RESEARCH REPORT
ENVIRONMENT

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Title: Mass balance of nutrients for the finishing phase as affected by dietary manipulation
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Industry Summary:

An experiment utilizing finisher pigs was conducted to determine the effects of dietary manipulation on pig growth performance, nutrient excretion, gaseous emissions, and the mass balance of nutrients for an entire 94-d period. A total of 88 pigs [Duroc x (Yorkshire x Landrace)] initially weighing 32.1 kg was blocked by weight and allotted to two dietary treatments. Dietary treatments were randomly allotted to four rooms with 2 pens (11 pigs/pen) per room (22 pigs/room). Dietary treatments consisted of a fortified corn-soybean meal diet and a Reduced Excretion (**REx**) diet. The REx diet had a 3% units decrease in CP with Lys, Thr, Met, and Trp added as needed and a reduction in available phosphorus of 0.10% with phytase inclusion. Also, in the REx diet, monocalcium P replaced dicalcium P and CaCl replaced 50% of the limestone in the control diet. Furthermore, organic sources of Fe, Zn, and Cu replaced inorganic sources of these minerals in the control diet. Inclusion levels of the organic sources provided the same supplemental level of each trace mineral as that supplied by the inorganic sources in the control diet. All diets within phase were formulated on a SID lysine basis (0.92, 0.79, 0.65, and 0.56% for Phases 1 to 4). The dietary treatments were fed in four phases: 32 to 55 kg, 55 to 82 kg, 82 to 102 kg, and 102 to 113 kg. 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, water disappearance was recorded, total pit volume was determined, and samples from the pit were obtained. The analyses of the feed and slurry samples were performed by the OSU Soil Testing Lab. 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.

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 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.

When a room of pigs reached approximately 114 kg, 6 pigs from each room were transported to the university meat lab and humanely slaughtered. Following this, the whole pig was ground and a sample was

taken to determine nutrient content of the pig. In addition, six pigs were slaughtered at the beginning of the test period to determine initial nutrient content

Following the end of the experiment, mass balance was calculated for N, P, and macro and micro-minerals by quantifying the total nutrients entering the room and the total nutrients exiting the room via the slurry and exhaust air. The calculations for intake minus output (slurry, exhaust air) were for the total growth period.

There were no effects of dietary treatment on ADG, ADFI, and F:G. However, the daily intake of N and P was reduced for pigs fed REx. There were no effects of treatment on carcass traits.

The predicted initial body composition of pigs entering the experiment was similar for both dietary treatments. The percentages and final weights of water, CP, fat, and ash were not affected by dietary treatment. Additionally, the whole body weights of N, the macro-minerals, and micro-minerals were similar for both dietary treatments.

Slurry volume and temperature were similar for pigs fed both dietary treatments. However, slurry pH was reduced for pigs fed the REx diet. Slurry from pigs fed the REx diet had lower concentrations of N, NH_4-N, P, Ca, K, Mg, and Fe. The daily excretion of DM, N, P, Ca, K, Mg, S, and Fe were reduced for pigs fed the REx diet. The cumulative excretion of DM, N, and P for the entire finishing period was reduced by 2.3, 0.89, and 0.24 kg/pig, respectively, for pigs fed the REx diet.

Airflow was similar for all rooms. However, the concentration (mg/m^3) of NH_3 in the exhaust air was reduced by 47% for pigs fed the REx diet. The decrease in concentration for pigs fed the REx diet resulted in a 47% decrease in ammonia emitted per pig per day. However, the concentration, emission rate, and emission per pig for H_2S were not affected by dietary treatment.

Calculation of the mass balance for other nutrients also was performed. Mass balance calculations revealed that a greater proportion of N, P, Ca, K, Mg, S, Fe, Zn, and Cu that entered the finisher exited via the market pig for those fed REx. These results suggest the dietary manipulations employed in this study markedly reduced nutrient excretion and shifted the proportion of nutrients exiting the finisher into the market pig. By increasing the proportion of nutrients leaving as a finished pig, a lower proportion of those nutrients is available to be released to the environment. This project was funded by the National Pork Checkoff.

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Scientific Abstract

Eighty eight crossbred (D x (L x Y)) pigs (32 to 114 kg BW) were used to evaluate the effects of reducing dietary CP, Ca, and P with the additions of phytase and organic trace minerals on nutrient excretion during a 94-d finishing period. Pigs were stratified by sex, weight, ancestry and randomly allotted to 1 of 2 dietary treatments. Pigs were housed in an environmentally-controlled building with 4 identical rooms. Each room contained a shallow pit, pull plug system (22 pigs/room, 2 rooms/trt). Dietary treatments were fed in 4 dietary phases and consisted of a fortified corn-soybean meal diet and a Reduced Excretion (REx) diet. The REx diet had a 3% units decrease in CP with Lys, Thr, Met, and Trp added as needed and a reduction in available phosphorus of 0.10% with phytase inclusion. Also, in the REx diet, monocalcium P replaced dicalcium P and CaCl replaced 50% of the limestone in the control diet. Furthermore, organic sources of Fe, Zn, and Cu replaced inorganic sources of these minerals in the control diet. All diets within phase were

formulated on a SID lysine basis (0.92, 0.79, 0.65, and 0.56% for Phases 1 to 4). Feed and slurry samples were collected weekly along with pig weights, feed intake, pit volume, and pH of slurry. Diet did not affect ($P < 0.10$) ADG (822 vs. 839 g), ADFI (2.27 vs. 2.28 kg), or F:G (2.74 vs. 2.73). Daily DM intakes were similar ($P > 0.10$), but N (57.8 vs. 47.4 g/d) and P (11.1 vs. 8.6 g/d) intakes were reduced ($P < 0.05$) for pigs fed REx. Initial and final whole body compositions were similar ($P > 0.05$) for both dietary treatments. Slurry volume and temperature were similar ($P > 0.05$) for pigs fed both dietary treatments; however, slurry pH was reduced (7.4 vs. 6.8; $P < 0.05$) for pigs fed REx. Slurry DM concentration was similar ($P > 0.05$), but slurry N, P, Ca, K, Mg, and Fe were reduced ($P < 0.08$) with REx. The daily excretion of DM, N, P, Ca, K, Mg, S, and Fe was reduced ($P < 0.08$) for pigs fed REx compared to those fed the control. Daily N and P excretion were reduced by 28 and 37%, respectively, for pigs fed REx. Furthermore, ammonia emissions were reduced ($P < 0.01$) 47% for pigs fed REx. Mass balance calculations revealed that a greater ($P < 0.05$) proportion of N, P, Ca, K, Mg, S, Fe, Zn, and Cu that entered the finisher exited via the market pig for those fed REx. These results suggest the dietary manipulations employed in this study markedly reduced nutrient excretion and shifted the proportion of nutrients exiting the finisher into the market pig. This project was funded by the National Pork Checkoff.

