Title: Improving milk production efficiency and mitigating feed costs in lactating sows through dietary crude protein abatement and crystalline amino acid supplementation under thermo neutral and thermal stress environment model – NPB #13-120

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Industry Summary:

Objectives:
To determine if lactating sows can be fed diets containing less protein in order to reduce the quantity of nitrogen excreted into the environment. To determine if sows fed reduced CP diets improve their lactation performance when housed under hot environmental temperature.

How research was conducted:
Lactating sows were fed different diets that contained lower amounts of protein and their nursing piglets were weighed and the milk was analyzed for nutrients. The amount of protein in the sows body was also measured to ensure that the diets fed would provide her with the protein that they needed. Sows were also housed each in small rooms where the temperature could be well controlled and increased to resemble the summer temperature. When animals are fed large amounts of proteins, it may result in more heat produced by the animal, which in turn is not desirable during hot weather. The amount of heat produced by sows that were fed diets with different levels of proteins was calculated by measuring how much oxygen was consumed and carbon dioxide was produced by the sows. The amount of nitrogen produced in the sows' urine and the ammonia in the air was also measured.

Research findings:
Sows fed reduced CP diets as low as 12% and containing crystalline amino acids maintain lactation performances and decrease the quantity of nitrogen excreted in the urine, which in turns decrease air emission of ammonia. Sows house in hot environmental conditions produce more heat however reduced CP diets do not reduce the heat produced by the sows and their piglets. When crystalline amino acid prices are favorable over protein feed prices, overall cost of production could be reduced if nitrogen excretion becomes regulated.

What these findings mean to the industry:

When amino acid prices are competitive with feed prices, feeding reduced CP diets with crystalline AA supplementation can be implemented for multiple parity lactating sows on the basis of reduction in N excretion and ammonia emission without impacting lactation performance and return to estrus.

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Scientific Abstract:

Objectives 1 and 2: Forty lactating multiparous Yorkshire sows were used to test the hypothesis that reducing dietary CP and supplementing with crystalline amino acids (CAA) increases dietary N utilization for milk production during early and peak lactation. Sows were assigned to 1 of 4 diets: [1] 16.0% CP (as-fed; analyzed contents; HCP); [2] 15.7% CP (MHCP); [3] 14.3% CP (MLCP); [4] 13.2% CP (LCP); diet HCP was formulated using soybean meal and corn as the only Lys sources. The reduced CP diets contained CAA to meet requirements of the limiting AA. Sow and piglet BW were measured on d 1, 3, 7, 14, 18 and 21 of lactation. Nitrogen retention was measured on sows between d 3 and 7 (early) and d 14 and 18 (peak) of lactation. Milk true protein output was calculated from estimated milk yield and analyzed true protein concentration. Sow BW change (overall mean: −4.2 ± 3.37 kg over the 21-d lactation period) and average daily DM intake (overall mean: 4.05 ± 0.18 and 6.12 ± 0.20 kg/d, early and peak lactation, respectively) did not differ between diets. Nitrogen intake decreased as dietary CP concentration decreased (114.3, 106.0, 107.4, and 99.0 ± 5.29 g/d and 169.5, 168.3, 161.2, and 145.1 ± 5.29 g/d for HCP, MHCP, MLCP, and LCP in early and peak lactation, respectively; L: $P < 0.05$). Sow loin eye area loss tended to increase as dietary CP concentration decreased (Linear (L): $P = 0.082$). Litter growth rate (LGR) over the 21-d lactation period tended to increase with decreasing dietary CP concentration (L: $P = 0.084$). In early lactation, N retention (N intake – fecal and urinary N) and milk true protein and casein output were not affected by dietary treatment. In early lactation, as dietary CP decreased, N retained as percentage of N intake tended to increase (L: $P = 0.093$) and estimated efficiency of using retained N for milk N output was not influenced by dietary CP concentration. In peak lactation, N retention (122.5, 123.8, 121.2, and 109.0 ± 4.88 g/d for HCP, MHCP, MLCP, and LCP, respectively) decreased (L: $P < 0.05$), N retained as percentage of N absorbed (N intake – fecal N) increased (L: $P < 0.05$), milk casein yield increased (P = 0.051), and estimated efficiency of using retained N for milk N output (44.5, 51.0, 54.9, and 62.9 ± 5.9 % for HCP, MHCP, MLCP, and LCP, respectively) increased (L: $P < 0.05$). Feeding lactating diets reduced in CP from 16.0 to 14.3% with CAA inclusion as partial replacement for limiting AA improved N retention and N utilization efficiency for milk protein production in peak lactation, while these effects were less pronounced in early lactation.

Objectives 3 and 4: The objective of this study was to test the hypothesis that feeding a diet containing lower dietary CP and supplemental crystalline AA compared to a diet formulated to meet Lys requirement with not supplemental AA, reduces ammonia emission and maintains lactation performance in sows housed under thermo-neutral and thermal heat stress environments. Thirty-six, parity 2 and 3, Yorkshire sows were allocated to a 2 × 2 factorial arrangement of 2 environmental temperatures, thermo-neutral (21°C; TN) and heat stress (31.5 °C; HS), and 2 dietary treatments, 17.16 (Control) and 11.82% CP (Low), in a randomized complete block design. The HS sows were acclimated between d 107 and 114 of gestation to increasing daytime temperature from 21 to 31.5 °C. During lactation, temperature for HS sows were incrementally changed (24 to 31.5 °C and 31.5 to 24°C) from 0500 to 1500 and 1800 to 0500, respectively. Control diet met SID Lys requirement with no added CAA and Low diet contained added crystalline Lys, Thr, Trp, Val and Phe. Sows were housed in individual environmentally controlled rooms with continuous emissions monitoring. Compared to Control, piglet ADG and sow feed intake (FI), true milk protein concentration (TMP), weight loss (ΔBW), heart rate (HR), and respiration rate (RR) of Low-fed sows did not differ. Compared to Control, MUN and ammonia emissions decreased for sows fed Low ($P < 0.0001$). Change in back fat thickness (ΔBF), body temp (BT), and days post weaning to estrus (WtE) did not differ between Control and Low. Compared to TN, BW loss, HR and RR of HS sows were greater ($P < 0.05$). Compared to TN, piglet ADG of HS sows were less ($P < 0.05$). Neither O_2 consumption nor CO_2 production differed between sows fed Control and Low diets under TN or HS environments. Diet costs increased with increasing dietary AA supplementation when using feed prices from 2012 however when using feed prices from 2012 and AA prices from 2015, diet costs only increased by 5%. In conclusion, feeding reduced CP diet to lactating sows improved N utilization and did not impact lactation performance of sows under either thermo-neutral or thermal heat stress environments. Feeding reduced CP diets does not decrease heat production. These results indicate that reduction of dietary CP in conjunction with aggressive CAA supplementation may be implemented for lactating sows on the basis of mitigating ammonia emissions. Reduced CP diets will be more competitive with higher protein feed cost or increased cost of N excretion. The impact of feeding reduced CP diets to lactating sows is largely the reduced excretion of N and ammonia emissions. The value of this dramatic decrease in N excretion and ammonia emission depends on environmental regulations including implementation of the clean air act (e.g., carbon tax). Given the increasing stringency of environmental regulation in agriculture and the pressure to reduce greenhouse gas emissions, feeding to decrease N excretion using synthetic amino acids is likely to become more economical.

Introduction:

The overall goal of this project was to determine the lactation performance of sows fed diets reduced in CP and containing crystalline amino acids. The following research questions were tested: Does feeding diets reduced in CP with CAA to meet the limiting AA requirements improve milk production and increases piglet quality at weaning? Does feeding diets reduced in CP with CAA to meet the limiting AA requirements increases lysine and N utilization and reduces N excretion? Does feeding diets reduced in CP with CAA to meet the limiting AA requirement reduces heat production, improves lactation performance and reduce weaning to estrus interval in sows exposed to high environmental temperature? What are the feed costs associated with feeding optimum levels of CAA?

Objectives:

Objective 1: Evaluate lactation performance in sows fed diets with four graded levels of CAA as substitute for CP. We will test the hypothesis that feeding diets reduced in CP with CAA to meet the limiting AA requirements improves milk production and increases piglet quality at weaning.

Objective 2: Assess dietary N and lysine utilization in sows fed diets with graded levels of CAA as substitute for CP. We will test the hypothesis that feeding diets reduced in CP with CAA to meet the limiting AA requirements increases lysine and N utilization and reduces N excretion.

Objective 3: Measure the energetic efficiency in sows fed diets with three graded levels of CAA as substitute for CP under thermo neutral and heat stress environment. We will test the hypothesis that feeding diets reduced in CP with CAA reduces heat production, improves lactation performance and reduce weaning to estrus interval in sows exposed to high environmental temperature.

Objective 4: Assess farm-level economic implications of switching to CAA from conventional protein sources in light of environmental temperature impact on sow lactation performance. We will predict the optimum level of CAA inclusion based on environmental constraint and feed costs scenarios needed to mitigate diet costs.

Materials & Methods:

The experimental protocol was approved by the Michigan State University Institutional Animal Care and Use Committee (AUF # 09/12-176-00) and followed the American Association for Laboratory Animal Science guidelines.

Objectives 1 and 2. In order to accomplish objectives 1 and 2, 2 experiments were conducted. Experiment 1 was designed to test a dietary lysine intake at which Lys would be marginally deficient in order to increase the sensitivity of the N balance response in Experiment 2 (the main experiment).

Animals and Feeding

Two experiments were conducted at the Michigan State University Swine Teaching and Research Center, with 24 and 40 purebred multiparous (parity 2+) Yorkshire sows in experiments 1 (objective 1; conducted in 1 block) and 2 (objective 2; conducted in 3 blocks), respectively. Sows were selected at d 110 of gestation, grouped by parity and within groups randomly assigned to 1 of 2 or 1 of 4 dietary treatments, in experiment 1 and 2, respectively. Sows were housed in conventional farrowing crates, and litters were standardized to 11 piglets within the first 24 h of birth with the objective of weaning 10 piglets per sow. After farrowing sows were progressively fed to reach a feed intake of 7.0 kg/d at d 12 of lactation, and an average of 6.0 kg/d over the 21-d lactation period (NRC, 2012). Feed was provided in 3 equal meals per day and intake, as well as refusal, were monitored daily. Water was provided ad libitum to both sows and piglets. Injection of iron and surgical castration were conducted on d 1 and 7, respectively. Piglets were not supplied with creep feed. In experiment 1, sows and piglets were weighed on d 1 (i.e., 24 h postpartum and after standardization of litter size) and every 3 d thereafter until weaning on d 22. In experiment 2, sows and piglets were weighed on d 1, before and after each N balance (i.e., d 3, 7, 14, and 18), and on d 21 (weaning). Sow back fat thickness and loin eye area (**LEA**) were measured between the 3rd and 4th rib on d 1 and 21. Corn oil was used as an ultrasound enhancing agent and the measurements were taken with ultrasound diagnostic equipment (ALOKA SSD-500V, Hitachi Aloka Medical, Ltd., Tokyo, Japan; 3.5 MHz probe head with a 126 mm probe and 60R, 60^{o} convex attachment) by trained personnel. Three separate measurements were taken on each sow and averaged for each scanning day.

