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# The effects of sodium sulfate in the water of nursery pigs and the efficacy of nonnutritive feed additives to mitigate those effects[1,2]

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**ABSTRACT:** Two experiments were conducted to investigate the effects of sodium sulfate water and the efficacy of nonnutritive feed additives in nursery pig diets. In Exp. 1, 320 barrows (5.4 ± 0.1 kg BW and 21 d of age) were allotted to 1 of 8 treatments for 24 d in a 2 × 4 factorial with 2 levels of sodium sulfate water (control or 3,000 mg sodium sulfate/L added), and 4 dietary zeolite (clinoptilolite) levels (0, 0.25, 0.50, or 1%). Fecal samples were collected on d 5, 9, 16, and 23; visually scored for consistency (1 = firm and 5 = watery); and analyzed for DM. No interactions of sodium sulfate × zeolite were observed for any response criteria. Overall (d 0 to 24), pigs drinking sodium sulfate water had decreased ($P <$ 0.01) ADG, ADFI, and G:F compared with pigs drinking control water. Pigs drinking sodium sulfate water also had increased ($P < 0.01$) fecal scores and lower ($P < 0.04$) fecal DM on d 5, 9, and 16 compared with pigs drinking control water. Increasing dietary zeolite increased (linear; $P < 0.05$) ADG and ADFI but had no effect on G:F. In Exp. 2, 350 barrows (5.7 ± 0.1 kg BW and 21 d of age) were allotted to 1 of 10 treatments in a 2 × 5 factorial for 21 d with 2 levels of sodium sulfate water (control or 2,000 mg sodium sulfate/L added) and 5 dietary treatments (control, 1 or 2% zeolite, 1% humic acid substance [HA], and 1% humic and fulvic acid substance [HFB]). Fecal samples were collected on d 5, 8, 15, and 21; visually scored for consistency (1 = firm and 5 = watery); and analyzed for DM. Overall (d 0 to 21), a water source × diet interaction was observed for ADG and G:F because pigs fed the 1% HA had decreased ($P < 0.01$) ADG and G:F when drinking sodium sulfate water compared with other treatments but increased ADG and G:F when drinking control water. Pigs drinking sodium sulfate water had decreased ($P < 0.01$) ADG and G:F and tended ($P < 0.08$) to have decreased ADFI compared with pigs drinking control water. Pigs drinking sodium sulfate water had increased ($P < 0.01$) fecal scores and decreased ($P < 0.01$) fecal DM on d 5 and 8. In conclusion, water high in sodium sulfate concentrations decreased growth performance and increased fecal moisture in newly weaned pigs. Although zeolite improved growth performance in the first experiment, it did not influence growth in the second study. The nonnutritive feed additives used in both experiments were unsuccessful in ameliorating the increased osmotic diarrhea observed from high sodium sulfate water.

**Key words:** nursery pigs, sodium sulfate, water, zeolite


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## INTRODUCTION

Water quality can be compromised by high concentrations of dissolved salts. The most common dissolved salts contaminating well water throughout North America are sulfates. A survey conducted by McLeese et al. (1991) indicated that over 25% of wells in Saskatchewan used for swine production have concentrations greater than 1,000 mg/L. Another survey in Ohio (Veenhuizen, 1993) concluded that wells ranged in concentrations of 6 to 1,629 mg/L sulfate. The most common form of sulfate salts are magnesium sulfate ($MgSO_4$) and sodium sulfate ($Na_2SO_4$), with both acting similarly at concentrations of 1,800 mg/L in the water supply of growing pigs (Veehuizen et al., 1992). The incidence of nonpathogenic diarrhea increased and reduced performance was observed in young pigs when

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[2]We would like to thank St. Cloud Mining Company (Truth or Consequences, NM) for supplying the natural zeolite (clinoptilolite) used in Exp. 1 and 2 and Humatech Inc. (Houston, TX) for supplying the humic substances used in Exp. 2.

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sulfate concentrations were high (>7,000 mg/L; Anderson et al., 1994). Researchers saw no decrease in growth performance (Patience et al., 2004) at lower concentrations (<2,650 mg/L), but diarrhea remained prevalent.