Introduction

The mass balance of nutrients for a swine building can be divided into those nutrients entering the facility via the pigs, feed, water, and air, and those leaving the facility via the pigs, exhaust air, and waste stream. In order to accurately calculate mass balance, accurate estimations of each of these variables are needed. The greatest input of nutrients into a facility is via the feed. Recent research at our station suggests that decreasing the input of nutrients into a facility will dramatically decrease the output of nutrients via the waste stream and exhaust air (for N & S) without affecting the nutrients leaving the facility via the pigs (Carter, S. D., 2007; Carter et al, 2008; Lachmann et al., 2008).

Because diet can greatly affect the excretion of nutrients, many studies have been performed in the last decade to determine the extent of dietary manipulation on nutrient excretion. These studies have shown that reducing crude protein concentration of the diet with crystalline amino acid additions can reduce nitrogen excretion by 30 to 50% (Cromwell and Coffey, 1993; Sutton et al., 1999; Kornegay and Verstegen, 2001; Shriver et al., 2003). In regards to phosphorus, the addition of phytase to low phosphorus diets has been shown to reduce phosphorus excretion by 30 to 50% (Cromwell and Coffey, 1993; Sutton et al., 1999; Kornegay and Verstegen, 2001). However, most of these estimates were obtained by using individually-fed pigs in well-controlled nutrient balance experiments.

While growth performance and carcass traits have been measured for group-housed pigs fed low protein, low phosphorus diets, only recently have manure characteristics been evaluated for pigs group-housed in conventional setting as opposed to individually-fed pigs. Recent research at our station (Lachmann et al., 2007) found that diet can have a profound effect on nutrient excretion over the course of a 16-week finishing period for pigs housed in buildings containing shallow pit, pull-plug systems.

Besides the need to accurately account for nutrients leaving via the waste stream, quantitative estimation of the nutrients leaving through the exhaust air (primarily N and S) is needed in order to calculate mass balance. The emission of NH_3 and H_2S can be affected by many factors including diet composition. Accurate measurement of these gases from the exhaust air as affected by dietary manipulation is important for establishing baseline aerial emissions and for the development of prediction equations on a per pig basis.

In a recently completed experiment (Carter, S.D., 2007), we found that dietary manipulation of protein, phosphorus, and trace minerals can greatly reduce N, P, trace mineral, and ammonia emissions for pigs over the course of a 110-d finishing period. In this study, retention of nutrients in the pigs also was determined in order to calculate mass balance. Based on this first experiment, the proportion of N and P entering the facility that was retained in the pigs was markedly increased with dietary manipulation. Thus,

the objectives of this experiment were to further evaluate the effects of dietary manipulation on the mass balance of nutrients for the finishing phase.

Objectives :

The objectives of this proposal were to:

i. Quantify the inputs of nutrients into the finishing phase including pigs, feed, water, and air, and

ii. Quantify the outputs of nutrients from the finishing phase including pigs, feed, slurry, and exhaust air, and

iii. Calculate the mass balance of nutrients (N, P, Ca, K, Mg, Na, S, Fe, Zn, Cu) for the finishing phase, and

iv. Determine the impact of dietary manipulation on the mass balance of nutrients during the finishing phase.

v. Develop or modify existing models for prediction of inputs and outputs of nutrients during the finishing phase

Materials and Methods:

Mass balance of nutrients through the finishing phase was determined for the entire finishing period. In this experiment, the input of nutrients (feed, water, and pigs) and the output of nutrients (slurry, pigs, and exhaust air) were quantified. The nutrients in the feed that were measured included: dry matter, total nitrogen, total phosphorus, carbon, calcium, potassium, magnesium, sodium, sulfur, iron, zinc, and copper. The slurry was analyzed for these nutrients plus NH_4-N, water soluble phosphorus, and pH. The exhaust air was analyzed for ammonia and hydrogen sulfide concentrations. In addition, pigs and feeder were weighed weekly to calculate body weight gain and total nutrient intake. Water balance was calculated summing water disappearance plus water added to recharge the pit minus final pit volume.

A total of 88 pigs [Duroc x (Yorkshire x Landrace)] initially weighing 32.1 kg was blocked by weight and allotted to two dietary treatments. Dietary treatments were randomly allotted to four rooms with 2 pens (11 pigs/pen) per room (22 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. Dietary treatments consisted of a fortified corn-soybean meal diet that met or exceeded NRC (1998) standards and a Reduced Excretion (**REx**) diet (Table 1). The REx diet had a 3% units decrease in CP with Lys, Thr, Met, and Trp added as needed and a reduction in available phosphorus of 0.10% with phytase inclusion. Also, in the REx diet, monocalcium P replaced dicalcium P and CaCl replaced 50% of the limestone in the control diet. These manipulations were included to make the diet more acidogenic (Kim and van Kempen, 2001). Furthermore, organic sources of Fe, Zn, Cu, and Se replaced inorganic sources of these minerals in the control diet. Inclusion levels of the organic sources provided the same supplemental level of each trace mineral as that supplied by the inorganic sources in the control diet. All diets within phase were formulated on a SID lysine basis (0.92, 0.79, 0.65, and 0.56% for Phases 1 to 4). The dietary treatments were fed in four phases: 32 to 55 kg, 55 to 82 kg, 82 to 102 kg, and 102 to 113 kg. 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, water disappearance was recorded, 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 was allowed to run the entire time the slurry was exiting 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 measured included: dry matter, total nitrogen, total phosphorus, carbon, calcium, potassium, magnesium, sodium, sulfur, iron, zinc, and copper. The slurry was analyzed for these nutrients plus NH_4-N, NO_3-N, and water soluble phosphorus. Total nitrogen and carbon of the samples were analyzed using a LECO Carbon/Nitrogen analyzer. Ammonium nitrogen 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 ammonia and hydrogen sulfide 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 19 minutes of the cycle was used to purge the sample line and equilibrate the analyzer. During the last minute 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.

Ammonia concentration in the exhaust air was measured by first oxidizing NH_3 to NO with an NH_3 converter and then detecting the NO with a chemiluminescence detector (Model 17C, Thermo Environmental Instruments, Franklin, MA). 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 measures 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 generation and emission rates of each gas were calculated according to Heber et al. (2001). 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.

When a room of pigs reached approximately 114 kg, 6 pigs from each room were transported to the university meat lab and humanely slaughtered. Following this, the whole pig was ground and a sample was taken to determine nutrient content of the pig. In addition, six pigs were slaughtered at the beginning of the test period to determine initial nutrient content. Nutrient retention was calculated by subtracting initial nutrient content from final content.

Following the end of the experiment, mass balance was calculated for N, P, and macro and micro-minerals by quantifying the total nutrients entering the room and the total nutrients exiting the room via the slurry and exhaust air. The calculations for intake minus output (slurry, exhaust air) were for the total growth period.

Data were analyzed as a randomized complete block design. The model included the effects of treatment, block, and block x treatment (error). A simple contrast was used to compare the control diet with the REx diet. Room served as the experimental unit.

