

Manipulation of Dietary Protein and Nonstarch Polysaccharide to Control Swine Manure Emissions

O. Grant Clark,* Soenke Moehn, Ike Edeogu, Jason Price, and Jeremy Leonard

ABSTRACT

Odor and greenhouse gas (GHG) emissions from stored pig (*Sus scrofa*) manure were monitored for response to changes in the crude protein level (168 or 139 g kg⁻¹, as-fed basis) and nonstarch polysaccharide (NSP) content [i.e., control, or modified with beet pulp (*Beta vulgaris* L.), cornstarch, or xylanase] of diets fed to pigs in a production setting. Each diet was fed to one of eight pens of pigs according to a 2 × 4, full-factorial design, replicated over three time blocks with different groups of animals and random assignment of diets. Manure from each treatment was characterized and stored in a separate, ventilated, 200-L vessel. Repeated measurements of odor, carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) emissions from the vessels were taken every two weeks for eight weeks. Manure from high-protein diets had higher sulfur concentration and pH ($P \leq 0.05$). High-NSP (beet pulp) diets resulted in lower manure nitrogen and ammonia concentrations and pH ($P \leq 0.05$). Odor level and hedonic tone of exhaust air from the storage vessel headspaces were unaffected by the dietary treatments. Mean CO₂ and CH₄ emissions (1400 and 42 g d⁻¹ m⁻³ manure, respectively) increased with lower dietary protein ($P \leq 0.05$). The addition of xylanase to high-protein diets caused a decrease in manure CO₂ emissions, but an increase when added to low-protein diets ($P \leq 0.05$). Nitrous oxide emissions were negligible. Contrary to other studies, these results do not support the use of dietary protein reduction to reduce emissions from stored swine manure.

ODOR, GREENHOUSE GAS, and related emissions from swine manure can have environmental, economic, safety, and regulatory consequences for pig producers. Odor emissions are a nuisance to neighbors and can influence zoning decisions about the siting of pig production operations. Reduced GHG emissions, as compared with conventional practices of the industry in question, are a potential source of marketable carbon credits given an appropriate regulatory climate, and are also indicative of increased nutrient and economic efficiencies. The reduction of related manure emissions, such as hydrogen sulfide (H₂S) and ammonia (NH₃), also has environmental, safety, and nutrient management benefits.

Nuisance odor from stored pig manure results largely from compounds, such as sulfides, volatile fatty acids, and phenols, which are the products of incomplete anaerobic digestion of protein and carbohydrate (Sutton et al., 1999). Greenhouse gases, including CO₂, CH₄,

and N₂O, are also emitted from swine manure. Previous work has indicated that matching dietary nutrients with the requirements of the pig reduces the excretion of excess nutrients, such as nitrogen and carbon (Sutton et al., 1999; Lenis and Jongbloed, 1999). Lower nutrient availability, in turn, has been shown to reduce odor and GHG emissions from manure (Sutton et al., 1999). Diet manipulation, therefore, has often been proposed as an appropriate strategy for the abatement of odor and GHGs produced during the biodegradation of excreted nutrients in pig manure (Laguë, 2003; Sutton et al., 1999).

Dietary protein content in pig feed can be reduced in a cost-effective way without reducing animal performance (Ball and Möhn, 2003). The amino acid profile of feed proteins does not exactly match the nutritional requirements of pigs. As feed protein is progressively reduced, the diet becomes deficient in certain amino acids (e.g., lysine, methionine, threonine, and tryptophan) before others. Synthetic amino acid supplements must therefore be used to balance the diet nutritionally and maintain animal performance. The relative prices of synthetic amino acids and other feed ingredients determine the level of protein reduction at which a nutritionally balanced diet is cost-optimized.

Changes in feed concentrations of NSPs, such as arabinoxylans, are also purported to affect manure emissions, although the effect is less straightforward than is the case for protein reduction. Most NSPs are not digested in the small intestine of the pig, but pass to the hindgut where they serve as bacterial fermentation substrates (Bedford, 1995). On one hand, when feed NSP concentration is high, more N and C pass to the hindgut of the pig, possibly remaining in the feces as microbial biomass and providing substrate for subsequent production of manure emissions. On the other hand, the presence of NSP influences the bacterial dynamics in the hindgut and directly impacts the production of odorous compounds such as volatile fatty acids, amines, and sulfides (Zhang et al., 2002). Jerusalem artichoke (*Helianthus tuberosus* L.), for example, contains a class of NSPs called fructans, and its inclusion in pig feed appears to make swine manure less malodorous (Farnworth et al., 1995). There is scant literature about the effect of dietary NSP on manure GHG emissions.

