

Combined Final Report for:

**Improving nutrient digestibility and air quality by manipulation of soluble
fiber (NSP) in swine diets**

AND

**Improving odor perception by manipulation of soluble fiber (NSP) in swine
diets**

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Introduction

Ammonia and volatile organic compounds are major contributors to air quality problems associated with swine production. Research conducted at UNC (Schiffman, 1998) implicated ammonia and odorous compounds from swine facilities as causative agents in health and emotional problems in humans living near swine facilities. This research continues and will likely focus on specific compounds in emissions from swine facilities that cause human health effects. Therefore, research is necessary to manipulate odorous emissions from swine and to understand how diet composition can affect individual compounds and overall odors.

Fiber is resistant to the digestion by endogenous enzymes from mammalian hosts and it will decrease the digestibility of nutrients in the feed and increase endogenous protein and fat losses (Noblet and Perez, 1993; De Lange et al., 1989). Dietary fiber, particularly soluble Non-Starch Polysaccharides (NSP), has high water binding capacity (Bach Knudsen, 2001; Antoniou and Marquard, 1981; Jensen and Jørgensen, 1994). Therefore, soluble NSP may hold more water in the colon, stimulate microbial activity and extend hindgut fermentation time. As a result, more substrate, in the form of NSP, undigested protein, and endogenous losses, will be available for fermentation in the cecum and large intestine. This fermentation is expected to increase the production of volatile organic compounds and will contribute to unpleasant odors. On the other hand, dietary NSP can shift nitrogen from urine to feces in the form of bacteria protein, thereby reducing ammonia emission (Shriver et al., 2003). Non-starch polysaccharides increase fecal bulk (Moeser et al., 2002), which needs to be considered when evaluating the effects of fiber compounds on overall odor emissions.

Studies that directly measure the impact of soluble fiber (NSP) on ammonia and odor production in swine are not available. Thus, the objectives of this project were to: 1) determine the effect of different levels of NSP (0, 2%, 4%, or 8% guar gum) on nutrient digestibility,

ammonia, and odor in growing pigs; and 2) determine the effect of different levels of dietary NSP in practical swine diets on manure mass and total production of ammonia and odor.

Experimental Procedures

Experiment 1: Effects of guar gum supplementation on nutrient digestibility, fecal characteristics, and manure odorants in growing pigs

Diets and animals: This study was conducted using two separate groups of pigs. In batch 1, 16 growing pigs with an initial average BW of 27.2 ± 1.43 kg were used. Pigs were assigned into four groups randomly and each group contained 4 pigs. Four diets with different levels (0, 2%, 4%, or 8%) of guar gum (Jaguar® 4500F, Rhodia, Cranbury, NJ) were fed to 4 pigs within each group. The diets were fed in mash form and formulated to meet or exceed NRC (1998) requirements for growing pigs (Table 1). In batch 2, 12 growing pigs with an initial BW of 26.2 ± 1.20 kg were used. Pigs were assigned into four groups randomly corresponding to the four diets and each group contained 3 pigs.

Pigs were housed at the swine educational unit (NCSU, Raleigh) for an adjustment period of 21 days. A minimal adjustment period of three weeks was considered necessary to allow for stabilization of the microflora in the large intestine (Longland et al., 1993). Pigs were then transferred to Grinnells laboratory (Raleigh, NC) where they were housed in metabolism cages (0.6 x 1.5 m) individually and given ad libitum access to feed and water.

After a 7-day adaptation period in metabolism cages, a 3-day collection period for feces and urine was conducted. Feces were collected quantitatively on wire screens and were frozen at -20°C until further chemical analysis was conducted. Urine was collected quantitatively on

slope-shaped stainless steel trays in plastic containers placed in ice to minimize gaseous losses of nitrogen. Quantity of feces and urine was recorded and frozen at -20°C as soon as it was collected, twice daily.

On day 11, pigs were anesthetized by i.m. injection of a combination of ketamine (15 mg/kg BW, Fort Dodge Animal Health, Fort Dodge, IA) and xylazine (2 mg/kg BW, Phoenix Scientific Inc., St. Joseph, MO). Blood samples were taken from the jugular vein for blood urea nitrogen (BUN) analysis. Then, pigs were killed by anesthetic overdose with sodium pentobarbital (200 mg/kg BW, Vortech Pharmaceutical, LTD, Dearborn, MI) administered i.v. Immediately after sacrifice, the gastrointestinal tract was removed and digested at the end of the small intestine (4 m from the ileo-cecal junction), cecum, and distal colon were sampled and frozen at -20°C for further analysis.

Chemical analyses: Frozen feces and urine were thawed. Then, feces and urine were mixed together at the rates they were produced when their temperatures were close to 0°C and homogenized within respective animal. A portion of this manure was used to determine fresh manure ammonia emission and the remaining manure was stored in 1-L plastic containers and allowed to sit at room temperature for 21 days of anaerobic aging. Fresh and aged manure were sub-sampled (10 ml) and sent to West Texas A&M University for odor hedonic tone and intensity evaluation by a professional panel. The panelists were asked to smell each sample individually and assign a designation of degree of pleasantness or unpleasantness according to a -10 to +10 hedonic tone scale, with 0 being neutral. They also were asked to assign a score for strength of odor by smelling the sample and comparing it to a series of standards. The intensity standards were prepared per ASTM E 544-99 with n-butanol, and the n-butanol concentrations for the 1-5 scale (very faint, faint, moderate, strong, and very strong) standards were 250, 750, 2250, 6750, and 20250 ppm, respectively (Guo et al., 2001). The panelists smelled the sample

and compared them to the standards for strength of odor and assigned a standard number (1, 2, 3, 4, or 5) that matched the strength of the sample. If a sample fell between 2 standards, a designation of 0.5 was used (0.5 if < 1, 1.5, 2.5, 3.5, 4.5, or 5.5 if > 5).