Results

All procedures were approved by the OSU Institutional Animal Care and Use Committee. The experiment began in March, 2008 and ended in July, 2008.

Growth Performance and Carcass data: There were no effects ($P > 0.10$) of dietary treatment on ADG, ADFI, and F:G (Table 2). However, daily intake of N and P was reduced ($P < 0.04$) for pigs fed REx. There were no effects of treatment on carcass traits (Table 3). These results are important in that pig performance and carcass data were not affected by consuming REx. These results are similar to previous reports from our station involving a 3 percentage unit reduction in CP and a 0.10% reduction in dietary P (Lachmann et al., 2007)

Whole Body Composition: Chemical composition of the whole body is shown in Table 4. The predicted initial body composition of pigs entering the experiment was similar for both dietary treatments (data not shown). The percentages and final weights of water, CP, fat, and ash were not affected ($P > 0.10$) by dietary treatment. Additionally, the whole body weights of N, the macro-minerals, and micro-minerals were similar ($P > 0.10$) for both dietary treatments. Because initial and final weights of the nutrients were similar, diet had little effect ($P > 0.10$) on accretion rate. The general lack of any effect of the REx on whole body composition or accretion suggests that the reduction in dietary crude protein, P (and other macro-minerals), and replacement of organic trace minerals with organic trace mineral sources did not negatively affect carcass composition.

Slurry Characteristics: Slurry volume was similar ($P > 0.10$) for pigs fed both dietary treatments. Also, temperature of the slurry was similar ($P > 0.10$) across all four rooms (Table 5). However, slurry pH was reduced ($P < 0.05$) for pigs fed the REx diet. This decrease in slurry pH is greater than that we have previously observed with dietary manipulation. This marked decrease in slurry pH is most likely a result of replacement of dicalcium phosphate and limestone in the control diet with monocalcium phosphate and calcium chloride in the REx diet. This dietary change resulted in the REx diet becoming more acidogenic resulting in a decrease in urine pH.

Nutrient concentration of the slurry is shown in Table 6. Slurry from pigs fed the REx diet had lower ($P < 0.10$) concentrations of N, NH_4-N, P, Ca, K, Mg, and Fe. Also, total water soluble P concentration of the slurry was reduced ($P < 0.05$) for pigs fed the REx diet.

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. Excretion of carbon was not affected ($P > 0.10$) by dietary treatment (Table 7). However, DM, N, P, Ca, K, Mg, S, and Fe excretion were reduced (P

< 0.08) for pigs fed the REx diet. The percentage decrease in nutrient excretion for pigs fed REx vs. the control ranged from 0% for Na to 37% for P (Figure 1). The cumulative excretion of DM, N, and P for the entire finishing period was reduced by 2.3, 0.89, and 0.24 kg/pig, respectively, for pigs fed the REx diet.

Airflow, NH_3 and H_2S Emissions: Airflow was similar (P > 0.10) for all rooms (Table 8). However, the concentration (mg/m^3) of NH_3 in the exhaust air was reduced (P < 0.01) by 47% for pigs fed the REx diet. The emission rate (mg/min) of ammonia also was reduced (P < 0.01) by a similar amount for pigs fed the REx diet. The decrease in emission rate for pigs fed the REx diet resulted in a 47% decrease in ammonia emitted per pig per day. However, the concentration, emission rate, and emission per pig for H_2S were not affected (P > 0.10) by dietary treatment which most likely was due to the short length of time (7 d) the manure remained in the pit for this shallow pit, pull-plug system.

Calculation of Mass Balance of Nitrogen and Phosphorus: Table 9 shows the calculations for mass balance of nitrogen and phosphorus during the 94-d finishing period. Nutrients entering the facility were assumed to enter via the feed and the pigs. Analysis of water entering the building suggested negligible amounts of these two nutrients entering via the water. Nutrients exiting the facility were assumed to be via the slurry, pigs, and exhaust air. Based on initial pig composition and chemical composition of the feed, the amount of N and P entering were reduced (P < 0.07) for pigs fed the REx diet. Based on reductions in the excretion of N and P, a reduction in NH_3-N emission, with no change in N and P content of the carcass, the amount of N and P exiting the facility was reduced (P < 0.08) for pigs fed the REx diet. Surprisingly, the calculation of mass balance for N and P was close to zero, or in other words, the amount of N and P exiting the facility was similar to that entering.

Figures 2 and 3 show the proportion of total N and P entering and exiting the room via the pigs, feed, slurry, and air. In the case of N, due to the decrease in N intake for pigs fed the REx diet, the proportion of N entering the facility via the pigs increased with the amount entering via the feed decreasing as compared with pigs fed the control diet (Figure 2). For N exiting the facility, the proportion exiting via the pigs increased from 47% for pigs fed the control diet to 55% for pigs fed the REx diet. This increase was due to the reduction in N exiting via slurry for pigs fed the REx diet (49 vs. 43%). Also, the amount of N exiting via the exhaust air decreased for pigs fed REx; however, the proportion of total N exiting the facility via exhaust air was small compared to that exiting via the pigs or slurry.

A similar trend was found for the proportion of P entering and exiting the facility via the pigs, feed, and slurry (Figure 3). The proportion of P entering the facility via the feed decreased (85 vs. 82%) for pigs fed the REx diet due to the decrease in dietary P. For total P exiting the facility, the amount of P exiting the facility via the pigs was similar with a marked reduction exiting via the slurry for pigs fed the REx diet. In fact the proportion of P exiting the facility in the slurry or pigs decreased from 52:48 to 41:59 (slurry P:pig P) for pigs fed the REx diet.

From these values it can be calculated that for pigs fed the REx diet that 55% of the nitrogen entering the room exited the room via the pigs versus 47% for pigs fed the control diet (Figure 4). Likewise, the amount of P exiting the room via the pigs as a percentage of that entering room increased from 49% for pigs fed the control diet to 60% for pigs fed the REx diet (Figure 4). These results suggest that a greater proportion of the N and P entering each room was retained by pigs fed the REx diet vs. those fed the control diet.

Calculation of the mass balance for other nutrients also was performed. For simplicity, the mass balance of these other nutrients is shown as percentage of the nutrient entering the finisher that exited via the finished pig (Figure 5). Using Ca as an example, 62% of the Ca that entered the finisher (pig, water, feed) exited the finisher in the market pig for those fed the control diet. This increased to 73% for pigs fed the REx diet. The same was true for all nutrients measured with the exception of Na. These results suggest that the dietary manipulations employed in this experiment resulted in a greater proportion of the total nutrients entering the finisher left as a finished pig. By increasing the proportion of nutrients leaving as a finished pig, a lower proportion of those nutrients are available to be released to the environment.

