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Nitrogen Excretion and Ammonia Emissions from Pigs Fed Modified Diets

D. M. Panetta
Iowa State University

Wendy J. Powers
Iowa State University

Hongwei Xin
Iowa State University, hxin@iastate.edu

Brian J. Kerr
United States Department of Agriculture

Kenneth J. Stalder
Iowa State University

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Abstract
Two swine feeding trials were conducted (initial body weight = 47 ± 2 and 41 ± 3 kg for Trials 1 and 2, respectively) to evaluate reduced crude protein (CP) and yucca (*Yucca schidigera* Roezl ex Ortgies) extract–supplemented diets on NH_3 emissions. In Trial 1, nine pigs were offered a corn–soybean meal diet (C, 174 g kg^{-1} CP), a Lys-supplemented diet (L, 170 g kg^{-1} CP), or a 145 g kg^{-1} CP diet supplemented with Lys, Met, Thr, and Trp (LMTT). In Trial 2, nine pigs were fed diet L supplemented with 0, 62.5, or 125 mg of yucca extract per kg diet. Each feeding period consisted of a 4-d dietary adjustment followed by 72 h of continuous NH_3 measurement. Urine and fecal samples were collected each period. Feeding the LMTT diet reduced ($P < 0.05$) average daily gain (ADG) and feed efficiency (G:F) compared to diet L. Fecal N concentration decreased with a reduction in dietary CP, but urinary ammonium increased from pigs fed diet LMTT (2.0 g kg^{-1}, wet basis) compared to those fed diet C (1.1 g kg^{-1}) or L (1.0 g kg^{-1}). When pigs were fed reduced CP diets NH_3emission rates decreased (2.46, 2.16, and 1.05 mg min^{-1} for diets C, L, and LMTT). Yucca had no effect on feed intake, ADG, or G:F. Ammonium and N concentrations of manure and NH_3 emission rates did not differ with yucca content. Caution must be executed to maintain animal performance when strategies are implemented to reduce NH_3 emissions.

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Nitrogen Excretion and Ammonia Emissions from Pigs Fed Modified Diets

D. M. Panetta, W. J. Powers,* H. Xin, B. J. Kerr, and K. J. Stalder

ABSTRACT

Two swine feeding trials were conducted (initial body weight = 47 ± 2 and 41 ± 3 kg for Trials 1 and 2, respectively) to evaluate reduced crude protein (CP) and yucca (*Yucca schidigera* Roezl ex Ortgies) extract–supplemented diets on NH_3 emissions. In Trial 1, nine pigs were offered a corn–soybean meal diet (C, 174 g kg^{-1} CP), a Lys-supplemented diet (L, 170 g kg^{-1} CP), or a 145 g kg^{-1} CP diet supplemented with Lys, Met, Thr, and Trp (LMTT). In Trial 2, nine pigs were fed diet L supplemented with 0, 62.5, or 125 mg of yucca extract per kg diet. Each feeding period consisted of a 4-d dietary adjustment followed by 72 h of continuous NH_3 measurement. Urine and fecal samples were collected each period. Feeding the LMTT diet reduced ($P < 0.05$) average daily gain (ADG) and feed efficiency (G:F) compared to diet L. Fecal N concentration decreased with a reduction in dietary CP, but urinary ammonium increased from pigs fed diet LMTT (2.0 g kg^{-1}, wet basis) compared to those fed diet C (1.1 g kg^{-1}) or L (1.0 g kg^{-1}). When pigs were fed reduced CP diets NH_3 emission rates decreased (2.46, 2.16, and 1.05 mg min^{-1} for diets C, L, and LMTT). Yucca had no effect on feed intake, ADG, or G:F. Ammonium and N concentrations of manure and NH_3 emission rates did not differ with yucca content. Caution must be executed to maintain animal performance when strategies are implemented to reduce NH_3 emissions.

Manure ammonia, produced when urinary urea is hydrolyzed by fecal microbial ureases, is volatilized to the atmosphere. The compounded impacts of decreased N value of the manures (Jensen, 2002), the risks of ammonia emissions on animal and human health (Donham, 1991), and the effects on environmental quality (National Research Council, 2003) have fueled interest in quantifying and reducing the volatilization of ammonia from animal manures.

Reduction of dietary CP content accompanied by supplementation with exogenous amino acids (AA) decreases intake of excess AA while meeting nutrient needs. Using mass balance methods or by directly measuring emissions from swine manure stored in vitro, dietary strategies have been shown to reduce ammonia emissions by 28 to 79% (Sutton et al., 1999). It has also been reported that N excretion from swine decreases an average 8.4% for every one-percentage unit decrease in dietary protein (Kerr, 1995), with much of the reduction likely in the form of urinary urea-N (National Research Council, 1998). However, the use of mass balance methods often assumes that all of the ingested N not accounted for in excreta or animal products was lost as ammonia, and that all of the excreted N could potentially volatilize as ammonia (van Kempen et al., 2003; Harper et al., 2000). No data are available that directly quantify dietary effects on ammonia emissions from swine.

Dietary addition of an extract of *Yucca schidigera* is believed to reduce emissions through the binding or conversion of ammonia to less volatile forms such as ammonium nitrogen (Headon et al., 1991). Some have suggested that yucca extract inhibits urease activity (Duffy and Brooks, 1998). Significant effects of yucca on urinary ammonium concentrations have not been established (Duffy and Brooks, 1998; Kemme et al., 1993).

The objective of this study was to directly quantify the effects of dietary strategies on ammonia emissions and ammonium and total Kjeldahl nitrogen (TKN) excretion from growing-finishing pigs. We hypothesized that a reduction of dietary CP would reduce measured ammonia emissions by reducing ammonium and N excretion, and that the dietary addition of yucca extract would reduce ammonia emissions by binding excreted N or decreasing urinary ammonium N concentration.

MATERIALS AND METHODS

Animals

Experiments were approved by the Iowa State University Committee on Animal Care, and conducted at the Livestock Environment and Animal Physiology (LEAP) lab (Ames, IA). Animals were obtained from the ISU Bilsland Memorial Swine Breeding Farm (Madrid, IA). Each trial used nine pigs with average initial body weights of 47 ± 2 and 41 ± 3 kg for Trials 1 and 2, respectively. Two gilts and one barrow were allocated to each of three environmentally controlled chambers (Xin and Harmon, 1996), randomly in Trial 1 and adjusted to provide similar group weights between chambers in Trial 2.

Housing

Each chamber (1.83 × 1.52 m) had a double nipple waterer and a two-hole Smidley stainless steel feeder (Marting Mfg. of Iowa, Britt, IA). Pigs were provided ad libitum access to feed and water throughout each period. A Tenderfoot coated floor (Tandem Products, Minneapolis, MN) was positioned over a plugged manure pit (380-L storage capacity) in each chamber. Manure (feces, urine, spilled feed, and water) was allowed to accumulate in the pits during each feeding period. Manure pits and chambers were emptied and thoroughly cleaned after each 7-d sampling period. Pigs were provided with artificial lighting for 12 h d^{-1} (0600 to 1800 h in Trial 1 and 0700 to 1900 h in

D.M. Panetta, W.J. Powers, and K.J. Stalder, Department of Animal Science, and H. Xin, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011. B.J. Kerr, USDA-ARS Swine Odor and Manure Management Research Unit, Ames, IA 50011. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable. Received 27 Oct. 2005. *Corresponding author (wpowers@iastate.edu).

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677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: AA, amino acids; ADG, average daily gain; BW, body weight; C, corn–soybean meal diet; CP, crude protein; DM, dry matter; G:F, feed efficiency; L, Lys-supplemented diet; LMTT, diet supplemented with Lys, Met, Thr, and Trp; TKN, total Kjeldahl nitrogen.

Trial 2). Temperature within the chambers was maintained between 21 and 26°C, and relative humidity was monitored, but not controlled.

Experimental Design

The three dietary treatments were assigned to each chamber for at least one of the four 7-d periods per trial, representing a partially replicated Latin square design. Each period consisted of a 4-d dietary adjustment followed by 72 h of continuous measurement of ammonia concentrations in the air exhausted from each chamber.