Dietary Treatments

Ingredient and nutrient composition of diets for both experiments are presented in Table 1. Diets were formulated based on nutrient requirements that were predicted using the NRC (2012) model and based on the following performance parameters, as determined in a previous study using similar genetics (i.e. Manjarín et al., 2012): mean sow BW at farrowing of 210 kg, litter size of 10 piglets, mean piglet gain of 282 g/d during a 21-d lactation period, mean feed intake of 6 kg/d, and with the protein to lipid ratio in BW change adjusted to a near zero value. Experiment 1 was conducted to assess if Lys was marginally deficient when fed at a concentration 20% below that of the NRC (2012) predicted requirement. This level of SID Lys was then used for the formulation of diets in Experiment 2 in order to optimize the estimation of utilization efficiency of SID Lys. Therefore, in experiment 1, sows were randomly assigned 1 of 2 dietary treatments containing either 1) Low CP (12.4% CP; diet 1) or 2) Low CP + Lys (12.3% CP). Diet Low CP contained SID Lys at 20% below the NRC (2012) predicted requirement (i.e., 0.74 %) and diet Low CP + Lys contained SID Lys at the NRC (2012) predicted requirement (i.e., 0.93 %). In both diets, supplemental CAA were included to meet the requirement of the other limiting AA (i.e., Ile, Met, Thr, Trp, and Val). In experiment 2, sows were assigned 1 of 4 dietary treatments: 1) High CP (**HCP**; 16.0% CP, as-fed, analyzed contents); 2) Medium high CP (**MHCP**; 15.7% CP); 3) Medium low CP (**MLCP**; 14.3% CP); 4) Low CP (**LCP**; 13.2 % CP). All diets in experiment 2 were formulated to contain 0.74% of SID Lys (i.e., 20% below predicted requirements, as outlined in experiment 1). The HCP diet was formulated using soybean meal and corn as the only sources of Lys. The other 3 diets had decreasing inclusion of soybean meal and increasing amounts of CAA supplementation to meet requirements for the AA that became limiting with the reductions in soybean meal inclusion. The LCP diet met the predicted N requirements (NRC, 2012). A new batch of feed was mixed for each block in experiment 2 and the average nutrient composition is presented in Table 1.

Nitrogen Balance Procedure and Blood and Milk Sampling

Nitrogen balances were conducted during early lactation (between d 3 and 7) and peak lactation (between d 14 and 18) on each sow in experiment 2. Total urine collection and fecal grab sampling were performed as described by Dourmad et al. (1996) and Möhn and de Lange (1998), respectively. Briefly, Foley urinary catheters (BARDEX® I.C., 2-way, Specialty, Tiemann Model, 30cc balloon, 18FR, Bard Medical, Covington, GA) were inserted into the bladder aseptically after primary and secondary scrubs with povidone-iodine (Betadine Microbicides, Stamford, CT). Catheters were lubricated and inserted flaccidly into the urethra and the balloon inflated with 30 mL of saline solution to retain the catheter in the bladder. Urine was collected in buckets joined to the catheters with polyvinyl tubing and acidified to a pH of less than 3 using H_2SO_4. After each successful 24-h collection, a representative subsample of 10% (wt) was obtained, pooled per sow and per N balance period, and stored at 4^oC. At the end of the N balance period, the urinary catheter was removed, the pooled aliquots were mixed thoroughly, and 2 subsamples were collected and frozen at -20^oC until further analysis. Fresh and uncontaminated feces were manually collected daily, pooled per sow and per N balance period, and frozen at -20^oC until further analysis. Feed refusals were recorded daily and a subsample was collected and frozen at -20^oC until further analysis.

Blood was collected 15 h post-prandial on d 3, 7, 14, and 18 relative to farrowing (d 0) by single jugular venipuncture in experiment 2. Blood samples (8.5 mL) were collected in vacutainers (RST™ Tube with Thrombin-Based Clot Activator and Polymer Gel, BD Medical Supplies, Franklin Lakes, NJ) and centrifuged for 20 min at 1,500 × g at 4^oC. Serum was aliquoted in microcentrifuge tubes, and subsequently stored at -20^oC until further analysis.

Milk was collected on d 7 and d 18 at the end of each N balance period in experiment 2. Piglets were removed from the sows for approximately 1 h, and sows were administered 1 mL of oxytocin IM (20 IU/mL oxytocin, sodium chloride 0.9% w/v, and chlorobutanol 0.5% w/v, VetTek™, Blue Springs, MO). Approximately 50 mL of milk was manually collected across all glands on one side. Piglets were then returned to the sow and allowed to suckle. A milk subsample was defatted as outlined by Guan et al. (2004), aliquoted and stored at -20^oC until further analysis.

Nutrient Analysis

Feed was subsampled weekly from each diet, pooled within batch and homogenized before analysis. Approximately 100 g of subsampled feed was shipped to the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, Columbia, MO) for AA and N analysis [AOAC Official Method 982.30 E (a,b,c), 45.3.05, 2006 and AOAC Official Method 990.03, 2006, respectively] to verify accuracy of feed mixing. Fecal samples were homogenized after each N balance period, and a 200-g sample was freeze-dried and homogenized using a Cyclotec® 1093 sample mill (Foss; Hillerød, Denmark). The DM content of diets and feed refusal was measured via oven drying for 2 h at 135ºC according to the AOAC (1997; Method 930.15). The DM and ash content of freeze-dried feces were determined after drying at 105°C for greater than 8 h and after 5 h combustion at 500°C in a muffle furnace, respectively (Stocks and Allen, 2013).

Urinary N content was measured according to the Hach method (Hach et al., 1987) and diet and fecal N were measured at the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, Columbia, MO) via combustion method (LECO; AOAC Official Method 990.03, 2006). Titanium concentrations in feces and diets were quantified according to standard AOAC procedures in duplicate (AOAC, 1997). Absorbance of standards and samples were measured by spectrophotometry (Beckman DU-7400; Beckman Instruments, Inc., Fullerton, CA) at 407 nm.

Serum urea N (**SUN**) was measured in triplicate according to manufacturer's instructions (Stanbio Laboratory, Boerne, TX) in 96-well plates. Standards were prepared at concentrations of 1.875, 3.750, 7.500, 15.000, and 30.000 mg urea/dL and 1 µL of each standard or sample was pipetted into each well. The plates were read with a microplate spectophotometer (SpectraMax Plus384; Molecular Devices, Sunnyvale, CA) at 340 nm.

Whole milk samples were analyzed for protein, lactose, total solids, and milk urea N (**MUN**) with infrared spectroscopy by the Michigan Dairy Herd Improvement Association (NorthStar Cooperative, Lansing, MI). Milk casein concentration was determined according to Guan et al. (2002).

Calculations and Statistical Analysis

Daily N retention was calculated as described by Möhn and de Lange (1998), with N retention including the N output in milk. Daily N intake was calculated from feed intake, feed wastage, and the analyzed N content of diet (Table 1), and N excretion was calculated from fecal and urinary N output (Möhn and de Lange, 1998). Fecal N output was calculated from N intake and apparent fecal N digestibility, with N digestibility estimated using titanium dioxide as an indigestible marker (Zhu et al., 2005). Sow milk yield was estimated according to NRC (2012) using 21 d litter growth rate (**LGR**), litter size, and a standard lactation curve (NRC, 2012; Eq. 8-71 and 8-72). Nitrogen output with true milk protein was estimated using analyzed true milk protein concentration and estimated milk yield. Nitrogen utilization efficiency was calculated and expressed several ways, including the efficiency of using either dietary N, absorbed N, or retained N for true milk protein production. For Experiment 1, the efficiency of using standardized ileal digestible (**SID**) Lys (based on analyzed dietary Lys concentration and estimated SID) for Lys output in milk protein was calculated according to NRC (2012). The efficiency calculation accounted for maternal maintenance requirements and the estimated contribution of maternal body protein mobilization based on sow BW change.

Statistical analysis of experiment 1 consisted of a student's t-test to evaluate the effect of dietary treatment with diet as fixed effect, and the number of piglets nursed, parity, and sow feed intake as covariates. When appropriate, a reduced model was used and only the main effects of dietary treatment are presented over the entire lactation. Statistical analyses of growth performance, milk composition, N balance and SUN in experiment 2 were conducted using the mixed model procedure of SAS with the repeated measure of day of lactation (excluding sow BW, LEA and back fat changes, which were analyzed as in experiment 1; SAS Inst. Inc., Cary, NC). In experiment 2, linear and quadratic contrasts were constructed to compare responses to dietary CP concentration during both early and peak lactation. Multiple contrasts were also constructed to compare each diet with the subsequent reduced dietary CP concentration in early and peak lactation, respectively.

Objective 3. All animal management and care are as described above in objectives 1 and 2.

Animals, dietary treatments and feeding regimen. Sow breed, parity and management was be as described under objectives 1 and 2, except that 1 dietary treatment was be tested against the Control diet as followed: 19.36% CP (Control) and 12.81% (Low). This objective was conducted using 36 sows in 3 replicated studies with 12 sows per replicate. For each replicate, sows were allocated to a 2 × 2 factorial arrangement of 2 environmental temperature (thermo-neutral and heat stress) and 2 diets (Control and Low) containing 17.36 %

CP (no CAA) and 12.81% CP + Lys, Thr, Met, Trp, Val, Ile, respectively) (4 sows/ treatment/ replicate). Sows were moved to the MSU Animal Air Quality Research Facility (AAQRF) 7 days prior to the expected farrowing date and housed in individual environmentally controlled rooms (2.14×3.97×2.59 m) each equipped with an elevated farrowing crate, and designed to continuously monitor incoming and exhaust concentrations of gases (Powers et al., 2007). Sows were fed at 0800, 1500, and 1900. Sows subjected to the heat stress treatment were be adapted to increasing environmental temperature over a 7-day period, with the basal temperature of 21 °C increased by 1.5 °C per day to a maximum of 31.5 °C by day 7 (~ day 114 of gestation). By day 3, when temperature begins exceeding 24°C, temperature was gradually decreased overnight to reach 24°C at 0500. During lactation, every day, the temperature was gradually increased from 24 °C beginning at 0500 to a maximum of 31.5 °C at 1500 and maintained at 31.5 °C until 1800. The temperature was gradually decreased beginning at 1800 until 0500 to reach 24 °C.