Prediction of Excretion: The ASABE model (2005) for estimating nutrient excretion was used to compare results of this experiment to those predicted by the model. The ASABE model allows for the input of data specific to a particular production phase. Input data such as pig weight, lean gain per day, carcass yield, average daily feed intake, average daily gain, and dietary characteristics such as crude protein and phosphorus percentage can be use to predict N and P excretion. These data were included in the model to estimate N and P excretion for pigs fed the control diet in the current experiment (Table 10). Estimates of excretion for N and P produced by the model for the control diet were 35.1 and 7.0 g/pig/d, respectively. The estimate of N excretion produced by the model is slightly higher than the actual excretion obtained in the current study (35.1 vs. 33.9) for pigs fed the control diet. The same was true for the REx diet. The model estimated P excretion as 7.0 g/pig/d whereas the actual result obtained in the current study was an excretion of P of 6.80 g/pig/d. For the REx diet, the predicted P excretion was very similar to that observed. Also, the predicted DM excreted was very similar to that measured for both the control and REx pigs. These estimates along with our previous work will be used in the future to refine the excretion model.

Discussion:

We have previously reported that a reduction of 3 percentage units in dietary crude protein decreased daily N excretion by 30% (Carter, S.D., 2007; Carter et al. 2008; Lachmann et al., 2007). In this study, as similar reduction in N excretion was observed with a 3 percentage unit reduction in dietary CP. Previous reports from our station demonstrated a 20 and 40% reduction in N excretion for pigs fed diets with crude protein reduced by 2 and 4 percentage units during the finishing phase (Lachmann et al., 2007). Many studies have shown that reducing crude protein concentration of the diet with crystalline amino acid additions can reduce nitrogen excretion by 30 to 50% (Cromwell and Coffey, 1993; Kerr and Easter, 1995; Sutton et al., 1999; Kornegay and Verstegen, 2001; Shriver et al., 2003).

Phosphorus excretion was reduced by 37% in this study for pigs fed the REx diet during the finishing phase. This is similar to a previous report from our station (Carter, S. D., 2007; Carter et al. 2008; Lachmann et al., 2007). Other reports have shown that feeding low P diets with phytase addition can reduce P excretion by 30 to 50% (Cromwell and Coffey, 1993; Sutton et al., 1999; Kornegay and Verstegen, 2001). Additionally, water soluble P was reduced for pigs fed the REx diet.

The excretion of the macro-minerals, Ca, K, Mg, and S, were reduced from 20 to 30% for pigs fed the REx diet compared to those fed the control diet. These decreases were primarily due to the reductions in soybean meal and phosphorus source in the diet. However, the reduction in the excretion of Ca was of a greater magnitude than the reduction in intake for pigs fed the REx diet suggesting that phytase may have also resulted in an improvement in Ca digestibility. Sulfur excretion responded in a similar fashion in that sulfur intake was reduced by 14%, but sulfur excretion was reduced by 28% for pigs fed the REx diet. The replacement of inorganic sources of trace minerals with the organic sources and reduction limestone and phosphorus source in the REx diet most likely improved the digestibility of sulfur.

In a previous study, we reported that trace mineral excretion could be dramatically reduced by the partial removal of the trace mineral premix from the diet (Carter, S. D., 2007; Carter et al. 2008; Lachmann et al., 2007). In this experiment, inorganic sources of Fe, Zn, and Cu were replaced with an organic source. Organic sources of trace minerals have been shown to reduce fecal mineral concentration or improve bioavailability (Creech et al., 2004; Rincker et al., 2005). In this experiment, although the excretion of Fe, Zn, and Cu were reduced by 8 to 17% with organic sources, this decrease was similar to the decrease in intake for the micro-minerals. Excretion as a percentage of intake was similar for the inorganic vs the organic sources of Fe, Zn, and Cu. This suggests that the organic sources had little effect on digestibility/excretion. However, by replacing the inorganic sources with the organic sources, sulfur excretion was markedly reduced.

Although the excretion of nutrients was reduced dramatically for pigs fed the REx diet, possible effects on growth performance and carcass traits cannot be overlooked. In this study, growth performance, carcass traits, and whole body composition were not affected in pigs fed the REx diet.

In addition to the effects on nutrient excretion, ammonia concentration and emission rates for pigs fed the REx diet were dramatically reduced. Ammonia emission was reduced by 47% for pigs fed the REx diet vs. those fed the control diet. In a previous study from our station, we reported a 56% reduction in ammonia emissions from pigs fed a reduced crude protein, amino acid-supplemented diet (Carter, S. D., 2007; Carter et al. 2008; Lachmann et al., 2008). These reductions in ammonia emission are similar to that reported by Panetta et al. (2006) of a 57% decrease for pigs fed a low crude protein, amino acid supplemented diet. One difference in the present study compared to our previous work is that monocalcium phosphate and calcium chloride replaced dicalcium phosphate and limestone, respectively, in the REx diet. Kim & van Kempen (2001) reported that use of monocalcium phosphate and CaCl increased the acidity of the diet and thus reduced urine pH and ammonia emissions. In our previous report, we attributed the reduction in ammonia emissions to the reduction in crude protein in the diet. However, in this experiment, we cannot discern whether the reduction in ammonia emissions from pigs fed REx was attributed to the protein content of the diet or to the Ca and P source used or a combination of both. The magnitude of decrease in ammonia emissions in this experiment was less than that observed in a previous experiment in the same facility using the same control diet (Carter, S. D., 2007, Carter et al. 2008; Lachmann et al., 2008). However, because of differences in time of year, temperature, etc., we cannot directly compare results of this experiment to previous experiments at our station. Nonetheless, the diet manipulations employed in this experiment dramatically reduced ammonia emissions. Further work is needed to determine if additive effects of dietary protein and Ca and P source exist.

Unlike ammonia, the effects of diet on hydrogen sulfide emissions were minimal. Our hope was that replacement of the inorganic sources of trace minerals with the organic sources would decrease H_2S emission. Although a reduction in sulfur excretion was observed for pigs fed REx, this did not translate into a reduction in H_2S emission. These results suggest that diet may have minimal impact on hydrogen sulfide emissions for pigs housed in facilities with shallow pit, pull-plug systems, with pit recharge on a weekly basis.

For total inclusive comprehensive nutrient management plans, accurate accounting of nutrient inputs and outputs from a facility are needed. In this study, we were able to account for both inputs and outputs for the finishing phase. Calculations from mass balance demonstrated that diet can have a pronounced effect on both inputs and outputs of these two nutrients for the finishing phase. Based on these data, a greater proportion of N and P entering the facility was retained in the pigs fed the REx diet. As such, the amount of N and P exiting the facility in the slurry or exhaust air as a percentage of these nutrients entering was greatly reduced for pigs fed the REx diet. These results are very similar to a previous report from our station (Carter, S. D., 2007; Lachmann et al., 2008). Also, this data suggest that approximately 2 to 4% of the nitrogen exiting the facility was due to NH_3 emissions. Many reports have shown that dietary manipulation can decrease N and P excretion dramatically, but in this experiment we were able to partition nutrients leaving the facility to pigs, slurry, and exhaust air. Very few studies have been performed to determine actual mass balance on nutrients for the finishing phase. Our results suggest that using the techniques employed, we were able to accurately account for nutrients entering and exiting the facility. Furthermore, it appears that the ASABE (2005) excretion model can be used to estimate the amount of N and P exiting the facility in the slurry based on inputs (pigs and feed) into the finisher.