Nutritional therapies may have the potential to reduce osmotic diarrhea from sodium sulfate water. Clinoptilolite is one of several natural zeolites, which are microporous aluminosilicate 3-dimensional structures known for their cation exchange and water adsorption capabilities (Mumpton and Fishman, 1977). Due to clinoptilolite's ability to adsorb water, it may help reduce fecal moisture associated with osmotic diarrhea. Humic substances are another natural feed additive that has been used in nursery diets to decrease the incidence and severity of diarrhea and its hydrophilic structure can also bind water (Trckova et al., 2005). Humic substances are largely made up of humic acid, fulvic acid, and humin along with small amounts of minerals such as Fe, Mn, Cu, and Zn.

The objectives of these experiments were to develop a sodium sulfate water–induced osmotic diarrhea model and to evaluate the efficacy of nonnutritive additives in reducing negative effects associated with sodium sulfate water.

## MATERIALS AND METHODS

Experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. Both experiments were conducted at the Kansas State University Segregated Early Weaning Research Facility in Manhattan, KS. Each pen (1.22 by 1.22 m) contained a 4-hole dry self-feeder and 1-cup waterer to provide ad libitum access to feed and water.

All diets in Exp. 1 and 2 were fed in 2 phases, with the same feed additive inclusion rates in both phases. The first-phase diets were manufactured at Kansas State University Grain Science Feed Mill and were presented in a pelleted form. The second-phase diets were manufactured at the Kansas State University Animal Science Feed Mill and were fed in meal form. All diets were formulated to meet or exceed nutrient requirement estimates (NRC, 1998; Table 1). Samples of the control diets were collected at the beginning and end of each feeding phase and were sent with samples of feed additives to a commercial laboratory (Ward Laboratories, Inc., Kearney, NE; Table 2) for proximate analysis of moisture (AOAC, 1990; method 935.29), CP (AOAC, 1990; method 990.03), crude fat (Ankom Technology, 2004), and ash (AOAC, 1990; method 942.05). Samples were also analyzed for Ca, P, K, Mg, Zn, Fe, Mn, Cu, S, and Na using wet chemistry digestion and inductively coupled argon plasma spectroscopy (Campbell and Plank, 1991) and NaCl and Cl using a potentiometric method previously described by AOAC (1990; method 969.10).

Experimental water treatments were achieved by mixing a stock solution of sodium sulfate ($Na_2SO_4$) water into the water supply (municipal water; Manhattan, KS) by medicator (Dosatron International Inc., Clearwater, FL) at a rate of 1:10. Samples collected from experimental water treatments were taken at the end of each feeding phase. These samples were refrigerated and sent to a commercial laboratory (Servi-Tech Laboratories Inc., Dodge City, KS) for analysis of mineral content using inductively coupled plasma–atomic emission spectrometry (Martin et al., 1994; method 200.7), pH, and electrical conductivity using methods described by Pfaff (1993; method 300.0) and the American Public Health Association (1999a,b). Calculations using electrical conductivity were used to estimate total dissolved solids and calculations to convert sulfur as sulfate ($SO_4$–S) to estimate water sulfate ($SO_4$) concentrations (Table 3).

Fecal collections were conducted in both experiments to evaluate fecal moisture and consistency by visual score and to determine DM of fecal samples. Samples were collected by rectal massage from either 2 or 3 pigs per pen. Then, 5 trained individuals, blinded to treatments, scored samples based on a visual moisture content using a numeric scale discussed by Smiricky et al. (2002) in which 1 = hard, dry pellet; 2 = firm, formed stool; 3 = soft, moist stool that retains shape; 4 = soft, moist stool that assumes shape of container; and 5 = watery liquid that can be poured. Afterward, scores were averaged over the 5 scores to determine an average score for each pen. Fecal samples were then frozen at –20°C and later thawed when both partial and laboratory DM techniques (Undersander et al., 1993) were conducted. Partial DM was achieved by drying whole fecal samples at 50°C in a forced-air drying oven for 24 h. Samples were cooled, weighed, ground, and stored at –20°C until laboratory DM was achieved by weighing a 1-g subsample from each fecal sample and drying at 100°C in a forced-air drying oven for 12 h.