Increasing feed NSP and thereby stimulating hindgut microbial activity also shifts N from the urine to feces, since more N is incorporated in bacterial protein. Urinary N is largely in the form of urea, which is readily convertible to NH₃, so the shift from urinary to fecal N reduces manure NH₃ concentrations (Payeur et al., 2002; Shriver et al., 2003). Furthermore, Canh et al. (1998)

O.G. Clark, S. Moehn, and J. Leonard, Department of Agriculture, Food, and Nutritional Science, 4-10 Ag/For Centre, University of Alberta, Edmonton, AB, Canada, T6G 2P5. I. Edeogu and J. Price, Agricultural Engineering Branch, Alberta Agriculture, Food, and Rural Development, Third Floor, J.G. O'Donoghue Building, 7000-113 St., Edmonton, AB, Canada, T6H 5T6. Received 15 Nov. 2004. *Corresponding author (grant.clark@ualberta.net).

Published in J. Environ. Qual. 34:1461–1466 (2005).
 Technical Reports: Atmospheric Pollutants and Trace Gases
 doi:10.2134/jeq2004.0434
 © ASA, CSSA, SSSA
 677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: dB_{od}, odor decibel; GHG, greenhouse gas; NSP, nonstarch polysaccharide.

reported that manure pH can be decreased by lowering dietary electrolyte balance while increasing NSP content. Ammonia is more soluble at lower pH, and so NH₃ emissions can be further controlled in this way. Canh et al. (1998) formulated a diet including sugar beet pulp, with low dietary electrolyte balance and high NSP content. Manure pH was decreased by 0.8 units compared with a control diet, and NH₃ emissions were reduced by 52 to 55% as a result.

If the intent of diet manipulation is to increase nutrient absorption by the pig and thereby decrease available N and C in the manure, then feed can be supplemented with NSP-degrading enzymes such as xylanase. This enzyme is intended to degrade arabinoxylans in the small intestine and so enhance digestion (Bedford, 1995), and has been shown to increase nitrogen and organic matter digestibility in pigs (Oryschak et al., 2002). Overall, however, the effects of xylanase supplementation on nutrient utilization and pig growth rate have been inconsistent (Chesson, 1993). The objective in this study was to investigate the effects of manipulating dietary protein and NSPs on odor and GHG emissions from anaerobically stored swine manure slurry.

MATERIALS AND METHODS

Eight diets, based on wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and soybean [*Glycine max* (L.) Merr.], were formulated with two levels of crude protein (168 and 139 g kg⁻¹, as-fed basis) and four NSP treatments (Table 1). The NSP treatments included a control and diets including the following ingredients: beet pulp, to elevate dietary NSP; cornstarch, to dilute the NSP fraction; and xylanase (Porzyme 9300; Danisco, Marlborough, UK), to enhance the digestion of arabinoxylans. To accommodate the inclusion of beet pulp and cornstarch in the experimental diets, the contents of barley, wheat, soybean meal, and canola (*Brassica napus* L.) meal were reduced proportionally within each protein level. To

achieve the amino acid contents as recommended by the National Research Council (1998), L-lysine HCl, L-threonine, and L-tryptophan were added to the diets as needed (Table 1).

Each of the eight diets was assigned to one pen of pigs in a single production room, according to a 2 × 4, full-factorial design. The trial was replicated over three time blocks during the period of July 2003 to February 2004, using different animals each time and completely randomizing the assignment of diets to pens within each time block. There were 14, 12, and 10 pigs per pen at the start of the first, second, and third blocks, respectively, the numbers being dictated by the limited availability of new animals from the closed research herd from which the subjects were drawn. Individual animals were occasionally removed from the experiment for health reasons. During each replicate of the trial, the pigs were allowed to consume the diets ad libitum for six weeks, during which time their mean weight increased from 50 to 85 kg. The amount of feed consumed per pen and the weight of the pigs were measured every two weeks to monitor animal performance.

The experiment was conducted in a single production room at the Swine Research and Technology Centre, University of Alberta, Edmonton, AB, Canada. The eight pens in the room were arranged side-by-side in a row extending the length of the room, with fully slatted floors underlain by four transverse gutters. The discharge plugs in the gutters were sealed and the manure from each pen was isolated by plastic partitions installed under the pen walls in the two gutters closest to the drinkers. The depth of manure in the gutters under each pen was monitored using a graduated measuring stick to detect any potential differences among pens due to water spillage from the drinkers, accumulation of wash water, or leakage around the partitions and discharge plugs. The gutters were completely emptied and thoroughly washed between trials, and the gutter partitions between pens were resealed.

Before emptying the gutters at the end of the six-week feeding period of each time block, the manure in each of the partitioned gutters under each pen was recirculated for 5 min with a centrifugal pump (Model WT30; Honda Canada, Toronto, ON) with a maximum discharge rate of 20 L s⁻¹. After the initial recirculation period, a T-valve was used to divert

Table 1. Ingredients and nutritional content of experimental pig diets.