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Table 1. Dietary composition for the four dietary phases (as-fed basis).

	Phase 1		Phase 2		Phase 3		Phase 4	
Ingredient, %	Control	REx	Control	REx	Control	REx	Control	REx
Corn	65.64	74.04	70.96	79.42	76.76	85.21	80.51	88.94
SBM, 48% CP	28.95	20.45	23.77	15.25	18.19	9.69	14.60	6.10
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
L-lysine	0.00	0.27	0.00	0.27	0.00	0.27	0.00	0.27
DL-methionine	0.00	0.08	0.00	0.07	0.00	0.07	0.00	0.06
L-threonine	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
L-tryptophan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Dicalcium phos.	0.85	0.00	0.72	0.00	0.60	0.00	0.46	0.00
Moncalcium phos	0.00	0.32	0.00	0.21	0.00	0.10	0.00	0.00
Limestone	0.96	0.51	0.94	0.49	0.91	0.45	0.89	0.43
Ca chloride		0.51		0.48		0.45	0.00	0.43
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
TM mix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin mix	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
Antibiotic	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05
ZinPro 100	0.00	0.11	0.00	0.11	0.00	0.11	0.00	0.11
CuPlex 100	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01
Avail-Fe 120	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.09
SelPlex 600	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03
EDDI mix	0.00	0.05	0.00	0.05	0.00	0.05	0.00	
Phytase	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02
Calculated composition								
ME, kcal/kg	3475	3475	3639	3623	3638	3623	3638	3622
CP, %	19.2	16.2	17.18	14.18	15.01	12.01	13.62	10.62
SID Lysine, %	0.92	0.92	0.79	0.79	0.65	0.65	0.56	0.56
Ca, %	0.65	0.50	0.60	0.45	0.54	0.39	0.49	0.35
Avail. P, %	0.23	0.13	0.20	0.10	0.17	0.07	0.14	0.04
K, %	0.84	0.68	0.74	0.59	0.64	0.49	0.58	0.42
Mg, %	0.19	0.16	0.18	0.15	0.17	0.14	0.16	0.13
Na, %	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
S, %	0.22	0.19	0.21	0.17	0.19	0.16	0.18	0.14
Fe, mg/kg	281	210	263	193	243	176	227	162
Zn, mg/kg	138	135	136	133	134	131	133	129
Cu, mg/kg	18.8	17.3	17.9	16.4	17.0	15.5	16.3	14.9
Se, mg/kg	0.32	0.31	0.31	0.29	0.30	0.28	0.29	0.28

Table 2. Growth performance and nutrient intake of pigs fed either the control diet or the REx diet[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
Initial wt, kg	32.1	32.1	0.08	0.89
Final wt, kg	113.1	114.0	0.15	0.16
Days on test	94	94	0.0	0.99
ADG, g	0.863	0.872	0.02	0.67
ADFI, g	2.367	2.365	0.03	0.77
F:G	2.74	2.71	0.01	0.48
Dry matter intake, g/d	2,073	2,073	54.5	0.99
N intake, g/d	57.8	47.4	1.39	0.04
P intake, g/d	11.14	8.57	0.24	0.02

[a]Least squares means for 2 rooms (22 pigs/room) per dietary treatment.

Table 3. Carcass data of pigs fed either the control diet or the REx diet[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
Live weight, kg	114.3	114.5	0.74	0.92
Hot carcass wt, kg	86.5	87.8	0.80	0.45
10^{th} rib fat depth, cm	2.19	2.10	0.11	0.66
LMA, cm^2	45.0	46.8	0.92	0.41
Carcass yield, %	75.6	76.7	0.22	0.19
Fat-free lean, %	52.2	52.9	0.39	0.41

[a]Least squares means for 2 rooms (4 pigs/room) per dietary treatment.

Table 4. Whole body composition and nutrient accretion of pigs fed either the control diet or the REx diet[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
Live weight, kg	114.6	115.4	3.65	0.72
H_2O, %	51.41	51.33	0.01	0.90
CP, %	16.32	16.30	0.01	0.91
Ash, %	2.97	2.98	0.01	0.90
Fat, %	27.42	27.52	0.02	0.90
N, %	2.62	2.61	0.01	0.89
P, %	0.52	0.52	0.01	0.95
H_2O, kg	58.9	58.1	0.01	0.78
CP, kg	18.69	18.44	0.01	0.78
Ash, kg	3.41	3.33	0.18	0.78
Fat, kg	31.5	30.5	2.23	0.78
N, kg	2.99	2.96	0.09	0.78
P, g	0.599	0.585	0.03	0.78
Ca, g	1015	1026	46.8	0.88
K, g	278	280	5.43	0.87
Mg, g	35.8	36.1	1.08	0.88
Na, g	115.4	116.2	3.39	0.89
S, g	184.5	185.3	3.39	0.87
Fe, mg	3022	3021	6.1	0.89
Zn, mg	2774	2791	73.3	0.85
Cu, mg	128.4	129.2	3.39	0.89

[a]Least squares means for 2 rooms (22 pigs/room) per dietary treatment.

Table 5. Volume, temperature, and pH measures of the pit contents for pigs fed either the control diet or the REx diet[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
Volume, L/pig/d[c]	2.51	2.60	0.29	0.87
Temperature, ^oC	21.22	21.27	0.09	0.77
pH	7.41	6.80	0.04	0.05

[a]Least square means for 2 rooms (22 pigs/room) per dietary treatment.

Table 6. Nutrient concentration (DM basis) of the slurry averaged for the 94-d period for pigs fed either the control diet or the REx diet[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
DM, %	2.22	2.03	0.08	0.36
C, %	61.46	59.46	7.24	0.87
N, %	15.1	11.76	0.73	0.08
NH_4-N, %	7.61	6.76	0.06	0.06
P, %	2.83	1.98	0.08	0.02
Water-soluble P, %	2.02	1.73	0.02	0.01
Ca, %	2.81	2.15	0.04	0.01
K, %	6.89	5.94	0.25	0.01
Mg, %	1.24	1.10	0.01	0.02
Na, %	1.18	1.32	0.09	0.40
S, %	1.29	1.02	0.08	0.15
Fe, ppm	1887	1751	1.01	0.01
Zn, ppm	1692	1731	37	0.60
Cu, ppm	254	249	3.46	0.44
C:N	4.08	5.02	0.37	0.22
N:P	5.33	5.99	0.57	0.50
WSP:P	0.71	0.88	0.03	0.06

[a]Least squares means for 2 rooms (22 pigs/room) per dietary treatment.