Diets

Three experimental diets were fed in each trial (Table 1). All diets were formulated, using book values for corn and soybean meal, to meet or exceed nutrient requirements for growing pigs (National Research Council, 1998) and were provided in meal form. A common corn and soybean meal batch was used throughout both feeding trials to minimize variation between batches. Diets were formulated to be isocaloric and to have equal Lys contents, with any supplemented AA added to meet ideal ratios relative to Lys. For Trial 1, the diets were: C, a control corn–soybean meal diet with no added AA (174 g CP kg^{-1} diet); L, a corn–soybean meal diet reformulated for reduced CP and including crystalline Lys (170 g CP kg^{-1} diet); and LMTT, a 145 g CP kg^{-1} diet with Lys, Met, Thr, and Trp (Table 1).

Diets offered in Trial 2 were based on the formulation for diet L in Trial 1 with the only treatment differences being the amount of *Yucca schidigera* extract (De-Odorase2X; Alltech, Nicholasville, KY) added during mixing. Although the specific mechanism is unknown, the extract of *Yucca schidigera* has been proposed to improve ammonia emissions by binding ammonia through the glyco-components contained within the extract or through an inhibition of urease activity (Colina et al., 2001). Diet L + 0 contained no yucca, L + 62.5 contained 62.5 mg of De-Odorase per kg of diet, and L + 125 included 125 mg De-Odorase kg^{-1} diet. The amount of yucca extract added was the amount recommended by the manufacturer in diet L + 62.5, based on in-house research conducted by Alltech (Cole and Tuck, 1995), and twice this amount in diet L + 125.

Diet samples were collected at mixing and weekly for proximate analyses. All samples were pooled by period for each chamber and ground using a Thomas-Wiley mill (Thomas Scientific, Swedesboro, NJ) through a 1-mm screen before analyses. Feed samples were analyzed for total Kjeldahl nitrogen (TKN) content (Iowa State University; AOAC International, 2002, Method 2001.11), proximate analyses and minerals (Dairy One, Ithaca, NY), and amino acid content (University of Missouri-Columbia Agricultural Experiment Station Laboratories).

Animal Measures and Manure Sampling

At the end of each 7-d period, pigs were weighed, individually, without prior withdrawal of feed or water, and feed refusals were weighed from each chamber to determine average daily feed intake, average daily gain (ADG), and gain per unit of feed consumed (G:F) for each chamber (experimental unit).

Grab samples of feces and urine were collected from each pig during the last 3 d of each feeding period and composited by chamber. Fecal and urine samples were held at 4°C until they could be composited. Then urine was frozen and feces were oven-dried at 50°C. Before laboratory analyses, urine was thawed at 4°C, and feces were ground with a Thomas-Wiley mill through a 2-mm screen. Urine and feces were analyzed to determine TKN and NH_4^+–N concentrations (AOAC International, 2002, Method 2001.11). Ammonium nitrogen content was measured by first alkalinizing the samples, followed by a distillation procedure, and titration with acid (AOAC International, 2002, Method 2001.11). All samples were analyzed in duplicate.

Ammonia Emissions Measurement

Aerial ammonia concentrations of chamber exhaust were measured during the last 72 h of each 7-d period with a TEI Model 17C chemiluminescence ammonia analyzer (Thermo Electron Corporation, Waltham, MA). The analyzer was cali-

Table 1. Ingredients and nutrient composition of diets utilized in a study of nitrogen excretion and ammonia emissions from pigs.

	Trial 1†			Trial 2‡		
	C	L	LMTT	L + 0	L + 62.5	L + 125
Ingredient, % of total						
Soybean meal	19.20	15.80	10.15	15.80	15.80	15.80
Premix§	2.03	2.07	2.09	2.07	2.07	2.07
L-Lys-HCl	–	0.13	0.32	0.13	0.13	0.13
DL-Met	–	–	0.03	–	–	–
L-Thr	–	–	0.08	–	–	–
L-Trp	–	–	0.03	–	–	–
De-Odorase	–	–	–	–	0.00625	0.0125
Total	100.0	100.0	100.0	100.0	100.0	100.0
Formulated composition (dry matter basis)						
ME, kcal kg^{-1}	3746	3741	3730	3741	3741	3741
CP, g kg^{-1}	174	160	138	160	160	160
Lys, g kg^{-1}	8.9	8.9	8.9	8.9	8.9	8.9
Analyzed composition (dry matter basis), g kg^{-1}						
CP	174	170	145	157	162	160
Lys	8.6	9.3	8.3	9.5	9.0	9.5
Met	3.1	2.8	2.6	2.7	2.6	2.7
Thr	6.7	6.3	6.0	6.1	5.8	5.9
Trp	2.2	2.0	2.0	2.0	1.9	2.1

† Treatments were a control corn and soybean meal diet (C), a reduced crude protein diet containing Lys (L), and a further reduced crude protein diet containing Lys, Met, Thr, and Trp (LMTT). L-Lys-HCl, L-Thr, and L-Trp were supplied by BioKyowa (Chesterfield, MO), and DL-Met was supplied by Adisseo (Alpharetta, GA).

‡ Treatments were a diet containing Lys and no yucca (L + 0), a diet with Lys and 62.5 mg kg^{-1} of a yucca product (L + 62.5), and a diet with Lys and 125 mg kg^{-1} of a yucca product (L + 125).

§ Provided a minimum of the following per kilogram of complete diet: 4.0 g Ca, 2.4 g NaCl, 1.8 g P, 85 mg Zn ($ZnSO_4$ and ZnO), 649 μg I (EDDI), 187 μg Se (Na_2SeO_3), 4968 IU of vitamin A, 18 μg of vitamin B_{12}, and 56 μg of choline.

brated before sampling each week using certified span gases (Matheson Tri-Gas, Joliet, IL), including ammonia in air (13.3 ppmv, analyzed), balance air, and nitric oxide in nitrogen (11.1 ppmv, analyzed, <0.05 ppmv NO_2). The chambers were maintained under positive pressure, so that air flowed out of the exhaust pipes, through a dust filter (Catalog no. 225-1747; SKC, Eighty Four, PA) contained within an inline 47-mm Teflon PFA filter holder (Savillex Corporation, Minnetonka, MN) then to a common sample line. The filters and sample line were constructed of Teflon (DuPont, Wilmington, DE), to prevent ammonia adsorption. The sample line was heated by electric heating cords with a power controller (Catalog no. H-03122-24 and H-02604-00; Cole-Parmer Instrument Co., Vernon Hills, IL) and insulated to prevent moisture condensation. Sample air was pumped by a Teflon PTFE-coated vacuum/pressure diaphragm pump (Item no. L-79200-30; Cole-Parmer Instrument Co.) into a Teflon calibration manifold and through a second filter before reaching the analyzer.

Air sampling progressed through each of the three chambers and a background sample on a rotating schedule, sampling for 20 min (Trial 1 and the first 2 wk of Trial 2) or 30 min (last 2 wk of Trial 2) from each chamber exhaust and the incoming air. A complete cycle required 80 min for Trial 1 and the first 2 wk of Trial 2, and 120 min for the last 2 wk of Trial 2. All but the last minute of each sampling time was used to purge the sample line and equilibrate the analyzer. During the second half of Trial 2, the purge time was increased to ensure adequate flushing between samples. Ammonia concentrations, measured every 2 s during the last minute of sampling, were automatically averaged through software control and recorded.

Airflow into each chamber was continuously measured by a thermoelectric air mass flow meter in each chamber (Model LS-4F; Teledyne Hastings-Raydist, Hampton, VA). In each chamber, temperature and relative humidity were monitored continuously with temperature and relative humidity probes (Model HMP35C; Campbell Scientific, Logan, UT). Chamber temperature data were used for automated correction of airflow measurements to a standard L min^{-1} basis. Environmental data were recorded with a PC-based environmental control and data acquisition system (CR10 module; Campbell Scientific).