### *Experiment 1*

A total of 320 barrows (1050; PIC, Hendersonville, TN: initially 5.4 ± 0.1 kg BW and 21 d of age) were used in a 24-d growth experiment to evaluate the potential negative effects of sodium sulfate water and the ability of natural zeolite (clinoptilolite; St. Cloud Mining Company, Truth or Consequences, NM), at different levels, to lessen those effects. Upon arrival at the facility (d 0), pigs were allotted to pens in 2 rooms by ranking the pigs within room by BW. The heaviest 32 pigs were then randomly assigned to pens and this process was repeated until all pigs were assigned to pens within room resulting in 5 pigs per pen. Pens within room were then randomly assigned to 1 of 8 treatments resulting in 8 pens per treatment. The 8 experimental treatments were arranged as a

**Table 1.** Composition of diets, Exp. 1 and 2 (as-fed basis)

| Item | Phase 1[1] | Phase 2[2] |
|---|---|---|
| Ingredient, % | | |
| Corn | 38.16 | 57.06 |
| Soybean meal (46.5% CP) | 16.99 | 25.90 |
| Dried distillers grains with solubles | 5.00 | – |
| Spray-dried animal plasma | 4.00 | – |
| Select menhaden fish meal | – | 4.50 |
| Spray-dried blood cells | 1.25 | – |
| Spray dried whey | 25.00 | 10.00 |
| Dried porcine solubles[3] | 3.00 | – |
| Monocalcium P (21% P) | 0.85 | 0.38 |
| Limestone | 0.85 | 0.58 |
| Salt | 0.30 | 0.30 |
| Zinc oxide | 0.39 | 0.25 |
| Trace mineral premix[4] | 0.15 | 0.15 |
| Vitamin premix[5] | 0.25 | 0.25 |
| L-Lys HCl | 0.20 | 0.25 |
| DL-Met | 0.13 | 0.13 |
| L-Thr | 0.08 | 0.11 |
| Phytase[6] | 0.13 | 0.17 |
| Acidifier[7] | 0.20 | – |
| Vitamin E, 20,000 IU | 0.05 | – |
| Choline chloride 60% | 0.04 | – |
| Zeolite (clinoptilolite)[8] | – | – |
| HA[9] | – | – |
| HFB[10] | – | – |
| Total | 100 | 100 |
| Calculated analysis | | |
| Standardized ileal digestible AA, % | | |
| Lys | 1.35 | 1.30 |
| Ile:Lys | 54 | 61 |
| Leu:Lys | 132 | 127 |
| Met:Lys | 30 | 35 |
| Met and Cys:Lys | 57 | 59 |
| Thr:Lys | 65 | 63 |
| Trp:Lys | 18 | 17 |
| Val:Lys | 72 | 68 |
| Total Lys, % | 1.51 | 1.43 |
| CP, % | 21.6 | 21.3 |
| ME, kcal/kg | 3,414 | 3,311 |
| Ca, % | 0.75 | 0.70 |
| P, % | 0.73 | 0.63 |
| Available P, % | 0.65 | 0.47 |
| Na, % | 0.75 | 0.25 |
| K, % | 1.07 | 0.97 |
| Added trace minerals, mg/kg | | |
| Zn | 2,973 | 1,965 |
| Fe | 165 | 165 |
| Mn | 40 | 40 |
| Cu | 17 | 17 |
| I | 0.3 | 0.3 |
| Se | 0.3 | 0.3 |

[1]Phase 1 diets were fed from d 0 to 10 in Exp. 1 and d 0 to 8 in Exp. 2.

[2]Phase 2 diets were fed from d 10 to 24 in Exp. 1 and d 8 to 21 in Exp. 2.

[3]DPS-50 (Nutra-Flo Company, Sioux City, IA).

continued

**Table 1.** (cont.)

[4]Vitamin premix provided 11,023 IU vitamin A, 1,378 IU vitamin $D_3$, 44 IU vitamin E, 4.41 mg vitamin K, 38.5 μg bitamin $B_{12}$, 49.6 mg niacin, 27.56 mg pantothenic acid, and 8.27 mg riboflavin per kilogram of the complete diet.

[5]Trace mineral premix provided 39.68 mg Mn, 151.84 mg Fe, 151.84 mg Zn, 15.18 mg Cu, 0.30 mg I, and 0.30 mg Se per kilogram of the complete diet.

[6]Natuphos 600 (BASF, Florham Park, NJ) provided 780 and 983 phytase units/kg of diet, respectively.

[7]Kem-gest (Kemin Industries Inc., Des Moines, IA).

[8]Used in Exp. 1 and 2 (St. Cloud Mining Company, Truth or Consequences, NM); replaced corn to provide 0, 0.25, 0.50, and 1% zeolite.

[9]HA = humic acid substance. In Exp. 2, 1% HA (DPX 5800; Humatech Inc., Houston, TX) was added to the control diet.

[10]HFB = humic and fulvic acid substance. In Exp. 2, 1% HFB (DPX 7702; Humatech Inc., Houston, TX) was added to the control diet.