Frozen fresh or aged manure samples were thawed in a water bath at approximately 20°C and 3 ml of manure samples were transferred to 15 ml test tubes immediately. pH values were measured by using a pH meter (Accumet® pH model 610 A, Fisher pH, Ambler, PA, USA). Odor compounds from headspace air were adsorbed by Solid Phase Microextraction (SPME) fibers (Carboxen™/Polydimethylsiloxane fiber, Supelco SPME Portable Field Sampler, Supelco, Bellefonte, Pa.) for 30 min and were analyzed by Gas Chromatography/Mass Spectrometry (GC/MS, GC HP 6890; MS HP 5973) immediately. Compounds were separated on a 30 m × 0.32 mm diameter × 0.25 μm film thickness Innowax PEG column (Agilent Technologies, Palo Alto, CA). Injector temperature was maintained at 245°C and detector temperature was 250°C. The column was programmed as follows: flow rate 0.5 ml/min, initial temperature 40°C, initial time 3 min, the temperature ramp was 12°C/min to 220°C then held for 10 min. The identities of odor compounds were determined by comparison to the retention times of known standards, and were further confirmed by comparing the mass spectra (see Figure 2 for a representative analysis report).

Ammonia emission of the manure samples was determined (Figure 1) by placing 400 ml of the manure mixture in a rectangular (28 L × 9.5 W × 6 H cm) container (Super Oval 1, Tupperware Co., Orlando, FL). Air was drawn through a flow meter (Cole Palmer, Vernon Hills, IL) at a rate of 1.4 L/min, the container with manure, and then through a gas dispersion tube (Fisher Scientific, Pittsburg, PA) placed in a 500 ml Erlenmeyer flask containing 400 ml dilute sulfuric acid (0.10 N) in order to trap the ammonia released from the manure. This sulfuric acid

solution was sampled (6 ml) at 12, 24, 36, 48, 72, and 96 h and was analyzed for ammonia using the procedure of Willis et al. (1996).

Blood urea nitrogen was determined by using a commercial kit (Sigma-Aldrich, St. Louis, MO) according to the manufacturer's instructions. Short-chain fatty acid (SCFA) concentrations of the cecal and fecal samples were conducted using a GC (model 3380, Varian Instruments, Walnut Creek, CA) equipped with a FID detector. Ten g of cecal digesta was centrifuged at 2,390 x g for 10 minutes. For fecal samples, 4 ml of dd water was added to 2 g of feces and centrifuged at 2,390 x g for 10 minutes. One ml of supernatant was further centrifuged at 21,000 x g for 15 minutes. Meta-phosphoric acid (0.2 ml) containing 2-ethylbutyric acid as the internal standard was added to the supernatant. A Nukol fused silica capillary column (Supelco Inc., Bellefonte, PA) was used to elute the SCFA. Calibrated SCFA standards were used to identify and quantify SCFAs in unknown samples. Branch-chain proportion (BCP) was used as protein fermentation indicator (Awati et al., 2006) and was calculated as follows:

$$\text{BCP(\%)} = \frac{(\text{Isobutyric} + \text{Isovaleric})}{\text{Total VFA}} \times 100\%.$$

Fecal and ileal digesta samples as well as urine samples were dried using a freeze dryer (Heto PowerDry LL3000, ATR, Laurel, MD). Subsequently, feces, ileal digesta samples and feed samples were ground through a 1 mm screen prior to chemical analysis. Dry matter content of 4 feed samples, 28 ileum digesta samples, 28 fecal samples were measured according to AOAC (1990) procedures. GE values of feed samples and all freeze dried samples (including dried urine samples) were determined by an adiabatic bomb calorimeter (model C5000, IKA, Wilmington, NC). All samples were then submitted to the Experimental Station Chemical Laboratories (University of Missouri-Columbia, MO 65211) for chromium and N analyses (urine samples were measured for N only). Chromium was measured by atomic absorption spectrometry after

digestion with perchloric acid. Nitrogen content was measured by the Kjeldahl method (AOAC, 1990).

Apparent ileal CP digestibility was calculated according to the following equation:

$$\text{Apparent ileal CP digestibility \%} = 100 - [(M_d \times CP_I) / (CP_d \times M_I)] \times 100$$

Where M_d = chromium concentration in the diet (mg/kg), CP_I = CP concentration in ileal digesta (g/kg), CP_d = CP concentration in the diet (g/kg), and M_I = chromium concentration in the ileal digesta (mg/kg).

The equations used for ileal GE calculation and fecal nutrients digestibility calculation were similar to the above equation but used the corresponding index.

Statistical analyses: Data were analyzed by two-way ANOVA using the GLM procedure of SAS (SAS Institute, Cary, NC). Least squares means among diet treatments were evaluated by PDIFF and STDERR and batch was included as blocking factor. Orthogonal contrast comparisons were conducted to determine linear and quadratic effects of guar gum supplementation.

Experiment 2: Effects of dietary NSP level on fecal digestibility in growing swine and odor concentrations in air

This experiment was divided into four identical trials. In each trial, 40 growing pigs with an initial BW of 20.4 kg were used. Pigs were blocked by weight and randomly assigned within block to four dietary treatments (10 pigs per treatment). Diets were formulated as a low fiber diet (degermed, dehulled corn (DGDH) and soybean protein isolate), a semi-low fiber diet (corn +

soybean protein isolate), a commercial control (corn + soybean meal), and a high fiber diet (corn + soybean meal + 10% soybean hulls). The diets were fed in mash form (Table 2).

Pigs were housed at the Swine Educational Unit at North Carolina State University and fed the experimental diets for two weeks to allow for adjustment to the diets. All pigs were fed ad libitum and all conditions were as similar as possible to those in a commercial facility. After the adaptation period, pigs were moved to Grinnells laboratory and 10 pigs within each treatment group were housed in one of four identical air controlled odor chambers. These chambers (3.0 m L × 2.4 m W × 2.0 m H) were designed to control and measure airflow and allow for collection of air from the chambers for ammonia and odor analysis. The chambers were equipped with fully slatted floors and shallow pits with pit recharge. Water (575 L) was pre-charged in each of the pits and resulted in a water depth of approximately 10 cm. The airflow through each chamber was measured by Dwyer DS-300 flow sensors (Dwyer instruments, Inc., Michigan City, IN) and was kept low, approximately 316 m³/h, for odorant accumulation. The temperature in the chambers was maintained at 25°C.

On day 6, ammonia emission was determined as described for Exp. 1 (Figure 1). Pigs were moved out of the chambers on day 8, however, ammonia collection was continued for an additional 2 days.

On day 7, TRS concentration of the chambers' exhaust air was measured using a Jerome meter (Arizona Instrument LLC., Tempe, Arizona). In addition, air samples were collected in 10 L Tedlar bags (SKC Gulf Coast Inc., Houston, TX) using a Vac-U-Chamber (Supelco, Bellefonte, Pa.) and were shipped overnight to Iowa State University Olfactometry and Air Quality Laboratory. Odor detection threshold (OTD) was evaluated by a professional panel with 8 panelists using an Ac'Scent International Olfactometer (St. Croix Sensory, Inc., Stillwater, MN). The evaluation was based on a forced-choice ascending concentration series method

(E679-04 standard practice) and values are reported as averages (geometric means) of the 8 individual responses.