Table 7. Nutrient excretion for pigs fed either the control diet or the REx diet averaged for the 94-d period[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
Daily excretion				
DM, g	240.2	216.0	0.13	0.01
C, g	147.7	127.3	12.7	0.37
N, g	33.9	24.4	0.67	0.01
P, g	6.80	4.29	0.37	0.05
Ca, g	6.74	4.64	0.04	0.02
K, g	16.50	12.82	0.55	0.05
Mg, g	2.98	2.38	0.03	0.05
Na, g	2.84	2.83	0.05	0.91
S, g	3.08	2.22	0.18	0.08
Fe, mg	454	379	2.79	0.04
Zn, mg	409	376	11.8	0.30
Cu, mg	61.4	53.9	1.02	0.12
Cumulative excretion[b]				
DM, kg/pig	22.58	20.30	0.01	0.01
N, kg/pig	3.19	2.30	0.06	0.01
P, kg/pig	0.639	0.403	0.03	0.05

[a]Least squares means for 2 rooms (22 pigs/room) per dietary treatment.
[b]Total excretion per pig for the 94-d period.

Table 8. Airflow, NH_3 and H_2S emissions for pigs fed either the control diet or the REx diet during a 94-d finishing period[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
Air flow, L/s	412	399	7.9	0.37
NH_3, mg/m^3	2.03	1.07	0.08	0.01
NH_3, mg/min	43.94	22.93	1.70	0.01
NH_3, g/pig/d	3.54	1.89	0.13	0.01
H_2S, ug/m^3	13.85	14.55	0.78	0.59
H_2S, ug/min	245.5	249.3	8.93	0.79
H_2S, mg/pig/d	25.99	25.89	0.89	0.95

[a]Least squares means for 2 rooms (22 pigs/room) per dietary treatment.

Table 9. Calculation of mass balance of N and P for pigs fed either the control diet or the REx diet during a 94-d finishing period[a].

	Dietary Treatment			
	Control	**REx**	**SE**	**P <:**
Total N entering, kg/pig	6.38	5.40	0.07	0.07
Pig Initial N, kg/pig	0.948	0.942	0.01	0.17
Feed N entering, kg/pig	5.43	4.46	0.13	0.04
Total N exiting, kg/pig	6.45	5.40	0.01	0.01
Slurry N, kg/pig	3.19	2.30	0.06	0.01
Pig Final N, kg/pig	2.99	2.96	0.09	0.78
NH_3-N, kg/pig	0.274	0.146	0.01	0.02
Difference, kg/pig	-0.08	0.00	0.09	0.60
Total P entering, g/pig	1225	983	13.9	0.05
Pig Initial P, g/pig	179	178	0.24	0.19
Feed P entering, g/pig	1047	805	22.7	0.02
Total P exiting, g/pig	1241	988	22.2	0.08
Slurry P, g/pig	641	403	8.2	0.04
Pig Final P, g/pig	600	585	33.1	0.78
Difference, g/pig	-15.1	-5.1	8.3	0.55

[a]Least squares means for 2 rooms (22 pigs/room) per dietary treatment.

Table 10. Predicted DM, N, and P excretion using the ASABE nutrient excretion model compared to the observed values of excretion[a].

	Dietary Treatment	
Model Input[a]	**Control**	**REx**
Initial Wt, kg	32.1	32.0
Final Wt, kg	113.2	114.0
Days on Test	94	94
ADFI, kg/d	2.37	2.37
Fat-free lean, g/d	347.8	350.1
Carcass yield, %	75.6	76.7
Diet DM, %	87.62	87.55
Diet N, %	15.26	12.52
Diet P, %	0.47	0.36

	Observed[c]		Predicted[d]	
Model Output	**Control**	**REx**	**Control**	**REx**
DM excretion, g/d	240.2	216.0	240.2	217.5
N excretion, g/d	33.9	24.4	35.1	25.3
P excretion, g/d	6.80	4.29	7.00	4.30
DM, kg/pig	22.58	20.30	22.58	20.44
N, kg/pig	3.19	2.30	3.36	2.38
P, kg/pig	0.639	0.403	0.658	0.404

[a]Data shown are for the entire 94-d finishing period.
[b]Model input data was entered by treatment within phase (e.g., initial and final wt., ADFI, DOT, diet DM, N, and P).
[c]Actual data from the experiment.
[d]Predicted estimates of excretion using the ASABE (2005) model and input data from the experiment.

Figure 1. Percentage reduction in nutrient excretion for pigs fed REx compared to pigs fed the control diet.

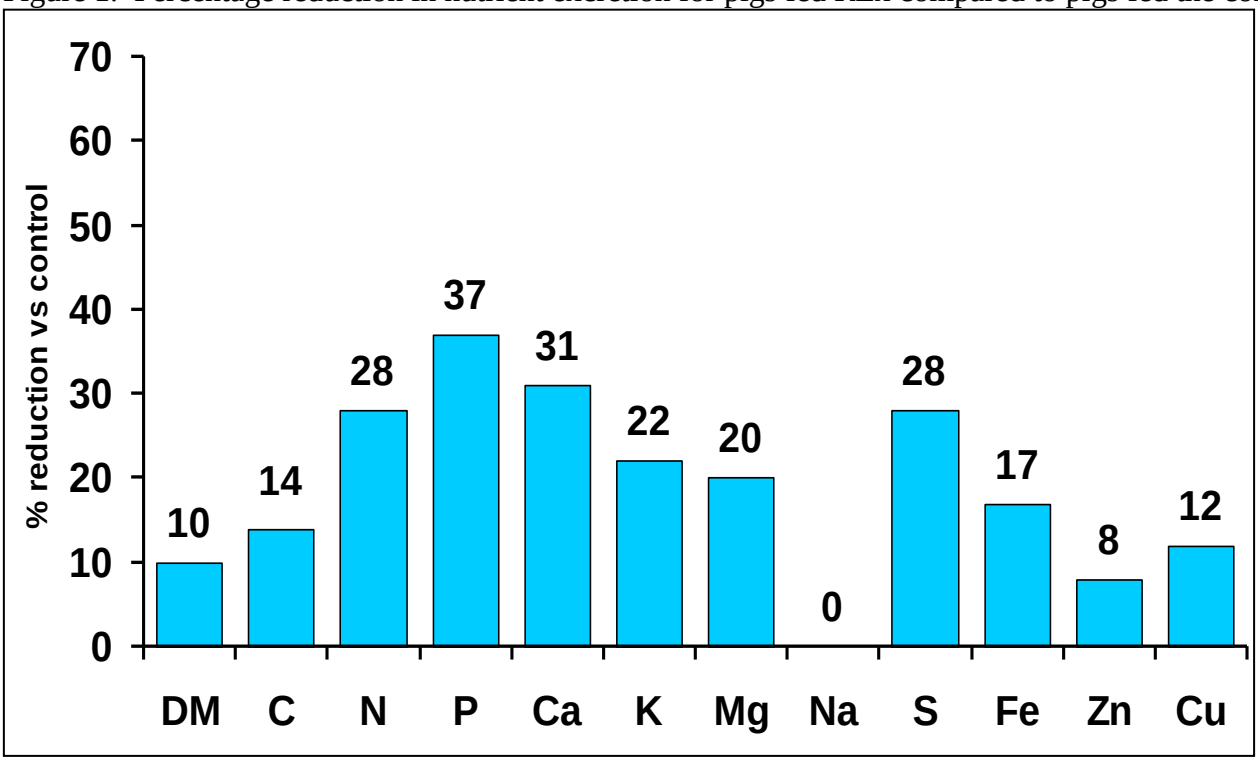


Figure 2. Proportion of total N entering and exiting the finisher for pigs fed the control or REx diet