2 × 4 factorial with 2 water treatments (control or water with 3,000 mg sodium sulfate/L; $Na_2SO_4$) and 4 dietary zeolite levels (0, 0.25, 0.5, and 1.0%). Water treatments remained the same from d 0 to 24. First-phase diets were fed from d 0 to 10, and second-phase diets were fed from d 10 to 24. Average daily gain, ADFI, and G:F were determined by weighing pigs and measuring feed disappearance on d 5, 10, 17, and 24 of the trial. Fecal collections were performed on d 5, 9, 16, and 23.

### *Experiment 2*

A total of 350 barrows (1050; PIC, Hendersonville, TN; initially 5.7 ± 0.1 kg BW and 21 d of age) were used in a 21-d study to evaluate the efficacy of natural zeolite and humic substances at alleviating the negative effects associated with sodium sulfate water. Upon arrival at the facility (d 0), pigs were allotted to pens in 2 rooms by ranking the pigs within room by BW. In room 1, the heaviest 40 pigs were then randomly assigned to pens and this process was repeated until all pigs were assigned to pens within room resulting in 5 pigs per pen. In room 2, a similar process was used but in groups of 30 pigs. Pens within room were then randomly assigned to 1 of 10 treatments resulting 7 pens per treatment. The 10 experimental treatments were arranged as a 2 × 5 factorial with 2 water treatments (control or water with 2,000 mg sodium sulfate/L) and 5 dietary regimens (control, 1 or 2% zeolite, 1% humic acid substance [**HA**], or 1% humic and fulvic acid substance [**HFB**]). Water treatments remained the same from d 0 to 21. First-phase diets were fed from d 0 to 8, and second-phase diets were fed from d 8 to 21. Average daily gain, ADFI, and G:F were determined. Fecal collections were performed on d 5, 8, 15, and 21.

### *Statistical Analysis*

For both experiments, data were analyzed as a generalized randomized block design using the MIXED

**Table 2.** Proximate and mineral analysis of control diets and feed additive ingredients[1]

| Item | Exp. 1[2] Phase 1 | Exp. 1[2] Phase 2 | Exp. 2[3] Phase 1 | Exp. 2[3] Phase 2 | Ingredient Zeolite[4] | Ingredient HA[5] | Ingredient HFB[6] |
|---|---|---|---|---|---|---|---|
| Moisture, % | 8.2 | 9.1 | 9.2 | 8.9 | 4.1 | 12 | 8.7 |
| CP, % | 20.9 | 22.5 | 21.3 | 21.4 | 0.1 | 4.7 | 2.8 |
| Ash, % | – | – | – | – | 91.2 | 24.8 | 55.26 |
| Ether extract, % | 4.8 | 2.5 | 4.8 | 2.6 | – | – | – |
| Ca, % | 0.93 | 0.75 | 0.81 | 1.00 | 1.79 | 0.47 | 0.56 |
| P, % | 0.80 | 0.66 | 0.70 | 0.69 | 0.05 | 0.05 | 0.05 |
| K, % | 1.18 | 1.09 | 1.21 | 1.07 | 0.86 | 0.07 | 0.09 |
| Mg, % | 0.17 | 0.17 | 0.15 | 0.17 | 0.44 | 0.06 | 0.13 |
| S, % | 0.44 | 0.28 | 0.45 | 0.29 | 0.05 | 0.32 | 0.29 |
| Na, % | 0.64 | 0.20 | 0.60 | 0.28 | 0.17 | 0.08 | 0.40 |
| NaCl, % | 1.12 | 0.66 | 1.07 | 0.93 | 0.04 | 0.03 | 0.03 |
| Cl, % | 0.68 | 0.40 | 0.65 | 0.56 | 0.02 | 0.02 | 0.02 |
| Zn, mg/kg | 2,966 | 1,297 | 2,909 | 2,243 | 45 | 40 | 79 |
| Cu, mg/kg | 32 | 15 | 20 | 27 | 7 | 14 | 14 |
| Fe, mg/kg | 593 | 249 | 414 | 414 | 6,078 | 5,767 | 9,265 |
| Mn, mg/kg | 117 | 54 | 80 | 87 | 255 | 121 | 148 |

[1]All samples were sent to Ward Laboratories Inc., Kearney, NE. Values are means of 2 samples collected at the beginning or end of each feeding phase or 2 subsamples from each additive ingredient.