Assessment of lactation performance and nutrient utilization. Sows and individual piglets will be weighed as described under Obj.1 and urine and fecal samples were collected using a large metal pan placed under each farrowing crate. Body temperature and respiration rate was recorded at 0700 and 1700. All nutrient and sample analyses were performed as described under objectives 1 and 2.

Measurements of Gaseous Concentrations. Each of the 12 rooms was sampled for a 15-min period every 195 min as described by Li et al. (2011), with line purged for the first 10 min and data saved for the remaining 5 min of the sampling period (concentration readings every 0.5 min and averaged over the 10 readings). A background sample was be collected for baseline readings for each 15-min sampling. CO_2, O_2, Ammonia (NH_3), methane (CH_4) and H_2S were be measured at outlined in Li et al. (2011). Gaseous concentrations were monitored for each room in a sequential manner through software control (Lab-VIEW, National Instruments Corp., Austin, TX). The daily mass of emitted gas was calculated by summing the mass emitted during each sampling period for that day (Powers et al., 2007). All emission factors were calculated from the emission mass, which was calculated based on the emission rate (the product of concentration and airflow). Gas emission rates were calculated as the product of ventilation rates and concentration differences between exhaust and incoming air as described by Li et al. (2011). Emissions in 1 full measurement cycle was estimated by multiplying the ER (g/min) by 195 min per cycle. Cumulative daily emissions were calculated as the sum of the mass from each of 7 or 8 daily measurement cycles. Heat production was estimated by measuring VCO2/ VO2 as described by Tess et al. (1984) and Nienaber et al. (1980).

Statistical Analysis. Emission, heat production, nutrient utilization and lactation performance data were analyzed using the MIXED model procedure of SAS. The model included the effects of diet, environment, diet × environment, phase of lactation (early: day 1 through 6; mid: day 7 through 13; peak: day 14 through 19), replicate, and sow nested within diet × environment.

Results (by objective):

Results for Objectives 1 and 2 (Tables 1 through 6)

Objective 1: Evaluate lactation performance in sows fed diets with four graded levels of CAA as substitute for CP. We will test the hypothesis that feeding diets reduced in CP with CAA to meet the limiting AA requirements improves milk production and increases piglet quality at weaning.
Objective 2: Assess dietary N and lysine utilization in sows fed diets with graded levels of CAA as substitute for CP. We will test the hypothesis that feeding diets reduced in CP with CAA to meet the limiting AA requirements increases lysine and N utilization and reduces N excretion.

Nutrient analysis for each diet in experiments 1 and 2 showed that CP and AA concentrations were comparable to calculated values (Table 1). In experiment 1 there were 11 sows per dietary treatment. In experiment 2 one sow on the LCP treatment did not have the urinary catheter inserted for the N balance period in early lactation (i.e., on d 3) due to prolonged farrowing, but recovered and was part of the N balance period in peak lactation. One sow from each the HCP and MLCP diet were removed due to illness before the N balance period in peak lactation (i.e., before d 14), and therefore any previous data collected from these sows were removed before analysis.

In experiment 1, estimated daily SID Lys intake over the 22-d lactation period was greater in sows fed the LCP + Lys diet versus sows fed the LCP diet ($P < .0001$; Table 2). Sow BW, LGR and sow feed intake did not differ between the LCP + Lys and LCP diets over the 22-d lactation period. Serum urea-N concentration tended to be greater ($P = 0.106$) in sows fed the LCP diet versus sows fed the LCP + Lys diet on d 7 of lactation and the efficiency of using SID Lys for milk protein production was greater in sows fed the LCP versus LCP + Lys diet ($P < 0.01$).

In experiment 2, sow initial BW, feed intake and litter size did not differ between dietary treatments (Table 3). Litter growth rate tended to increase with decreasing dietary CP concentration (Linear, P = 0.084) but there was no effect of dietary CP concentration on piglet ADG. Sow LEA loss tended to increase (Linear, P = 0.082) as dietary CP concentration decreased, and sow overall BW change and back fat thickness were not affected by dietary treatment. In experiment 2, milk yield and N balance responses were most sensitive during peak lactation, even though there was no interaction between dietary CP concentration and stage of lactation. Results are presented within both stages of lactation; main effects of dietary CP concentration and stage of lactation are not presented.

In early lactation, estimated milk yield, true milk protein and casein concentration, and true milk protein and casein output did not differ across diets, MUN decreased (Linear, P < 0.01) and lactose concentration increased with decreasing dietary CP concentration (Linear, P < 0.05); sows fed MHCP tended to have greater milk yield than sows fed HCP diet ($P = 0.099$) and sows fed MHCP diet had greater MUN than sows fed MLCP diet ($P < 0.05$; Table 4). In peak lactation, estimated milk yield increased with decreasing dietary CP concentration (Linear, $P < 0.05$); sows fed the MHCP diet had a greater estimated milk yield than sows fed the HCP diet ($P < 0.05$; Table 4). True milk protein, and casein concentrations did not differ between treatments, however, true protein and casein yield increased with decreasing dietary CP concentration (Linear, P < 0.05). Milk urea-N decreased with decreasing dietary CP concentration (Linear, $P < 0.01$; Quadratic, $P < 0.05$); sows fed MLCP had greater MUN than sows fed LCP diet ($P < 0.05$).

In early and peak lactation, N intake, N absorbed (intake – excreted in feces), total N excreted (urine + feces), and N excreted in urine decreased with decreasing dietary CP concentration (Linear, $P < 0.05$; Table 5). In peak lactation sow N intake and N absorbed were greater for sows fed the MHCP diet than sows fed the LCP diet ($P < 0.05$), total N excreted tended to be greater for sows fed the MHCP diet than sows fed the MLCP diet ($P = 0.093$), and urinary N excretion was greater for sows fed the MHCP diet than sows fed the MLCP diet ($P < 0.05$).

During both early and peak lactation, daily urine produced and N excreted in feces did not differ between dietary treatments. During the early lactation N balance period, N retention (N intake – N output in urine and feces) did not differ between dietary treatments, and N retained as a percentage of N intake tended to increase with decreasing CP concentration (Linear, $P = 0.093$). During peak lactation, N retention decreased with decreasing dietary CP concentration (Linear, $P < 0.05$) and the efficiency of retaining consumed N did not differ between diets; N retention tended to be greater for sows fed the MLCP diet than sows fed the LCP diet in peak lactation ($P = 0.072$). During both the early and peak lactation N balance periods, the efficiency of retaining absorbed N increased (Linear, $P = 0.063$ and $P < 0.05$, respectively) with decreasing dietary CP concentration, and tended to be higher for sows fed the MLCP diet than sows fed the MHCP diet ($P = 0.082$) in peak lactation. True milk protein N yield and the efficiency of using retained N for milk protein did not differ between diets during the early lactation N balance period and increased with decreasing dietary CP concentration during the peak lactation N balance period (Linear, $P < 0.05$); true milk protein N output tended to be greater in sows fed the MHCP diet than sows fed the HCP diet in peak lactation ($P = 0.076$). Decreasing dietary CP concentration tended to decrease SUN on d 3 (Linear, $P = 0.073$), and decreased SUN on d 7, d 14, and d 18 (Linear, $P < 0.05$; Table 6). On d 3 sows fed the MLCP diet tended to have greater SUN concentration than sows fed the LCP diet ($P = 0.098$). On d 7, 14, and 18 sows fed the MHCP diet had greater SUN concentration than sows fed the MLCP diet ($P < 0.05$, $P = 0.078$ and $P = 0.070$ for days 7, 14, and 18, respectively).

Table 1. Ingredient composition and nutrient content of experimental diets (as-fed)

	Experiment 1		Experiment 2			
	Low CP	Low CP + Lys	HCP[1]	MHCP	MLCP	LCP
Ingredient composition, %						
Corn	66.40	66.15	64.57	66.38	66.92	67.49
Soybean meal, 48 % CP	11.73	11.73	23.00	19.32	15.55	11.73
Choice white grease	4.49	4.49	3.33	3.36	3.74	4.09
Soy hulls	6.73	6.73	0	1.50	3.97	6.50
Sugar food product[2]	5.00	5.00	5.00	5.00	5.00	5.00
L-Lys·HCl	0.33	0.58	0	0.11	0.22	0.33
L-Ile	0.14	0.14	0	0.01	0.07	0.14
DL-Met	0.15	0.15	0.03	0.07	0.11	0.14
L-Thr	0.25	0.25	0.09	0.14	0.19	0.25
L-Trp	0.07	0.07	0.01	0.03	0.05	0.07
L-Val	0.36	0.36	0.16	0.23	0.29	0.36
Vitamin mix[3]	0.25	0.25	0.25	0.25	0.25	0.25
Mineral mix[4]	0.125	0.125	0.125	0.125	0.125	0.125
Sow pack [5]	0.25	0.25	0.25	0.25	0.25	0.25
Se 200	0.068	0.068	0.068	0.068	0.068	0.068
Sodium chloride	0.50	0.50	0.50	0.50	0.50	0.50
Limestone	1.38	1.38	1.17	1.16	1.15	1.11
Monocalcium phosphate	1.78	1.78	1.35	1.40	1.45	1.50
Titanium dioxide	0	0	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutrient content[6]						
NE, Kcal/kg	2600	2602	2600	2600	2600	2600
CP, %	12.82	13.03	16.58	15.35	14.15	12.89
SID Lys, %[7]	0.74	0.93	0.74	0.74	0.74	0.74
SID Ile, %	0.53	0.53	0.59	0.53	0.53	0.53
SID Met + Cys, %	0.50	0.50	0.50	0.50	0.50	0.50
SID Thr, %	0.59	0.59	0.59	0.59	0.59	0.59
SID Trp, %	0.18	0.18	0.18	0.18	0.18	0.18
SID Val, %	0.81	0.81	0.81	0.81	0.81	0.81
SID Arg, %	0.63	0.63	0.95	0.85	0.74	0.63
SID His, %	0.28	0.28	0.39	0.36	0.32	0.28
SID Leu, %	0.96	0.96	1.27	1.18	1.08	0.97
SID Phe, %	0.49	0.49	0.70	0.63	0.56	0.49
SID Phe + Tyr, %	0.81	0.81	1.15	1.05	0.93	0.82
STTD P, %	0.49	0.49	0.44	0.44	0.44	0.44
Total Ca, %	1.02	1.02	0.88	0.88	0.88	0.89
Fermentable fiber, %	10.00	9.98	10.25	10.00	10.00	10.00
Analyzed nutrient content, %						