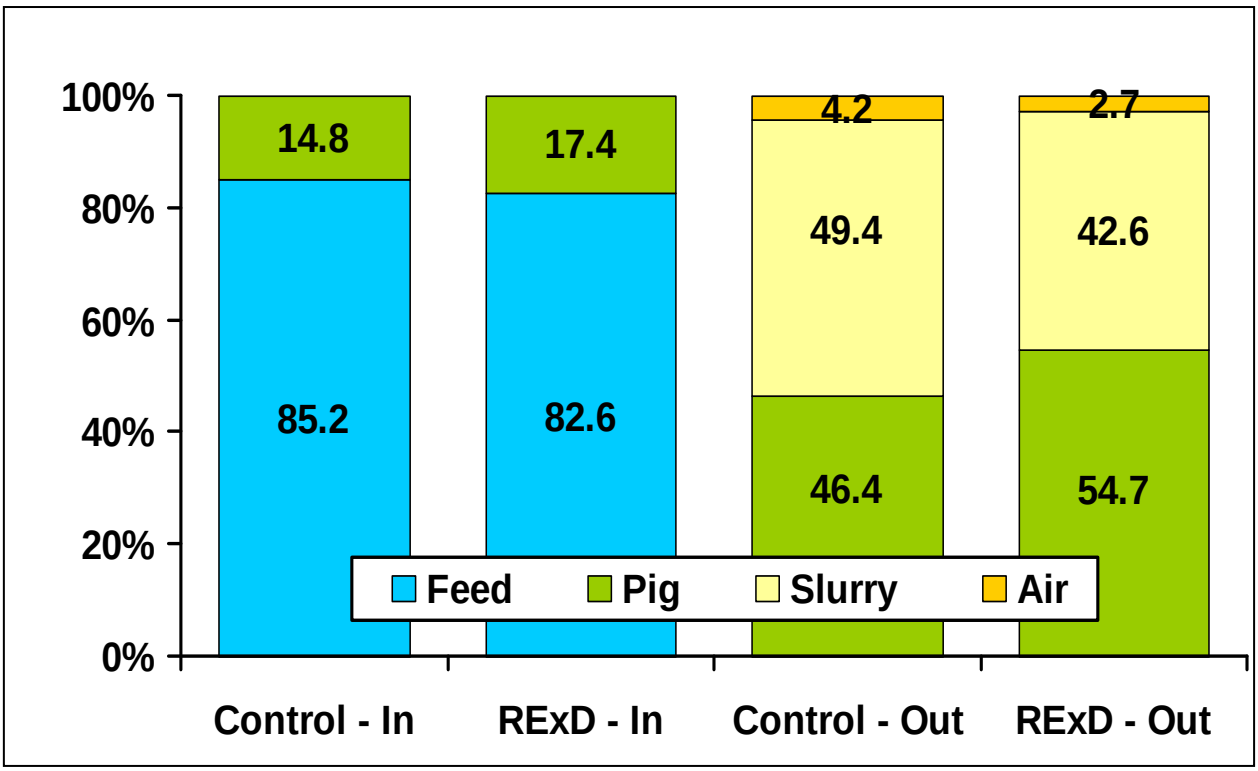


Figure 3. Proportion of total P entering and exiting the facility for pigs fed the control or REx diet.

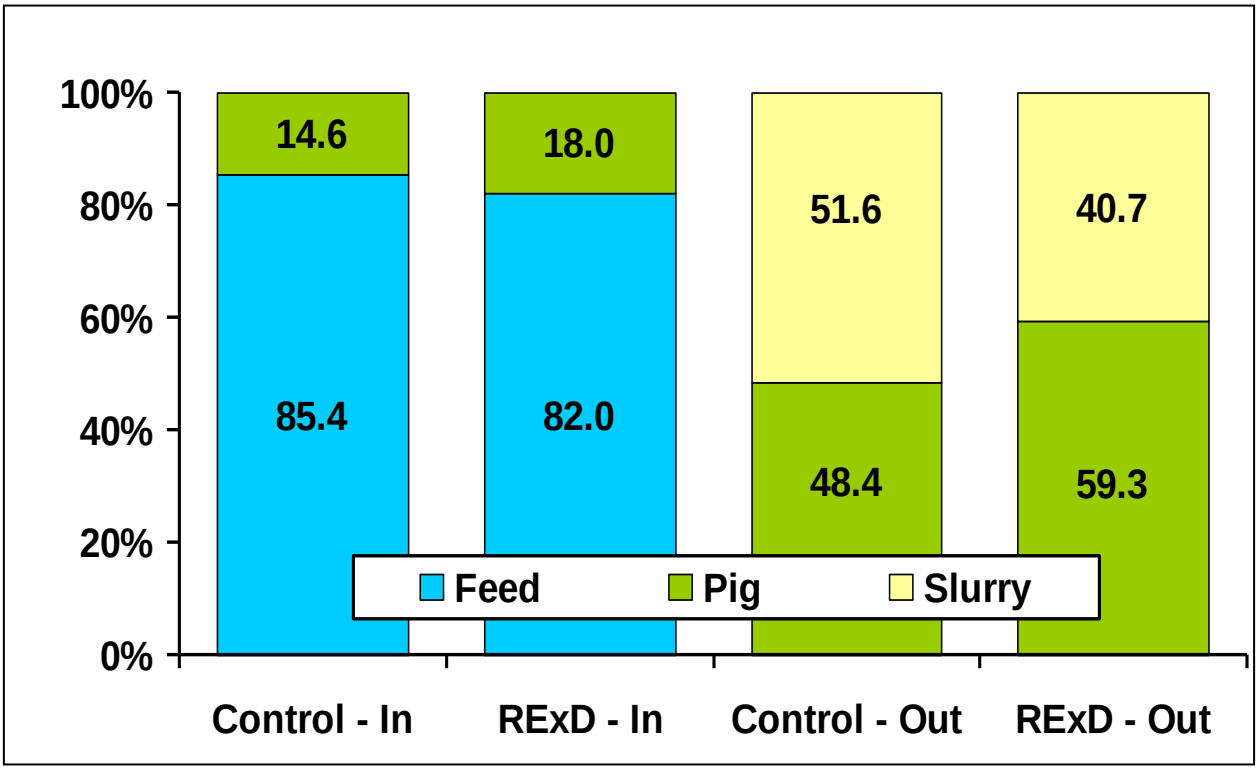


Figure 4. Proportion of N and P entering the finisher that exited via the market pig for pigs fed the control or REx diet.