[2]Phase 1 diets were fed from d 0 to 10 in a pelleted form, and phase 2 diets were fed from d 10 to 24 in a meal form.

[3]Phase 1 diets were fed from d 0 to 8 in a pelleted form, and phase 2 diets were fed from d 8 to 21 in a meal form.

[4]One source of zeolite was used for both experiments: St Cloud Mining Inc., Truth or Consequences, NM.

[5]HA = humic acid substance; DPX 5800 (Humatech Inc., Houston, TX).

[6]HFB = humic and fulvic acid blended substance; DPX 7702 (Humatech Inc., Houston TX).

**Table 3.** Analyzed composition of water[1]

| Item, mg/L | Exp. 1[2] Control water | Exp. 1[2] 3,000 mg sodium sulfate/L | Exp. 2[3] Control water | Exp. 2[3] 2,000 mg sodium sulfate/L |
|---|---|---|---|---|
| $SO_4$ | 84 | 2,000 | 77 | 1,700 |
| $SO_4$-S | 28 | 660 | 26 | 565 |
| Cl | 65 | 49 | 51 | 39 |
| Na | 38 | 750 | 34 | 565 |
| Ca | 25 | 26 | 13 | 14 |
| Mg | 12 | 12 | 10 | 10 |
| K | 6 | 7 | 6 | 6 |
| Fe | 0.06 | 0.1 | 0.1 | 0.1 |
| Mn | 0.01 | 0.01 | 0.01 | 0.01 |
| pH, units | 9.1 | 9.0 | 8.8 | 8.7 |
| Electrical conductivity, mS/cm | 0.502 | 4.320 | 0.363 | 2.760 |

[1]Samples were analyzed by Servi-tech Laboratories, Dodge City, KS.

[2]Two samples were collected on d 10 and 24, and values are the mean of the sample analysis.

[3]Two samples were collected on d 8 and 21, and values are the mean of the sample analysis.

[4]Total Dissolved Solids was not measured directly but was calculated from electrical conductivity.

procedure of SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit and room as a random effect. Treatment means were analyzed using the LSMEANS statement and preplanned CONTRAST statements in SAS, with barn location as a random effect. Fecal scores and fecal DM measured over time (d) were analyzed as repeated measures. The REPEATED function in SAS was used to account for the covariance within pen over time. A Kenward-Rodgers degrees of freedom adjustment was used in the repeated measures analysis. In Exp. 1, preplanned contrasts included control water vs. sodium sulfate water, linear and quadratic effects of increasing levels of dietary zeolite, and the interactions of water treatment and dietary zeolite treatment. The coefficients for the unequally spaced linear and quadratic contrasts were derived using the PROC IML procedure in SAS. For Exp. 2, preplanned contrasts included control vs. sodium sulfate water, linear and quadratic effects of increasing dietary zeolite, control diet vs. 1% HA, control diet vs. 1% HFB, 1% zeolite vs. 1% HA, 1% zeolite vs. 1% HFB, 1% HA vs. 1% HFB, and the interactions of water treatments within each dietary treatment. Differences among treatments were considered significant at $P \leq 0.05$, tendencies at $P >$ 0.05 and $P \leq 0.10$, and trends if $P > 0.05$ and $P \leq 0.10$ for linear and quadratic comparisons.

## RESULTS

### *Experiment 1*

During phase 1 (d 0 to 10), a water treatment × dietary zeolite interaction (linear; $P < 0.04$) was observed for ADFI (Table 4), which occurred because ADFI increased as dietary zeolite increased for pigs drinking sodium sulfate water but decreased with increasing dietary zeolite for pigs drinking control water. No other interactions were observed for any response criteria. Sodium sulfate addition to the water and dietary zeolite did not influence ADG, ADFI, or G:F from d 0 to 10.

During phase 2 (d 10 to 24), increasing zeolite improved (linear; $P < 0.01$) ADG and ADFI with no effect on G:F. Also, ADG, ADFI, and G:F worsened ($P < 0.02$) for pigs drinking sodium sulfate water compared with pigs drinking control water.

Overall (d 0 to 24), increasing zeolite increased (linear; $P < 0.05$) ADG and ADFI, but G:F was not affected. Pigs drinking sodium sulfate water had decreased ($P < 0.01$) ADG, ADFI, and G:F compared with pigs drinking control water.