Calculations and Statistical Analyses

Ammonia concentrations of incoming and exhausted chamber air and exhaust airflow rates were used to calculate ammonia emission rates for each chamber over time as follows:

$$ER = (C_e - C_i) \times 10^{-6} \times D \times F$$

where ER = ammonia emission rate (mg min^{-1}), C_e = ammonia concentration in exhaust air (ppmv), C_i = ammonia concentration in incoming air (ppmv), D = density of ammonia at STP (759 mg L^{-1}), and F = airflow rate (standard L min^{-1}).

All data were analyzed using the MIXED procedure of SAS 8.2 (SAS Institute, 2001). For air and emissions data, collected continuously throughout each 72-h sampling period, the model included diet as a fixed effect, and hours since manure pit cleanout and hours since feeding (both within week) as linear covariates. The quadratic effect of the covariates was also tested, but was removed from the model when not significant ($P > 0.10$). Chamber within diet by week was included as a random effect and as the subject of a repeated statement in the model used to analyze the data. Animal performance and excreta composition data were analyzed using a model that excluded the linear covariates, because the data were not collected repeatedly within any week. Week of measurement was evaluated as a fixed effect to account for differences associated with growth of the pigs over time. When fixed effects were significant ($P < 0.10$), differences in means between each pair of diets or weeks were evaluated and declared significant when $P < 0.05$.

RESULTS AND DISCUSSION

Trial 1

Animal Performance

No treatment-related health problems were observed in the pigs during the experiments. Weekly feed disappearance did not differ among groups of pigs fed diets with different CP content (48.2 ± 2.1 kg, $P = 0.411$; Table 2). However, there were dietary differences in group ADG ($P = 0.070$) and G:F ($P = 0.020$). Groups of pigs fed diet L had greater rates of gain (2.61 kg d^{-1}; Table 2) than groups fed LMTT (1.97 kg d^{-1}, $P = 0.027$), while ADG of groups fed diet C (2.35 kg d^{-1}) did not differ from groups fed L ($P = 0.283$) or LMTT ($P = 0.135$). Because ADG in pens offered the C diet was intermediate to pens offered either the LMTT or L diets, the reduction in CP does not offer an easy explanation for gain differences. Figueroa et al. (2003) reported an ADG of 834 g d^{-1} for pigs fed a 160 g kg^{-1} CP control diet, similar to the gains of pigs offered the L diet in this study when reported on a per pig basis.

Feed efficiency was poorer in groups of pigs fed LMTT (0.277 kg gain kg^{-1} feed, as fed; Table 2) than in groups fed diets C (0.356, $P = 0.034$) or L (0.391, $P = 0.008$).

Table 2. Least squares means of animal performance measures from a study of nitrogen excretion and ammonia emissions from pigs.†

	Feed disappearance	Average daily gain	Gain to feed ratio
	kg wk^{-1} as-fed	kg d^{-1}	kg kg^{-1} as-fed
	Trial 1 (n = 12)		
Diet C‡	46.3	2.35bc#	0.356b
Diet L	47.7	2.61b	0.391b
Diet LMTT	50.5	1.97c	0.277c
SEM	2.1	0.15	0.021
Week 1	35.6c	1.75c	0.350
Week 2	49.9b	2.40b	0.344
Week 3	48.5b	2.70b	0.387
Week 4	58.7a	2.40b	0.285
SEM	2.4	0.18	0.024
Diet effect (P =)§	0.411	0.070	0.020
Week effect (P =)	0.003	0.044	0.107
	Trial 2 (n = 12)		
Diet L + 0¶	41.5	2.40	0.413
Diet L + 62.5	41.3	2.24	0.386
Diet L + 125	44.9	2.63	0.412
SEM	1.7	0.32	0.053
Week 1	35.1c	2.47	0.498
Week 2	45.0b	2.38	0.372
Week 3	44.4b	1.75	0.272
Week 4	45.8b	3.09	0.472
SEM	2.0	0.37	0.061
Diet effect (P =)	0.316	0.710	0.921
Week effect (P =)	0.027	0.190	0.125

† Performance measures are reported by chamber (three pigs per chamber). Means of four periods per trial are reported.

‡ Treatments were a control corn and soybean meal diet (C), a reduced crude protein diet containing Lys (L), and a further reduced crude protein diet containing Lys, Met, Thr, and Trp (LMTT).

§ P values < 0.10 indicate a significant difference occurred when pigs were fed the three diets.

¶ Treatments were a diet containing Lys and no yucca (L + 0), a diet with Lys and 62.5 mg kg^{-1} of a yucca product (L + 62.5), and a diet with Lys and 125 mg kg^{-1} of a yucca product (L + 125).

Within a column, trial, and effect, means without a common lowercase letter differ ($P < 0.05$).

Both feed disappearance and ADG increased as the weeks of the trial progressed (Table 2), such that G:F did not differ by week (0.342 ± 0.024).

In some cases, including the current study, reduced performance has been observed when feeding reduced CP diets to pigs (Gomez et al., 2002; Figueroa et al., 2002, 2003). Whereas feeding of the 145 g kg^{-1} CP, LMTT diet resulted in reduced rates of gain compared to the 170 g kg^{-1} CP, Lys-supplemented diet, a linear reduction in growth performance with CP reduction was not observed in this study. The lack of difference between diets C and L in ADG and G:F may be attributed to the only 4 g kg^{-1} unit reduction in analyzed CP content of diet L compared to C. Other studies have observed significant performance differences only when CP was reduced by more than two percentage units (Gomez et al., 2002; Figueroa et al., 2002, 2003). Still others have reported no performance depression when CP was reduced by up to six percentage units and accompanied by AA supplementation (Zervas and Zijlstra, 2002a, 2002b; Kerr et al., 1995; Kerr and Easter, 1995).

How closely the control diet met AA requirements (Figueroa et al., 2002) and whether the low protein diets were adequately supplemented with all limiting AA, may also affect growth performance comparisons. The determination of which AA is fifth-limiting has recently been investigated. In the case of the current study, Val and other AA were not likely limiting the growth of pigs fed the 145 g kg^{-1} CP (LMTT) diet because CP was reduced only to the point of meeting the requirement of the fourth-limiting AA (Trp).

Excreta Composition

For the purposes of this experiment, ammonia emissions were a greater focus than N balance, so excreta were allowed to collect in the manure pits and contribute to emissions. Urine and fecal grab samples were only used to determine TKN and ammonium concentrations and determine which measure would be a stronger indicator of the potential to reduce ammonia emissions. Fecal TKN content was reduced in pigs fed LMTT (0.37 g kg^{-1} dry matter [DM]; Table 3) compared to pigs fed C (0.40 g kg^{-1} DM, $P = 0.027$). In contrast, fecal TKN content from pigs fed L (0.39 g kg^{-1} DM) was not different from those fed C ($P = 0.471$) or LMTT ($P = 0.075$). One possible explanation for the reduction in fecal TKN concentration is that the crystalline AA improved N digestibility (Otto et al., 2003). Nitrogen digestibility could have also been affected by the changes in ingredient ratios (corn to soybean meal) if the corn was more digestible than soybean meal. There have been mixed effects of reduced CP diets on digestibility in other studies. A reduction in N digestibility of low CP diets was observed by Zervas and Zijlstra (2002a) and Canh et al. (1998). Otto et al. (2003) noted N digestibility increased from 80.3 to 85.5% when dietary CP content was reduced from 150 g kg^{-1} to 60 g kg^{-1}. In contrast, Zervas and Zijlstra (2002b) observed no difference in N digestibility.

The reduction of dietary CP accompanied by AA supplementation has the potential to alter total N excreted, the chemical forms of N excreted (ammonium versus organic N; Sutton et al., 1999), the ratio of urinary to fecal N (Zervas and Zijlstra, 2002a, 2002b), the concentrations of N in excreta, and the mass of excreta that results from moisture content, all of which may affect the ammonia emission potential. Fecal NH_4^+–N content did not differ among pigs fed diets with different CP content (0.046 ± 0.0014 g kg^{-1} DM, $P = 0.116$; Table 3). Urinary TKN content did not differ among pigs fed diets C, L, and LMTT (9.9 ± 1.4 g kg^{-1}, $P = 0.403$; Table 3), but urinary NH_4^+–N content was increased in pigs fed LMTT (2.0 g kg^{-1}, as-excreted; Table 3) compared to those fed C (1.1 g kg^{-1}, $P = 0.005$) or L (1.0 g kg^{-1}, $P = 0.005$). Others have reported that reduced CP diets resulted in decreased ammonium in fresh and stored manure (Sutton et al., 1999) which contrast the findings of the current study whereby reduced CP diets increased urinary ammonium with no change in fecal ammonium. Fecal and urinary TKN and NH_4^+–N contents did not vary with the weeks of the trial ($P \geq 0.18$; Table 3).

