGS. The excretion of N was numerically increased for sows fed DDGS. However, little effect was observed for the other nutrients. The concentrations of NH_3, H_2S, CH_4, and N_2O in exhaust air were increased for sows fed DDGS.

In summary, these results suggest that feeding high levels of DDGS to finishing pigs and gestating sows may increase environmental issues for swine facilities. Increasing DDGS in the diet increased DM and S excretion dramatically, while N excretion can be limited. These tremendous increases in excretion resulted in significant increases in CH_4 and H_2S emissions for swine fed DDGS. Ammonia and N_2O emissions can be controlled by minimizing the increase in dietary CP when feeding DDGS. Methods to enhance DM

digestibility and reduce S content of DDGS must be explored to limit the environmental implications when feeding high levels of DDGS. This project was funded by the National Pork Checkoff.

Contact Information:
Scott D. Carter, Ph.D.
212B Animal Science
Oklahoma State University
Stillwater, OK 74078
Phone: 405-744-8869
Email: scott.carter@okstate.edu

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Scientific Abstract

A total of 80 crossbred pigs was used to determine the effects of increasing DDGS on nutrient excretion during the finishing phase (37 to 135 kg). Pigs were housed in an environmentally-controlled building with four identical rooms (20 pigs/room), each with a shallow pit, pull-plug system. Pigs were stratified by BW, sex, and ancestry, and randomly assigned to one of four rooms. Diets were randomly allotted in 4 x 4 Latin square design with four rooms and four dietary phases. The four dietary treatments included fortified corn-soybean meal based diets containing 0, 10, 20 or 40% DDGS which replaced corn, soybean meal, and dicalcium phosphate. Crystalline Lys was used to limit the increase in dietary CP for diets containing DDGS and Trp was added as needed to maintain ratios in all phases. All diets, within the four dietary phases, were balanced on SID Lys and digestible P. Each phase consisted of a 1-wk adjustment period followed by a 3-wk slurry collection period. Inclusion of 10 or 20% DDGS had little effect on ADG or G:F, but 40% DDGS reduced performance (quad, $P < 0.05$). However, DDGS did not affect ADFI. Slurry pH decreased (linear, $P < 0.01$) and volume increased ($P = 0.02$) as DDGS increased. The daily intakes of N ($P < 0.09$), Mg and S ($P < 0.01$) were increased linearly with increasing DDGS. However, P intake decreased (linear; $P < 0.07$), but DDGS did not affect DM and Ca intakes. Excretion (g/d) of DM, N, Mg, and S were increased (linear; $P < 0.01$) by 165, 145, 159, and 279% for pigs fed 40% DDGS. Increasing DDGS slightly increased (linear, $P = 0.10$) P excretion, but did not affect Ca and K excretion. The emissions of NH_3, H_2S, CH_4, and N_2O were dramatically increased ($P < 0.01$) for pigs fed increasing DDGS.

In Exp. 2, a total of 80 crossbred pigs was used to determine the effects of DDGS on nutrient excretion during the entire finishing phase (39 to 125 kg). Pigs were housed in the same building used for Exp. 1. Pigs were stratified by BW, sex, and ancestry, and randomly assigned to one of four rooms. Pigs were stratified by sex, weight, ancestry and randomly allotted to 1 of 2 dietary treatments. Dietary treatments were fed in 4 dietary phases and consisted of a fortified corn-soybean meal diet and a control diet with 25% DDGS. Lysine HCl was used in the DDGS diet to maintain similar CP concentration as the control, and Thr and Trp were added as needed to maintain AA ratios. Digestible P was decreased by phase for pigs fed the control diet, but in the DDGS diet, digestible P was unable to be decreased due to the contribution from DDGS. All diets within phase were formulated on a SID Lys basis. Feed and slurry samples were collected weekly along with pig weights, feed intake, pit volume, and pH of slurry. Addition of DDGS slightly decreased ($P < 0.05$) ADG, but had no effect ($P > 0.10$) on ADFI or G:F. Intakes of DM and N were not affected ($P > 0.01$) but S intake increased ($P < 0.01$) for pigs fed DDGS. Slurry volume was numerically increased, while slurry pH decreased ($P < 0.02$) with DDGS. The daily excretion of DM and S were increased by approximately 38% for pigs fed DDGS. However, N excretion was not affected ($P > 0.10$) by feeding DDGS with the amino acid supplementation strategy used. The emission of H_2S and CH_4 were increased ($P < 0.06$), but no effect on NH_3

or N_2O emissions were observed for pigs fed DDGS. These results suggest that DM (CH4) and S (H_2S) excretion increase with DDGS inclusion in the diet, but N (NH_3) excretion can be limited with dietary formulation.

In Exp. 3, a total of 88 sows (212 kg; parity = 2.5) were used to determine the effects of distillers dried grains with solubles (DDGS) on nutrient excretion during the gestation period. Sows were stratified by BW, parity, and status of gestation, and housed in one of two identical environmentally-controlled buildings (experimental unit) with shallow pit, pull-plug systems. Dietary treatments were randomly assigned to one of two buildings in a 2 (trt) x 2 (building) crossover design. The control diet consisted of a fortified corn-soybean meal based diet formulated to 12% CP, 0.47% SID Lys and 0.39% digestible P. The experimental diet (DG40) contained 40% DDGS and was formulated to 16% CP, 0.47% SID Lys and 0.39% digestible P. DDGS replaced corn, soybean meal and dicalcium phosphate and Lys HCl was used to adjust dietary levels of CP and SID Lys. Each of two phases consisted of a 6-wk period which included a 2-wk adjustment period followed by a 4-wk slurry collection period. At the end of the initial 6-wk period, treatments were switched between buildings to allow for another 6-wk period. There was no difference ($P > 0.10$) in feed intake (2.28 vs. 2.20 kg) for sows fed control vs. DG40. Also, slurry pH (7.66 vs. 7.65), temperature (16.6 vs. 17.2 °C), and volume (38.4 vs. 42.7 L) were similar ($P > 0.10$). Daily intakes of DM, P, Ca, K, Fe, Zn, Cu, and Mn were similar ($P > 0.10$) for both dietary treatments. However, daily N intake tended to increase ($P = 0.10$), but Mg, Na, and S intake increased ($P < 0.05$) for sows fed 40% DDGS. Inclusion of DDGS in the diet increased ($P = 0.04$) daily excretion of DM and S by 28 and 68%, respectively. The daily excretion of Ca and Mg tended to increase ($P < 0.08$) with DDGS. Daily N excretion increased by 20% with inclusion of DDGS in the diet; however, this was not significant ($P = 0.12$). The concentrations of NH_3, H_2S, and CH_4 in exhaust air were increased ($P < 0.07$) for sows fed DDGS. In conclusion, 40% inclusion of DDGS in the diet of gestating sows markedly increases DM and S excretion and NH_3, H_2S, and CH_4 concentrations.

These results suggest that addition of DDGS to corn-soybean meal diets increases DM and S excretion. These increases in excretion resulted in marked increases in CH_4 and H_2S concentration or emissions for swine fed DDGS. The daily excretion of N andNH_3 emission can be controlled for pigs fed DDGS using dietary strategies that limit the increase in dietary CP with DDGS inclusion. Based on these results, methods to increase DM digestibility (reducing DM excretion) and reduce S content of DDGS warrant further investigation to limit the environmental implications associated with feeding DDGS.

Introduction

With the Federal policy to increase ethanol production, the abundance of corn-based distillers dried grains with solubles (DDGS) will continue to increase. The increasing supply of DDGS provides an alternative feed ingredient for swine producers to use in diet formulation. Recommended levels of DDGS range from 20 to 30% in swine finishing diets and up to 40% in gestation diets. These inclusion levels of DDGS in swine diets offer pork producers opportunities to decrease diet (feed) costs. While much research has been conducted evaluating the effect of DDGS on swine performance and carcass characteristics, little research has been conducted to evaluate the effects of DDGS on the comprehensive nutrient management plan for production units. Inclusion of DDGS in swine diets, depending on dietary formulation, has the potential to increase total solids, N, and S excretion by swine. These changes in excretory patterns may lead to an increase in the N:P ratio in swine manure which affects fertilizer value of manure. Additionally, the potential increase in DM, N, and S excretion may increase the emission of ammonia, hydrogen sulfide, and greenhouse gases from buildings where pigs are fed DDGS. The following proposal attempts to quantify the impact of DDGS on nutrient excretion and gaseous emissions of finishing pigs and gestating sows.

Objectives:

The objectives of this proposal were to:

i. Determine the effect of varying inclusion levels of corn distillers dried grain with solubles on nutrient excretion (DM, TKN, NH_4-N, total P, and macro-and micro-minerals) during the finishing period,
ii. Quantify the effect of varying inclusion of DDGS in the diet of finishing pigs on CO_2, CH_4, NH_3, N_2O, and H_2S emissions during the finishing phase, and
iii. Determine the effect of DDGS inclusion in sow gestation diets on nutrient excretion (DM, TKN, NH_4-N, total P, and macro-and micro-minerals).

Materials and Methods:

Three experiments were conducted to determine the impact of adding DDGS to the diet on nutrient excretion and gaseous emissions. Experiment 1 and 2 were conducted using finishing pigs and experiment 3 utilized gestating sows.

Finishing Pigs (Exp. 1): Nutrient excretion during the finishing phase was determined on a weekly basis. In this experiment, the input of nutrients (feed) and the output of nutrients (slurry and air) were quantified. The nutrients in the feed analyzed included: DM, total N, total P, Ca, K, Mg, Na, S, Fe, Cu, Zn, and Mn. The slurry was measured for these nutrients plus NH_4-N and pH. The exhaust air was measured for CO_2, CH_4, NH_3, N_2O, and H_2S concentrations. In addition, pigs and feeders were weighed weekly to calculate body weight gain and total nutrient intake.

A total of 80 pigs initially weighing 36.8 kg were blocked by weight and allotted to four dietary treatments. Dietary treatments were randomly allotted to four rooms with 2 pens per room (20 pigs/room). Each room was housed within the same building with each room receiving the same incoming air. Each room was equipped with a shallow pit, pull-plug manure system. Thus, each room served as the experimental unit. All pigs within a room were fed one of four diets.

Corn DDGS was purchased from a new generation ethanol plant (Table 1) and analyzed before mixing the diets. The four dietary treatments (Table 1) included a fortified corn-soybean meal diet (control) or a corn-soybean meal diet with the addition of 10, 20, or 40% distillers dried grains with solubles (DDGS). The DDGS diets were formulated to a similar standardized ileal digestible (SID) Lys content and digestible P content as the control diet. Thus, all diets contained similar levels of DM, SID Lys, and digestible P. However, CP and S concentrations increased with increasing DDGS levels. Also, macro- and micro-mineral concentrations varied among diets due to the contribution from DDGS.