	High-protein diets			Low-protein diets		
	Control†	Beet pulp	Starch	Control†	Beet pulp	Starch
Ingredients						
Barley, kg Mg ⁻¹	324	246	276	420	321	364
Wheat, kg Mg ⁻¹	445	337	379	473	361	410
Starch, kg Mg ⁻¹	0	0	160	0	0	150
Beet pulp, kg Mg ⁻¹	0	200	0	0	200	0
Canola oil, kg Mg ⁻¹	35	50	2	30	52	4
Soybean meal, kg Mg ⁻¹	75.0	56.5	63.5	50.0	38.1	43.3
Canola meal, kg Mg ⁻¹	100.0	75.1	84.3	0.0	0.0	0.0
L-Lysine HCl, kg Mg ⁻¹	0.90	1.89	2.01	2.98	3.42	3.68
L-Threonine, kg Mg ⁻¹	0.00	0.70	0.72	0.75	1.14	1.23
L-Tryptophan, kg Mg ⁻¹	0.00	0.30	0.26	0.00	0.20	0.18
Vitamin premix‡, kg Mg ⁻¹	20	20	20	23	23	23
Total, kg Mg ⁻¹	1000	1000	1000	1000	1000	1000
Nutrients§						
Metabolizable energy, MJ kg ⁻¹	13.4	13.3	13.4	13.4	13.3	13.4
Crude protein, g kg ⁻¹	168	168	168	139	139	139
Lysine, g kg ⁻¹	6.4	6.4	6.4	6.4	6.4	6.4
Methionine, g kg ⁻¹	2.5	3.2	3.1	2.0	2.5	2.3
Cysteine, g kg ⁻¹	3.1	2.4	2.6	2.6	2.0	2.2
Threonine, g kg ⁻¹	4.7	4.7	4.7	4.3	4.3	4.3
Tryptophan, g kg ⁻¹	1.7	1.7	1.7	1.3	1.3	1.3

† Rations were also formulated that were identical to the controls except for the addition of 0.8 kg Mg⁻¹ of commercial xylanase (Porzyme 9300; Danisco, Marlborough, UK).

‡ Breeder 4; Consultant Feeds, Calmar, AB, Canada.

§ Nutrients quantified on an as-fed basis.

75 L of slurry from the pump discharge into a 200-L storage vessel (Fig. 1). At the same time, a 1-L jar was filled with a representative subsample for chemical analysis by a commercial laboratory (Enviro-Test Laboratories, Saskatoon, SK, Canada). This process was repeated for both partitioned gutters, so that the storage vessel for each pen ultimately contained 150 L of manure slurry with a 50-L headspace. The pump and lines were flushed with water between sampling from different pens. The manure was stored in the vessels for eight weeks during each replicate of the trial, and the storage vessels were emptied, washed with bleach solution, and rinsed with water between repetitions.

Each plastic storage vessel (Fig. 1) had an airtight lid. A stirring paddle near the bottom of each vessel was fastened to a 16-mm-diameter stainless steel shaft extending through a sealed bearing in the lid of each vessel. A variable-speed motor (Catalog no. M11150021; Leeson Electric Corp., Grafton, WI) turned the shaft and paddle continuously at 5 rpm. This was considered fast enough to keep some solids in suspension, but too slow to cause aeration. Two, 6-mm-diameter stainless steel ports (inlet and outlet) in each lid directed airflow through the vessel headspace at 2 L min^{-1} . Inlet air was supplied by a compressor (Model CP6502516; Coleman Powermate, Kearney, NE) fitted with a precision pressure regulator (Model R352; Arrow Pneumatics, Broadview, IL). The air passed through a custom-made, 2.5-L activated charcoal filter into a distribution manifold, from which separate flow meters (Cole-Parmer, Vernon Hills, IL) regulated the air flow to each vessel through 6-mm-diameter plastic tubing. The exhaust air was vented to a fume hood.

Air samples were collected for odor analysis every two weeks during the eight-week manure storage period of each repetition. The vessels were checked on the day before each sampling event and any solids that had accumulated on the surface of the slurry were stirred back into the sample. Preliminary observations indicated that at least 5 h of ventilation was required to achieve stable gas concentrations, and so the ventilation was turned on at least 24 h before sampling. Air