Because the volume of urine excreted may be reduced by as much as one third when reduced CP diets are fed to pigs (Crocker and Robison, 2002), a reduction in urinary TKN concentration would not be a requisite

Table 3. Least squares means of concentrations of nitrogen in excreta from a study of nitrogen excretion and ammonia emissions from pigs.†

	Fecal ammonium N	Fecal TKN‡	Urinary ammonium N	Urinary TKN
	—— g kg^{-1} DM ——		– g kg^{-1}, as-excreted –	
Trial 1				
Diet C§	0.048	0.40b††	1.1c	11.0
Diet L	0.047	0.39bc	1.0c	9.4
Diet LMTT	0.043	0.37c	2.0b	9.3
SEM	0.0014	0.0053	0.15	1.4
Week 1	0.044	0.38	1.3	11.0
Week 2	0.045	0.38	1.4	9.0
Week 3	0.044	0.40	1.3	9.4
Week 4	0.049	0.39	1.5	11.0
SEM	0.0017	0.0061	0.17	1.6
n =	27	25	26	24
Diet effect (*P* =)¶	0.116	0.062	0.007	0.403
Week effect (*P* =)	0.180	0.211	0.759	0.855
Trial 2				
Diet L + 0#	0.046	0.36	1.4	10.0
Diet L + 62.5	0.048	0.36	1.4	9.4
Diet L + 125	0.050	0.36	1.1	8.2
SEM	0.0012	0.013	0.23	1.6
Week 1	0.040c	0.34	1.2	9.5
Week 2	0.043c	0.37	1.1	8.1
Week 3	0.056b	0.36	1.5	10.0
Week 4	0.055b	0.37	1.3	9.2
SEM	0.0013	0.015	0.27	1.9
n =	25	25	26	25
Diet effect (*P* =)	0.149	0.925	0.603	0.646
Week effect (*P* =)	<0.001	0.585	0.747	0.848

† Excreta were pooled by chamber (three pigs per chamber). Means of four collection periods per trial are reported.
‡ Total Kjeldahl nitrogen.
§ Treatments were a control corn and soybean meal diet (C), a reduced crude protein diet containing Lys (L), and a further reduced crude protein diet containing Lys, Met, Thr, and Trp (LMTT).
¶ *P* values < 0.10 indicate a significant difference occurred when pigs were fed the three diets.
# Treatments were a diet containing Lys and no yucca (L + 0), a diet with Lys and 62.5 mg kg^{-1} of a yucca product (L + 62.5), and a diet with Lys and 125 mg kg^{-1} of a yucca product (L + 125).
†† Within a column and trial, means without a common lowercase letter differ (*P* < 0.05).

component of reduced urinary TKN or ammonium efflux. It is not clear why in this study urinary ammonium excretion doubled relative to urinary TKN. However, if urine and feces excretion volumes were not different among pigs fed diets differing in CP content nor was there a difference in total nitrogen mass excreted, a reduction in fecal non-ammonium TKN concentration accompanied by an increase in urinary ammonium concentration (i.e., a shift in route of excretion) would indicate an increased ammonia emission potential because urinary ammonium nitrogen is more volatile than fecal nitrogen. Although the increased urinary ammonium concentration observed for pigs fed diet LMTT suggests increased volatility of N in that urine as ammonia, the total amounts of TKN and ammonium N excreted from pigs fed each diet, as well as the excreta pH may have had greater effects on ammonia emissions than the urinary ammonium concentration, allowing for increased urinary ammonium concentration in the LMTT diets while maintaining reduced ammonia emissions.

Based on the findings of the current study, fecal N appears to be the best indicator of ammonia emission potential.

Air Quality

Chamber temperatures remained between 21 and 24°C and relative humidity between 51 and 83% throughout each air sampling period in Trial 1 (data not shown). Differences attributed to the feeding of the different diets to pigs and the time that had elapsed since chamber cleaning and feeding were detected in data used to calculate ammonia emission rates (Table 4). Airflow rates were not different when pigs were fed the different diets (1308 ± 105 L min^{-1}, $P = 0.833$), but ammonia concentration of exhaust air, corrected for the concentrations in the incoming air, was different ($P = 0.002$ and $P = 0.088$, respectively; Table 4). Adjusted ammonia concentrations were greater ($P = 0.041$) when pigs were fed diet C (2.66 ± 0.22 ppmv) than diet L (1.93 ± 0.22 ppmv), and greater ($P = 0.020$) when pigs were fed diet L than diet LMTT (1.05 ± 0.22 ppmv).

Air entering the chambers had measured ammonia concentrations of 0.03 to 0.50 ppmv ($n = 683$). One exhaust ammonia concentration value in Chamber 4, diet LMTT, was removed from statistical analysis because it was less than the ammonia concentration of incoming air, and thus provided a negative emission rate for that sampling. No explanation is available for why this was observed for a single observation.

During Trial 1, aerial ammonia concentration varied linearly with the time since chambers were cleaned ($P < 0.001$; Table 4). Airflow rates varied linearly only with the time since chamber cleaning ($P = 0.007$). Quadratic effects of either covariate were not significant ($P > 0.10$).

Ammonia emission rates decreased with decreasing dietary CP content (2.46, 2.15, and 1.05 mg min^{-1} for groups of pigs fed diets C, L, and LMTT, respectively, $P = 0.098$; Fig. 1). Emission rates were reduced for groups of pigs fed LMTT compared to groups fed diet C ($P = 0.044$) or L ($P = 0.099$).

Table 4. Least squares means of airflow rate, ammonia concentration and calculated ammonia N concentration from pigs fed control and reduced crude protein diets.

	Air flow	NH_3 in exhaust air†	NH_3–N in exhaust air†
	L min^{-1}	ppmv	
Trial 1 ($n = 683$)‡			
Diet C§	1259	2.66a‡‡	2.14b
Diet L	1350	1.93b	1.65bc
Diet LMTT	1314	1.05c	0.90c
SEM	105	0.22	0.35
Diet effect (P =)¶	0.833	0.002	0.088
Time since cleaned linear effect (P =)	0.007	<0.001	<0.001
Trial 2 ($n = 600$)‡			
Diet L + 0#	1208	1.45	1.20
Diet L + 62.5	1166	1.30	1.07
Diet L + 125	1218	1.17	0.96
SEM	68	0.14	0.12
Diet effect (P =)¶	0.852	0.404	0.404
Time since cleaned linear effect (P =)	0.061	<0.001	<0.001
Time since cleaned quadratic effect (P =)††	0.082	–	–

† Ammonia concentrations in exhaust were adjusted by subtracting incoming air ammonia concentrations. Ammonia emissions (mg min^{-1}) are calculated by multiplying the adjusted ammonia concentrations (ppmv times 10^{-6}) by the density of ammonia at STP (759 mg L^{-1}) and the airflow rate (standard L min^{-1}).

‡ Least squares means of chamber environment conditions measured n times during the last 3 d of each of four sampling periods are reported.

§ Treatments were a control corn and soybean meal diet (C), a reduced crude protein diet containing Lys (L), and a further reduced crude protein diet containing Lys, Met, Thr, and Trp (LMTT).

¶ P values < 0.10 indicate a significant difference occurred when pigs were fed the three diets.

Treatments were a diet containing Lys and no yucca (L + 0), a diet with Lys and 62.5 mg kg^{-1} of a yucca product (L + 62.5), and a diet with Lys and 125 mg kg^{-1} of a yucca product (L + 125).

†† When quadratic effects were not significant ($P > 0.10$), they were removed from the mixed model.