The experimental design consisted of a 4 x 4 Latin square with 4 rooms and 4 dietary phases. Within each phase, the four dietary treatments were allotted to each room. Initially, the dietary treatments were allotted randomly to the four rooms. Following the completion of each phase, rooms were re-allocated to dietary treatments. Carryover effects of treatments were balanced in that a dietary treatment could only follow a specific treatment only once. Upon completion of the four dietary phases, there were four replications for each dietary treatment. Each dietary phase consisted of a 1-week adaptation period, followed by a 3-week collection period.

Feed was weighed before filling the feeders, and each room was equipped with a water meter to determine water disappearance. Each week, the pigs were removed from each room and weighed. At this time, the feeders were weighed to calculate feed intake and a feed sample was collected from each feeder. Also, at this time, total pit volume was determined and sampling the pit commenced. To sample the pit, a submersible pump was placed in the pit and used to circulate the slurry contents. Also, the output from the pump was used to wash the remaining fecal material into the pit. After recirculating the pit for 20 minutes, a sampling pump was placed at the pull-plug. The plug was pulled and as the slurry exited the pit, the sampling pump pulled a continuous sample from the exiting slurry. The sampling pump ran the entire time the slurry exited the pit, and the sample was collected into a five-gallon bucket. At this time, slurry pH was measured. Following these measurements, a mixing-sampling unit was placed in the bucket to mix the sample while 2 one liter bottles were filled for later analyses. One sample bottle of slurry was acidified to a pH of 2 to 3. The two sample bottles were frozen for later analyses.

The analyses of the feed and slurry samples were performed by the OSU Soil Testing Lab. This lab is certified by the Manure Analysis Proficiency Program administered by the Soil Science Society of America since 2004 (three times per year) and the National Forage Testing Association's Forage Analysis Certification Program since 1993 (five times per year). The nutrients in the feed to be measured include: DM, total N, total P, Ca, K, Mg, Na, S, Fe, Cu, Zn, and Mn. The slurry was measured for these nutrients plus NH_4-N and pH. Total N of the samples were analyzed using a LECO Carbon/Nitrogen analyzer. Ammonium N and nitrate were analyzed by extracting nitrate and ammonium from the slurry samples with 1.0 M KCl. Ammonium and nitrate were simultaneously measured on a flow-injection analyzer. The ammonium was analyzed using the salicylate method, and the nitrate was measured using the cadmium reduction method. Mineral concentrations in the feed and slurry were analyzed by digestion in a digestion block at 120˚ C with concentrated nitric acid and hydrogen peroxide. The resulting solution was analyzed on an ICP. All analyses were performed according to Recommended Methods for Manure Analysis, 2003, University of Wisconsin-Extension A3769. Nutrient concentration of the slurry was multiplied by total pit volume to achieve total nutrient output per week, by dietary phase, and for the entire finishing period.

In addition to the slurry data, the rooms were monitored for CO_2, CH_4, NH_3, N_2O, and H_2S concentrations. Each room was equipped with two variable speed fans (PH 4E40Q, Multifan, Bloomington, IL). Air samples were collected from ducts attached to each exhaust fan. Sampling ports were inserted into the ducts, and air samples were drawn from each duct to a stationary control instrumentation trailer. Air samples from each duct were automatically switched sequentially between eight sampling manifolds and one background sample. Gases were measured for a twenty minute period for each fan. The first 15 minutes of the cycle was used to purge the sample line and equilibrate the analyzer. During the last 5 minutes of each cycle, gas measurements were averaged and recorded with data software. A total of eight samples were analyzed per fan per day (16 measures per room per day) for a total of 56 measures per fan per week.

Carbon dioxide, CH_4, NH_3, and N_2O concentrations in the exhaust air were measured using a Fourier Transformed Infrared (FTIR) spectroscopy (California Analytical Instruments, Orange, CA). Hydrogen sulfide was measured using a Model 450C-TL (Thermo Electron Corporation, Franklin, MA). Each analyzer was calibrated weekly using a multigas calibration system (Model 146C, Thermo Environmental Instruments, Franklin, MA). Sample lines (Teflon, Dupont, Wilmington, DE) were inspected regularly.

Airflow from each fan was continuously measured using current transducers (Hawkeye 822, Portland, OR) attached to each fan control unit. Voltage readings were regressed against actual flow from each fan to generate prediction equations for each fan. Airflow was determined for each fan using a flowhood (8400 Flow Hood, Scottsdale, AZ) that measured the total volume of air exhausted by each fan. Voltage was regressed against airflow across the range for the minimum speed fan (40 to 100%) and for the 2nd stage fan (40 to 100%). The minimum speed fan was set to run at all temperatures with a minimum speed of 40% of maximum fan speed. The 2nd stage fan turned on at minimum speed when the ambient temperature in each room exceeded 5 degrees from the set point. Fans were calibrated each week when the pigs were removed from the room for weighing. The flow rates were logged using a data logger (Omega Engineering, Inc) for each sampling cycle. Data for air flow rates and gas concentration were downloaded daily to a personal computer. The emission rates for Rooms 1 to 4 were based on the mean gas concentration in the exhaust air of each room and the total airflow rate for each sampling cycle.

Nutrient excretion and gaseous emissions were determined during the 3-week collection period within each phase. Data were analyzed as a 4 x 4 Latin square. Dietary treatment and period were considered random effects and room were considered as a fixed effect. Linear and curvilinear effects were used to test the effects of increasing DDGS. Room served as the experimental unit.

Finishing pigs (Exp. 2): Due to the fact that four dietary treatments cannot be evaluated for the entire finishing period in our environmental finisher, a second finisher experiment evaluated the effects of 0 vs. 25% DDGS inclusion in the finishing phase for the entire 96-d finishing period.

A total of 80 pigs initially weighing 39 kg were blocked by weight and allotted to two dietary treatments. Dietary treatments were randomly allotted to four rooms with 2 pens (10 pigs/pen) per room (20

pigs/room). Each room was housed within the same building with each room receiving the same incoming air. Each room was equipped with a shallow pit with a pull-plug. Thus, each room served as the experimental unit. All pigs within a room were fed one of two diets (Table 3). The two dietary treatments included a fortified corn-soybean meal diet (control) or a corn-soybean meal diet with the addition of distillers dried grains with solubles (DDGS). The corn DDGS was purchased from a new generation ethanol plant (Table 1). The DDGS diet was formulated to a similar SID Lys content and digestible P content as the control diet. Crystalline Lys, Thr, and Trp were added as needed to the DDGS diet in order to equalize CP similar that in the control diet. Digestible P was allowed to decrease with age in the control diet, but it remained higher in the DDGS diet due to the contribution from DDGS. In addition, phytase was added to each diet. Thus, both diets contained similar levels of DM, CP, and SID Lys. Digestible P and S content were greater in the DDGS diet. Also, macro- and micro-mineral concentration varied between diets due to the contribution from DDGS. The dietary treatments were fed in four phases: 39 to 50 kg, 50 to 77 kg, 77 to 100 kg, and 100 to 125 kg.

Growth performance, nutrient excretion, and gaseous emissions were determined as described for Exp.1, with the exception that these data were collected for the entire finishing period. Data were analyzed as a randomized complete block design. The model included the effects of treatment, block, and the block x treatment interaction (error). The diet containing DDGS was contrasted vs. the control diet. The room served as the experimental unit.

Gestating sows (Exp. 3): Two similar gestation barns, each housing 44 sows, were used to determine the effect of DDGS inclusion in gestation diets on nutrient excretion. Sow parity and gestation stage (early, mid, late gestation) were equalized between barns. Two dietary treatments (Table 4) consisting of a fortified corn-soybean meal diet and an experimental diet with 40% DDGS inclusion ere compared during a 2-phase crossover design. Each period consisted of a 2-week adaptation period, followed by a 4-week collection period. Following the 2-week adjustment where sows were fed their respective dietary treatment, a 4-week collection period began. Following this 1st period, dietary treatments were switched between barns and the 2nd six-week period commenced. Slurry analysis and calculation of excretion were similar to that described for the finishing experiments. Gestation barn was considered the experimental unit.

Results

All procedures were approved by the OSU Institutional Animal Care and Use Committee.

Experiment 1:

Initial weights were similar (P > 0.10) for all treatments (Table 5). However, ADG tended to decrease (quad, P < 0.06) with increasing DDGS; pigs fed 40% DDGS had the lowest ADG. The decrease in ADG resulted in a tendency (linear, P < 0.10) for final weight to decrease for pigs fed increasing levels of DDGS. Increasing DDGS did not affect (P > 0.10) ADFI. However, G:F ratio increased (quad, P < 0.05) with increasing DDGS. The daily intake of DM was similar (P > 0.10) among dietary treatments. However, N and S intakes increased (P < 0.02) with increasing DDGS. The intake of P tended to decrease (linear, P < 0.09) with increasing DDGS.

Slurry volume tended to increase (linear, P < 0.06) for pigs fed increasing DDGS (Table 6). Pigs fed 40% DDGS had a 15% greater slurry volume compared with pigs fed 0% DDGS. Slurry temperature was similar (P > 0.10) for pigs fed all dietary treatments. However, slurry pH was reduced (linear, P < 0.01) for pigs fed increasing DDGS. Water use was similar (P > 0.10) among dietary treatments; however, water use was numerically greater for pigs fed DDGS.

Nutrient concentration of the slurry is shown in Table 7. The concentrations of DM, Mg, and S increased (linear, P < 0.03) markedly with increasing DDGS. Although not significant, N concentration of the slurry was increased by 25% for pigs fed 40% DDGS. Increasing DDGS reduced (linear, P < 0.02) Fe concentration most likely due to the reduced need for dicalcium phosphate in the DDGS diets. The ratio of N:P in the slurry increased (linear, P < 0.02) with increasing DDGS.

Nutrient concentration of the slurry was multiplied by total volume of the slurry and divided by the number of pigs and days on test to calculate excretion on a g/pig/d basis (Table 8). The excretion of DM, N, Mg, Na, and S were increased (linear, P < 0.01) markedly for pigs increasing DDGS. The excretion of P, Ca, Cu, and Zn also tended to be increased (linear, P < 0.11) for pigs fed DDGS.

Airflow was similar (P > 0.10) for all rooms (Table 9). Increasing DDGS increased (linear, P < 0.05) the concentration of NH_3, H_2S, CO_2, CH_4, and N_2O in the exhaust air. The emission rates (mg/min) of these gases was also increased (linear, P < 0.02) with increasing DDGS. When calculated on a per pig basis, the emissions of these gases were increased (linear, P < 0.04) with increasing DDGS.

Experiment 2:

Initial weights were similar (P > 0.10) for both treatments (Table 10). Addition of 25% DDSG tended to slightly reduce (P < 0.06) ADG resulting in a slight reduction (P < 0.10) in final weight. Addition of 25% DDGS did not affect (P > 0.10) feed intake or gain:feed ratio. The daily intakes of DM and N were similar (P > 0.10) for both dietary treatments. However, S intake increased (P < 0.01) with the addition of DDGS. The intake of P tended to increase (P < 0.07) with DDGS.