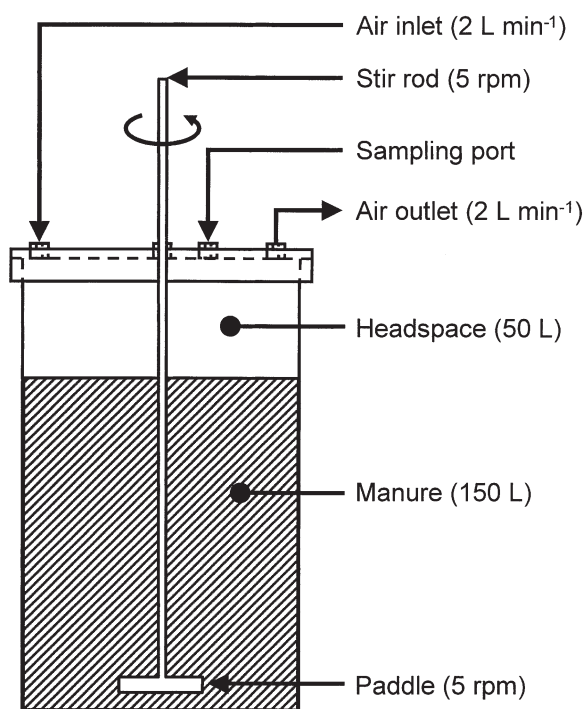


Fig. 1. Manure storage vessel.

was collected simultaneously from the inlet manifold and the exhaust port of each vessel over a period of about 10 min, in 17-L sample bags made in-house from Tedlar film (SKC, Eighty Four, PA). Two sets of samples were taken during each sampling event. The odor concentrations of the samples were measured in terms of odor units per cubic meter of sample air ($\text{OU}_E \text{ m}^{-3}$; European Committee for Standardisation, 2003) with a dynamic, forced-choice olfactometer (Feddes et al., 2001), and then converted to odor level, measured in decibels (dB_{od}), for analysis and reporting (European Committee for Standardisation, 2003). Hedonic tone was also measured simultaneously with odor concentration, whereby the olfactometer panelists rated the odor on a nine-category scale (from “dislike extremely” to “like extremely”). The responses of the panelists were automatically recorded as integer values ranging from 1 to 9, corresponding to the categories in the scale, and the mean response of the panel for each odor sample was considered as a datum for statistical analysis.

Quadruplicate air samples for GHG analysis were taken weekly from the headspace of each vessel and the inlet manifold during the eight-week manure storage period of each repetition. A syringe and hypodermic needle were used to draw air through sample ports sealed with butyl septa. Each 20-mL sample was injected into a 12-mL glass tube (Exetainer; Labco, High Wycombe, UK), pre-evacuated on-site to 90 kPa of vacuum using a single-stage, oil-sealed, high-vacuum pump (Speedivac Model 1SC0; BOC Edwards, West Sussex, UK). The samples were kept in cold storage until analysis for CO_2 , CH_4 , and N_2O concentrations. Two samples from each source were analyzed for N_2O concentration on a gas chromatograph (Varian Model 3400; Agilent Technologies Canada, Mississauga, ON) with a Porapak-QS column and an electron capture detector. Three samples from each source were analyzed for CO_2 and CH_4 on a second gas chromatograph (Varian Model HP 5890 Series II; Agilent Technologies Canada) with an HP-PLOT Q column and a thermal conductivity detector.

Data analysis for all aspects of this study was performed with the SAS software package (SAS Institute, 2001), according to a 2×4 , full-factorial design, with repeated sampling where appropriate and full replication over three time blocks. An α value of 5% ($P \leq 0.05$) was used throughout. For analysis and reporting, odor concentration measurements ($\text{OU}_E \text{ m}^{-3}$) were converted to odor decibels (dB_{od}), which is ten times the logarithm (base 10) of the odor concentration measurements (European Committee for Standardisation, 2003). This transformation accommodates the logarithmic human response to changes in odor concentration, similar to the way that the decibel system is used in the measurement of sound pressure. The difference between the outlet and inlet odor levels for the headspace of each storage vessel was calculated and used in statistical analysis. The differential gas concentrations were similarly calculated, and then normalized using a logarithmic (base 10) transformation. The SAS Mixed Procedure was used to analyze each data set with a statistical model including all experimental and treatment factors and their interactions (Wang and Goonewardene, 2004; SAS Institute, 1996). The model was then simplified to retain the two dietary treatment factors (protein and NSP) and their primary interaction, whether or not their effects were significant, and the time variable (week) corresponding to the repeated measures. Any other factors or interactions that were not significant in their effects were excluded from the model. Table 4 is included as an illustrative example showing the results of statistical analysis of the odor levels; other data were similarly analyzed but, for brevity, statistical tables are not shown.