Odor compounds were adsorbed by solid phase microextraction (SPME) fibers (CarboxenTM/Polydimethylsiloxane fiber, Upelco SPME portable field sampler, Supelco, Bellefonte, Pa.). The fibers were exposed to the exhaust air stream with an air flow of approximately 4.81 m/s for 30 min and were analyzed by a GC/MS (GC HP 6890; MS HP 5973) immediately as described in Exp. 1.

On day 8, fresh feces from the concrete slats of each chamber were sampled and frozen at -20°C for further analysis. Subsequently, the first batch of 40 pigs was removed. The slurry of each chamber was sampled and the pH values were measured by using a pH meter (Accumet[®] pH model 610 A, Fisher pH, Ambler, PA, USA). After the 2 days of continual trapping of ammonia without pigs, the chambers were thoroughly cleaned. The entire procedure was then repeated another three times to achieve a total of 4 replicates per treatment. Treatments were assigned to each of the chambers such that each dietary treatment occurred in each of the chambers one time to avoid confounding between treatment and chamber.

Fecal samples were processed and analyzed as described in Exp. 1. Fecal digestibility of CP, GE, NDF, and ADF were calculated using the marker method as described in Exp. 1.

Statistical analyses: Data were analyzed by two-way ANOVA using the GLM procedure of SAS (SAS Institute, Cary, NC). Least squares means among diet treatments were evaluated by PDIFF and STDERR and batch was included as blocking factor.

Results and Discussion

Experiment 1: Effects of guar gum supplementation on nutrient digestibility, fecal characteristics, and manure odorants in growing pigs

Body weight at the end of the three week dietary adjustment period decreased linearly ($P < 0.001$) with increasing levels of guar gum (Table 3). Similarly, weight gain and feed intake decreased linearly ($P < 0.05$) during the time pigs were on metabolism crates, although feed efficiency was not affected. This is consistent with results of incorporation of soluble NSP rich ingredients in weaned pig diets, which resulted in decreased body weight gain (Hopwood et al., 2004). Pigs were not able to increase their feed intake with decreasing DE content of guar gum diets to maintain energy intake; in fact, intake was decreased with guar gum supplementation.

Pigs fed increasing levels of guar gum had higher (linear, $P = 0.01$) wet feces weigh, in spite of lower feed intake (Table 4). A trial by Wang et al. (2004) showed sugar- beet pulp and wheat bran inclusion in growing pig diets significantly increased the mass of fecal excretion. In the current trial, there were no differences in total fecal dry matter production. Therefore, the increased fecal mass appeared to be due primarily due to a linear increase ($P < 0.001$) in fecal moisture content. Similarly, the dry matter content of ileal digesta decreased linearly ($P < 0.001$) with increasing levels of guar gum, which may have been related to the water-holding capacity of guar gum itself. No significant differences between treatments were found in daily urine weight. Urine GE concentration tended ($P = 0.06$) to increase linearly with increasing dietary guar gum and the non-urea GE concentration of urine samples tended to increase quadratically ($P = 0.06$) with dietary guar gum level.

Dietary guar gum linearly decreased ileal digestibility of CP ($P < 0.01$) and fecal digestibility ($P < 0.001$) of CP and GE (Table 5). Similarly, Owusu-Asiedu et al. (2006) observed decreased CP and energy digestibility in pigs fed diets containing 7% guar gum and

attributed these effects to decreased digesta passage rate, increased digesta viscosity and increased growth of bacterial populations in the GI tract. The reduction in CP digestibility in pigs fed guar gum in the present study resulted in a tendency ($P = 0.07$) for increased N excretion in feces. No significant differences were found, however, in urinary N excretion. This is in contrast to our expectation that increased dietary NSP would result in a shift in N excretion from urine to feces as reported by Canh et al. (1997). The reduced N intake in pigs fed guar gum and the reduced ileal digestibility of N would have been expected to decrease urinary nitrogen excretion. Nitrogen retention (g/d) linearly decreased ($P = 0.03$) with increasing guar gum inclusion, which is consistent with observed reductions in growth rate. A tendency for a quadratic effect ($P = 0.09$) of guar gum supplementation was observed for BUN, with the greatest concentration of BUN at 4% guar gum inclusion, indicating decreased efficiency of protein utilization with increasing levels of guar gum.

Cumulative ammonia emission from fresh manure samples linearly increased with increasing levels of guar gum ($P < 0.05$) only during the first 12 and 24 h of the 96 h collection period (Table 6). In contrast, our original expectation was that ammonia emission would be decreased by dietary fermentable carbohydrate supplementation. Urinary excretion of N was not affected by guar gum supplementation and, therefore, the amount of urea from urine in manure samples as substrate for ammonia formation would not be expected to be different. On the contrary to the result of fresh manure samples, ammonia emission from aged manure samples decreased linearly ($P < 0.04$) with increasing levels of guar gum. After 21 days of anaerobic fermentation in the aged samples, the fermentation of the aged manure would be expected to yield greater levels of volatile fatty acids in the guar gum groups, which would reduce pH and subsequently could decrease ammonia emission.

Guar gum supplementation had no significant effects on phenol, p-cresol, indole or skatole emissions from fresh manure samples (Table 7). Emission of phenol, dimethyldisulfide and dimethyltrisulfide from aged manure samples was increased linearly ($P < 0.05$) by dietary guar gum supplementation. Studies focusing on fecal odorant concentrations showed that guar gum addition decreased fecal p-cresol, and skatole levels (Knarreborg et al., 2002). Le (2006) reported that crystalline Trp, Tyr, and Phe supplementation did not affect odor emission from pig manure. However, crystalline S-containing amino acid supplementation caused increased odor.