Slurry volume was increased by 16% for pigs fed DDGS; however, this difference was not significant (P = 0.23) (Table 11). Slurry temperature was similar (P > 0.10) for pigs fed both dietary treatments. However, slurry pH was reduced (P < 0.02) for pigs fed 25% DDGS. Water use was similar (P > 0.10) between dietary treatments.

Nutrient concentration of the slurry is shown in Table 12. Slurry from pigs fed 25% DDGS had numerically greater concentrations of DM, P, Mg, Na, S, and water soluble P compared with pigs fed the control; however, with the exception of S (P < 0.08) and water soluble P (P < 0.02), these differences were not significant (P > 0.10). On the other hand, slurry from pigs fed 25% DDGS tended to have lower concentrations of N (P =0.11), but few differences were noted in other nutrient concentrations.

Nutrient concentration of the slurry was multiplied by total volume of the slurry and divided by the number of pigs and days on test to calculate excretion on a g/pig/d basis (Table 13). The excretion of DM, Na, and S were increased ($P < 0.03$) markedly for pigs fed 25% DDGS. Cumulative excretion of DM and S per pig for the entire finishing period was increased ($P < 0.06$) for pigs fed DDGS.

Airflow was similar ($P > 0.10$) for all rooms (Table 14). Unlike Exp. 1, the concentration and emission of NH_3 was similar ($P > 0.10$) for pigs fed both diets most likely due to the equalization of protein content in the diets. However, H_2S concentration and emission rate was increased ($P < 0.05$) for pigs fed DDGS. Also, the emission of CH_4 per pigs was increased ($P < 0.06$) with DDGS. The concentration and emissions of CO_2 and N_2O were not affected ($P > 0.10$) by diet.

Experiment 3:

Body weight, parity, and sow gestation status were similar ($P > 0.10$) for sows fed both diets (Table 15). The daily intakes of DM and P were similar ($P > 0.10$). However, N intake tended to be increased ($P < 0.10$) and S intake increased ($P < 0.02$) for sows fed DDGS.

Pit characteristics, pH, temperature, and volume, were similar ($P > 0.10$) for sows fed both diets (Table 16). However, volume was increased by 12% for sows fed DDGS. Nutrient concentration of the slurry was numerically increased for sows fed DDGS; however, only S content was increased ($P < 0.05$) for sows fed DDGS. (Table 17).

The daily excretion of DM, Mg, and S were increased ($P < 0.08$) for sows fed DDGS (Table 18). The excretion of N was numerically ($P = 0.12$) increased for sows fed DDGS. However, little effect was observed for the other nutrients. The concentrations of NH_3, H_2S, CH_4, and N_2O were increased ($P < 0.10$) for sows fed DDGS (Table 19). The concentration of CO_2 was numerically increased for sows fed DDGS, but this difference was not significant ($P > 0.10$).

Discussion:

Results from these three experiments suggest that feeding DDGS to finishing pigs and gestating sows has significant impacts on nutrient excretion and gaseous emissions. The effects on pig performance were minimal. In Exp. 1, increasing DDGS in the diet decreased ADG, but did not affect ADFI or G:F. These results are similar to that observed by Cromwell et al. (2011) where these authors observed a decrease in ADG with 45% DDGS inclusion. Because the diets in Exp. 1 were similar to those used by Cromwell et al. (2011), these results suggest that DDGS inclusion greater than 40% of the diet during the entire finishing period decreases growth performance. In Exp. 2, 25% inclusion of DDGS resulted in a slight decrease in ADG, but no effects on ADFI or G:F were noted. In Exp. 2, amino acid supplementation was more aggressive than that used in Exp. 1 to equalize CP content of the diet. The increase in amino acid usage may have led to a slight deficiency of an amino acid if the estimated amino acid digestibility was lower than expected in the DDGS. There were no effects on gestating sow performance due to DDGS.

Inclusion of DDGS in the diet resulted in increases in slurry volume and a decrease in slurry pH in both Exp. 1 and 2. The increase in slurry volume was most likely due to the increased DM excretion observed in both experiments with DDGS inclusion. The decrease in pH is similar to previous research conducted at our station with another high fiber ingredient, soyhulls (Shriver et al., 2003; Bundy et al., 2008). The use of high fiber diets can increase DM excretion which provides more substrate for microbial fermentation in the pit with greater VFA production thus decreasing slurry pH.

As stated, DM excretion was increased in all experiments with DDGS inclusion. In Exp. 1, DDGS increased DM excretion from 299 g/d for the control diet to 495 g/d for pigs fed 40% DDGS. This represents an increase of 165%. In Exp. 2 with 25% DDGS inclusion, DM excretion increased by 137%. These results suggest that DM excretion is increased by approximately 16% for each 10% inclusion of DDGS in the diet of finishing pigs. Furthermore, the daily excretion of DM was similar for pigs in both Exp. 1 and 2. Daily DM excretion in Exp. 3 with gestating sows fed DDGS was increased by approximately 28%. This increase is much

lower than that observed in the finishing pigs most likely due to the greater ability of the sow to utilize fiber. The percentage increase in daily DM excretion for all three experiments is shown in Figure 1.

The effect of DDGS on N excretion varied with experiment. The diets used in Exp. 1 were modeled on those used by Cromwell et al. (2011) where CP concentration was allowed to increase with increasing DDGS. The increase in CP with increasing DDGS in Exp. 1 resulted in an increase of 148% in N excretion for pigs fed 40% DDGS compared with pigs fed the control diet. Based on the results of Exp. 1, the diets in Exp. 2 were equalized in CP concentrations with more aggressive amino acid usage. In this experiment, N excretion was similar for pigs fed the control and DDGS diet. These results suggest that if the CP content of DDGS diets is maintained similar to that in a corn-soybean meal diet that the increase in N excretion can be limited. In Exp. 3, daily N excretion was increased by 20% for sows fed 40% DDGS (Figure 2).

It is well known that the availability of P in DDGS is greater than that in corn. Thus, inclusion of DDGS in the diet reduces the amount of dicalcium phosphate added to the diet to meet P needs. Based on this assumption, DDGS inclusion should decrease P excretion when diets containing DDGS are formulated to similar digestible P content as corn-soybean meal diets. In Exp. 1, all diets were formulated to a similar digestible P concentration. However, P excretion tended to increase with increasing DDGS which was surprising. The increase in P excretion with DDGS may be explained by the digestibility coefficient used for the DDGS used in this experiment. Digestible P concentration of the DDGS was estimated using coefficients suggested by Pedersen et al. (2007). If, in fact, we overestimated the digestibility of P in this source of DDGS, this could have resulted in the increase in P excretion. Another issue with P in DDGS is that P content of the diet can only be decreased so much. For example, in Exp. 2, dietary digestible P concentration could only be decreased to 0.28% in Phase 4 which greatly exceeds the requirement of the pig. In normal corn-soybean meal diets, P content of the diet would decrease with increasing weight of the pig; however, when using DDGS this decrease is not possible due to the content of P in DDGS. In Exp. 2, dietary P was reduced with advancing phase for pigs fed the corn-soybean meal control, but for pigs fed DDGS, dietary P was much greater and did not decrease with phase. Additionally, phytase was added to both diets to mimic formulation used in the commercial industry. Daily P excretion tended to increase by approximately 17% for pigs fed DDGS. For the gestating sow, daily P excretion increased by 19% for those fed DDGS. These results suggest that even though DDGS is known to have greater P availability compared with corn, P excretion may be increased for pigs fed DDGS depending on the dietary formulation.

In all experiments, S excretion was dramatically increased for pigs/sows fed DDGS (Figure 3). The DDGS used in Exp. 1 and Exp. 2-3 contained 0.75 and 0.62% S, respectively. When included in the diet, S concentrations markedly increased resulting in much greater S intakes for those fed DDGS vs. the control diet. The daily excretion of S increased linearly in Exp. 1 with pigs fed 40% DDGS having 280% greater excretion. In Exp. 2, pigs fed 25% DDGS had 170% greater excretion and sows fed 40% DDGS had 168% greater S excretion. Because sulfuric acid is often used in the manufacturing of DDGS, it is not surprising that the S content of DDGS is relatively high; however, the S content of the two DDGS sources used in these experiments varied greatly. Thus, the plant of manufacture of DDGS can affect the S content which has tremendous impact on S excretion.

The daily excretion of Mg tended to increase with DDGS addition and Fe excretion tended to decrease with DDGS. However, the excretion of other nutrients was impacted very little by DDGS inclusion in the diet. The increase in Mg excretion was most likely due to the increase Mg content of the diet with DDGS inclusion. The excretion of Fe tended to decrease with DDGS due to the reduction in dicalcium phosphate needed in the diet.

Gas concentrations and emission rates responded markedly to DDGS inclusion in the diet. In Exp. 1, the concentration and emission rates of NH_3, H_2S, CO_2, CH_4, and N_2O increased markedly for pigs fed DDGS. Of these, NH_3, H_2S, and CH_4 responded the greatest with pigs fed 40% DDGS having at least a 200% increase in daily H_2S emissions per pig. In Exp. 2, daily H_2S and CH_4 emissions per pig were increased for pigs fed 25% DDGS. Unlike Exp. 1, NH_3 and N_2O emissions were not affected by feeding DDGS. This was most likely due to the more aggressive amino acid utilization in the DDGS diets to maintain CP concentrations equal to that in

the control diet which limited the increase in N excretion associated with DDGS as observed in Exp. 1. Results obtained with the gestating sow fed 40% DDGS were similar. The concentrations of NH_3, H_2S, CH_4, and N_2O were increased for sows fed 40% DDGS. Of these, H_2S and CH_4 were increased by at least 200% for sows fed 40% DDGS. As a whole, the results of these three experiments suggest that feeding DDGS markedly increases H_2S and CH_4 emissions. Ammonia emissions for pigs fed DDGS can be controlled by limiting the increase in CP concentration of the diet with amino acid supplementation.

A recent report by Li et al. (2011) reported that pigs fed 20% DDGS had increased emissions of NH_3, H_2S, and CH_4. Our results are similar to these reported results in that DDGS increased the emissions of these gases; however, our H_2S and NH_3 emissions were of greater magnitude while CH_4 emissions in our study were of lower magnitude. The greater magnitude of increase in H_2S and NH_3 emissions in our study may be explained by dietary S and N concentrations. The increase in dietary S with DDGS inclusion in our studies was of a much greater magnitude than that observed in the diets of Li et al. (2011) which dramatically increased S excretion by finishing pigs. As far as NH_3 is concerned, Li et al. reported a 41% increase in N excretion with an 8% increase in NH_3 emission for pigs fed 20% DDGS. In Exp. 1, we observed a 25% increase in daily N excretion with a 2-fold increase in NH_3 emissions. In Exp. 2, however, using a more aggressive amino acid supplementation strategy, we were able to limit N excretion and NH_3 emission. Li et al. (2011) observed an 85% increase in CH_4 emissions with 20% DDGS whereas we observed a 49% increase. The differences in the magnitude of increase associated with feeding DDGS observed between our study and that of Li et al. (2011) may be explained by diet formulation, housing, and management of the slurry. Nonetheless, both of these studies suggest that DDGS fed to finishing pigs results in serious environmental implications.