Table 2. Feed consumption, weight gain, and feed conversion ratio for experimental diets.†

	Feed consumption	Weight gain	Feed conversion ratio
	kg d ⁻¹ pig ⁻¹ (dry basis)	kg d ⁻¹ pig ⁻¹	kg kg ⁻¹
	High-protein diet		
Control	2.3 (0.1)	0.90 (0.03)	2.6 (0.1)
Beet pulp	2.1 (0.1)	0.86 (0.03)	2.4 (0.1)
Starch	2.2 (0.1)	0.88 (0.03)	2.5 (0.1)
Xylanase	2.1 (0.1)	0.85 (0.03)	2.5 (0.1)
	Low-protein diet		
Control	2.1 (0.1)	0.81 (0.03)	2.6 (0.1)
Beet pulp	2.2 (0.1)	0.87 (0.03)	2.5 (0.1)
Starch	2.4 (0.1)	0.90 (0.03)	2.7 (0.1)
Xylanase	2.3 (0.1)	0.92 (0.03)	2.5 (0.1)
Overall mean	2.2 (0.1)	0.87 (0.01)	2.5 (0.1)

† Values are least-squares estimates of the mean, with standard errors in parentheses. There were no statistically significant differences between any treatments at any level.

RESULTS AND DISCUSSION

Pig Performance

Average feed consumption was 2.3 kg pig⁻¹ d⁻¹ (2.2 kg pig⁻¹ d⁻¹ dry basis) with a standard error of the mean (SE) of 0.1 kg pig⁻¹ d⁻¹, among diets (Table 2). Wastage was not considered in the calculation of feed consumption. The mean weight gain and mean feed conversion ratio were calculated for each pen for every two-week period during each repetition of the trial. The overall mean weight gain for all pigs over the entire experiment was 0.87 kg pig⁻¹ d⁻¹ (SE = 0.01 kg pig⁻¹ d⁻¹) and the mean feed conversion ratio was 2.5 (kg dry feed per kg weight gain) (SE = 0.1) (Table 2). The treatment factors had no significant effect on pig performance in terms of any of these measures ($P > 0.05$).

The results confirm that a moderate reduction in dietary protein is not detrimental to pig performance if amino acids are balanced appropriately. Aside from other benefits, protein reduction can be cost-effective up to a point determined by ingredient prices (Ball and Möhn, 2003). In the Canadian feed industry, swine diets are least-cost formulated by reducing high-protein ingredients and supplementing with synthetic amino acids

such as lysine, threonine, methionine, and tryptophan (R.T. Zijlstra, University of Alberta, personal communication, 2004). At the time that this experiment was performed, for instance, the high-protein diet and the low-protein diet supplemented with amino acids were similar in cost. The diets amended with beet pulp, however, were about 30% more expensive than the control and xylanase diets, and the diets amended with cornstarch were about 50% more expensive. The latter treatments would therefore have been of little importance in a commercial Western Canadian context at the time the experiment was performed.

Manure Chemistry

The results of the manure chemistry analysis are shown in Table 3 as least-squares mean values by dietary treatment factor. These data are reported for the most part as concentrations per kg of dry manure, to avoid distortion due to potentially uneven accumulation of drinking or wash water in the gutters under different pens, although there were no differences in the manure solids content associated with the various diets ($P > 0.05$).

Reduced protein was associated with significantly lower manure pH and sulfur concentration, but higher iron, manganese, and zinc concentrations ($P \leq 0.05$). Lower protein affected neither total nor ammoniacal nitrogen ($P > 0.05$), failing to corroborate the expected reduction in manure nitrogen content that would result from the lowered nitrogen excretion when feeding diets with reduced protein contents (Lenis and Jongbloed, 1999; Sutton et al., 1999). Sulfur and nitrogen are of interest in this context because volatile sulfur compounds and NH₃ affect the odor of stored manure, and pH influences the solubility of NH₃. The expected reduction in excreted nitrogen associated with lower dietary protein content, well-documented in the aforementioned studies, could have been masked by volatilization of NH₃ during the storage of the manure in the gutters during the feeding period and losses of N₂O and NH₃ during recirculation of manure (Béline et al., 1999). Manure emissions from the gutters were not monitored