There were no significant differences in the cecal content of SCFA between treatment groups (Table 8). The branch-chain proportion of the cecal SCFA profile was not affected by guar gum supplementation, indicating that protein fermentation was not altered by providing additional NSP. This is in contrast to the results of Awati et al. (2006), who reported that fermentable fiber reduced protein fermentation along the GIT. Short chain fatty acid concentrations in feces linearly increased ($P < 0.05$) when the level of guar gum supplementation increased, except for isobutyric and isovaleric acid (Table 9). This suggests that the main site of fermentation of guar gum was in the colon. As a result of increased total SCFA concentrations with increasing guar gum and no change in branch chain FA, fecal BCP was linearly decreased ($P < 0.001$) by increasing dietary guar gum addition, which indicated relatively less protein fermentation for the high NSP treatments. This agrees with the results of previous research (Sauer et al., 1991; Wang et al., 2004; Bikker et al., 2006).

There were no significant differences among treatments for pH values of ileal or cecal content (Table 10). Colonic pH values and pH of aged manure samples linearly decreased ($P < 0.001$) with increasing levels of guar gum. However, the pH values of fresh manure samples were not affected by dietary treatment. These results coincide with our observation that SCFA

concentration in fecal samples increased with increasing levels of guar gum, but were unaffected in cecal samples.

Odor intensity and hedonic score of headspace air samples from fresh or aged manure samples were not affected by dietary treatment, except for a tendency ($P = 0.08$) for odor intensity of aged manure samples to increase linearly with increasing levels of guar gum (Table 11). Thus, the increased concentrations of dimethyldisulfide, dimethyltrisulfide, and phenol in the headspace of aged manure samples with increasing levels of guar gum did not result in clear differences in odor perception by a professional panel.

Experiment 2: Effects of dietary NSP level on fecal digestibility in growing swine and odor concentrations in air

Body weight gain of pigs fed the corn-soybean meal diet and the diet with 10% soy hulls was significantly higher ($P < 0.001$) compared to the low fiber diets (Table 12). Feed intake was higher ($P < 0.05$) for pigs fed the soy hull diet compared to the DHDG diet. Feed efficiency was improved in pigs fed the corn-soybean meal control diet or the soy hull diet compared to the low fiber diet. Moeser et al. (2002) reported no differences in body weight gain and GI tract weight of pigs fed a low fiber diet containing degermed, dehulled corn. The major difference between the diets in the current trial and those used by Moeser et al. (2002) was that in the current trial soy protein isolate was used to replace soybean meal. The very fine particle size of soy protein isolate may have caused a decrease in feed intake and a subsequent reduction in ADG.

Fecal digestibility of GE, CP, NDF, and ADF was decreased ($P < 0.01$) as dietary fiber level in the diets increased. Sohn et al. (1994a) reported that the apparent fecal DM and CP digestibility of soy protein isolate was significantly higher than that of soybean meal. Similarly, the ileal digestibility of amino acids from soy protein isolate was significantly higher than that of soybean meal (Sohn et al., 1994b). Bakker et al. (1995) reported soybean hull supplemented diets significantly decreased apparent crude protein digestibility. Fecal DM was greatest in the diet with DHDG corn and SPI and decreased with increasing levels of fiber.

Ammonia emission from chambers was measured for 2 days with pigs in the chamber and again for 2 days after pigs had been removed. Ammonia concentrations decreased as dietary fiber level increased when pigs were present in the chambers (Table 14). This is in agreement with the result of previous research (Sohn et al., 1994a; Mroz et al., 2000). Ammonia emission on day 3 was lower only for pigs fed the SPI diet compared to the DHDG diet. No significant

differences were observed among treatments on day 4. Thus, the impact of dietary fiber on ammonia emission may differ, depending on when it is measured relative to excretion of feces and urine. Canh et al. (1998) reported that both fecal N and fecal ammonium concentrations were increased by dietary fiber addition, and, over time, these potential sources of ammonia can volatilize when the pH of the slurry increases. The highest concentration of ammonia in exhaust air was 2.12 ppm in the present trial. This is a relatively low concentration of ammonia relative to the odor threshold value (OTV) of ammonia of 4.7 ppm (Tamminga, 1992).

Emission of TRS was increased ($P < 0.05$) with increasing levels of dietary fiber (Table 15). Total reduced Sulfur is defined as all of the gaseous unoxidized sulfur compounds, and the major compound is H_2S (Clanton and Schmidt, 2000). Compared to ammonia, H_2S may contribute more to the overall odor as its OTV is 0.5 ppb (Tamminga, 1992) and the range of TRS data in the current trial was 4.21 to 8.50 ppb. Hobbs et al. (2000) indicated that H_2S , p-cresol, and acetic acid were the three major odorants correlated with olfactory data. Slurry pH value of pigs fed DGDH was higher ($P < 0.05$) than the other groups. Shriver et al. (2003) reported a similar trend. A lower pH in slurry from pigs fed the higher levels of fiber may explain, in part, the lower ammonia emission from these pigs.

Main odorant peaks analyzed by GCMS indicated that emissions of SCFA were increased ($P < 0.05$) with increasing dietary fiber level (Table 16). The amount of odorants that are volatilized from manure not only depends on their concentrations in the manure, but also on manure pH (Conn et al., 2007). The possible reason for a more significant difference in H_2S emission is that the pKa of H_2S is 7.1, which is very close to the pH values of the slurry. The pKa of NH_3 is 9.3 and this may explain why NH_3 emission was not as sensitive to changes in pH of the manure. The pKa values for VFA are approximately 4.8 to 5 (Perrin and Dempsey, 1974; Mikkelsen et al., 2004). Emission of phenol from pigs fed the soy hull diet was higher ($P < 0.05$)

than that of the DGDH and SPI treatments, but there were no differences in p-cresol ($P=0.398$), indole ($P=0.347$), and skatole ($P=0.512$) concentrations. These results contradict those reported by Jensen and Hansen (2006) with chicory root (inulin) which showed that SCFA emissions were not different between control and a high fiber diet, but p-cresol, indole, and skatole concentrations tended to be decreased by dietary inulin addition.

It was reported that the major odorants in animal housing were carried by dust (Hartung and Rokicki, 1984; Oehrl et al., 2001). Indeed, Kaspers (2002) reported that odorants adsorbed on SPME fibers were much lower after pigs had been removed from odor chambers compared to when they were present, however, panel evaluation data of air samples collected in Tedlar bags were unaffected by the presence or absence of pigs (Kai et al., 2006).

Odor detection threshold evaluation in the present study showed that dietary fiber increased ($P < 0.05$) odor intensity, which agrees with our observed increases in of SCFA, TRS, and phenol emissions. Thus, increasing dietary fiber in practical swine diets decreased ammonia emission, but increased odor compounds and odor intensity.