DM	89.65	90.33	89.95	89.89	90.08	89.90
CP	12.43	12.34	16.03	15.70	14.29	13.22
Lys	0.83 (0.84) [8]	0.98 (1.03)	0.90 (0.86)	0.91 (0.85)	0.88 (0.85)	0.87 (0.84)
Ile	0.60 (0.60)	0.57 (0.60)	0.69 (0.67)	0.70 (0.62)	0.64 (0.60)	0.62 (0.60)
Met + Cys	0.42 (0.58)	0.43 (0.58)	0.54 (0.58)	0.53 (0.58)	0.53 (0.58)	0.52 (0.57)
Thr	0.62 (0.68)	0.60 (0.68)	0.67 (0.70)	0.67 (0.69)	0.65 (0.68)	0.65 (0.68)
Trp	0.18 (0.19)	0.16 (0.19)	0.22 (0.20)	0.23 (0.20)	0.21 (0.20)	0.20 (0.19)
Val	0.88 (0.90)	0.82 (0.90)	0.97 (0.92)	0.98 (0.92)	0.93 (0.91)	0.92 (0.91)
Arg	0.67 (0.69)	0.65 (0.69)	1.05 (1.03)	0.98 (0.92)	0.85 (0.81)	0.71 (0.69)
His	0.30 (0.33)	0.29 (0.33)	0.43 (0.45)	0.41 (0.41)	0.37 (0.37)	0.32 (0.33)
Leu	1.12 (1.11)	1.06 (1.11)	1.53 (1.45)	1.47 (1.35)	1.32 (1.24)	1.16 (1.12)
Phe	0.57 (0.57)	0.54 (0.57)	0.83 (0.80)	0.79 (0.73)	0.69 (0.65)	0.59 (0.58)
Phe + Tyr	0.96 (0.96)	0.92 (0.96)	1.40 (1.34)	1.33 (1.22)	1.18 (1.09)	1.02 (0.97)

[1]HCP: 16.0% CP (as-fed; analyzed contents); MHCP: 15.7% CP; MLCP: 14.3% CP; LCP 13.2% CP.
[2]Sugar food product (International Ingredient Corporation, St. Louis, MO) to increase diet palatability supplied per kg: NE 2842 kcal; fermentable fiber 0.05 %; CP 1.00 %.
[3]Provided the following amounts of vitamins per kg of diet: vitamin A, 3,000 IU; vitamin D_3, 300 IU; vitamin E, 20 IU; menadione (vitamin K), 1 mg; vitamin B_{12}, 20 µg; riboflavin, 4 mg; d-pantothenic acid, 10 mg; niacin, 15 mg.
[4]Provided the following amounts of trace minerals per kg of diet: Fe, 640 mg as $FeCO_3$; Zn, 260 mg as ZnO; Mn, 36 mg as MnO_2; Cu, 20 mg as $CuCl_2$; I, 0.58 mg as ethylenediamine dihydroiodide.
[5]Provided the following amounts of vitamins per kg of diet: biotin, 0.10 mg; choline, 250 mg as choline chloride; folic acid, 0.75 mg; vitamin B_6, 2.3 mg as pyridoxine HCl; vitamin E, 10 IU as dl-tocophorol acetate; chromium, 90 µg as chromium picolinate; carnitine, 23 mg as L-carnitine.
[6]Based on nutrient content in feed ingredients according to NRC (2012).
[7]SID: standardized ileal digestible (NRC, 2012).
[8]Calculated amino acid contents are shown in parentheses.

Table 2. Sow and litter performance in experiment 1over a 22 d lactation period

Item	Low CP	Low CP + Lys	SEM[1]	*P*-value[2]
No. of sows	11	11		
Parity	3.7	3.8	0.3	-
Sow initial BW, kg	222	227	4	0.529
Sow ADFI, kg/d, as-fed	6.12	6.00	0.02	0.195
Estimated SID Lys intake, g/d[3]	44.7	53.2	0.5	<.0001
Litter size at weaning	9.7	9.8	0.1	0.510
Litter growth rate, kg/d	2.53	2.57	0.06	0.627
Piglet ADG, g/d	268	271	9	0.857
Sow BW change, kg	-4.5	-2.6	1.8	0.475
Sow serum urea N overall, mg/dL	7.6	6.7	0.5	0.169
Sow serum urea N d 7, mg/dL	7.4	6.2	0.5	0.106
Sow serum urea N d 14, mg/dL	7.9	7.2	0.5	0.319
Lys utilization efficiency, %[4]	72.3	58.2	2.5	0.009

[1] Maximum value of the standard error of the means.
[2] *P*-value is overall effect of dietary treatment.
[3] Based on estimated SID of Lys (NRC, 2012) and analyzed total Lys in the diets.
[4] For milk production; calculated according to NRC (2012) and corrected for Lys requirements for maintenance and sow BW change.

Table 3. Sow and litter growth performance in experiment 2 for sows fed high CP (16.0 %) or reduced CP diets over a 21-d lactation period

	Diet					*P* - value		*P*- value		
Item	HCP[2]	MHCP	MLCP	LCP	SEM[1]	Linear	Quadratic	HCP vs MHCP	MHCP vs MLCP	MLCP vs LCP
No. of sows	9	10	9	10						
Parity	3.7	3.3	3.5	3.5	0.5	-	-	-	-	-
Sow initial BW, kg	237	235	243	236	5	0.816	0.697	0.700	0.246	0.353
Sow ADFI, kg/d, as-fed	5.48	5.70	5.76	5.74	0.14	0.165	0.373	0.251	0.756	0.946
Litter size at weaning	10.0	10.2	10.1	10.3	0.2	0.343	0.869	0.406	0.730	0.526
Litter growth rate, kg/d	2.32	2.53	2.41	2.60	0.21	0.084	0.911	0.122	0.358	0.132
Piglet ADG, g/d	238	256	243	260	22	0.215	0.907	0.168	0.285	0.183
Sow BW change, kg	-3.0	-3.7	-4.0	-6.0	3.4	0.530	0.833	0.883	0.948	0.648
Sow loin eye area change, cm^2	0.2	-0.8	-1.2	-2.7	1.2	0.082	0.795	0.547	0.808	0.318
Sow back fat change, mm	-0.1	-0.2	-0.1	-0.2	0.08	0.584	0.935	0.394	0.327	0.313

[1] Maximum value of the standard error of the means.

[2] HCP: 16.0% CP (as-fed; analyzed contents); MHCP: 15.7% CP; MLCP: 14.3% CP; LCP 13.2% CP.

Table 4. Milk composition from sows fed high CP (16.0 %) or reduced CP diets between d 3 and 7 of lactation (early lactation) and between d 14 and 18 of lactation (peak lactation)

Item	Diet				SEM[1]	*P* - value		*P* - value		
	HCP[2]	MHCP	MLCP	LCP		Linear	Quadratic	HCP vs MHCP	MHCP vs MLCP	MLCP vs LCP
Early lactation (d 3-7)										
Estimated milk yield, kg/d[3]	5.91	6.76	6.37	6.87	0.36	0.122	0.625	0.099	0.420	0.298
True protein content, %	5.17	5.07	5.38	5.23	0.29	0.365	0.840	0.391	0.177	0.517
True protein output, g/d	311	349	343	361	22	0.147	0.635	0.218	0.845	0.554
Casein, % in defatted milk	3.63	3.30	3.64	3.50	0.17	0.926	0.560	0.152	0.146	0.552
Casein output, g/d	220	225	229	239	17	0.407	0.856	0.856	0.829	0.657
Urea nitrogen, mg/dL	7.55	9.42	5.38	3.42	1.21	0.003	0.099	0.243	0.014	0.239
Lactose content, %	5.60	5.74	5.71	5.82	0.19	0.033	0.902	0.161	0.895	0.577
Peak lactation (d 14-18)										
Estimated milk yield, kg/d	8.42	9.61	9.02	9.75	0.36	0.036	0.502	0.022	0.224	0.135
True protein, %	4.15	4.18	4.02	4.43	0.20	0.194	0.165	0.806	0.466	0.104
True protein, g/d	347	402	380	431	22	0.011	0.472	0.076	0.458	0.411
Casein, % in defatted milk	3.29	3.21	3.38	3.41	0.17	0.486	0.744	0.731	0.472	0.906
Casein, g/d	281	310	305	332	17	0.051	0.934	0.215	0.828	0.249
Urea nitrogen, mg/dl	10.99	11.84	10.58	6.74	1.21	0.009	0.048	0.605	0.447	0.023
Lactose, %	5.78	5.88	5.73	5.78	0.20	0.583	0.841	0.324	0.486	0.801

[1] Maximum value of the standard error of the means.
[2] HCP: 16.0% CP (as-fed; analyzed contents); MHCP: 15.7% CP; MLCP: 14.3% CP; LCP 13.2% CP.
[3] Estimated milk yield based on measured 21 d litter growth rate, litter size and a standard lactation curve (NRC, 2012).

Table 5. Nitrogen utilization in sows fed high CP (16.0%) or reduced CP diets between d 3 and 7 of lactation (early lactation) and between d 14 and 18 of lactation (peak lactation)

Item	Diet				SEM[1]	*P* - value		*P*- value		
	HCP[2]	MHCP	MLCP	LCP		Linear	Quadratic	HCP vs MHCP	MHCP vs MLCP	MLCP vs LCP
Early lactation (d 3-7)[3]										
No. of sows	10	10	10	9						
Feed intake, kg/d, DM	4.0	3.8	4.2	4.2	0.2	0.272	0.590	0.401	0.458	0.514
Sow body weight change, kg/d[4]	-0.26	-0.99	-0.66	-0.80	0.41	0.460	0.445	0.176	0.542	0.804
Total Lys intake, g/d[5]	39.9	38.6	42.3	39.7	1.9	0.686	0.737	0.588	0.136	0.327
Estimated SID Lys intake, g/d[6]	33.8	33.6	37.1	35.0	1.7	0.340	0.557	0.942	0.118	0.367
N intake, g/d	114.3	106.0	107.4	99.0	5.3	0.055	0.997	0.232	0.839	0.250
Total N excretion, g/d	42.7	35.3	36.0	31.7	2.7	0.010	0.549	0.047	0.843	0.258
Fecal N, g/d	13.1	12.3	12.6	11.2	1.3	0.313	0.793	0.624	0.851	0.406
Urinary N, g/d	29.6	23.0	23.4	20.5	1.9	0.002	0.300	0.010	0.869	0.267
N retention, g/d[7]	71.6	70.7	71.4	67.4	4.9	0.567	0.736	0.887	0.913	0.547
N absorbed, g/d[8]	101.2	93.7	94.8	87.8	4.6	0.052	0.947	0.213	0.854	0.270
True milk protein N, g/d[9]	48.7	54.7	53.8	56.6	3.5	0.147	0.635	0.218	0.845	0.554
Urine weight, kg/d	12.0	8.0	7.6	7.2	2.2	0.129	0.395	0.186	0.870	0.914
N retained, % of intake	62.3	66.7	66.3	68.0	2.2	0.093	0.512	0.141	0.896	0.595
N retained, % of absorbed	70.3	75.2	75.2	76.5	2.3	0.063	0.401	0.102	0.982	0.662
True milk protein N output, % of retained N	74.1	80.7	76.4	85.4	5.9	0.258	0.837	0.412	0.580	0.263
Peak lactation (d 14-18)										
No. of sows	9	10	9	10						
Feed intake, kg/d, DM	6.0	6.0	6.3	6.2	0.2	0.255	0.658	0.809	0.231	0.386
Sow body weight change, kg/d[10]	-0.20	-0.09	0.00	-0.16	0.41	0.907	0.740	0.856	0.863	0.774
Total Lys intake, g/d	59.2	61.3	61.0	58.7	1.9	0.853	0.253	0.438	0.926	0.398
Estimated SID Lys intake, g/d	51.2	53.3	53.3	51.7	1.7	0.821	0.254	0.353	0.999	0.490
N intake, g/d, DM	169.5	168.3	161.2	145.1	5.3	0.001	0.150	0.861	0.330	0.029