Table 3. Manure properties by dietary treatment factor.†

Property‡	Protein treatment		Nonstarch polysaccharide treatment			
	High	Low	Control	Beet pulp	Starch	Xylanase
Solids, g kg ⁻¹	32 (2)	33 (2)	31 (4)	34 (4)	27 (4)	37 (4)
pH	7.4A (0.04)	7.2B (0.04)	7.3a (0.06)	7.1b (0.06)	7.3a (0.06)	7.4a (0.06)
Total organic C, g kg ⁻¹	410 (3)	410 (3)	410b (5)	410b (5)	390c (5)	420a (5)
Ammoniacal N, g kg ⁻¹	118 (7)	112 (7)	140ab (10)	80c (10)	140ab (10)	100bc (10)
Total N, g kg ⁻¹	146 (7)	137 (7)	160a (10)	110b (10)	170a (10)	130b (10)
P, g kg ⁻¹	30 (2)	32 (2)	36a (2)	21b (2)	36a (2)	31a (2)
K, g kg ⁻¹	50 (3)	46 (3)	54a (4)	42b (4)	55a (4)	40b (4)
S, g kg ⁻¹	13A (0.6)	11B (0.6)	12 (0.8)	12 (0.8)	13 (0.8)	11 (0.8)
Na, g kg ⁻¹	10 (1)	11 (1)	10 (1)	12 (1)	13 (1)	8.0 (1)
Ca, g kg ⁻¹	23 (0.5)	24 (0.5)	22b (0.7)	27a (0.7)	24b (0.7)	20c (0.7)
Mg, g kg ⁻¹	12 (0.5)	12 (0.5)	13 (0.8)	11 (0.8)	11 (0.8)	12 (0.8)
Cu, g kg ⁻¹	0.13 (0.01)	0.16 (0.01)	0.16 (0.02)	0.13 (0.02)	0.18 (0.02)	0.12 (0.02)
Fe, g kg ⁻¹	1.6B (0.1)	1.9A (0.1)	1.5b (0.1)	2.4a (0.1)	1.6b (0.1)	1.4b (0.1)
Mn, g kg ⁻¹	0.31B (0.01)	0.35A (0.01)	0.33 (0.02)	0.31 (0.02)	0.35 (0.02)	0.33 (0.02)
Zn, g kg ⁻¹	0.69B (0.03)	0.81A (0.03)	0.77 (0.04)	0.66 (0.04)	0.82 (0.04)	0.74 (0.04)

† Values are least-squares estimates of the mean, with standard errors in parentheses. Values within rows and within treatment factors that have different letters differ at $P \leq 0.05$. Interactions between factors were not significant.

‡ All concentrations are based on dry weight, except for solids.

during the feeding period or recirculation of the manure in this study.

The NSP treatments had varied effects on manure chemistry (Table 3). The addition of beet pulp was associated with decreased manure pH and concentrations of ammoniacal and total N compared with the control treatment ($P \leq 0.05$), confirming the results of other studies (Shriver et al., 2003; Payeur et al., 2002; Canh et al., 1998). There was also a corresponding decrease in the concentrations of phosphorous and potassium ($P \leq 0.05$). The starch treatment resulted in the lowest concentration of total organic carbon and the xylanase treatment resulted in the highest ($P \leq 0.05$). Xylanase was also associated with significant reductions in total manure nitrogen, potassium, and calcium ($P \leq 0.05$).

Odor

The results of the analysis of the odor level data (dB_{od}) are shown in Table 4; other variables were analyzed similarly. The overall mean odor levels of the inlet and exhaust air streams were 22 and 34 dB_{od} , respectively. Neither the change in dietary protein nor the NSP treatments used in this study had any significant effect on the odor level of the exhaust air stream ($P > 0.05$). The mean hedonic tone of the storage vessel exhaust air was 2.7 (SD = 0.4), a value falling between the corresponding descriptions of "dislike very much" (2) and "dislike moderately" (3) on the aforementioned nine-category scale. The dietary treatments had no significant effect on the hedonic tone of the odor samples ($P > 0.05$).

It should be noted that odor was only quantified in this study after the manure was transferred to the storage vessels. Although the dietary protein levels used in this study had no significant effect on the odor emitted from the manure storage vessels, it might be speculated that the effect on odor emissions from the overall production system could be significant, as indicated by other research (Laguë, 2003; Sutton et al., 1999). This study, however, offers no direct evidence to support or refute this conjecture. With respect to NSP manipulation, the addition of beet pulp in this study did significantly reduce manure nitrogen concentration and pH ($P \leq 0.05$) which, if the effect were more pronounced, could conceivably result in reduced NH_3 emissions and associated odor.

Table 4. Significance of effects included in the statistical model for analysis of odor level.[†]

Source of variation [‡]	Numerator df	Denominator df	F value	P > F
Rep	2	38.2	17	<0.0001
Week	3	41	1.3	0.30
Protein	1	37.5	2.2	0.15
NSP	3	37.5	0.16	0.92
Protein × NSP	3	37.4	0.77	0.52

[†] Analysis was performed using the SAS Mixed Procedure (SAS Institute, 1996).

[‡] Rep = trial replicate (time block); Week = time variable associated with repeated measures within block; Protein and NSP (nonstarch polysaccharide) = treatment factors.

Greenhouse Gases

The least-squares means of the concentration increases (from the inlet to the outlet of the storage vessel headspace) for CH_4 and CO_2 are shown in Table 5. The data were analyzed and are reported in the table as base-10 logarithms, since the logarithmic transformation was necessary to normalize the data set. The arithmetic means of the concentration changes for CH_4 and CO_2 were $330 \mu\text{L L}^{-1}$ (SD = 400) and $3980 \mu\text{L L}^{-1}$ (SD = 2010), respectively, equivalent to mass emission rates of 42 and $1400 \text{ g d}^{-1} \text{ m}^{-3}$ manure. There were no significant N_2O emissions from the manure storage vessels in this study ($P > 0.05$).