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Table 1. Formulation of the experimental diets in Exp. 1 (as fed basis)

Ingredients (%)	Control	2% guar gum	4% guar gum	8% guar gum
DGDH corn ¹	77.00	75.00	73.00	69.00
Guar gum	-	2.00	4.00	8.00
Soybean protein isolate ²	16.00	16.00	16.00	16.00
Corn oil	3.00	3.00	3.00	3.00
Dicalcium phosphate	1.00	1.00	1.00	1.00
Limestone	1.20	1.20	1.20	1.20
Salt	0.40	0.40	0.40	0.40
Vitamin/Mineral mixture ³	0.30	0.30	0.30	0.30
Cr ₂ O ₃	0.10	0.10	0.10	0.10
Celite ⁴	1.00	1.00	1.00	1.00
Calculated nutrient composition				
DE (Mcal/kg)	3.67	3.64	3.62	3.57
CP (%)	18.81	18.68	18.55	18.28
Ca (%)	0.66	0.66	0.66	0.66
Available P (%)	0.29	0.29	0.28	0.28
Lysine (%)	0.99	0.98	0.98	0.97

¹The nutrient values of DGDH (degermed, dehulled) corn were taken from Moeser et al. (2002).

²Cargill, Minneapolis, MN

³Provided the following per kilogram of complete diet: vitamin A, 6,358 IU; vitamin D₃, 636 IU; vitamin E, 50 IU; vitamin K, 1.91 mg; riboflavin, 4.81 mg; niacin, 14.41 mg; d-pantothenic acid, 14.41 mg; vitamin B₁₂, 21.195 µg; Zn, 115 mg; Fe, 230 mg; Mn, 19.2 mg; Cu, 9.6 mg; I, 0.29 mg; and Se, 0.29 mg.

⁴A diatomite product, Celite Corporation, Lompoc, California.

Table 2. Formulation of the experimental diets in Exp. 2 (as fed basis)

Ingredients (%)	Low fiber diet	Semi-low fiber diet	Corn soybean	10% Soy hulls
DGDH corn ¹	80.24	–	–	–
Corn	0	82.91	69.42	62.55
Soybean meal	–	–	26.20	23.10
Soybean protein isolate ²	15.1	12.40	–	–
Soy hulls	–	–	–	10.00
Corn oil	1.00	1.00	1.00	1.00
Dicalcium phosphate	1.08	1.13	0.82	0.94
Limestone	0.88	0.86	0.86	0.71
Salt	0.35	0.35	0.35	0.35
Vitamin/Mineral mixture ³	0.25	0.25	0.25	0.25
Cr ₂ O ₃	0.10	0.10	0.10	0.10
Celite ⁴	1.00	1.00	1.00	1.00
Calculated nutrients composition				
ME (Mcal/kg)	3.44	3.36	3.34	3.18
CP (%)	18.25	17.52	18.21	17.26
Calcium (%)	0.62	0.62	0.62	0.62
P (%)	0.52	0.52	0.53	0.53
Lys (%)	1.15	1.04	0.97	0.92
NSP (%)	0	8.04	12.42	16.19

¹The nutrient values of DGDH (degermed, dehulled) corn were taken from Moeser et al. (2002).

²Cargill, Minneapolis, MN.

³Provided the following per kilogram of diet: vitamin A, 6,358 IU; vitamin D₃, 636 IU; vitamin E, 50 IU; vitamin K, 1.91 mg; riboflavin, 4.81 mg; niacin, 14.41 mg; d-pantothenic acid, 14.41 mg; vitamin B₁₂, 21.195 µg; Zn, 115 mg; Fe, 230 mg; Mn, 19.2 mg; Cu, 9.6 mg; I, 0.29 mg; and Se, 0.29 mg.

⁴A diatomite product, Celite Corporation, Lompoc, California.

Table 3. Growth performance of growing pigs fed low NSP diets containing different levels of guar gum¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Dietary adjustment period (0 to 21 days)							
Initial body weight (kg)	26.6	26.6	26.8	26.9	0.58	0.668	0.992
3 wk body weight (kg)	38.5	35.8	36.0	32.3	0.91	<0.001	0.939
Metabolism crate period (22 to 32 days)							
Final body weight (kg)	48.1	44.7	43.6	39.9	1.19	<0.001	0.564
ADG (g/d)	963	889	756	773	0.06	0.032	0.197
ADFI (kg/d)	1.87	1.76	1.60	1.53	0.11	0.029	0.513
G/F (g/kg)	518	505	483	505	22	0.661	0.333

¹Least squares means of 2 pens (3 or 4 pigs/pen) per treatment for the 3 week adjustment period and 7 pigs per treatment for the metabolism study.

Table 4. Effect of different levels of guar gum supplementation on waste excretion and feces and ileal sample dry matter¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Feces weight (kg/d)	0.220	0.336	0.417	0.379	0.0396	0.0129	0.020
Fecal dry matter (%)	48.9	39.0	30.0	32.2	2.20	<0.001	0.002
Feces dry matter output (kg/d)	0.108	0.128	0.127	0.116	0.0110	0.807	0.181
Ileal content dry matter (%)	13.5	11.7	7.3	7.7	0.82	<0.001	0.012
Urine weight (kg/d)	2.73	3.12	2.98	2.80	0.330	0.947	0.438
GE of urine (kcal/kg DM)	2527	2613	2713	2668	51.15	0.062	0.091
non-urea GE of urine (kcal/kg) ²	920	1122	1204	1108	85.28	0.191	0.057

¹Least squares means of 7 pigs per treatment

²Calculated as GE of urine minus GE of urea

Table 5. Effects of different levels of guar gum on nutrient digestibility and N retention¹.