‡‡ Within a column and trial, means without a common lowercase letter differ ($P < 0.05$).

Ammonia emission rates also varied linearly with the amount of time that elapsed since chamber cleanout within sampling week ($P < 0.001$; Fig. 2). The number of hours that had elapsed between chamber cleanout and the start of air sampling varied by week (Fig. 2) because of variation in the times when chamber cleanings were completed and in the times when instrument calibrations were completed, with sampling commencing immediately after calibration. Week 1 air samplings occurred from 110 to 181 h after cleaning; Week 2, 107 to 186 h; and Week 4, 91 to 161 h. During Week 3, the drainage systems for Chambers 3 and 4 were clogged at the normal chamber cleanout time. Chamber 2 was cleaned at that time, but the pits in Chambers 3 and 4 were cleaned 35 h later. Air sampling occurred from 23 to 102 h after cleaning for Chambers 3 and 4, and from 58 to 136 h for Chamber 2. In all weeks, pigs were offered new diets for at least 58 h before air and excreta samplings began, and 70 to 80 h of air sampling followed.

In the current and other studies, ammonia emissions have decreased as dietary CP was reduced. The percent of reduction in emissions for each percentage unit reduction in CP content has varied across studies, and is probably not constant across the full range of CP contents. In the current study, ammonia emissions from pigs fed diet LMTT were 57% of those from pigs fed diet C, or reduced almost 20% for each percentage unit reduction

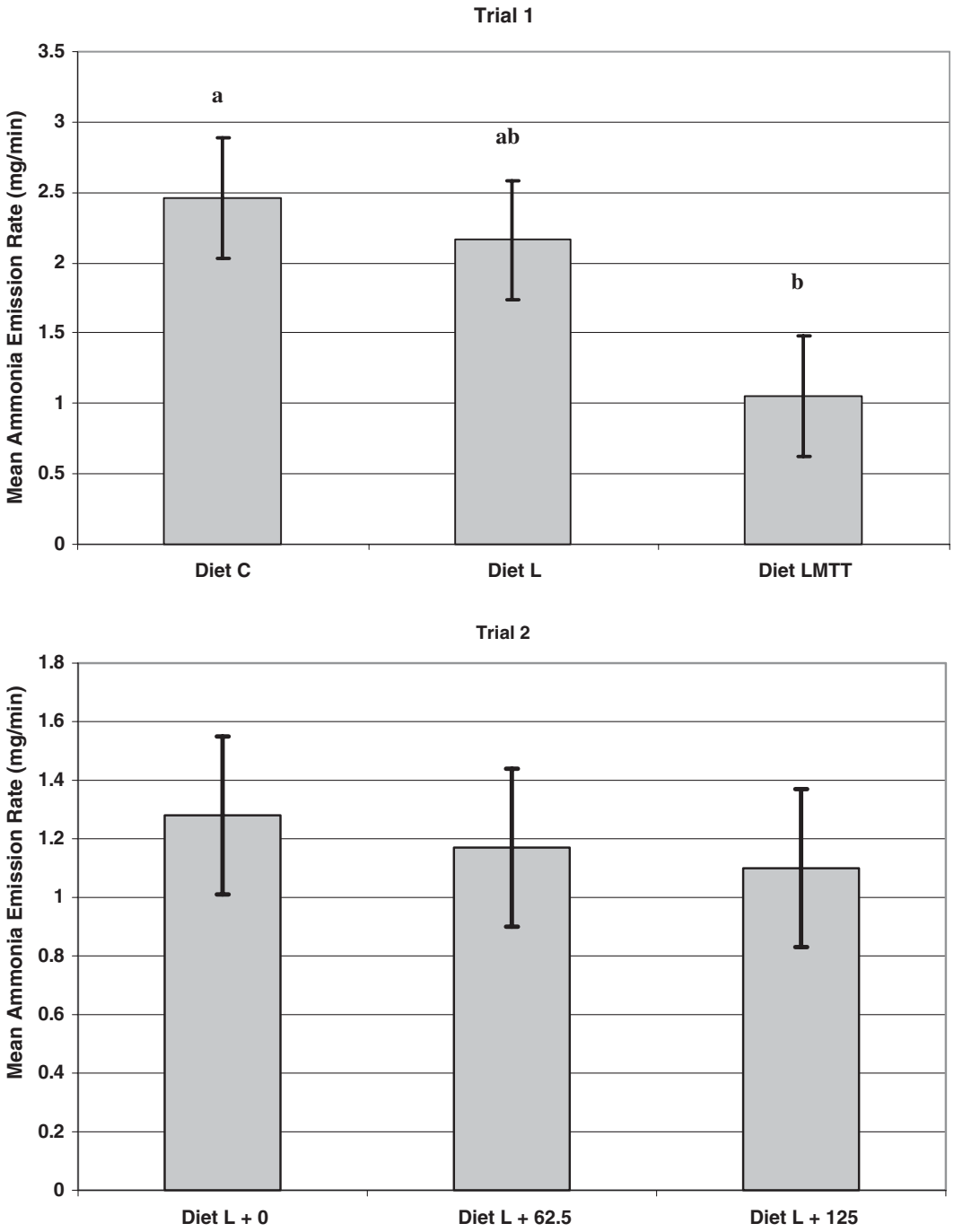

Fig. 1. Least squares means of ammonia emission rates from growing-finishing pigs. In Trial 1 (n = 683, SEM = 0.43 mg min^{-1}; P = 0.098), pigs were fed a control corn and soybean meal diet (C), a reduced crude protein diet containing Lys (L), and a further reduced crude protein diet containing Lys, Met, Thr, and Trp (LMTT). In Trial 2 (n = 600, SEM = 0.27 mg min^{-1}; diet P = 0.885), pigs were fed a diet containing Lys and no yucca (L + 0), a diet with Lys and 62.5 mg kg^{-1} of a yucca product (L + 62.5), and a diet with Lys and 125 mg kg^{-1} of a yucca product (L + 125). Means without a common superscript letter differ (P < 0.05).

in dietary CP. These results are similar to the findings for in vitro ammonia emission reductions by Turner et al. (1996) and Otto et al. (2003). However for other feeding trials, reductions in emissions of only 8 to 10% for every percentage unit of CP reduction were observed (Kay and Lee, 1997). Otto et al. (2003) found that a 90 g kg^{-1} CP diet minimized ammonia emissions, as there was no difference when compared to 60 g kg^{-1} CP and protein-free diets.

The pattern of ammonia emission rates observed in this study over time suggests that emission rates did not reach a peak within the week that manure accumulated. Canh et al. (1998) observed that in vitro ammonia emission rates peaked within 2 to 5 d, depending on the diet pigs were fed. Whereas Canh et al. (1998) accounted for 14 to 24% of the daily N excretion in the ammonia emitted over 7 d, using the excreta TKN concentrations