The effects of the protein and NSP treatment factors on the change in CO_2 headspace concentration, and their two-way interaction, were all significant ($P \leq 0.05$). The effect of the time block, its two-way interaction with NSP, and its three-way interaction with both treatment factors were also significant ($P \leq 0.05$). The effect of the sampling time (week) was significant ($P \leq 0.05$), although its interactions with other factors were not ($P > 0.05$).

The high-protein diets resulted in lower CO_2 emissions than did the low-protein diets ($P \leq 0.05$) (Table 5). This result was not expected, but it might be speculated that differences in the manure micronutrient profiles (Table 3) resulted in elevated microbial activity in manures from the low-protein diets. With respect to the effect of NSP treatments on CO_2 emissions, manure from the xylanase diets had the highest emission rate, followed by the control, beet pulp, and starch diets, in that order. The significance of differences between mean emission rates, as analyzed according to NSP treatments and interactions between protein and NSP treatments, is reflected in Table 5. Manure from the control and xylanase diets had a higher CO_2 emission rate than did

Table 5. Concentration change of carbon dioxide and methane from storage vessel headspace inlet to outlet, by dietary treatment factor.[†]

Dietary treatment factor	Logarithm (base 10) of concentration change	
	Carbon dioxide	Methane
	log ₁₀ $\mu\text{L L}^{-1}$	
	Protein	
High (H)	3.54b (0.01)	2.37b (0.01)
Low (L)	3.58a (0.01)	2.41a (0.01)
	Nonstarch polysaccharide	
Beet pulp (B)	3.52b (0.01)	2.40a (0.02)
Control (C)	3.60a (0.01)	2.39a (0.01)
Xylanase (X)	3.59a (0.01)	2.39a (0.01)
Starch (S)	3.52b (0.01)	2.38a (0.02)
	Interactions	
H × B	3.51ef (0.02)	2.43ab (0.03)
H × C	3.63b (0.01)	2.37c (0.02)
H × X	3.48f (0.01)	2.29d (0.02)
H × S	3.56cd (0.02)	2.41bc (0.03)
L × B	3.53de (0.01)	2.38bc (0.02)
L × C	3.58c (0.01)	2.42b (0.02)
L × X	3.71a (0.01)	2.48a (0.02)
L × S	3.49f (0.01)	2.35c (0.02)

[†] Values are least-squares estimates of the mean, with standard errors in parentheses. Values within columns and within treatment factors that have different letters differ at $P \leq 0.05$.

manure from the beet pulp and starch diets. The mean increase in CO₂ concentration in the vessel headspace was the smallest for the high-protein xylanase, but largest for the low-protein xylanase diet. This might be due to differences in the NSP profiles of the high and low-protein base diets, corresponding to the different proportions of ingredients used in each (Table 1).

The protein treatment factor, its interaction with NSP, and the week had statistically significant effects on CH₄ emissions from the manure, as did the time block and all of the two and three-way interactions between the time block and the treatment factors ($P \leq 0.05$) (Table 5). Methane emissions increased with lower dietary protein which, as with CO₂, would not have been expected on the basis of literature. The NSP treatment alone had no significant effect on CH₄ emissions, but the interaction effects between protein level and NSP treatment indicate that, as with CO₂ emissions, the enzyme was effective in the high-protein diet but not in the low-protein diet.

CONCLUSIONS

Neither moderate reduction of dietary crude protein, from 168 to 139 g kg⁻¹, nor manipulation of the NSP fraction of pigs' diet in a production setting significantly affected the odor level or hedonic tone of emissions from the resulting manure when stored in ventilated, laboratory-scale vessels. It is possible that larger protein reduction or increased statistical power might show significant changes in manure odor, as suggested in the literature. It must also be emphasized that this study was focused solely on manure emissions; neither enteric emissions nor atmospheric concentrations in the production room were quantified. The dietary manipulations used in this study could potentially affect odor emissions from the overall production system, and this remains an avenue for more comprehensive research. The protein reduction was associated with lower manure pH and sulfur concentration ($P \leq 0.05$). Higher dietary NSP (diets with beet pulp) decreased the manure pH and total and ammoniacal nitrogen ($P \leq 0.05$). Xylanase in high-protein diets effectively reduced CO₂ and CH₄ emissions ($P \leq 0.05$), but the opposite effect was observed with low-protein diets ($P \leq 0.05$), perhaps because of differences in the NSP profiles of those diets. These interaction effects might justify further research on the efficacy of enzyme additives at different feed protein levels. Manure CO₂ and CH₄ emissions both increased in response to reduced dietary protein ($P \leq 0.05$), a result that is contrary to findings from other studies. Future work related specifically to the facilities and apparatus used in this experiment might include the determination of how emission rates vary with respect to the volume and surface area of the manure in a storage vessel, the method and rate of agitation, and the ventilation rate of the headspace.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support of Alberta Agriculture, Food, and Rural Development and

the Alberta Agricultural Research Institute. Thanks are also extended to the staff of the Swine Research and Technology Centre and the AFNS Olfactometry Laboratory (University of Alberta), Dr. R. Zijlstra, M. Nagpal, J. Lee, and B. Morin. The constructive suggestions of several anonymous reviewers helped to greatly improve this article.