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
N intake (g/day)	59.2	55.5	49.9	48.3	3.36	0.025	0.420
N excretion from feces (g/day)	4.99	6.63	7.03	6.95	0.66	0.072	0.123
N excretion from urine (g/day)	16.4	13.8	14.0	12.5	2.33	0.298	0.741
N retention (g/day)	37.9	35.0	28.9	28.8	3.00	0.033	0.324
Hindgut N disappearance (g/d)	12.15	10.16	16.33	12.97	2.48	0.559	0.506
Apparent ileal digestibility, %							
CP	69.2	66.3	50.1	51.0	4.56	0.005	0.219
GE	66.7	62.8	58.7	61.2	4.22	0.368	0.343
Apparent fecal digestibility, %							
CP	89.9	85.3	81.6	78.4	0.93	<0.001	0.030
GE	93.3	90.5	88.0	87.0	0.66	<0.001	0.013
BUN (mM/dl)	8.83	10.15	10.45	10.07	0.55	0.190	0.094

¹Least squares means of 7 pigs per treatment

Table 6. Effects of different levels of guar gum on cumulative ammonia emissions of 400 ml fresh or aged manure samples¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Ammonia emission from fresh manure, mmol							
12 h	1.65	2.27	2.79	3.40	0.56	0.042	0.673
24 h	6.50	12.1	13.9	21.9	4.26	0.020	0.929
36 h	37.6	31.7	29.7	37.1	5.95	0.933	0.268
48 h	47.7	47.3	47.6	45.4	3.03	0.593	0.802
72 h	49.3	47.2	46.4	47.3	1.25	0.343	0.170
96 h	46.4	45.7	42.9	45.6	1.54	0.661	0.174
Ammonia emission from aged manure, mmol							
12 h	44.9	34.3	26.9	24.0	2.81	<0.001	0.029
24 h	56.4	50.0	43.2	41.0	2.55	<0.001	0.104
36 h	55.0	53.7	48.2	49.3	1.66	0.012	0.143
48 h	55.2	49.5	48.6	48.8	1.44	0.013	0.025
72 h	52.5	49.3	46.7	46.8	1.60	0.021	0.136
96 h	48.2	45.8	44.7	44.8	1.06	0.039	0.137

¹Least squares means of 7 pigs per treatment

²Manure samples were mixed from individual feces and urine samples at the ratios they were produced.

³Manure samples after anaerobic aging at room temperature for 21 days

Table 7. Effects of different levels of guar gum on feces p-cresol and main indolic compounds concentrations ¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Fresh manure headspace odorant peak area by SPME (log ₁₀) ²							
Phenol	6.14	6.49	6.22	6.45	0.237	0.504	0.881
p-Cresol	7.72	7.84	7.82	7.92	0.098	0.179	0.815
4-ethylphenol	4.34	6.09	5.41	6.14	0.769	0.202	0.504
Indole	6.20	6.24	6.21	6.34	0.264	0.646	0.859
Skatole	6.84	6.79	6.61	6.69	0.180	0.515	0.582
Aged manure headspace odorant peak area by SPME (log ₁₀) ³							
Dimethyldisulfide	7.96	8.32	8.57	8.55	0.158	0.017	0.104
Dimethyltrisulfide	7.03	7.45	7.76	7.92	0.174	0.002	0.162
Phenol	7.45	7.67	7.81	7.80	0.110	0.041	0.140
p-Cresol	8.23	8.20	8.32	8.25	0.078	0.693	0.586
Indole	6.67	6.72	6.91	6.65	0.166	0.946	0.293
Skatole	6.78	6.80	6.79	6.73	0.115	0.752	0.799

¹Least squares means of 7 pigs per treatment

²Manure samples were mixed from individual feces and urine samples at the ratios they were produced.

³Manure samples after anaerobic aging at room temperature for 21 days

Table 8. Effects of different levels of guar gum on short chain fatty acids of cecal content¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Fatty acid concentration, mM							
Acetic acid	46.3	40.7	41.0	48.9	4.99	0.557	0.221
Propionic acid	32.8	30.5	35.9	39.2	5.36	0.296	0.813
Isobutyric acid	0.65	0.86	0.85	0.87	0.20	0.501	0.582
Butyric acid	18.0	11.6	10.9	15.0	2.90	0.661	0.0751
Isovaleric acid	0.90	1.34	1.29	1.25	0.32	0.515	0.442
Valeric acid	7.35	5.40	6.05	8.31	1.92	0.569	0.344
Total	106	90.4	96.0	114	12.5	0.483	0.259
Acetic acid/propionic acid	1.52	1.49	1.16	1.32	0.16	0.269	0.315
Branch-chain proportion, % ²	1.58	3.42	2.09	2.04	0.80	0.926	0.368

¹Least squares means of 7 pigs per treatment

²Branched-chain proportion = 100% x (isobutyric+isovaleric)/total VFA

Table 9. Effects of different levels of guar gum on short chain fatty acids in feces¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Fatty acid concentration, mM							
Acetic acid	61.9	131	110	142	13.5	0.002	0.137
Propionic acid	21.4	44.3	48.3	50.2	6.04	0.007	0.042
Isobutyric acid	4.06	5.57	3.54	5.55	0.59	0.246	0.452
Butyric acid	8.84	23.3	25.0	29.7	3.75	0.002	0.090
Isovaleric acid	8.42	10.6	6.08	9.94	1.25	0.751	0.272
Valeric acid	5.48	9.30	7.53	10.4	1.39	0.045	0.692
Total	110	224	200	248	23.9	0.002	0.115
Acetic acid/propionic acid	10.1	9.62	7.33	7.42	0.84	0.018	0.318
Branch-chain proportion, % ²	11.4	7.93	5.25	6.19	0.87	0.001	0.002

¹Least squares means of 7 pigs per treatment

²Branched-chain proportion = 100% x (isobutyric+isovaleric)/total VFA

Table 10. Effects of different levels of guar gum on pH values of ileal, cecal, and colon contents and fresh or aged manure¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Ileum	6.43	6.69	6.38	6.68	0.253	0.632	0.851
Cecum	6.19	6.40	6.22	6.14	0.187	0.650	0.576
Colon	6.71	6.48	6.25	6.23	0.086	0.001	0.050
Fresh manure ²	8.46	8.80	8.56	8.57	0.089	0.912	0.159
Aged manure ³	9.19	8.95	8.78	8.78	0.067	<0.001	0.017

¹Least squares means of 7 pigs per treatment

²Manure samples were mixed from individual feces and urine samples at the ratios they were produced

³Manure samples after anaerobic aging at room temperature for 21 days

Table 11. Effects of different levels of guar gum on manure odor intensity and hedonic score¹

Variable	Guar gum, %				SEM	P value	
	0	2	4	8		Linear	Quadratic
Odor intensity ²							
Fresh manure ³	1.88	1.77	1.98	1.89	0.121	0.727	0.857
Aged manure ⁴	2.96	3.27	3.40	3.35	0.142	0.083	0.124
Hedonic score ⁵							
Fresh manure	-3.05	-2.73	-2.76	-2.89	0.236	0.799	0.357
Aged manure	-5.00	-4.57	-4.84	-5.56	0.310	0.108	0.152

¹Least squares means of 7 pigs per treatment

²Odor intensity was evaluated by comparing the odor intensity of the headspace air to the odor intensities of a series of concentrations of n-butanol

³Manure samples were mixed from individual feces and urine samples at the ratios they were produced.