Total N excretion, g/d	47.2	44.5	40.0	36.1	1.9	<.001	0.735	0.323	0.093	0.148
Fecal N, g/d	19.6	18.4	19.9	19.3	1.3	0.944	0.787	0.450	0.367	0.707
Urinary N, g/d	27.4	26.2	20.1	16.8	1.9	<.001	0.591	0.622	0.022	0.213
N retention, g/d	122.5	123.8	121.2	109.0	4.9	0.045	0.158	0.851	0.697	0.072
N absorbed, g/d	149.9	149.9	141.3	125.8	4.6	<.001	0.084	0.995	0.172	0.016
True milk protein N, g/d	54.4	63.2	63.8	67.6	3.5	0.011	0.472	0.076	0.901	0.411
Urine weight, kg/d	10.3	11.9	8.3	7.8	2.2	0.244	0.621	0.589	0.229	0.874
N retained, % of intake	72.7	73.2	75.1	75.0	1.3	0.111	0.801	0.761	0.275	0.959
N retained, % of absorbed	82.0	82.1	85.7	86.4	1.4	0.012	0.823	0.950	0.082	0.705
True milk protein N, % of retained N	44.5	51.0	54.9	62.9	5.9	0.025	0.892	0.425	0.628	0.318

[1] Maximum value of the standard error of the means.

[2] HCP: 16.0% CP (as-fed; analyzed contents); MHCP: 15.7% CP; MLCP: 14.3% CP; LCP 13.2% CP.

[3] The main effect of period was significant for all variables except urinary N excretion and urine weight ($P < 0.05$).

[4] Between d 1 and 7 (early lactation).

[5] Total Lys intake calculated with analyzed total Lys content (% in DM) and sow DM intake.

[6] Based on estimated SID of Lys (NRC, 2012) and analyzed total Lys in the diets.

[7] N intake – N excreted in feces – N excreted in urine.

[8] N intake – N excreted in feces.

[9] Calculated based on true protein content of milk and predicted milk output (NRC, 2012; Table 4).

[10] Between d 14 and 21 (peak lactation).

Table 6. Serum urea nitrogen concentration in sows fed high CP (16.0 %) or reduced CP diets during lactation, mg/dL

Day	Diet				SEM[1]	*P* - value		*P* - value		
	HCP[2]	MHCP	MLCP	LCP		Linear	Quadratic	HCP vs MHCP	MHCP vs MLCP	MLCP vs LCP
3	9.1	10.6	9.1	7.1	1.3	0.073	0.100	0.409	0.397	0.098
7	11.7	11.0	7.0	6.9	1.3	<.0001	0.761	0.669	0.021	0.940
14	12.5	10.9	7.9	7.0	1.3	<.0001	0.746	0.356	0.078	0.477
18	11.0	13.0	9.8	8.8	1.3	0.033	0.169	0.261	0.070	0.431

[1] Maximum value of the standard error of the means.

[2] HCP: 16.0% CP (as-fed; analyzed contents); MHCP: 15.7% CP; MLCP: 14.3% CP; LCP 13.2% CP.

Results for Objective 3 (Tables 7 through 13 and Figures 1 through 5): Measure the energetic efficiency in sows fed diets with three graded levels of CAA as substitute for CP under thermo neutral (TN) and heat stress (HS) environment. We will test the hypothesis that feeding diets reduced in CP with CAA reduces heat production, improves lactation performance and reduce weaning to estrus interval in sows exposed to high environmental temperature.

Diet (Control and Low) ingredient composition and calculated and analyzed nutrient concentration are presented in Tables 7, 8 and 9. Analyzed CP and amino acid closely aligned with the calculated values. Sow core body temperature, respiration rate and heart rate are presented in Table 10. Exposure to HS increased respiration ($P < 0.01$) and heart rate ($P < 0.05$), in particular in the afternoon but these parameters were not reduced by feeding a Low CP diet compared to Control diet. Exposure to HS decreased sow voluntary feed intake (Table 11 and Figure 1) ($P < 0.001$), piglet ADG (Table 11 and Figure 2) and litter growth 11) ($P < 0.01$), increased weight loss ($P < 0.05$) but did not impact litter size at weaning, backfat thickness or return to estrus (Table 1).

Under TN environment during peak lactation, sows fed the Low diet had higher feed intake ($P < 0.05$) compared to Control (Figure 4). Feed intake of sows was not impacted by diets during the overall lactation period under either environment. Piglet ADG (Table 11 and Figure 3), litter growth rate, sow body weight and backfat loss, and return to estrus did not differ between diets (Table 11). Milk nutrient concentrations including fat, lactose, true protein and casein did not differ between diets or environments (Table 12).

Sows fed the Low diet had lower ($P < 0.001$) milk urea N (Table 12 and Figure 3) and urinary urea N excretion (Figure 3) compared to Control fed sows during both early and peak lactation. Sows fed the Low diet had dramatic decrease ($P < 0.001$) in ammonia emissions compared to sows fed Control (Table 13), in particular during peak lactation period (Figure 4). Sows fed the Control (High) under HS had lower ($P < 0.05$) ammonia emissions compared to sows fed Control (High) under TN because of their reduced feed intake under HS compared to TN.

Elimination of CO_2 and consumption of O_2 (Figure 5) increased ($P < 0.001$) with advancement of lactation, reflecting increased metabolic demand for milk production and piglet growth. Heat stress increased ($P < 0.01$) O_2 consumption and did not affect CO_2 elimination (Table 13). Heat production (Table 13) was unaffected by diet and was higher ($P < .01$) under heat stress environment when expressed relative to metabolic body weight. CH_4 emission was higher ($P < 0.01$) for sows fed reduced CP diet under both thermo-neutral and heat stress environments.

Table 7. Ingredient composition of diets

Item	High	Low
Corn	61.64	65.57
Soybean meal, dehulled, solvent extracted	25.20	11.73
Choice white grease	3.82	4.77
Sugar food by-product[1]	5.00	5.00
Soybean Hulls	-	7.50
L- Lys·HCl	-	0.41
L-Val	-	0.21
L-Thr	-	0.15
L-Trp	-	0.04
DL-Met	-	0.06
L-Phe	-	0.07
L-Ile	-	0.04
Limestone	1.45	1.38
Mono calcium phosphate	1.60	1.78
Vitamin premix[2]	0.25	0.25
Mineral premix[3]	0.125	0.125
Sow pack[4]	0.25	0.25
Se 270[5]	0.0675	0.0675
Salt	0.50	0.50
Titanium oxide	0.10	0.10
Total	100.00	100.00

[1]CP 1.00 %; NE = 2719 kcal/kg (estimated using ME equation of Noblet et al. (2003)); fermentable fiber 0.05 % (International Ingredient Corporation, St. Louis, MO).
[2]Vitamin Premix provided the following per kg of diet: 3,000 IU vitamin A, 300 IU vitamin D_3, 20 IU vitamin E, 1 mg menadione (vitamin K), 20 µg vitamin B_{12}, 4 mg riboflavin, 10 mg D-pantothenic acid, 15 mg niacin.
[3]Mineral Premix provided the following per kg of diet: 640 mg Fe (as $FeCO_3$), 260 mg Zn (as ZnO), 36 mg Mn (as MnO_2), 20 mg Cu (as $CuCl_2$), 0.58 mg I (as ethylenediamine dihydroiodide).
[4]Sow Pack provided the following per kg of diet: 0.10 mg biotin, 250 mg choline (as choline chloride), 0.75 mg folic acid, 2.3 mg vitamin B_6 (as pyridoxine·HCl), 10 IU vitamin E (as DL-tocophorol acetate), 90 µg chromium (as chromium picolinate), 23 mg carnitine (as L-carnitine).
[5]Se 270 mg premix as Na_2SeO_3 (Cargill Incorporated, Minneapolis, MN).

Table 8. Calculated nutrient composition of diets

Item	High	Low
Net energy, kcal/kg	2582	2582
Fermentable fiber, %	10.58	10.22
Total P, %	0.68	0.65
Standardized total digestible P, %	0.74	0.44
Carbon, %	38.09	38.17
Ca, %	0.89	0.89
SID[2] CP, %	14.57	9.74
SID AA		
Arg, %	1.02	0.63
His, %	0.41	0.28
Ile, %	0.62	0.43
Leu, %	1.32	0.96
Lys, %	0.78	0.78
Met, %	0.24	0.23
Met + Cystine, %	0.48	0.41
Phe, %	0.74	0.56
Phe-Tyr, %	1.22	0.81
Thr, %	0.53	0.49
Trp, %	0.18	0.15
Val, %	0.68	0.66
SID Lys/NE, g/Mcal	3.013	3.030

[1]Nutrient values were calculatedbased on feed ingredient nutrient composition (NRC, 2012).
[2]Standardized Ileal Digestible.