REFERENCES

- Ball, R.O., and S. Möhn. 2003. Feeding strategies to reduce greenhouse gas emissions from pigs. *Adv. Pork Prod.* 14:301–311.
- Bedford, M.R. 1995. Mechanism of action and potential environmental benefits from the use of feed enzymes. *Anim. Feed Sci. Technol.* 53:145–155.
- Béline, F., J. Martinez, D. Chadwick, F. Guizoui, and C.-M. Coste. 1999. Factors affecting nitrogen transformations and related nitrous oxide emissions from aerobically treated piggery slurry. *J. Agric. Eng. Res.* 73:235–243.
- Canh, T.T., A.J.A. Aarnink, J.B. Schutte, A. Sutton, D.J. Langhout, and M.W.A. Verstegen. 1998. Dietary protein affects nitrogen excretion and ammonia emission from slurry of growing-finishing pigs. *Livest. Prod. Sci.* 56:181–191.
- Chesson, A. 1993. Feed enzymes. *Anim. Feed Sci. Technol.* 45:65–79.
- European Committee for Standardisation. 2003. Air quality—Determination of odour concentration by dynamic olfactometry. Publ. EN 13725. European Committee for Standardisation (CEN), Brussels.
- Farnworth, E.R., H.W. Modler, and D.A. Mackie. 1995. Adding Jerusalem artichoke (*Helianthus tuberosus* L.) to weanling pig diets and the effect on manure composition and characteristics. *Anim. Feed Sci. Technol.* 55:153–160.
- Feddes, J.J.R., G. Qu, C.A. Ouellette, and J.J. Leonard. 2001. Development of an eight-panelist single port, forced-choice, dynamic dilution olfactometer. *Can. Biosyst. Eng.* 43:6.1–6.5.
- Laguë, C. 2003. Management practices to reduce greenhouse gas emission from swine production systems. *Adv. Pork Prod.* 14:287–300.
- Lenis, N.P., and A.W. Jongbloed. 1999. New technologies in low pollution swine diets: Diet manipulation and use of synthetic amino acids, phytase, and phase feeding for reduction of nitrogen and phosphorus excretion and ammonia emission—Review. *Asian-Australas. J. Anim. Sci.* 12:305–327.
- National Research Council. 1998. Nutrient requirements for swine. 10th revised ed. Natl. Academies Press, Washington, DC.
- Oryszak, M.A., P.H. Simmins, and R.T. Zijlstra. 2002. Effect of dietary particle size and carbohydrase and/or phytase supplementation on nitrogen and phosphorus excretion of grower pigs. *Can. J. Anim. Sci.* 82:533–540.
- Payeur, M., S.P. Lemay, R.T. Zijlstra, S. Godbout, L. Chénard, E.M. Barber, and C. Laguë. 2002. A low-protein diet including fermentable carbohydrates combined with canola oil sprinkling for reducing ammonia emissions of pig barns. Paper no. 02-503. CSAE/SCGR, Winnipeg, MB, Canada.
- SAS Institute. 1996. SAS system for mixed models. SAS Inst., Cary, NC.
- SAS Institute. 2001. The SAS system for Windows. Release 8.2. SAS Inst., Cary, NC.
- Shriver, J.A., S.D. Carter, A.L. Sutton, B.T. Richert, B.W. Senne, and L.A. Pettey. 2003. Effects of adding fiber sources to reduced-crude protein, amino acid-supplemented diets on nitrogen excretion, growth performance, and carcass traits of finishing pigs. *J. Anim. Sci.* 81:492–502.
- Sutton, A.L., K.B. Kephart, M.W.A. Verstegen, T.T. Canh, and P.J. Hobbs. 1999. Potential for reduction of odorous compounds in swine manure through diet modification. *J. Anim. Sci.* 77:430–439.
- Wang, Z., and L.A. Goonewardene. 2004. The use of mixed models in the analysis of animal experiments with repeated measures data. *Can. J. Anim. Sci.* 84:1–11.
- Zhang, Q., J. Feddes, I. Edeogu, M. Nyachoti, J. House, D. Small, C. Liu, D. Mann, and O.G. Clark. 2002. Odour production, evaluation, and control. Project MLMMI 02-HERS-03. Manitoba Livestock Manure Management, Winnipeg, MB, Canada.