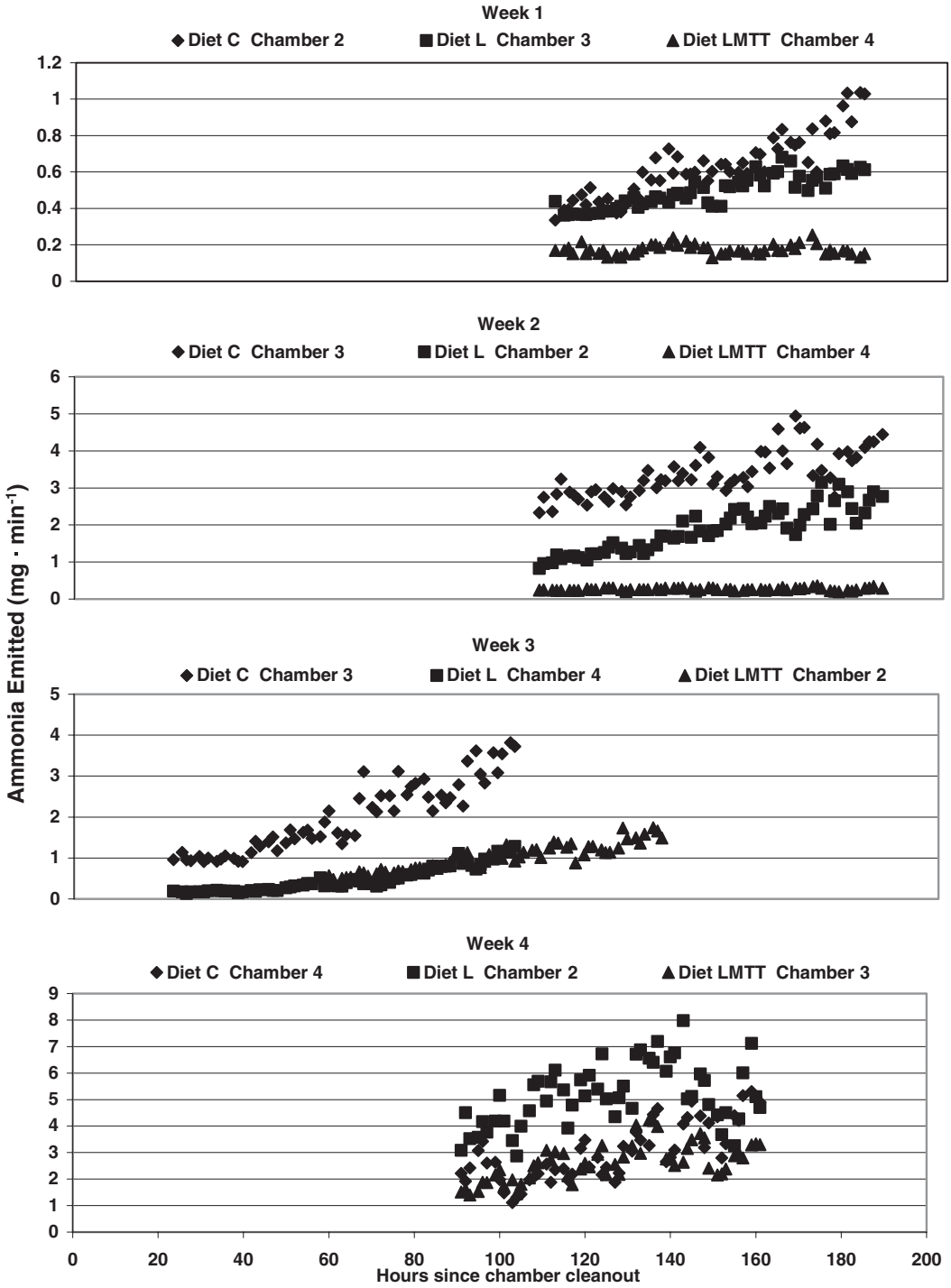

Fig. 2. Ammonia emission rates as time after chambers were cleaned out progressed within each week. Three growing-finishing pigs in each chamber were fed a control corn and soybean meal diet (C), a reduced crude protein diet containing Lys (L), and a further reduced crude protein diet containing Lys, Met, Thr, and Trp (LMTT). Diet effect ($P = 0.098$); time since cleaning within week linear covariate effect ($P < 0.001$).

observed in this study and excreta amounts obtained from American Society of Agricultural Engineers (2003), less than 2% of the calculated N excreted was accounted for in ammonia emissions. This difference could be attributed to the continuous accumulation of manure, brief storage periods, and the different diets of this study. Ammonia emissions were also measured differently in the two studies.

Trial 2

Animal Performance

There was no effect of dietary yucca inclusion on group ADG (2.42 ± 0.32 kg, $P = 0.710$; Table 2), weekly feed disappearance (42.6 ± 1.7 kg, $P = 0.316$), or G:F (0.404 ± 0.053, $P = 0.921$). Feed disappearance was increased during Weeks 2 (45.0 kg, $P = 0.013$), 3 (44.4 kg, $P = 0.016$),

and 4 (45.8 kg, $P = 0.009$), compared to Week 1 (35.1 kg; Table 2). Group ADG and G:F did not differ with week of the trial ($P = 0.190$ and $P = 0.125$, respectively).

Similar results were reported by Colina et al. (2001) and Yen and Pond (1993), when feeding 125 m g kg^{-1} of yucca extract to nursery pigs, by Amon et al. (1995) feeding 65 m g kg^{-1} to growing pigs, and by Van den Berghel et al. (2000) feeding 120 m g kg^{-1} to growing-finishing pigs. In contrast, Mader and Brumm (1987) noted a significant improvement in feed efficiency of finishing pigs fed 63 m g kg^{-1} of yucca sarsaponin, and Cole and Tuck (1995) noted improvements in ADG when feeding growing-finishing pigs 120 mg kg^{-1} of yucca. Cromwell et al. (1985) reported a tendency for improvement in growth performance when feeding nursery pigs diets containing 62 or 125 mg kg^{-1} yucca, but no effect when feeding growing-finishing pigs a diet containing 62 m g kg^{-1} yucca.

Improvements in performance associated with the feeding of yucca extract have generally been attributed to health improvements related to reducing aerial ammonia concentrations in confinement buildings (Colina et al., 2001). In this study, aerial ammonia concentrations were kept low by the relatively high ventilation rates, and neither the growth performance (Table 2) nor aerial ammonia concentrations (Table 4) were affected by the dose of yucca fed to pigs.

Excreta Composition

Dietary inclusion of yucca extract did not affect fecal TKN concentration of pigs fed those diets with and without yucca extract (0.36 ± 0.013 g kg^{-1} DM, $P = 0.925$; Table 3) nor urinary TKN (9.2 ± 1.6 g kg^{-1} as excreted, $P = 0.646$; Table 3). Likewise, fecal NH_4^+–N (0.48 ± 0.0012 g kg^{-1} DM, $P = 0.149$; Table 3) and urinary NH_4^+–N (1.3 ± 0.23 g kg^{-1}, $P = 0.603$; Table 3) were not different between pigs fed the three diets. Linear dose effects of yucca on pig performance and excreta composition are not reported because of the lack of treatment differences. Fecal NH_4^+–N concentrations were greater during Weeks 3 (0.056 g kg^{-1} DM) and 4 (0.055 g kg^{-1} DM) than Weeks 1 (0.040 g kg^{-1} DM) and 2 (0.043 g kg^{-1} DM, $P < 0.001$; Table 3). Week of feeding had no effect on fecal TKN ($P = 0.585$), urinary TKN ($P = 0.848$), or urinary NH_4^+–N ($P = 0.747$; Table 3).

Yucca extract was once believed to exert its effects on ammonia volatilization through inhibition of urease by its saponin fractions (Preston et al., 1987). However, because the magnitude of its effects are much too great to be completely explained by its only weak inhibitory properties (Killeen, 1995) and because liberation of radioactively labeled carbon dioxide of urea origin by jack bean urease was not impaired by yucca (Headon et al., 1991), the mode of action of yucca extract is now believed to be through a binding or conversion of ammonia (Headon et al., 1991).

In this study, there were no effects of yucca on urinary or fecal TKN and ammonium concentrations when pigs were fed isonitrogenous diets. Duffy and Brooks (1998) noted reductions in urinary ammonium concentrations for pigs supplemented with 120 m g kg^{-1} of yucca that failed to reach significance. Kemme et al. (1993) found no effects of dietary yucca on fecal N, total fecal plus urinary N, and the ratio of urinary to fecal N, and concluded that the effects of yucca are likely independent of any interference with the urea cycle in pigs. Colina et al. (2001) fed nursery pigs a diet with 125 m g kg^{-1} yucca and observed no differences in plasma urea, manure N, and manure ammonium concentrations, or manure pH.

Because pig feces are typically low in ammonium content, an ammonia binding agent would have its major effects only after excretion, assuming that urinary urea and fecal urease are then allowed to come into contact with each other. Feeding yucca extract to pigs may still be worthwhile if it results in reduced ammonia emissions, and especially if supplying the additive to the feed rather than applying directly to manure slurry reduces labor costs or improves the product's distribution throughout the slurry.