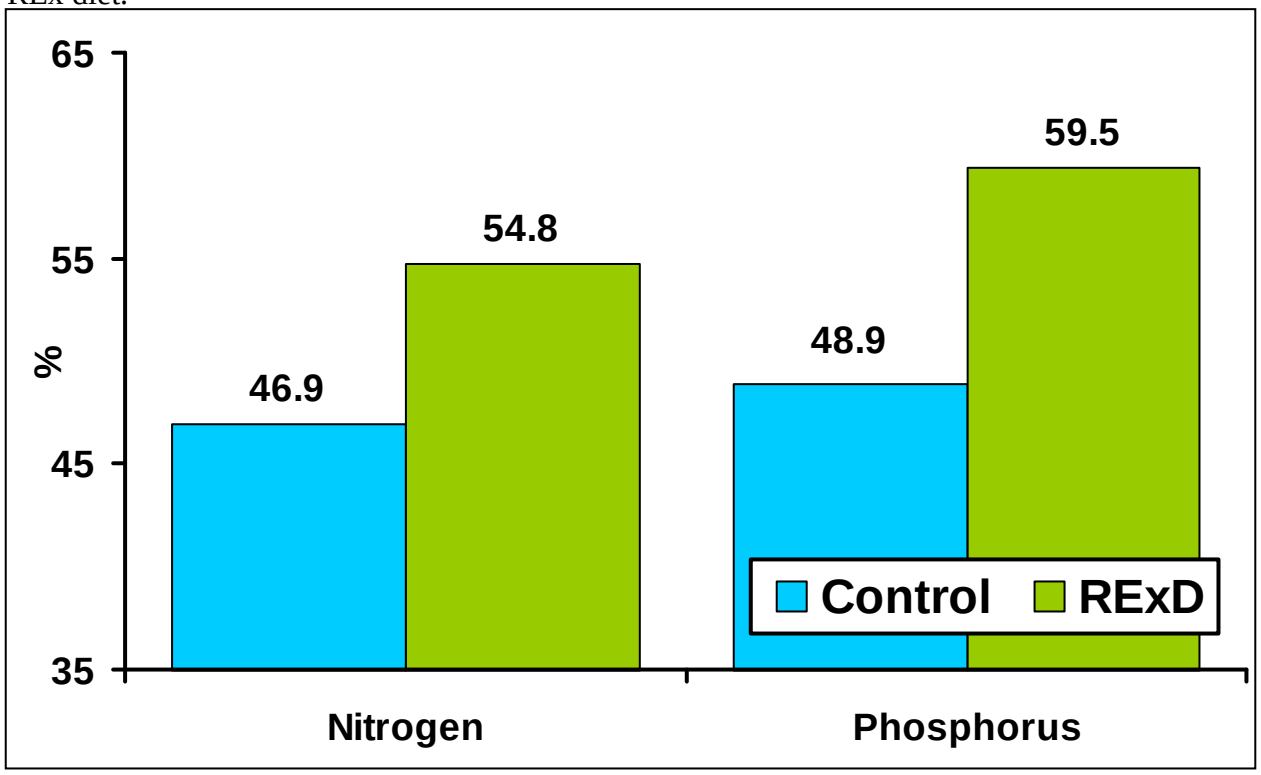
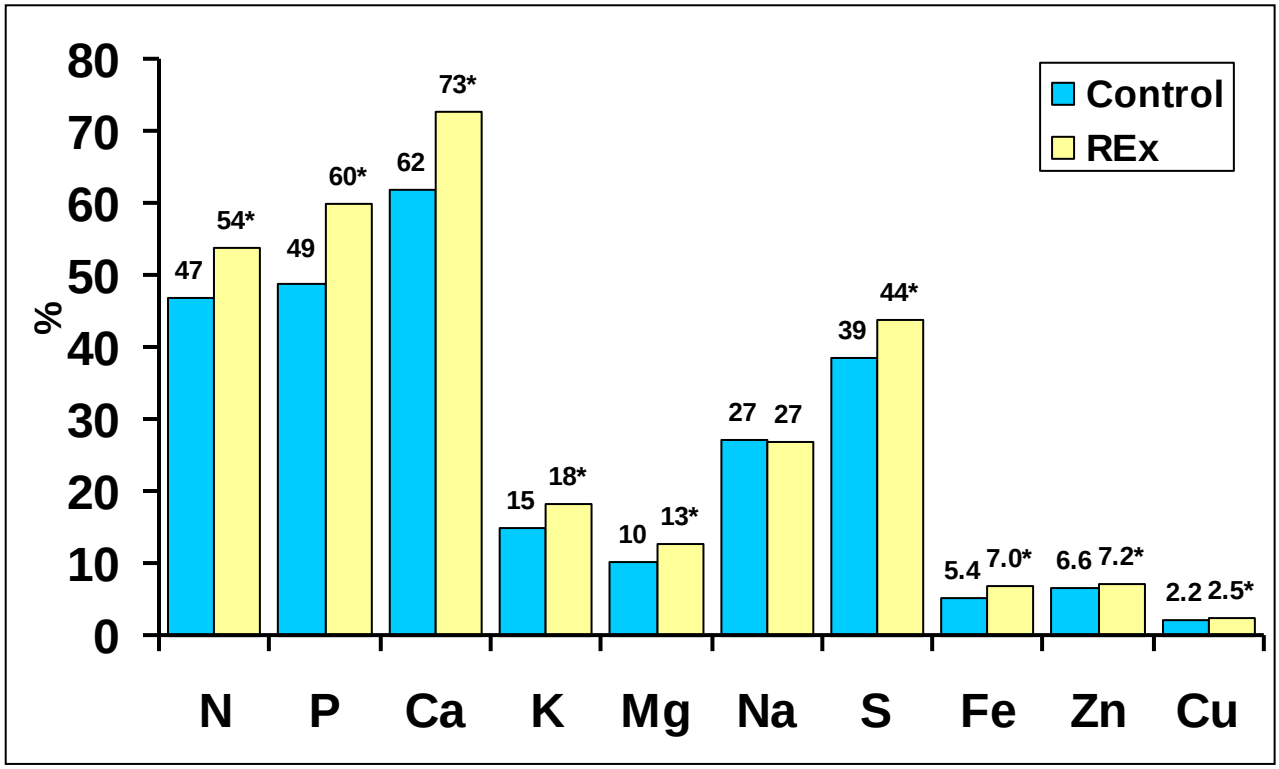


Figure 5. Percentage of nutrients entering the finisher that exited in the market pig for pigs fed the control or REx diet[a].



[a]Least squares means for two rooms (22 pigs per room) per treatment.
*Control vs. REx, $P < 0.05$.