To further evaluate the impacts of DDGS on gaseous emissions, the data from Exp. 1 and 2 with finishing pigs were combined. Because of differences in intake and excretion between the two studies, the emission of H_2S and CH_4 for pigs fed DDGS was calculated as percentage of the control diet and regressed against nutrient excretion for pigs fed DDGS as a percentage of those fed the control diet. Figure 4 clearly shows that as S excretion increased, H_2S emissions increased ($R^2 = 0.98$). Likewise, CH_4 emissions increased dramatically with increasing DM excretion ($R^2= 0.97$, Figure 5). These results suggest for every 10% increase in DM and S excretion, CH_4 and H_2S emissions will increase by approximately 15 and 10%, respectively. Because the increases in DM and S excretion are directly attributed to increasing DDGS in the diet, these results suggest that means to improve DM digestibility and limit S concentration in DDGS should be high priority for further research. Furthermore, Figure 6 and 7 illustrate the strong effect of S excretion and S intake on H_2S emissions. These results suggest the marked effect that S content of DDGS has on H_2S emission. Data from the University of Minnesota list the average S content of DDGS as 0.57% with a low of 0.33% and a maximum of 0.92%. The S content of the DDGS used in Exp. 1 and 2 ranged from 0.62 to 0.75%. Thus, as DDGS is added to the diet in increasing amounts, total S intake will increase resulting in increased S excretion and H_2S emissions. Li et al. (2011) explored the effects of replacing an inorganic trace mineral mix containing minerals in sulfate form with an organic mineral premix. These authors reported a decrease in H_2S emissions with the organic trace mineral mix; however, this methodology, while decreasing S contribution from the mineral premix, does not affect the S contribution from DDGS. Unfortunately, the S content of the DDGS used in the study by Li et al. (2011) was not reported nor was S excretion. Thus, methods to reduce S content of DDGS should be explored in an effort to limit the increase in H_2S emissions for pigs fed DDGS.

Another emerging concern related to gaseous emissions is the emission of CO_2 equivalents. The 100-yr global warming potential for CH_4 is 21 times that of CO_2 and N_2O is 310 times that of CO_2 (Grubb et al., 1999). Because DDGS had such a dramatic effect on CH_4 emissions, the total CO_2 equivalents for pigs fed DDGS were calculated. Totals CO_2 equivalents increased with DDGS in Exp. 1 (Figure 8). While all the gases contributed to the increase, it is clearly visible from the graph that CH_4 was the major contributor. These results suggest that feeding DDGS will increase the 100-yr global warming potential. In Exp. 2 where N excretion and N_2O emissions were limited, the overall CO_2 equivalent increased only slightly; although, CH_4 was increased markedly for pigs fed 25% DDGS. These results are similar to Li et al. (2011) which reported a significant increase in CH_4 equivalents, but little increase in the 100-yr global warming potential for pigs fed 20% DDGS.

In summary, these results suggest that feeding high levels of DDGS to finishing pigs and gestating sows may increase environmental issues for swine facilities. Increasing DDGS in the diet increased DM and S excretion dramatically, while N excretion can be limited. These tremendous increases in excretion resulted in significant increases in CH_4 and H_2S emissions for swine fed DDGS. Ammonia and N_2O emissions can be controlled by minimizing the increase in dietary CP when feeding DDGS. Methods to enhance DM digestibility and reduce S content of DDGS must be explored to limit the environmental implications when feeding high levels of DDGS.

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Table 1. Chemical composition of DDGS samples used in Exp. 1, 2, and 3.

Chemical Component	Exp. 1	Exp. 2 & 3
DM, %	88.40	87.37
Crude protein, %	27.83	28.40
Crude fat, %	10.86	11.69
Crude fiber, %	5.83	5.99
Ash, %	4.18	4.08
Lys, %	1.13	0.93
Thr, %	1.06	1.00
Methionine, %	0.54	0.57
Trp, %	0.23	0.21
Ca, %	0.08	0.07
P, %	0.80	0.79
K, %	0.90	1.02
Mg, %	0.32	0.28
Na, %	0.09	0.16
S, %	0.75	0.62
Fe, ppm	130.8	100.0
Zn, ppm	61.4	46.0
Cu, ppm	12.3	<0.12
Mn, ppm	22.6	11.0
DON, ppm		2.2
Zearalenone, ppb		200.0

Table 2. Composition of dietary treatments used in Exp. 1 (as fed basis).

	Phase 1				Phase 2				Phase 3				Phase 4			
	----------DDGS, %--------				----------DDGS, %--------				----------DDGS, %--------				----------DDGS, %---------			
	0	10	20	40	0	10	20	40	0	10	20	40	0	10	20	40
Corn grain	65.83	59.42	53.01	40.20	70.95	64.54	58.14	45.32	76.53	70.12	63.71	50.90	80.13	73.72	67.31	54.50
Soybean meal	28.94	25.38	21.81	14.69	23.77	20.21	16.65	9.52	18.20	14.64	11.08	3.96	14.62	11.06	7.50	0.38
DDGS	0.00	10.00	20.00	40.00	0.00	10.00	20.00	40.00	0.00	10.00	20.00	40.00	0.00	10.00	20.00	40.00
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
L-lysine HCl	0.00	0.05	0.10	0.20	0.00	0.05	0.10	0.20	0.00	0.05	0.10	0.20	0.00	0.05	0.10	0.20
L-tryptophan	0.00	0.01	0.02	0.03	0.00	0.01	0.02	0.03	0.00	0.01	0.02	0.03	0.00	0.01	0.02	0.03
Dicalcium P	0.99	0.75	0.50	0.00	0.99	0.75	0.50	0.00	0.99	0.75	0.50	0.00	0.99	0.75	0.50	0.00
Limestone	0.69	0.85	1.01	1.33	0.73	0.89	1.05	1.37	0.73	0.88	1.04	1.36	0.70	0.86	1.02	1.34
NaCl	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vit. premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
TM premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Tylan-40	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated Analysis																
ME, kcal/kg	3481	3484	3486	3491	3482	3485	3487	3492	3485	3487	3489	3494	3487	3489	3492	3497
DM, %	89.57	89.43	89.29	89.01	89.52	89.38	89.24	88.96	89.46	89.32	89.18	88.91	89.42	89.28	89.15	88.87
Fat, %	6.41	7.13	7.86	9.32	6.45	7.18	7.91	9.37	6.50	7.23	7.96	9.42	6.53	7.26	7.99	9.45
CP, %	19.21	19.79	20.38	21.54	17.18	17.76	18.35	19.51	15.00	15.58	16.17	17.33	13.60	14.18	14.76	15.93
Lys, %	1.05	1.07	1.10	1.16	0.90	0.93	0.96	1.02	0.75	0.78	0.81	0.86	0.65	0.68	0.71	0.76
SID Lys, %	0.92	0.92	0.92	0.92	0.79	0.79	0.79	0.79	0.65	0.65	0.65	0.65	0.56	0.56	0.56	0.56
Ca, %	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.58	0.58	0.58	0.58	0.56	0.56	0.56	0.56
P, %	0.57	0.56	0.55	0.53	0.55	0.54	0.53	0.51	0.52	0.52	0.51	0.49	0.51	0.50	0.49	0.48
Dig. P, %	0.26	0.26	0.27	0.29	0.25	0.26	0.27	0.28	0.24	0.25	0.26	0.27	0.24	0.25	0.25	0.27
S, %	0.22	0.27	0.32	0.42	0.21	0.26	0.31	0.41	0.19	0.24	0.29	0.39	0.18	0.23	0.28	0.38

Table 3. Composition of dietary treatments used in Exp. 2 (as fed basis).

	Phase 1[a]		Phase 2[a]		Phase 3[a]		Phase 4[a]	
DDGS, %:	0	25	0	25	0	25	0	25
Corn	62.70	51.63	68.43	56.43	72.34	60.09	78.17	659.90
Soybean meal	32.11	17.98	26.66	13.22	22.92	9.52	17.13	3.71
DDGS		25.00		25.00		25.00		25.00
L-lysine HCl		0.33		0.31		0.31		0.31
L-threonine		0.03		0.03		0.02		0.03
Soybean oil	3.00	3.00		3.00	3.00	3.00	3.00	3.00
L-tryptophan								0.01
Dicalcium phosphate	0.58	0.02	0.18		0.02			
Limestone	1.04	1.44	1.16	1.44	1.16	1.48	1.13	1.48
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Tylan-40	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Ronozyme CT	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated Analysis								
ME, kcal/kg	3491	3503	3508	3506	3502	3506	3513	3508
DM, %	89.9	89.3	89.8	89.2	89.4	89.9	89.4	89.8
Fat, %	6.41	8.48	6.47	8.57	6.51	8.55	6.56	8.60
CP, %	20.2	20.2	18.35	18.35	16.89	16.89	14.62	14.62
Lys, %	1.13	1.17	0.98	1.02	0.88	0.92	0.72	0.76
SID Lys, %	1.00	1.00	0.86	0.86	0.77	0.77	0.62	0.62
Ca, %	0.64	0.64	0.59	0.63	0.54	0.63	0.51	0.61
P, %	0.49	0.47	0.41	0.45	0.36	0.43	0.34	0.41
Dig. P, %	0.30	0.30	0.24	0.29	0.21	0.29	0.20	0.28
S, %	0.22	0.25	0.21	0.24	0.20	0.22	0.18	0.21

[a]Phase 1 = 39 to 50 kg; Phase 2 = 50 to 77 kg; Phase 3 = 77 to 100 kg; and Phase 4 = 100 to 125 kg

Table 4. Composition of dietary treatments used in Exp. 3 (as fed basis).

	DDGS, %	
	0	40
Corn	81.81	52.74
Soybean meal	11.33	0.64
L-lysine HCl		0.15
Soybean oil	3.00	3.00
DDGS		40.00
Dicalcium phosphate	1.32	0.34
Limestone	1.31	1.90
Salt	0.50	0.50
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Sow add pak	0.25	0.25
Ronozyme CT	0.02	0.02
CTC 90	0.06	0.06
Total	100.0	100.0
Calculated analysis		
ME, kcal/kg	3440	3457
CP, %	12.17	16.13
Lys, %	0.56	0.65
SID Lys, %	0.47	0.47
Ca, %	0.84	0.84
P, %	0.55	0.49
Avail. P, %	0.39	0.39
S, %	0.17	0.24

Table 5. Growth performance and nutrient intake of pigs fed increasing levels of DDGS – Exp. 1[a].