⁴Manure samples after anaerobic aging at room temperature for 21 days

⁵Hedonic score is the degree of pleasantness or unpleasantness according to a -10 to +10 scale

Table 12. Growth performance of pigs fed diets with differing fiber content during a 2 week adaptation period¹

Variable	DGDH²	SPI³	SBM⁴	Soy hulls	SEM	P Value
Initial body weight (kg)	20.45	20.31	20.29	20.31	0.078	0.466
Final body weight (kg)	25.98 ^a	25.94 ^a	27.42 ^b	27.37 ^b	0.331	0.014
ADG (kg/d)	0.395 ^a	0.402 ^a	0.509 ^b	0.504 ^b	0.020	0.004
ADFI (kg/d)	1.10 ^a	1.11 ^{ab}	1.26 ^{ab}	1.27 ^b	0.030	0.003
G/F	0.355 ^a	0.360 ^{ab}	0.403 ^b	0.395 ^b	0.012	0.051

¹Least squares means of 4 chambers per treatment with 10 pigs per chamber

²Degermed, dehulled corn and soybean protein isolate diet

³Corn and soybean protein isolate diet

⁴Corn and soybean meal diet

^{ab}Means within a row with different superscripts differ ($P < 0.05$).

Table 13. Apparent nutrient digestibility and dry matter of fecal samples¹

Variable	DGDH ²	SPI ³	SBM ⁴	Soy hulls	SEM	P Value
Apparent fecal digestibility (%)						
GE	92.9 ^a	80.4 ^b	78.8 ^{bc}	72.9 ^d	0.82	<0.001
CP	86.4 ^a	76.8 ^b	76.1 ^{bc}	69.0 ^d	1.00	<0.001
NDF	75.9 ^a	47.3 ^b	42.1 ^b	45.7 ^b	2.29	<0.001
ADF	81.2 ^a	56.6 ^b	36.2 ^b	44.4 ^b	6.63	0.005
Fecal dry matter (%)	35.2 ^a	33.4 ^a	31.7 ^{ab}	28.8 ^b	1.20	0.023

¹Least squares means of 4 chambers per treatment with 10 pigs per chamber

²Degermed, dehulled corn and soybean protein isolate diet

³Corn and soybean protein isolate diet

⁴Corn and soybean meal diet

^{abcd}Means within a row with different superscripts differ (P < 0.05).

Table 14. Ammonia concentrations in the exhaust air from chambers¹

Variable	DGDH ²	SPI ³	SBM ⁴	Soy hulls	SEM	P Value
With pigs housed in the chambers						
Day 1 (ppm)	1.35 ^a	0.63 ^{bc}	0.78 ^b	0.49 ^c	0.075	<0.001
Day 2 (ppm)	2.12 ^a	1.50 ^b	1.08 ^c	0.97 ^c	0.129	<0.001
Without pigs in the chambers						
Day 3 (ppm)	2.10 ^a	1.09 ^b	1.14 ^{ab}	1.20 ^{ab}	0.308	0.135
Day 4 (ppm)	0.81	1.43	1.45	1.16	0.256	0.319

¹Least squares means of 4 chambers per treatment with 10 pigs per chamber

²Degermed, dehulled corn and soybean protein isolate diet

³Corn and soybean protein isolate diet

⁴Corn and soybean meal diet

^{abc}Means within a row with different superscripts differ (P < 0.05)

Table 15. Total reduced sulfur concentrations in the exhaust air from chambers and slurry pH¹

Variables	DGDH²	SPI³	SBM⁴	Soy hulls	SEM	P Value
Total reduced S (ppb)	4.21 ^a	4.88 ^{ab}	7.92 ^c	8.50 ^{cd}	0.24	<0.001
Slurry pH	7.97 ^a	7.25 ^b	7.24 ^b	6.93 ^b	0.14	0.003

¹Least squares means of 4 chambers per treatment with 10 pigs per chamber

²Degermed, dehulled corn and soybean protein isolate diet

³Corn and soybean protein isolate diet

⁴Corn and soybean meal diet

^{abcd} Means within a row with different superscripts differ (P < 0.05)

Table 16. Peak area of main odorants by SPME and results of odor detection threshold by a professional odor panel¹

Variable	DGDH ²	SPI ³	SBM ⁴	Soy hulls	SEM	P Value
Acetic acid	6.42 ^a	6.61 ^a	6.78 ^{ab}	7.26 ^b	0.197	0.0717
Propionic acid	6.49 ^a	6.85 ^a	7.23 ^b	7.39 ^b	0.122	0.0023
Butyric acid	6.74 ^a	6.89 ^a	7.54 ^b	7.69 ^b	0.111	0.0004
Phenol	5.78 ^a	5.96 ^a	6.14 ^{ab}	6.65 ^b	0.215	0.0881
p-Cresol	6.90	6.86	6.98	7.21	0.149	0.398
Indole	4.49	6.17	5.94	6.13	0.215	0.347
Skatole	6.06	6.21	6.01	6.36	0.172	0.512
Odor detection threshold ⁵	144 ^a	174 ^{ab}	208 ^{ab}	251 ^b	30.49	0.149

¹Least squares means of 4 chambers per treatment with 10 pigs per chamber

²Degermed, dehulled corn and soybean protein isolate diet

³Corn and soybean protein isolate diet

⁴Corn and soybean meal diet

⁵Odor detection threshold was evaluated by an 8 member panel using a forced-choice ascending concentration series method.