Table 9. Calculated and analyzed crude protein and amino acid composition of diets

Amino acid	High		Low	
	Calculated	Analyzed	Calculated	Analyzed
Crude Protein	17.16	17.33	11.82	12.19
Essential				
Arginine	1.10	1.06	0.69	0.66
Histidine	0.47	0.49	0.33	0.36
Isoleucine	0.71	0.73	0.46	0.52
Leucine	1.50	1.51	1.11	1.12
Lysine	0.90	0.92	0.88	0.90
Methionine	0.28	0.25	0.27	0.23
Phenylalanine	0.85	0.86	0.64	0.66
Threonine	0.64	0.65	0.58	0.57
Tryptophan	0.20	0.21	0.16	0.16
Valine	0.80	0.79	0.76	0.75
Non-essential				
Taurine	-	0.15	-	0.16
Aspartic Acid[2]	-	1.70	-	1.09
Serine	-	0.79	-	0.55
Glutamic Acid[3]	-	2.96	-	2.03
Proline	-	1.01	-	0.77
Glycine	-	0.69	-	0.51
Alanine	-	0.86	-	0.65
Cysteine	-	0.26	-	0.19
Tyrosine	-	0.54	-	0.40

[1]Calculated values for CP and essential AA based on feed ingredient nutrient composition (NRC, 2012).

[2]Aspartate + Asparagine.

[3]Glutamate + Glutamine.

Table 10. Sow core body temperature, respiration rate and heart rate taken in the morning (AM) and late afternoon (PM) under thermoneutral and heat stress environments, and during early and peak lactation

Item	Early Lactation				Peak Lactation				SEM	*P*-value						
	TN		HS		TN		HS									
	AM	PM	AM	PM	AM	PM	AM	PM		Env	Stage	Env* Stage	Time	Env* Time	Time* Stage	Env* Time* Stage
Core body temp, C°	38.9	39.0	37.1	39.5	38.2	37.0	39.2	36.0	1.1	0.42	0.26	0.08	0.14	0.23	0.03	0.05
Respiration Rate, breath/min	49	68	76	100	53	70	83	88	5	<0.01	0.13	0.47	<0.01	0.60	0.13	0.26
Heart Rate, beat/min	89	66	85	86	93	71	93	85	6	0.02	0.03	0.27	<0.01	<0.01	0.67	0.33

Table 11. Sow and Litter Performance from day 1 to 21 of lactation

Item	Thermo-Neutral (TN)		Heat Stress (HS)		SEM	*P*-value	
	Control	Low	Control	Low		Diet	Env
Number of sows	9	9	9	8			
Feed intake, kg/d	5.17	5.51	3.67	4.33	0.39	0.15	<0.001
Litter size at weaning	9.9	10.0	9.8	9.8	0.2	0.75	0.27
Litter growth/d	2.6	2.8	2.4	2.3	0.1	0.51	<0.01
Piglet ADG, g	265	279	244	238	11	0.56	<0.01
Sow BW change, kg/d	-0.5	-0.3	-0.7	-0.8	0.19	0.76	0.03
Sow backfat change, cm	-1.4	-2.7	-3.2	-2.1	0.99	0.89	0.51
Return to estrous, d	7.6	6.9	6.6	5.3	1.19	0.37	0.28

Table 12. Nutrient composition of whole milk

Item	Early Lactation				Peak Lactation				SEM	Diet	Env	Diet* Env	Stage	Diet* Stage
	Thermo-Neutral		Heat Stress		Thermo-Neutral		Heat Stress							
	Control	Low	Control	Low	Control	Low	Control	Low						
Fat, %	9.00	9.40	9.68	9.81	8.75	8.69	8.37	8.74	0.61	0.52	0.56	0.9	0.01	0.86
True protein, %	4.87	4.69	5.13	4.96	4.21	4.08	4.23	4.19	0.16	0.20	0.11	0.8	<.0001	0.62
Lactose, %	4.95	4.99	4.87	4.92	5.38	5.58	5.61	5.46	0.16	0.77	0.95	0.44	<.0001	0.95
MUN[1], mg/dL	7.59	2.99	7.9	1.79	10.55	1.87	10.83	1.77	0.9	<.0001	0.77	0.44	0.02	<.0001
Casein[2], %	2.77	2.81	3.5	3.14	2.65	2.45	2.57	2.64	0.36	0.62	0.19	0.88	0.04	0.83
Casein, % true protein	69.13	73.90	81.09	75.46	75.82	73.37	74.95	78.26	8.60	1.00	0.37	0.81	0.89	0.93

[1]Milk urea nitrogen
[2]Analyzed on defatted milk and corrected using milk fat concentration.

Table 13. Air gas emissions during lactation in sows fed control and Low diets under thermos-neutral and heat stress environment

Item	LCP		Control		SEM	Diet	Environment	Diet × Environment
	Thermo-Neutral	Heat Stress	Thermo-Neutral	Heat Stress				
Air Flow, L/min	8,687.89[a]	9,106.70[b]	8,810.50[ab]	8,978.14[ab]	161.66	0.98	0.02	0.31
Humidity, %	60.77[a]	39.70[b]	57.63[c]	41.23[b]	1.87	0.20	0.01	0.01
Temperature, ˚C	21.01[a]	26.89[b]	21.16[a]	26.23[b]	0.11	-	0.01	0.01
H_2S, mg/d	81[a]	163[b]	49[ac]	130[bd]	25	0.06	0.01	0.98
CH_4, mg/d	23,215[a]	18,481[b]	9,873[c]	11,781[d]	1251	0.01	0.01	0.01
NMTHC, mg/d	914.69[a]	907.47[a]	807.41[b]	737.09[b]	56.29	0.01	0.21	0.31
CO_2, g/d	7,196[a]	6,180[b]	6,901[a]	6,222[b]	205	0.30	0.01	0.17
O_2, g/d	-10,250[ab]	-10,210[ab]	-9,619[b]	-10,500[a]	362	0.47	0.08	0.06
NH_3, g/d	8.01[a]	8.22[a]	18.74[b]	15.92[c]	1.55	0.01	0.13	0.09
VCO_2, L/d	3,384[a]	2,906[b]	3,245[a]	2,926[b]	96	0.30	0.01	0.17
VO_2, L/d	-6,630[ab]	-6,600[ab]	-6,219[a]	-6,789[b]	234	0.47	0.08	0.06
RQ	0.56[a]	0.47[b]	0.56[a]	0.44[b]	0.03	0.36	0.01	0.60
HP, MJ/d	12,425[ab]	12,136[ab]	11,691[a]	12,454[b]	4,182	0.44	0.38	0.06
Average BW, Kg	87.92	87.8	89.93	88.39	8.63	0.88	0.92	0.93
Average $BW^{0.75}$, Kg	23.28	23.07	23.57	23.21	2.21	0.92	0.89	0.97
HP, MJ/$BW^{0.75}$/d	11,636[a]	14,216[b]	11,313[a]	14,068[b]	1,653	0.79	0.00	0.92
CO_2, g/$BW^{0.75}$/d	3.11	3.39	3.14	3.29	0.39	0.87	0.33	0.76
O_2, g/$BW^{0.75}$/d	6.23[a]	7.73[b]	6.02[a]	7.67[b]	0.90	0.78	0.01	0.88

Figure 1. Daily feed intake in sows exposed to heat stress (HS) and thermo-neutral temperature (TN) and fed a Low protein diet or a Control diet during lactation (note: statistical inferences are presented in Table 11; ***$P < 0.05$** between Low and Control under TN environment).

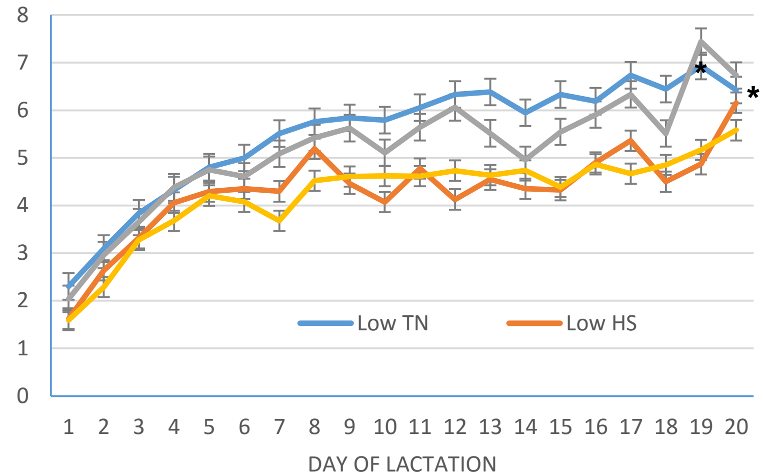


Figure 2. Piglet average daily gain (ADG) (g) from sows exposed to heat stress (HS) and thermo-neutral temperature (TN) and fed a Low protein diet or a Control diet during lactation (note: statistical inferences are presented in Table 11).

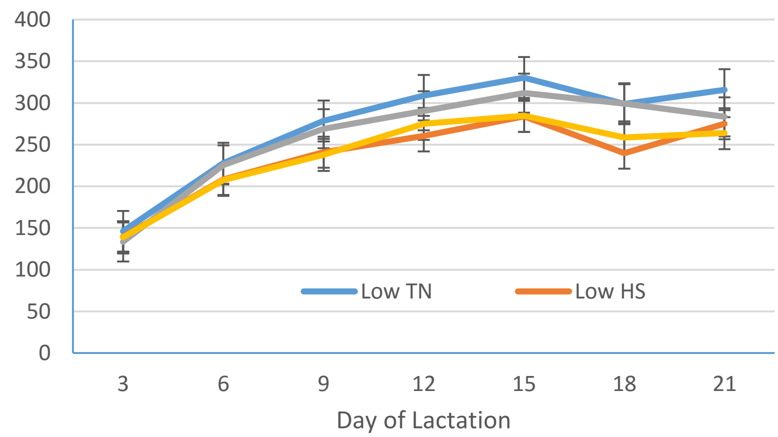


Figure 3. Milk (Left panel) and urinary (Right panel) urea nitrogen (mg/dL and g/d, respectively) from sows exposed to heat stress (HS) and thermo-neutral temperature (TN) and fed a Low protein diet or a Control diet during lactation (note: statistical inferences are presented in Table 12).