	DDGS, %					P <:		
	0	10	20	40	SE	Lin	Quad	Cub
Initial wt, kg	75.4	74.8	75.4	74.9	0.39	0.61	0.96	0.21
Final wt, kg	96.1	96.2	96.3	94.8	0.44	0.07	0.17	0.68
ADG, g	940.2	961.1	937.4	892.8	10.2	0.01	0.06	0.25
ADFI, g	2628	2576	2566	2555	54.9	0.42	0.63	0.84
G:F	0.37	0.39	0.38	0.36	0.01	0.11	0.05	0.32
DM int., g/d	2309	2268	2256	2252	48.84	0.48	0.63	0.90
N intake, g/d	60.74	65.17	66.51	68.05	1.51	0.02	0.19	0.63
P intake, g/d	13.79	13.46	13.13	12.39	0.52	0.09	0.96	0.99
S intake, g/d	4.97	5.68	7.37	9.59	0.26	0.01	0.76	0.18

[a]Least squares means for 4 rooms (20 pigs/room) per dietary treatment.

Table 6. Volume, temperature, and pH measures of the pit contents for pigs fed increasing levels of DDGS – Exp. 1[a].

	DDGS, %					P <:		
	0	10	20	40	SE	Lin	Quad	Cub
Vol, L/p/d	10.60	10.75	12.13	12.25	0.58	0.06	0.55	0.34
Temp, ^{o}C	17.69	17.83	17.33	18.33	0.43	0.36	0.34	0.42
pH	7.50	7.37	7.39	7.22	0.05	0.01	0.96	0.31
Water, L/p/d	5.51	6.32	6.49	6.42	0.47	0.27	0.30	0.77

[a]Least squares means for 4 rooms (20 pigs/room) per dietary treatment.

Table 7. Nutrient concentration of the slurry for pigs fed increasing levels of DDGS – Exp. 1[a].

	DDGS, %					P <:		
	0	10	20	40	SE	Lin	Quad	Cub
DM, %	2.72	3.20	3.74	3.89	0.25	0.02	0.23	0.69
N, %	0.227	0.260	0.269	0.284	0.026	0.19	0.59	0.81
P, %	0.074	0.079	0.081	0.076	0.007	0.92	0.48	0.98
Ca, %	0.047	0.054	0.061	0.057	0.005	0.21	0.20	0.75
K, %	0.133	0.136	0.133	0.123	0.010	0.47	0.67	0.89
Mg, %	0.028	0.034	0.036	0.039	0.002	0.03	0.34	0.68
Na, %	0.032	0.035	0.033	0.035	0.002	0.48	0.92	0.37
S, %	0.026	0.036	0.046	0.060	0.002	0.01	0.33	0.97
Cu, ppm	2.81	3.44	3.46	3.22	0.22	0.38	0.08	0.53
Fe, ppm	44.7	48.6	43.5	34.7	2.69	0.02	0.14	0.36
Mn, ppm	10.02	10.41	10.25	9.49	0.67	0.50	0.50	0.87
Zn, ppm	21.4	24.5	24.1	23.2	1.32	0.56	0.18	0.51
NH_4-N, %	0.208	0.221	0.200	0.234	0.024	0.51	0.66	0.51
N:P	3.09	3.31	3.31	3.74	0.15	0.02	0.72	0.52
NH4-N:N	0.92	0.86	0.74	0.82	0.05	0.20	0.11	0.34
Water-sol. P, %	0.056	0.062	0.058	0.063	0.006	0.58	0.96	0.61
WSP:P	0.76	0.79	0.73	0.83	0.05	0.36	0.39	0.37

[a]Least squares means for 4 rooms (20 pigs/room) per dietary treatment.

Table 8. Daily nutrient excretion for pigs fed increasing levels of DDGS – Exp. 1[a].

	DDGS, %					P <:		
	0	10	20	40	SE	Lin	Quad	Cub
Daily excretion								
DM, g	299.1	358.9	406.0	494.7	33.94	0.01	0.79	0.93
N, g	25.30	29.49	31.63	37.02	1.17	0.01	0.57	0.58
P, g	8.26	9.15	9.56	9.84	0.56	0.10	0.41	0.88
Ca, g	5.33	6.30	7.39	7.53	0.86	0.11	0.41	0.80
K, g	14.70	15.60	15.59	15.96	0.69	0.29	0.62	0.68
Mg, g	3.19	3.95	4.28	5.09	0.29	0.01	0.55	0.65
Na, g	3.70	4.15	3.91	4.80	0.18	0.01	0.41	0.12
S, g	2.87	4.20	5.53	8.03	0.53	0.01	0.91	0.98
Cu, mg	32.04	39.30	41.47	42.77	3.74	0.11	0.31	0.77
Fe, mg	507.7	565.9	523.4	463.2	41.22	0.30	0.30	0.48
Mn, mg	112.9	119.2	121.7	124.9	7.41	0.31	0.71	0.91
Zn, mg	247.0	282.0	291.5	315.6	25.31	0.11	0.64	0.77

[a]Least squares means for 4 rooms (20 pigs/room) per dietary treatment.

Table 9. Airflow and gaseous emissions for pigs fed increasing levels of DDGS – Exp. 1[a].

	DDGS, %					P <:		
	0	10	20	40	SE	Lin	Quad	Cub
AF, mg/min	7.626	8.130	7.868	7.929	0.20	0.5703	0.3746	0.2271
NH_3, mg/m^3	0.909	1.305	2.076	2.464	0.33	0.01	0.47	0.54
NH_3, mg/min	0.107	0.152	0.277	0.316	0.05	0.02	0.48	0.45
NH_3, g/pig/d	1.975	2.757	3.962	4.548	0.48	0.01	0.35	0.56
H_2S, ug/m^3	11.18	14.99	17.66	27.05	0.07	0.05	0.24	0.61
H_2S, ug/min	1.11	1.21	1.36	1.36	1.40	0.001	0.50	0.63
H_2S, mg/pig/d	16.93	25.83	30.89	48.47	3.24	0.001	0.80	0.60
CO_2, g/m^3	1.27	1.38	1.72	1.89	20.84	0.03	0.77	0.21
CO_2, mg/min	175.9	171.2	232.6	246.8	98.61	0.01	0.49	0.29
CO_2, kg/pig/d	2.34	2.70	3.20	3.46	112.11	0.001	0.09	0.36
CH_4, mg/m^3	0.839	0.973	1.356	1.937	0.03	0.004	0.84	0.52
CH_4, mg/min	0.102	0.119	0.181	0.256	0.14	0.001	0.65	0.55
CH_4, g/pig/d	1.866	2.144	2.777	3.752	0.24	0.001	0.74	0.61
N_2O, mg/m^3	0.207	0.199	0.260	0.284	0.01	0.08	0.86	0.19
N_2O, mg/min	0.027	0.023	0.034	0.036	0.02	0.04	0.98	0.29
N_2O, g/pig/d	0.401	0.423	0.519	0.539	0.04	0.04	0.54	0.41

[a]Least squares means for 4 rooms (20 pigs/room) per dietary treatment.

Table 10. Growth performance and nutrient intake of pigs fed a control diet or a diet containing 25% DDGS for the entire finishing period – Exp. 2[a].

	DDGS, %			
	0	25	SE	P <:
Initial wt, kg	39.00	38.93	0.09	0.66
Final wt, kg	125.35	123.17	0.21	0.09
ADG, g	0.899	0.877	0.01	0.05
ADFI, g	2.503	2.461	0.02	0.35
G:F	0.360	0.357	0.01	0.51
DM intake, g/d	2196	2180	15.6	0.61
N intake, g/d	63.06	62.03	0.66	0.47
P intake, g/d	10.07	11.04	0.08	0.07
S intake, g/d	5.21	6.92	0.02	0.01

[a]Least squares means for 2 rooms (20 pigs/room) per dietary treatment.

Table 11. Volume, temperature, and pH measures of the pit contents for pigs fed a control diet or a diet containing 25% DDGS for the entire finishing period – Exp. 2[a].

	DDGS, %			
	0	25	SE	P <:
Vol, L/p/d	12.06	14.01	0.71	0.23
Temp, ^{o}C	18.93	19.12	0.06	0.26
pH	7.34	6.96	0.04	0.02
Water, L/p/d	7.42	6.60	1.43	0.72

[a]Least squares means for 2 rooms (20 pigs/room) per dietary treatment.

Table 12. Nutrient concentration of the slurry averaged for pigs fed a control diet or a diet containing 25% DDGS for the entire finishing period – Exp. 2[a].

	DDGS, %			
	0	25	SE	P <:
DM, %	2.768	3.165	0.08	0.14
N, %	0.272	0.269	0.001	0.11
P, %	0.047	0.051	0.002	0.30
Ca, %	0.065	0.063	0.002	0.23
K, %	0.147	0.122	0.011	0.35
Mg, %	0.031	0.034	0.002	0.30
Na, %	0.027	0.035	0.001	0.15
S, %	0.019	0.029	0.001	0.08
Cu, ppm	2.281	1.709	0.25	0.43
Fe, ppm	29.72	25.23	2.70	0.43
Mn, ppm	8.879	7.499	0.52	0.31
Zn, ppm	20.80	15.38	2.88	0.58
NH_4, ppm	2076	1730	124	0.31
N:P	5.801	5.302	0.18	0.42
NH_4N:TN	0.764	0.649	0.02	0.25
WSP, ppm	375.2	410.2	1.2	0.02
WSP:TP	0.805	0.812	0.03	0.60

[a]Least squares means for 2 rooms (20 pigs/room) per dietary treatment.

Table 13. Nutrient excretion for pigs fed a control diet or a diet containing 25% DDGS for the entire finishing period – Exp. 2[a].

	DDGS, %			
	0	25	SE	P <:
Daily excretion				
DM, g	304	419	13.85	0.03
N, g	33.3	35.68	1.80	0.45
P, g	5.74	6.73	0.27	0.13
Ca, g	7.97	8.33	0.40	0.59
K, g	17.87	16.21	0.70	0.24
Mg, g	3.80	4.48	0.17	0.11
Na, g	3.35	4.63	0.17	0.03
S, g	2.27	3.86	0.09	0.01
Cu, mg	27.75	22.88	1.17	0.10
Fe, mg	362	337.3	14.05	0.33
Mn, mg	108.9	100.1	5.53	0.38
Zn, mg	255.3	208.1	28.14	0.36
Cumulative excretion				
DM, kg	339	421	14.3	0.06
N, kg	3.20	3.43	0.17	0.46
P, g	0.55	0.65	0.03	0.13
S, g	0.22	0.37	0.01	0.01

[a]Least squares means for 2 rooms (20 pigs/room) per dietary treatment.