Ammonia Emissions

Chamber temperatures remained between 21 and 26°C and relative humidity between 50 and 84% throughout each air sampling period in Trial 2 (data not shown). Airflow rates (1197 ± 68 standard L min^{-1}, $P = 0.852$; Table 4, Trial 2) and ammonia (1.31 ± 0.14 ppmv, $P = 0.404$) and ammonia N concentrations of exhaust air (1.08 ± 0.12 ppmv, $P = 0.404$), adjusted for their concentrations in the incoming air, did not differ among groups of pigs fed diets with different inclusion rates of yucca. Incoming air contained 0.12 to 0.27 ppmv as ammonia (data not shown).

Aerial ammonia and ammonia N concentrations varied linearly with the time since chambers were cleaned ($P < 0.001$; Table 4). Airflow rates varied linearly ($P = 0.061$) and quadratically ($P = 0.082$) with the time since chamber cleaning, and linearly with the time since feeding ($P < 0.001$; Table 2).

Averaged over the four feeding periods, ammonia emission rates were not different between pigs fed diets L + 0, L + 62.5, and L + 125 (1.18 ± 0.270 mg min^{-1}, $P = 0.885$; Fig. 1). Ammonia emission rates varied with the amount of time that elapsed since chamber cleanout within sampling week ($P < 0.001$; Fig. 3). Air sampling occurred 82 to 161 h after the chambers had been cleaned out (Fig. 3) for all chambers each week.

Linear decreases in ammonia emissions and aerial ammonia concentrations with increased dosage of yucca fed to pigs were not detected in this study. Likewise, Colina et al. (2001) observed only a tendency for reduced ammonia concentrations measured by aspiration tubes when feeding yucca at 125 m g kg^{-1}, and a nonsignificant reduction when measured by diffusion tubes. In both the current study and that of Colina et al. (2001), aerial ammonia concentrations and ammonia emission rates were low for all diets compared to Cromwell et al. (1999), Cole and Tuck (1995), and Amon et al. (1995), potentially because of high airflow rates. Furthermore, the use of nipple waterers may have increased wasted water (Brumm et al., 2000) and reduced aerial ammonia

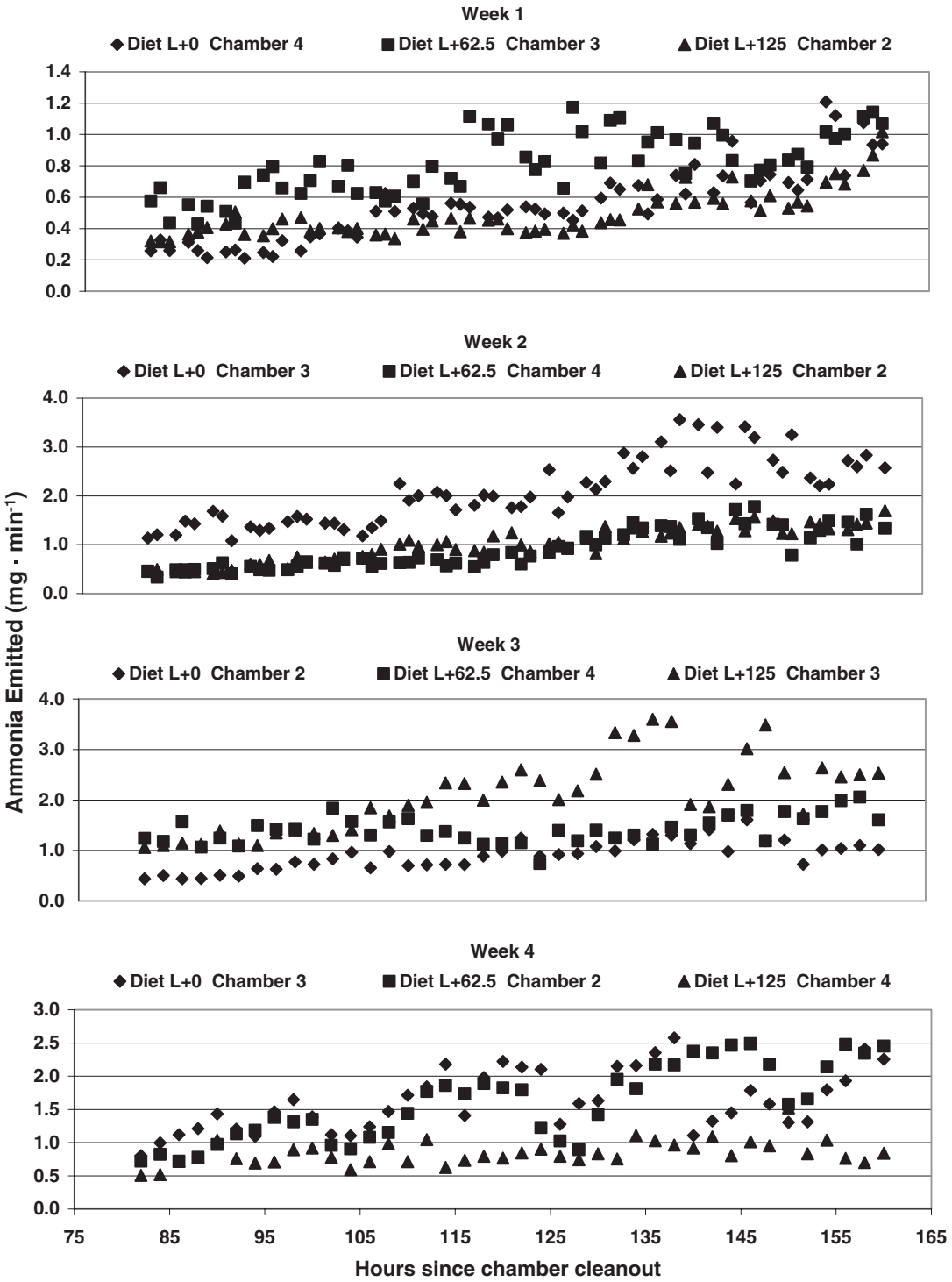

Fig. 3. Ammonia emission rates as time after chambers were cleaned out progressed within each week. Three growing-finishing pigs in each chamber were fed a control corn and soybean meal diet with Lys and no yucca (L + 0), a diet with 62.5 mg kg^{-1} yucca product (L + 62.5), and a diet with 125 mg kg^{-1} yucca product (L + 125). Diet effect ($P = 0.885$); time since cleaning within week linear covariate effect ($P < 0.001$).

concentrations because of dilution of slurry in the collection pits (Voermans et al., 1996).

The methods used in this study to determine the effects of feeding yucca on ammonia emissions have several differences from much of the work published on this topic. First, this study measured emissions rather than just concentrations (unlike Cole and Tuck, 1995; Headon and Walsh, 1993), allowing us to evaluate ammonia volatilization from slurry without the potentially confounding effects of different airflow rates. Second, the current study measured emissions from manure held in the same location as the animals, making the study more like a commercial setting when compared to in vitro studies (such as Cromwell et al., 1999; Duffy and Brooks, 1998)

because of the effects of continuous addition of excreta as well as wasted feed and drinking water. Third, the study was conducted in environmental chambers, where temperature and ventilation rates could be measured and controlled more precisely when compared to many on-farm trials (such as Cole and Tuck, 1995; Headon and Walsh, 1993). Finally, aerial ammonia concentrations were measured using a chemiluminescent ammonia analyzer, which has much greater precision than many diffusion or aspiration sampling tubes (used in Colina et al., 2001; Amon et al., 1995).

In contrast to the current study, several experiments have shown significant reductions of 15 to 35% in ammonia concentrations or emissions when feeding growing-finishing pigs were fed yucca extract (Amon et al., 1995; Cole and Tuck, 1995; Cromwell et al., 1999). Cole and Tuck (1995) and Amon et al. (1995) measured aerial ammonia in European swine buildings, and Cromwell et al. (1999) measured ammonia emitted from simulated anaerobic manure storage containers. In the case of Amon et al. (1995), a 26% reduction in emissions was the result of not only feeding yucca, but also simultaneously adding it directly to the slurry. In the current study, numerical reductions in ammonia emissions of 8 to 10% per dose of yucca extract were observed, while in Panetta et al. (2005), yucca added to the slurry at the same dose rates tended to reduce ammonia volatilization by 14 to 16% per dose. In the study conducted by Amon et al. (1995) the product was fed to nursery pigs and growing pigs (24 through 80 d of age) with dietary inclusion of the product of 165 mg kg^{-1} of feed (Days 24–50) and 65 mg kg^{-1} of feed (Days 51–80). The differences in duration of feeding the product and the age of the pigs may account for the ammonia concentration differences observed between Amon et al. (1995) and the current study.