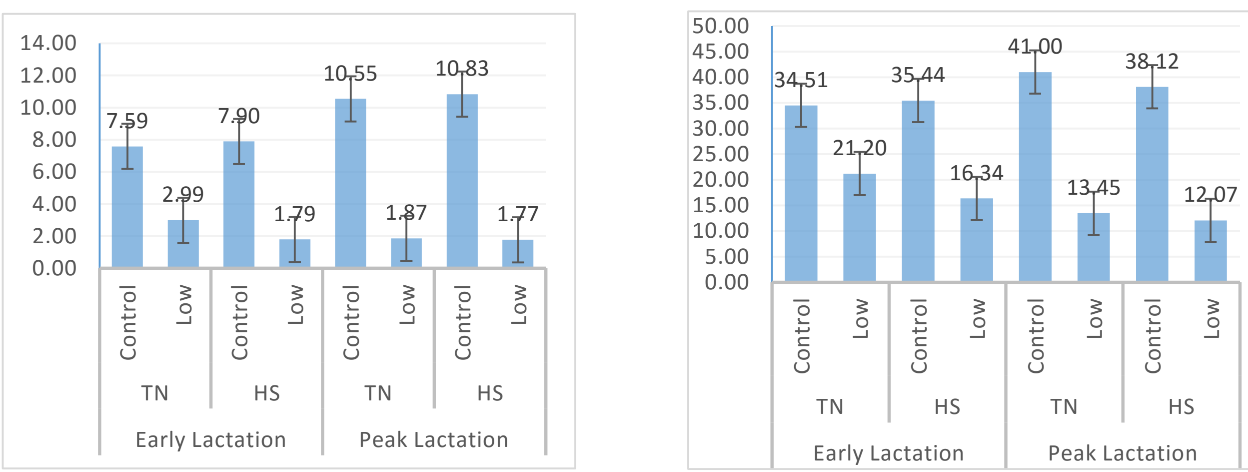


Figure 4. Ammonia emissions (mg/d) from sows fed Low and Control (High) diets in HS and TN environments (Note: statistical inferences are presented in Table 13).

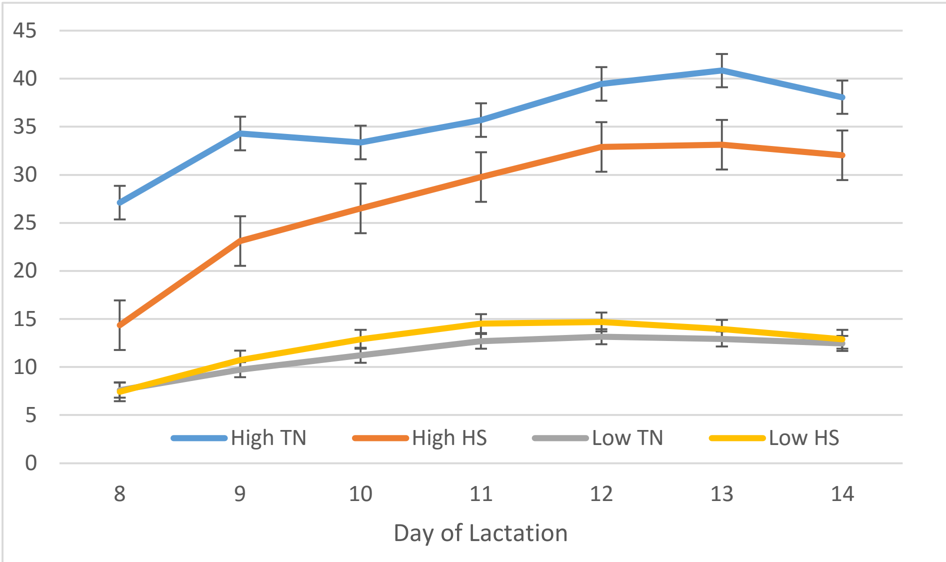
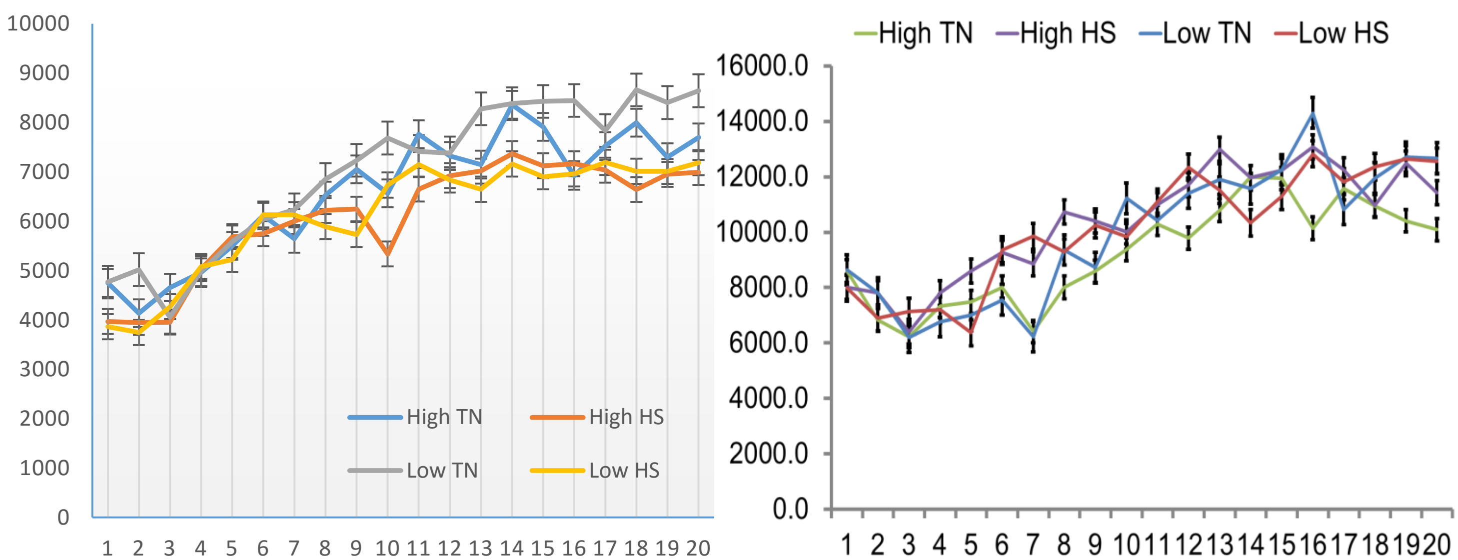


Figure 5. Carbon dioxide elimination (g/d) (Left panel) and oxygen consumption (g/d) (Right panel) in sows exposed to heat stress (HS) and thermo-neutral temperature (TN) and fed a Low protein diet or a Control (High) diet during lactation (Note: there was no difference between TN and TN or between High and Low).



Results for Objective 4 (Tables 14 and 15): Assess farm-level economic implications of switching to CAA from conventional protein sources in light of environmental temperature impact on sow lactation performance. We will predict the optimum level of CAA inclusion based on environmental constraint and feed costs scenarios needed to mitigate diet costs.

Cost analysis was performed on the standard non-reduced CP diet (16.0% CP), and diets reduced in CP (15.7, 14.3, and 13.2 % CP) and containing increasing concentration of CAA (diets from objectives 1 and 2) (Table 14). Since these diets were formulated to meet requirement of sows assuming no loss in lean body mass, valine inclusion rate was fairly high (SID 0.81%). Feed prices (corn, soybean meal and soy hulls) and AA prices from October 2012 at the time of grant submission and in December 2015 were used to calculate diet costs (Table 14). In 2012, cost of corn and soybean meal were high, as well as the cost of amino acids, in particular those of valine and isoleucine. Reducing CP from 16.0% to 13.2% increased feed cost from $ 400 to 490/ton, which represents a 12.15% increase. This increase in diet cost with increasing inclusion level of AA was due to the cost of valine and isoleucine. Removing valine and isoleucine from these formulations resulted in a lower cost, from $ 393 (16% CP) to 385/ton (13.2 % CP) (not shown in Table 14). In December 2015, prices of corn and soybean meal decreased drastically, and also those for AA, in particular valine and lysine. Consequently, the cost of a diet not reduced in CP was $268/ton compared to $400/ton in 2012. In 2015, reducing the CP to 13.2 % with AA inclusion increased diet cost from $268 to $326/ton, representing a 14.6% increase. If the cost of corn and soybean meal from 2012 were used to simulate a diet cost with recent AA prices (New scenario, Table 14), the cost of a standard diet (16% CP) would be $397/ton (compared to $400/ton) and cost of most reduced CP diet (13.2% CP) would be $453/ton (compared to $490), which represents a 9.8% vs. 12.15% increase in diet cost.

In table 15, two diets are presented (from objective 3) that were formulated to allow for loss in lean body mass. Hence the non-reduced CP diet (i.e., 17.33% CP) did not require valine inclusion, bringing the cost down for this diet from $400/ton in objective 2 to $382/ton in objective 3. Reducing CP corresponding to the minimum dietary N required to 12.19% CP increased diet cost to $425/ton, which represents a 10% increase ($425 vs. 382). In 2015, costs for those same diets were $251 and 278/ton (9.8% increase). If the cost of corn and soybean meal from 2012 were used to simulate a diet cost with recent AA prices (New scenario, Table 14), as done above for objective 2 diets, the cost of a reduced CP diet (12.19 % CP) would be $404/ton (vs. $382), which represents a 5.5% increase in diet cost. The diets presented in Table 14 resulted in litter weight gain and overall lactation performances similar to those seen under objective 2 and fed diets presented in Table 14. The latter indicates that the AA inclusion rates in objective 3 better mirrored the actual lactation performance and AA utilization capacity for these sows. The new scenario presented in Table 15 exemplifies the potential for aggressive dietary AA supplementation strategy with minimal increase in diet cost when using current AA prices and high feed prices.

Table 14. Cost analysis of a control, standard non-reduced CP diet (16.0% CP) and diets reduced in CP (15.7, 14.3, and 13.2 % CP) and containing increasing concentration of CAA

Item	October 2012 feed and AA prices				December 2015 feed and AA prices				New scenario-2012 feed prices and 2015 AA prices			
	% CP				% CP				% CP			
	16.0	15.7	14.3	13.2	16.0	15.7	14.3	13.2	16.0	15.7	14.3	13.2
Corn	8.08	8.77	9.27	9.79	3.58	3.89	4.11	4.34	8.08	8.77	9.27	9.79
Soybean meal	6.92	5.48	4.01	2.48	5.00	3.96	2.90	1.79	6.92	5.48	4.01	2.48
Choice white grease	1.49	1.38	1.38	1.37	1.49	1.38	1.38	1.37	1.49	1.38	1.38	1.37
Soy hulls	0.00	0.19	0.51	0.84	0.00	0.13	0.37	0.60	0.00	0.19	0.51	0.84
Sugar food products	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
L-Lys-HCl	0.00	0.20	0.41	0.63	0.00	0.12	0.24	0.37	0.00	0.12	0.24	0.37
L-Ile	0.00	0.00	0.41	2.04	0.00	0.00	0.41	2.04	0.00	0.00	0.41	2.04
DL-Met	0.00	0.04	0.12	0.17	0.00	0.05	0.14	0.20	0.00	0.05	0.14	0.20
L-Thr	0.00	0.08	0.17	0.28	0.00	0.08	0.19	0.30	0.00	0.08	0.19	0.30
L-Trp	0.00	0.00	0.23	0.51	0.00	0.00	0.17	0.39	0.00	0.00	0.17	0.39
L-Val	0.34	1.28	2.14	3.16	0.18	0.68	1.13	1.68	0.18	0.68	1.13	1.68
Vitamin mix	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Mineral mix	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Sow pack	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Selenium 200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium chloride	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Limestone	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calcium phosphate (mono)	0.54	0.57	0.58	0.61	0.54	0.57	0.58	0.61	0.54	0.57	0.58	0.61
$/100 lbs	19.99	20.60	21.83	24.48	13.41	13.47	14.21	16.29	19.83	19.93	20.64	22.66
$/ ton	400	412	437	490	268	269	284	326	397	399	413	453
% change		**3.07**	**5.98**	**12.15**		**0.46**	**5.53**	**14.61**		**0.51**	**3.56**	**9.83**