Table 14. Airflow and gaseous emissions for pigs fed a control diet or a diet containing 25% DDGS for the entire finishing period – Exp. 2[a].

	DDGS, %			
	0	25	SE	P <:
Air flow, m^3/d	578	569	13.1	0.72
NH_3, mg/m^3	2.88	2.61	0.07	0.22
NH_3, mg/min	0.36	0.34	0.01	0.41
NH_3, g/pig/d	1.67	1.49	0.21	0.62
H_2S, ug/m^3	35.3	67.1	2.48	0.01
H_2S, ug/min	4.45	8.71	0.15	0.01
H_2S, mg/pig/d	20.4	38.3	3.0	0.05
CO_2, g/m^3	4.46	4.57	0.09	0.52
CO_2, mg/min	563	595	26.0	0.49
CO_2, kg/pig/d	2.58	2.59	0.002	0.19
CH_4, mg/m^3	4.90	7.75	0.83	0.13
CH_4, mg/min	0.62	1.01	0.13	0.17
CH_4, g/pig/d	2.83	4.38	0.28	0.06
N_2O, mg/m^3	0.58	0.58	0.01	0.88
N_2O, mg/min	0.073	0.076	0.001	0.02
N_2O, g/pig/d	0.34	0.33	0.01	0.78

[a]Least squares means for 2 rooms (20 pigs/room) per dietary treatment.

Table 15. Sow characteristics and nutrient intake of sows fed a control diet or a diet containing 40% DDGS – Exp. 3[a].

	DDGS, %			
	0	40	SE	P <:
Initial BW, kg	216.0	214.1	2.98	0.71
Final BW, kg	220.2	214.5	3.68	0.39
ADFI, kg/d	2.29	2.20	0.21	0.80
Parity	2.47	2.47	0.05	1.00
Status	1.75	1.92	0.06	0.18
DM intake, g/d	2044	2004	183.8	0.89
N intake, g/d	46.10	55.02	2.28	0.10
P intake, g/d	13.48	12.85	1.06	0.71
S intake, g/d	4.11	7.56	0.38	0.02

[a]Least squares means for 2 buildings (44 sows/room) per dietary treatment.

Table 16. Volume, temperature, and pH measures of the pit contents for sows fed a control diet or a diet containing 40% DDGS – Exp. 3[a].

	DDGS, %			
	0	40	SE	P <:
pH	7.66	7.65	0.14	0.95
Temp, ^{o}C	16.56	17.16	1.59	0.81
Vol, L/sow/d	38.35	42.74	2.58	0.35

[a]Least squares means for 2 rooms (44 sows/room) per dietary treatment.

Table 17. Nutrient concentration of the slurry for sows fed a control diet or a diet containing 40% DDGS – Exp. 3[a].

	DDGS, %			
	0	40	SE	P <:
DM, %	0.52	0.64	0.05	0.22
N, g/L	0.54	0.62	0.05	0.35
P, g/L	0.17	0.19	0.02	0.42
Ca, g/L	0.25	0.30	0.02	0.28
K, g/L	0.29	0.27	0.02	0.61
Mg, g/L	0.07	0.09	0.01	0.18
Na, g/L	0.15	0.17	0.01	0.36
S, g/L	0.07	0.11	0.01	0.05
Cu, ppm	0.41	0.49	0.06	0.45
Fe, ppm	15.19	16.32	1.61	0.67
Mn, ppm	1.70	1.95	0.19	0.46
Zn, ppm	5.62	6.48	0.60	0.42
NH_4, ppm	0.52	0.59	0.04	0.32
N:P	3.29	3.33	0.26	0.93
WSP, ppm	0.14	0.16	0.01	0.56
WSP:TP	0.85	0.82	0.02	0.38

[a]Least squares means for 2 rooms (44 sows/room) per dietary treatment.

Table 18. Daily nutrient excretion for sows fed a control diet or a diet containing 40% DDGS – Exp. 3[a].

	DDGS, %			
	0	40	SE	P <:
DM, g	199.4	255.3	7.72	0.04
N, g	20.69	24.88	1.11	0.12
P, g	6.48	7.71	0.40	0.16
Ca, g	9.69	12.05	0.47	0.07
K, g	10.90	10.62	0.59	0.77
Mg, g	2.68	3.56	0.18	0.08
Na, g	5.57	6.74	0.32	0.12
S, g	2.65	4.44	0.26	0.04
Cu, mg	16.27	19.61	1.29	0.21
Fe, mg	589.8	654.8	39.6	0.37
Mn, mg	66.0	77.8	3.97	0.17
Zn, mg	218.0	263.3	16.82	0.20

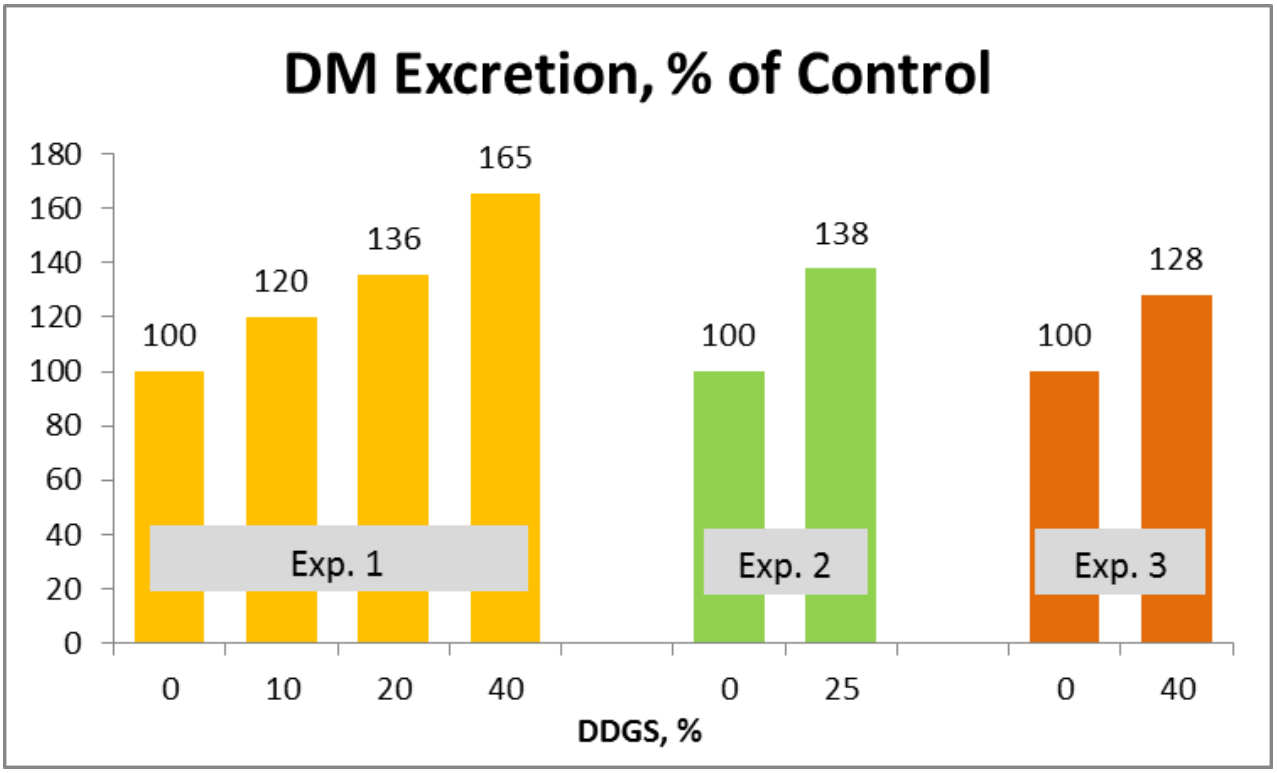
[a]Least squares means for 2 rooms (44 sows/room) per dietary treatment.

Table 19. Gaseous concentrations for sows fed a control diet or a diet containing 40% DDGS – Exp. 3[a].

	DDGS, %			
	0	40	SE	P <:
NH_3, mg/m^3	1.82	2.94	0.15	0.04
H_2S, ug/m^3	31.6	62.8	6.35	0.07
CO_2, g/m^3	4.26	4.50	0.15	0.36
CH_4, mg/m^3	5.77	13.71	0.82	0.02
N_2O, mg/m^3	0.60	0.61	0.002	0.10

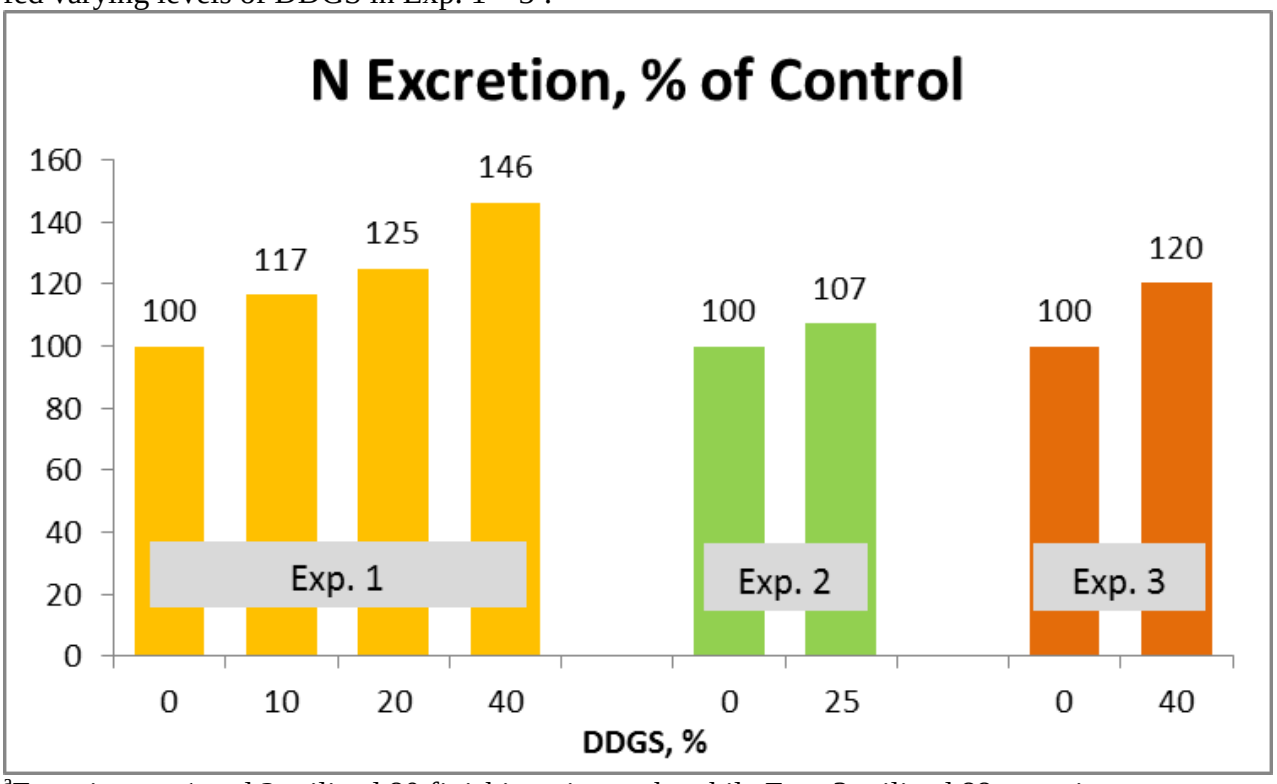
[a]Least squares means for 2 rooms (44 sows/room) per dietary treatment.