For both trials in the current study, the graphs of ammonia emission rates over time since chamber cleaning demonstrate that emission rates generally increased during each sampling period as manure accumulated in the storage pits, though this was not the case for all diets during each sampling week. Emission rates did not seem to consistently (across diets and weeks) reach a maximum within 186 h of storage. The failure to reach equilibrium during short-term storage may explain why overall emission rates were relatively low compared to other reports (Canh et al., 1998). These results suggest that cleaning frequency may pose some merit as a strategy to reduce ammonia emissions from swine housing and manure collection areas. While neither the intent nor focus of the current study, our findings raise this as a researchable area. By cleaning barns more often, the source of ammonia would be removed from the facility. However, the ammonia may still be emitted from the long-term manure storage area unless additional strategies are employed to retain N in the storage structure.

Diet Cost

Ration costs were calculated using the monthly Iowa average prices of corn and soybeans for 2004 (Iowa Department of Agriculture and Land Stewardship-Agricultural Marketing Bureau, 2004). Prices for Lys, Met, and Trp were obtained from van Heugten and van Kempen (2000) and Thr from Reese (2004). In Trial 1, ration costs for diets L and LMTT were compared to diet C (Table 5). Diet L cost $3.16 per metric ton less than the diet containing no crystalline AA ($125.52 per 1000 kg and $122.36 per 1000 kg, respectively, Table 5). Diet LMTT ($130.46 per 1000 kg) cost $4.94 per ton more than C ($125.52 per 1000 kg) and $8.10 more than L ($122.36 per 1000 kg). When feed cost differences were calculated on an ammonia emission basis (Table 5), the feeding of diet L was associated with a decreased feed cost of $39.01 for every 1 kg reduction in observed ammonia emissions than was the feeding of diet C ($3.16 diet cost savings per 1000 kg of feed divided by 0.081 kg of ammonia emitted per 1000 kg of feed). Every 1 kg of reduced ammonia emission observed when pigs were fed diet LMTT was associated with an increased feed cost of $15.11, compared to when pigs were fed diet C. These

Table 5. Estimated ration costs and observed ammonia emissions from a study of nitrogen excretion and ammonia emissions from pigs.

		Trial 1‡			Trial 2§		
Ingredient	Cost†	C	L	LMTT	L + 0	L + 62.5	L + 125
	$ per 1000 kg						
Corn	89.76	70.70	73.60	78.36	73.60	73.60	73.60
Soybean meal	271.53	52.13	42.90	27.56	42.90	42.90	42.90
Premix¶	132.45	2.69	2.74	2.77	2.74	2.74	2.74
L-Lys-HCl	2403.00	–	3.12	7.69	3.12	3.12	3.12
DL-Met	2689.59	–	–	0.81	–	–	–
L-Thr	3527.34	–	–	2.82	–	–	–
L-Trp	34832.45	–	–	10.45	–	–	–
De-Odorase	2494.80	–	–	–	–	0.16	0.31
Total cost, $ per 1000 kg diet as fed		125.52	122.36	130.46	122.36	122.52	122.67
Ammonia emitted, kg per 1000 kg of diet fed		0.536	0.455	0.209	0.311	0.285	0.246
Marginal cost, $ per kg ammonia emission reduction		–	−39.01#	15.11	–	6.15	4.77

† Prices for corn and soybeans obtained from Iowa Department of Agriculture and Land Stewardship-Agricultural Marketing Bureau (2004; annual averages); premix from Heartland Co-op (Alleman, IA); Lys, Met, and Trp from van Heugten and van Kempen (2000); Thr from Reese (2004),;and De-Odorase from Alltech.

‡ Treatments were a control corn and soybean meal diet (C), a reduced crude protein diet containing Lys (L), and a further reduced crude protein diet containing Lys, Met, Thr, and Trp (LMTT).

§ Treatments were a diet containing Lys and no yucca (L + 0), a diet with Lys and 62.5 mg kg^{-1} of a yucca product (L + 62.5), and a diet with Lys and 125 mg kg^{-1} of a yucca product (L + 125).

¶ Premix composition provided in Table 1.

Because diet L cost less than diet C, a negative value represents money saved concurrent with less ammonia emitted.

marginal costs become important when weighing dietary cost increases with pollution contribution, particularly when regulations are established.

Because the reduction of CP in corn–soybean meal diets involves a substitution of some of the soybean meal with corn and addition of crystalline AA, the relative cost of such diets is sensitive to the prices of soybeans, corn, and AA. The economic decision of feeding low CP diets should also consider the effects on manure N content and how the manure will be used, as well as the cost of environmental compliance for air emissions associated with alternative strategies.

In Trial 2, ration costs for diets containing yucca were compared to the diet containing no yucca (Table 5). The yucca product increased the costs of mixed rations by \$0.16 per metric ton at the recommended dosage (L + 62.5) and by \$0.31 per ton for a double dose (L + 125). All other ingredients of the ration cost the same for all three diets. When feed cost differences were calculated on an ammonia emission basis (Table 5), the feeding of diet L + 62.5, compared to feeding the L + 0 diet, was associated with an increased feed cost of \$6.15 for every kilogram of reduced ammonia emissions. The feeding of diet L + 125 was associated with an increased feed cost of \$4.77 per kilogram of ammonia emission reduction (Table 5).

Because yucca extract is a feed additive, its inclusion in swine diets increases feed costs. However, the recommended dosage is so small that the increased cost is negligible. Because our findings contradict what others have observed when feeding yucca extracts to swine, there is potential merit in conducting further studies on the effects of feeding yucca to growing-finishing pigs to determine whether reductions in ammonia emissions can be reliably maintained over time. While our study measured emissions, previous work measured concentrations of ammonia, only (Amon et al., 1995). Note that it is the emissions of ammonia and other gases that are regulated in the United States. Whether yucca has any physiological effect on swine, and how it binds or converts ammonia in slurry also remain unclear.

CONCLUSIONS

Feeding a reduced crude protein, amino acid–supplemented diet is an effective tool for reducing ammonia emissions from growing-finishing swine housing. Results from the current study demonstrated a 13 to 58% reduction in ammonia emissions, depending on the diet, when compared to the control diet. However, proper formulation is essential to ensure that animal nutrient needs are met or negative effects on performance could be observed (rate of gain and/or feed conversion efficiency). Slight performance differences were observed when the lowest crude protein diet was fed compared to an intermediate diet. As environmental regulations become stricter, producers may have to consider strategies that have slight impacts on performance as part of an effort to optimize, rather than maximize, animal performance. However, at the present time there is little incentive to not maximize animal performance.

The feeding of yucca extract may not consistently reduce ammonia emissions measured in swine buildings, based on the current and previous work. Difference in observations may be due to the measurement of concentration of ammonia compared to ammonia emissions, or due to the duration or age of pigs fed. However, at the present time, it appears that there are better, more consistent, dietary strategies available to producers for reducing ammonia emissions.

Dietary strategies can economically reduce ammonia emissions from swine manure depending on the relative feed costs, associated animal performance, and the economic incentive to reduce ammonia emissions. Because the reduction of CP in corn–soybean meal diets involves a substitution of some of the soybean meal with corn and addition of crystalline AA, the relative cost of such diets is sensitive to the prices of soybeans, corn, and AA. The economic decision of feeding low CP diets should also consider the effects on manure N content and how the manure will be used, as well as the cost of environmental compliance for air emissions associated with alternative strategies.

Because ammonia emission rates increased, generally, as manure accumulated in the manure pits, short-term manure storage may reduce ammonia emissions in swine buildings from reaching maximum rates. This would translate into more frequent barn cleanings as a management practice. However, further prevention of volatilization, once manure is moved to long-term storage, must be considered as part of a whole-farm plan to minimize ammonia emissions.

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