^{ab}Means within a row with different superscripts differ (P < 0.05)

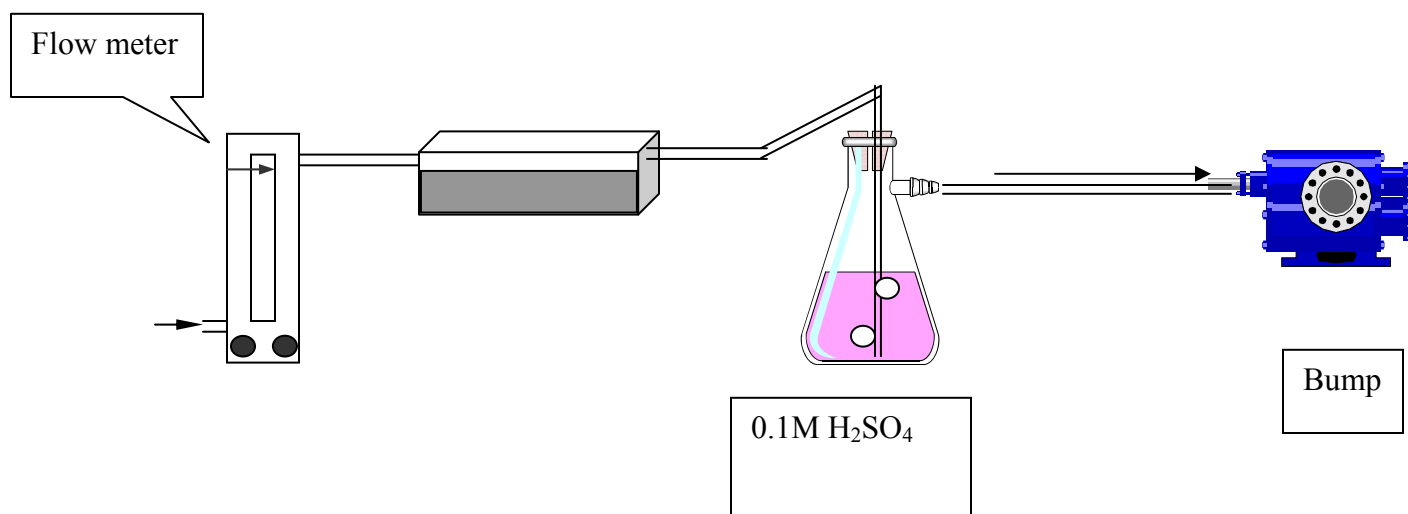


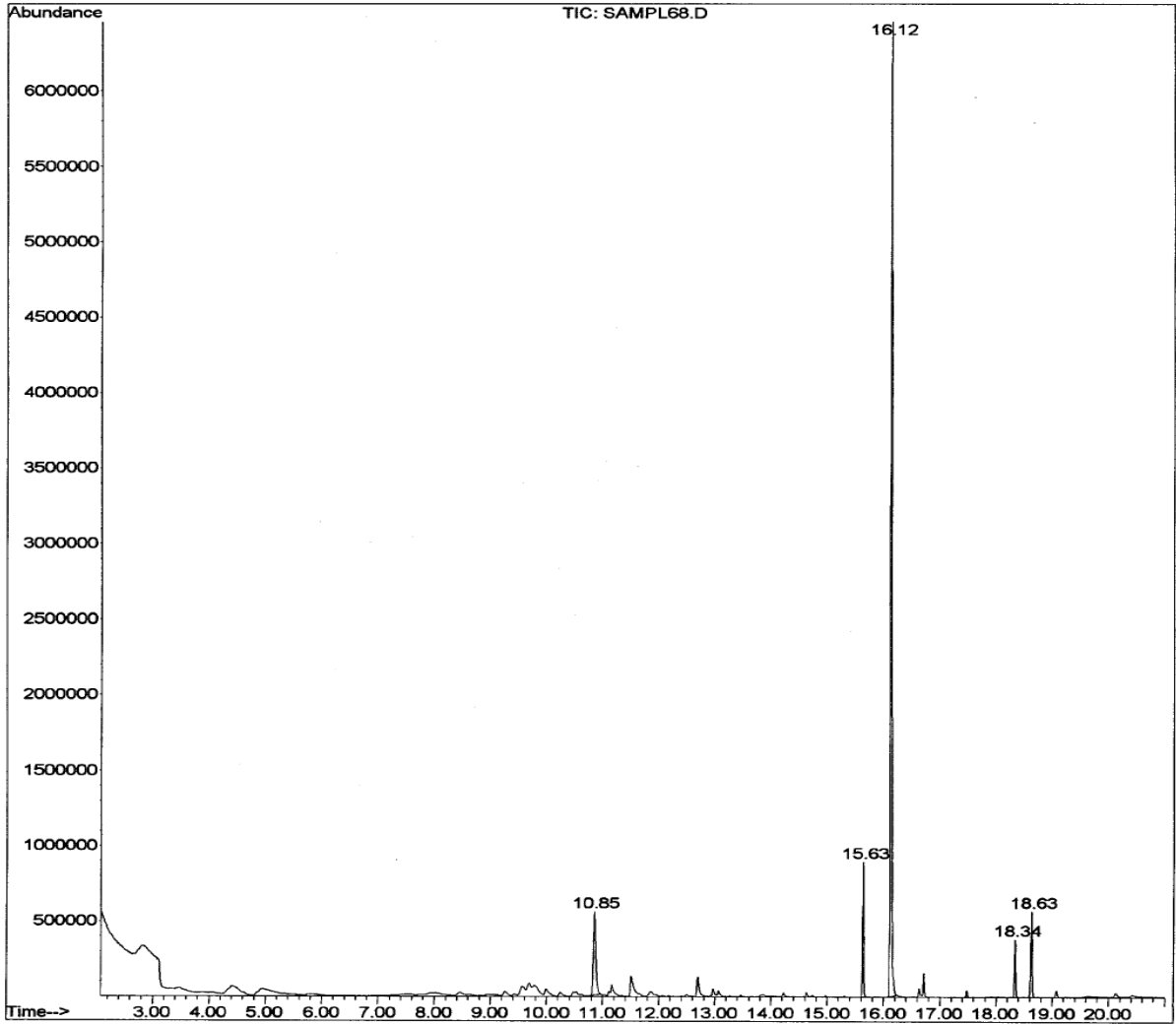
Figure 1 Diagram of the ammonia set-up

Area Percent Report

Data File : D:\DATA\ZHANG\SAMPL68.D
Acq On : 19 Oct 2006 13:16
Sample : fresh manure fiber1(3)
Misc : spme 5 min desorption

Vial: 1
Operator: wz
Inst : Instrum
Multiplr: 1.00
Sample Amount: 0.00

MS Integration Params: autoint1.e
Method : C:\MSDCHEM\1\METHODS\WFANG100920062.M (Chemstation Integrat
Title :



SAMPL68.D WFANG100920062.M

Thu Oct 19 13:37:56 2006

Page 2

Figure 2. Representative area percent report of manure headspace odorant analysis by GC/MS