Figure 1. Daily DM excretion, expressed as a percentage of the control diet (0% DDGS), for pigs fed varying levels of DDGS in Exp. 1 – 3[a].



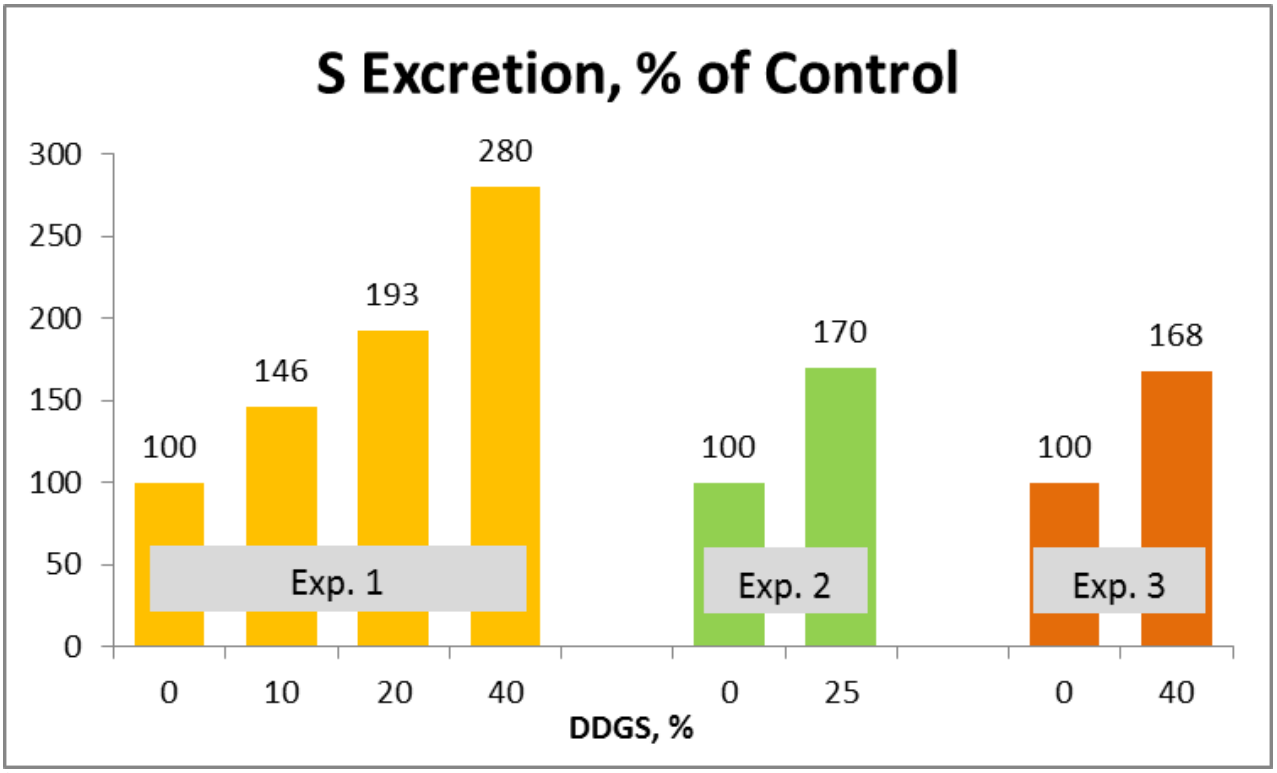
[a]Experiments 1 and 2 utilized 80 finishing pigs each, while Exp. 3 utilized 88 gestating sows.

Figure 2. Daily N excretion, expressed as a percentage of the control diet (0% DDGS), for pigs fed varying levels of DDGS in Exp. 1 – 3[a].



[a]Experiments 1 and 2 utilized 80 finishing pigs each, while Exp. 3 utilized 88 gestating sows.

Figure 3. Daily S excretion, expressed as a percentage of the control diet (0% DDGS), for pigs fed varying levels of DDGS in Exp. 1 – 3[a].



[a]Experiments 1 and 2 utilized 80 finishing pigs each, while Exp. 3 utilized 88 gestating sows.

Figure 4. Daily H_2S emission, expressed as a percentage of the control diet (0% DDGS), versus daily N excretion (% of control diet) combined for finishing pigs fed varying levels of DDGS in Exp. 1 and 2.

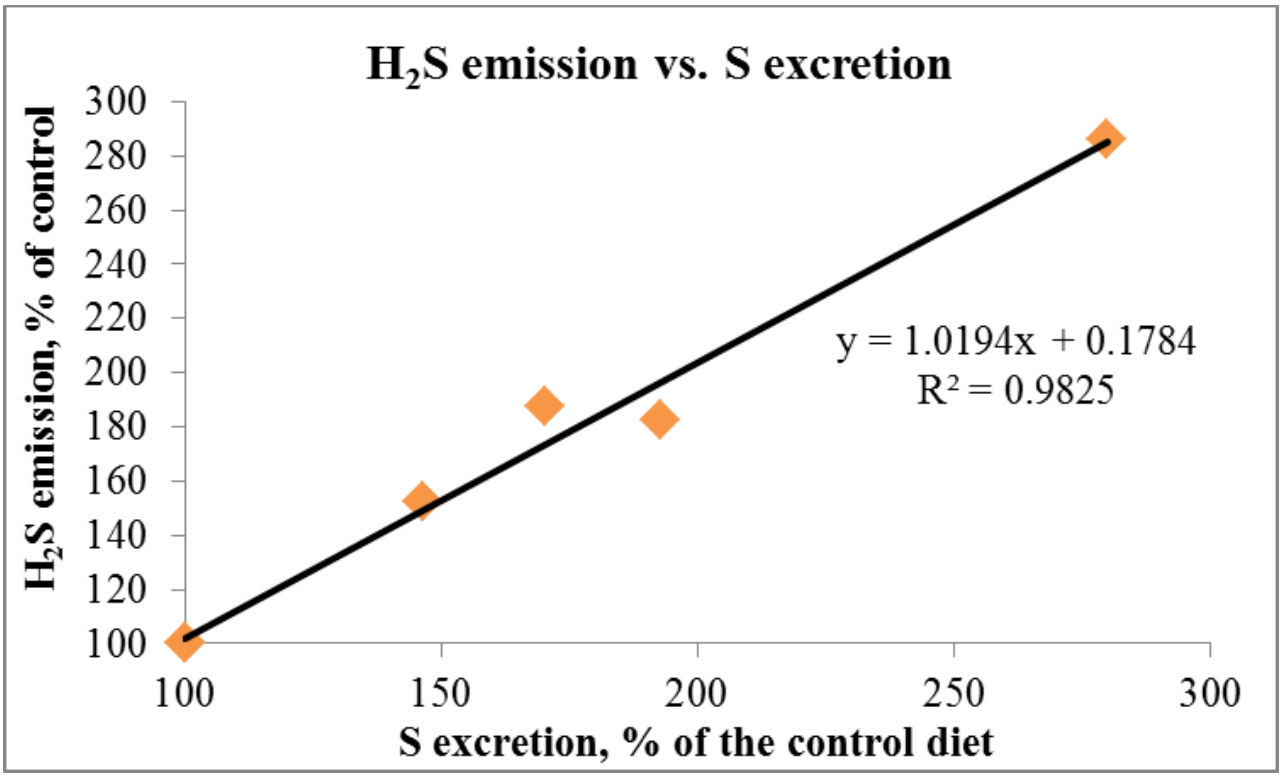


Figure 5. Daily CH_4 emission, expressed as a percentage of the control diet (0% DDGS), versus daily N excretion (% of control diet) combined for finishing pigs fed varying levels of DDGS in Exp. 1 and 2.

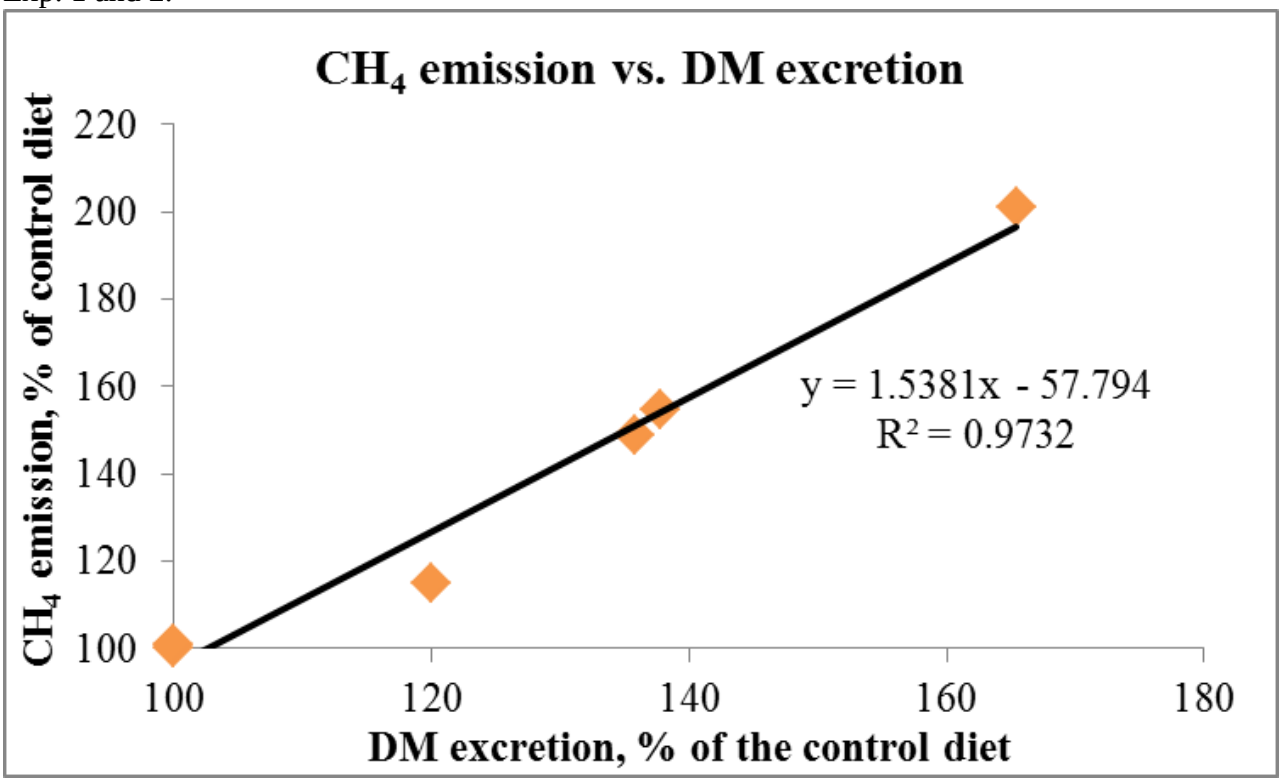


Figure 6. Daily H_2S emission (mg/pig/d) versus daily S excretion (g/pig/d) combined for finishing pigs fed varying levels of DDGS in Exp. 1 and 2.