Table 15. Cost analysis of a control, standard non-reduced CP diet (17.33 % CP) and a diet reduced in CP (12.19 % CP) with supplemental CAA

Item	October 2012 feed and AA prices		December 2015 feed and AA prices		New scenario-2012 feed prices and 2015 AA prices	
	% CP		% CP		% CP	
	17.33	12.19	17.33	12.19	17.33	12.19
Corn	8.94	9.51	3.96	4.22	8.94	9.51
Soybean meal	5.67	2.64	4.10	1.91	5.67	2.64
Choice white grease	1.34	1.67	1.34	1.67	1.34	1.67
Soy hulls	0.00	0.94	0.00	0.68	0.00	0.94
Sugar food products	1.95	1.95	1.95	1.95	1.95	1.95
L-Lys-HCl	0.00	0.43	0.00	0.25	0.00	0.25
L-Ile	0.00	0.54	0.00	0.54	0.00	0.54
DL-Met	0.00	0.12	0.00	0.14	0.00	0.14
L-Thr	0.00	0.16	0.00	0.17	0.00	0.17
L-Trp	0.00	0.23	0.00	0.17	0.00	0.17
L-Val	0.00	1.80	0.00	0.95	0.00	0.95
l-Phe	0.00	0.00	0.00	0.00	0.00	0.00
Vitamin mix	0.35	0.35	0.35	0.35	0.35	0.35
Mineral mix	0.08	0.08	0.08	0.08	0.08	0.08
Sow pack	0.16	0.16	0.16	0.16	0.16	0.16
Selenium 200	0.00	0.00	0.00	0.00	0.00	0.00
Sodium chloride	0.03	0.03	0.03	0.03	0.03	0.03
Limestone	0.03	0.03	0.03	0.03	0.03	0.03
Calcium phosphate (mono)	0.54	0.61	0.54	0.61	0.54	0.61
$/100 lbs	19.10	21.25	12.55	13.91	19.10	20.20
$/ton	382	425	251	278	382	404
% change		**10.11**		**9.79**		**5.46**

Discussion: Explain your research results and include a summary of the results that is of immediate or future benefit to pork producers.

The overall goal of the study was to determine whether reducing dietary CP concentration with incremental inclusion of CAA increases the utilization of dietary N for milk production of lactating sows.

In objectives 1 and 2, the diet containing the lowest level of dietary CP and highest inclusion rate of CAA was based on the estimated N requirement (NRC, 2012) and was tested in experiment 1. In order to maximize the sensitivity of the N balance and utilization response to a decreasing concentration of CP in Experiment 2, diets were formulated to be marginally Lys deficient (i.e., 20 % below the predicted requirement of 0.93 %; NRC, 2012), and to meet predicted requirements for other limiting AA. The lack of performance response to added Lys in experiment 1 suggests the actual SID Lys requirement for those sows was less than what the NRC (2012) model had predicted. However, the calculated Lys utilization efficiency was greater in the LCP fed sows (i.e., 72%) and greater than the NRC (2012) predicted efficiency of 67 %. In addition, a tendency for greater SUN indicated that Lys was marginally limiting in the LCP diet. Therefore, the same dietary Lys level was used in Experiment 2.

We had hypothesized that utilization of dietary N for milk production increases in response to decreasing dietary CP concentration and increasing CAA supplementation, provided that the supply of potentially limiting AA (i.e., Ile, Lys, Met, Thr, Trp and Val) met their estimated requirements. With emerging regulations to mitigate N excretion into the environment, there is an increasing need to assess the impact of reducing dietary CP concentrations on performance and efficiency in lactating sows. The premise of our hypothesis stems from a series of previous NPB funded studies pointing to an improvement in mammary AA utilization and casein yield in sows fed diets with improved AA balance profiles. To further explore these concepts this study was designed to maintain dietary concentrations of SID Lys constant across dietary treatments and to meet estimated requirements of other AA (i.e., Met plus Cys, Ile, Thr, Trp, Val) with graded reduction in dietary CP concentrations.

As dietary CP decreased and CAA inclusion rates increased, the SUN decreased, indicating that the dietary AA balance improved. Within this range of dietary CP concentration and the conditions of this study, improving the dietary AA balance increased estimated milk yield and estimated true milk protein yield during peak lactation, improved retained N utilization efficiency for milk protein production, and maintained N retention, except for the lowest CP diet in peak lactation. Together, these results indicate that mammary milk protein production increased in response to improvement in dietary AA balance. The linear increase in estimated milk and milk protein yields with decreasing dietary CP were however largely attributed to differences in LGR between the HCP and MHCP diets. Nonetheless, these results are consistent with previous studies conducted by the PI. A major focus of this study was to generate N utilization efficiency values, which are determined independent from LGR, that up to now have been limited in the literature.

Sow BW and back fat thickness change over the 21-d lactation were both small and not influenced by dietary CP concentration in the current study. These results suggest that, despite no differences in LGR and estimated milk yield among the 3 lowest CP diets, there is some effect of dietary CP concentration on muscle protein mobilization which appears independent of intake of energy and limiting essential AA.

Milk urea N and SUN, indicators of AA catabolism, both decreased linearly with decreasing dietary CP concentration in the current study, consistent with improvements in N utilization efficiency across treatments. Nitrogen excretion (from urine and feces) decreased linearly with decreasing dietary CP concentration. Sows fed reduced CP diets showed improved true milk protein output and N utilization efficiency, expressed as either N retained as a percent of digestible N intake or true milk protein production as a percent of retained N, especially during the peak lactation period. These results suggest that retained protein is increasingly directed toward milk protein and not body protein retention, with decreasing dietary CP concentrations and improved dietary AA balance.

The reduced N retention in sows fed the LCP diet may reflect an underestimation of dietary requirements in NRC (2012) for N or an essential AA for which the dietary concentrations were lowest in diet LCP (e.g. Arg, His, Leu, Phe, Phe plus Tyr). The need for these essential AA or N may have contributed to the observed increase in LEA loss, indicative of muscle protein mobilization, with reductions in dietary CP concentrations, in order to maintain milk protein output and LGR. It is also possible that reduced intake of some of the AA or soybean meal (e.g., Leu or some soy isoflavones), provides a reduction in anabolic drive for maternal body protein gain thereby favoring the partitioning of AA towards milk protein production rather than maternal body protein gain.

Similar lactation performance response was observed in experiments under objective 3 when sows were fed a considerably reduced CP diet (12.19 vs. 17.33 % CP) whereby no change in lactation performance was found. We had hypothesized that sows exposed to heat stress would perform better when fed a reduced CP diet. Sows fed as low as 12.19% CP diet had a transient increase in feed intake during a short period of peak lactation, although this was observed under the thermo-neutral environment condition only. As observed in experiments of objectives 1 and 2, sows fed the 12.19% CP diet had a marked reduction in urinary urea N excretion and a dramatic decrease in ammonia emissions compared to sows fed a non-reduced CP diet containing 17.33% CP. The premise for proposing an improved response to low CP diet was based on the known theoretical energy cost associated with excess AA catabolism and urea synthesis. While heat stress environment increased heat production from sows there was no reduction in heat production however associated with reduced consumption of crude protein. It is noteworthy to mention that gases were measured in individual chamber housing both sows and her litter. The heat generated by the piglets is thus part of the heat production measurement based on O_2 and CO_2. Consequently, it is possible that changes, if any, in heat production from the sow could not be detected because of the conceivable variability in heat produced by the piglets. While we had not expected to see any changes in CH_4 emission, sows fed the reduced CP diet emitted more CH_4. It is possible that soy hulls addition to the reduced CP diet in order to maintain the same fermentable fiber concentration as that of control diet decreased the carbohydrate digestibility of the reduced CP diet. Alternative sources of fiber or no additional fiber should be considered in future experiments to ensure that CH_4 emission do not increase.

The data generated by the projects described above generated information previously unavailable to the swine industry. Feeding reduced CP diets with crystalline AA supplementation can be implemented for multiple parity lactating sows on the basis of reduction in N excretion and ammonia emission without impacting lactation performance and return to estrus.

Summary of Results

Improvement in dietary AA balance is achieved first by reducing dietary CP in order to decrease the concentration of both non-essential AA and some essential AA that are naturally found in excess in a standard diet. Second, depending on the level of CP reduction, essential AA become limiting, and the concentrations can be easily adjusted to meet requirements by adding those specific AA in their crystalline form. The efficiency of using dietary crude protein (nitrogen) for nitrogen retention and mammary milk protein production increase in response to improvement in dietary AA balance, resulting in a massive reduction in urinary N excretion. Reduced CP diets, as low as 12.19% CP, can be fed to lactating sows without negative impact on lactation performance. In fact piglet litter growth rate increased slightly in experiments of objectives 1 and 2 when sows were fed reduced dietary CP concentration and improved AA balance, making this a feasible option to reduce N excretion into the environment. Sows exposed to high environmental temperatures in this project, which was aimed at mimicking the summer season, did not respond to reduced CP diet by increasing lactation performance and reducing heat production. Nonetheless, the reduced CP diet resulted in dramatic reduction in N excretion and ammonia emissions under either heat-stress or thermo-neutral environment. Higher methane and H_2S gasses associated with feeding a reduced CP diet was likely due in this experiment to the soy hulls added to this diet. Soy hulls were added to maintain equal fermentable fiber concentration between the non-reduced and reduced CP diets. Alternative fiber ingredients will be sought in the future in order to ensure that those gases are either decreases as well or at least not affected. Reduced CP diets will be more competitive with higher protein feed costs or increased cost of N excretion. The impact of feeding reduced CP diets to lactating sows is largely the reduced excretion of N and ammonia emissions. The value of this dramatic decrease in N excretion and ammonia emission depends on several factors: 1) the health effect on sows and the workers, which remains to be better researched and documented, and 2) environmental regulations including implementation of the clean air act (e.g., carbon tax). Given the increasing stringency of environmental regulation in agriculture and the pressure to reduce greenhouse gas emissions, feeding to decrease N excretion using crystalline amino acids is likely to become more economical.