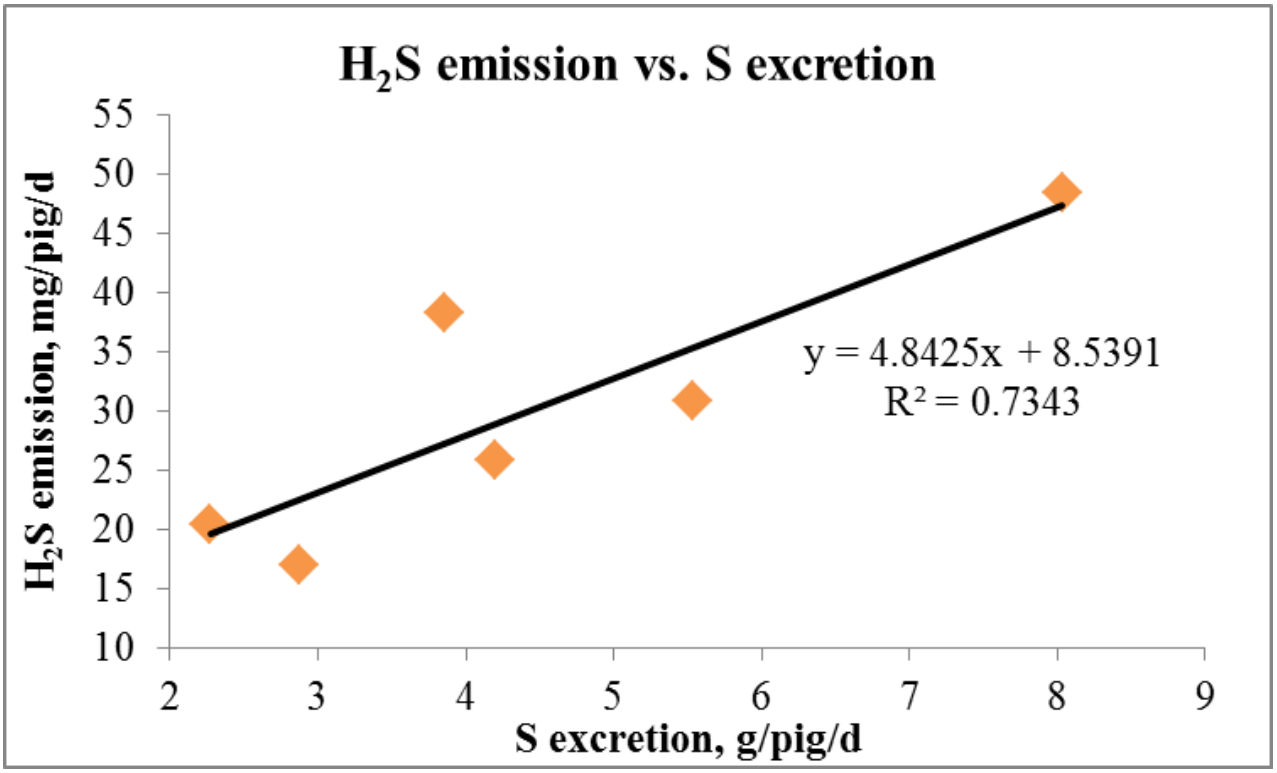


Figure 7. Daily H_2S emission (mg/pig/d) versus daily S intake (g/pig/d) combined for finishing pigs fed varying levels of DDGS in Exp. 1 and 2.

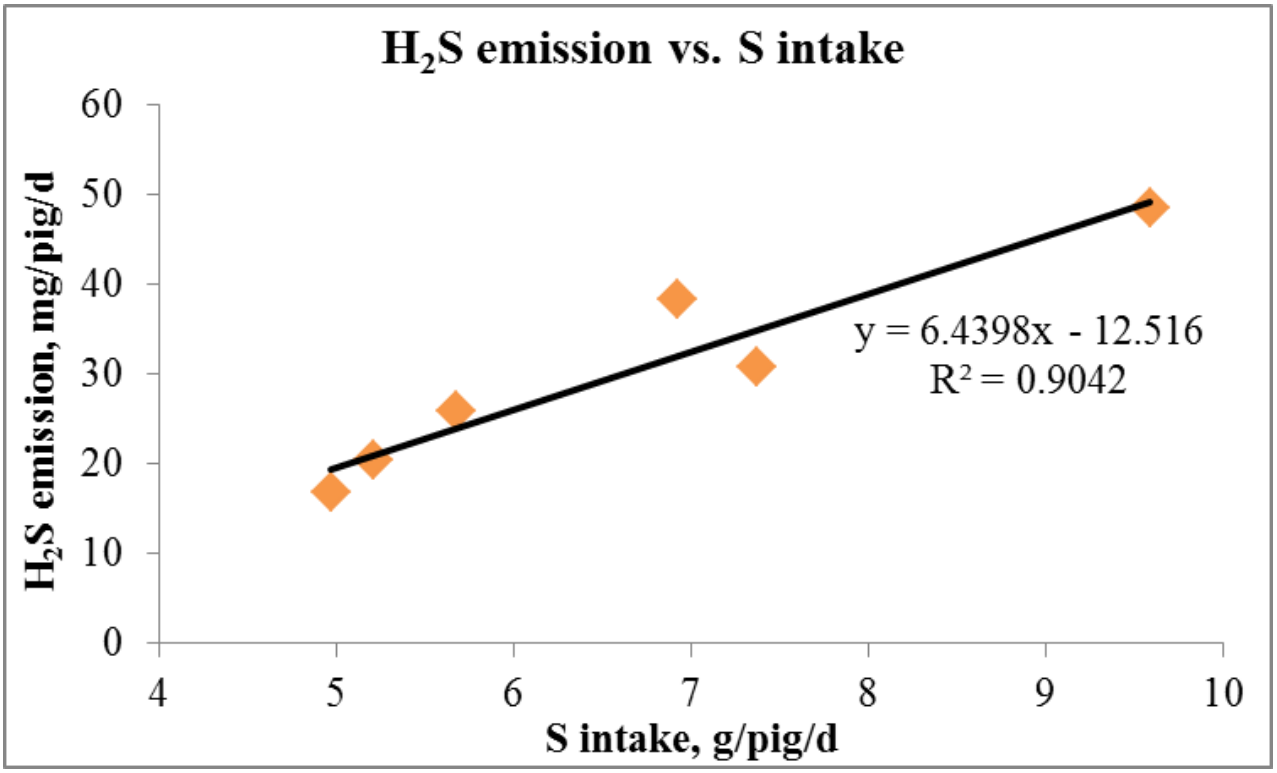
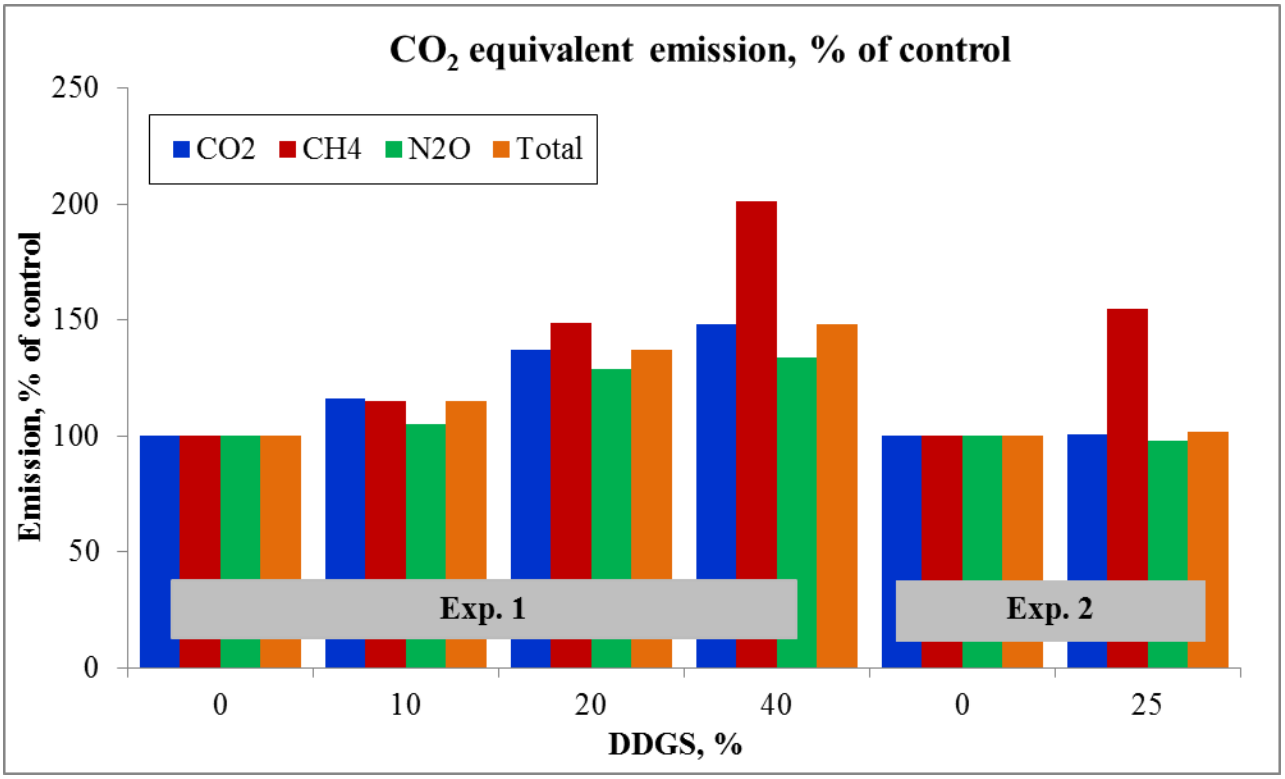


Figure 8. Daily CO_2 equivalent emission (expressed as a percentage of the control diet) for finishing pigs fed varying levels of DDGS in Exp. 1 and 2[a].



[a]Experiments 1 and 2 utilized 80 finishing pigs each.