For fecal moisture scores, a water × day interaction ($P < 0.01$) was observed because pigs drinking sodium sulfate water had decreasing fecal scores over time, and fecal matter became firmer, whereas pigs drinking control water had

**Table 4.** Effects of sodium sulfate water and dietary zeolite on early nursery pig growth performance[1]

| Water sodium sulfate, mg/L | Dietary zeolite, % | d 0 to 10 | | | d 10 to 24 | | | d 0 to 24 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ADG, g | ADFI, g | G:F | ADG, g | ADFI, g | G:F | ADG, g | ADFI, g | G:F |
| 0 | 0 | 167 | 166 | 1.01 | 354 | 497 | 0.71 | 276 | 359 | 0.77 |
| | 0.25 | 163 | 162 | 1.01 | 370 | 524 | 0.71 | 284 | 373 | 0.76 |
| | 0.50 | 151 | 150 | 0.99 | 388 | 530 | 0.73 | 283 | 364 | 0.78 |
| | 1.00 | 143 | 150 | 0.94 | 409 | 543 | 0.75 | 291 | 370 | 0.79 |
| 3,000 | 0 | 127 | 138 | 0.87 | 309 | 442 | 0.70 | 229 | 311 | 0.73 |
| | 0.25 | 168 | 162 | 1.03 | 324 | 465 | 0.69 | 259 | 339 | 0.76 |
| | 0.50 | 151 | 153 | 1.00 | 352 | 508 | 0.69 | 268 | 360 | 0.74 |
| | 1.00 | 147 | 163 | 0.90 | 349 | 508 | 0.69 | 265 | 364 | 0.73 |
| SEM | | 13 | 9 | 0.05 | 20 | 22 | 0.02 | 13 | 15 | 0.02 |
| | | Probability, $P <$ | | | | | | | | |
| Interactions | | | | | | | | | | |
| Sodium sulfate × zeolite linear | | 0.17 | 0.04 | 0.24 | 0.68 | 0.49 | 0.14 | 0.43 | 0.08 | 0.18 |
| Sodium sulfate × zeolite quadratic | | 0.21 | 0.34 | 0.18 | 0.65 | 0.66 | 0.94 | 0.25 | 0.37 | 0.30 |
| Main effects | | | | | | | | | | |
| Sodium sulfate | | 0.40 | 0.62 | 0.36 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 |
| Zeolite linear | | 0.51 | 0.90 | 0.97 | 0.01 | 0.01 | 0.32 | 0.05 | 0.02 | 0.85 |
| Zeolite quadratic | | 0.31 | 0.90 | 0.12 | 0.39 | 0.21 | 0.86 | 0.20 | 0.23 | 0.43 |

[1]A total of 320 weanling pigs (PIC 1050 barrows, initial BW of 5.4 kg and 21 d of age) were used with 5 pigs per pen and 8 pens per treatment.

consistent fecal scores throughout the study. Pigs drinking sodium sulfate water had ($P < 0.01$) higher fecal moisture scores on d 5, 9, 16, and 23 and for overall mean fecal moisture scores than pigs drinking control water (Table 5). Dietary zeolite did not influence fecal moisture score.

A water × day interaction ($P < 0.01$) was observed for fecal DM because DM increased over time for pigs drinking sodium sulfate water, and pigs drinking control water had consistent fecal DM throughout the length of the study. Pigs drinking sodium sulfate water had decreased fecal DM ($P < 0.04$) on d 5, 9, and 16 and for overall mean fecal DM compared with pigs drinking control water (Table 6). Dietary zeolite did not affect fecal DM score.

### *Experiment 2*

From d 0 to 8 (phase 1), there was a tendency for a water × dietary treatment interaction for ADG ($P <$ 0.06) because pigs fed the 1% HA diet had poorer ($P <$ 0.01) ADG than other treatments when drinking sodium sulfate water but improved ADG when drinking control water (Table 7). A water × dietary treatment interaction ($P < 0.01$) was also observed for G:F because pigs fed the 1% HA diet had decreased ($P < 0.01$) G:F when drinking sodium sulfate water compared with other treatments but improved G:F when drinking control water.

During the second phase (d 8 to 21), no water × dietary treatment interactions were observed, but pigs fed the 1% HA diet had decreased ($P < 0.01$) ADG and ADFI and tended to have decreased ($P < 0.06$) G:F when drinking sodium sulfate water compared with control water. In addition, pigs consuming diets with 1% zeolite tended ($P < 0.09$) to have lower G:F when drinking sodium sulfate water compared with control water. Regardless of interactions, pigs drinking sodium sulfate water had decreased ($P < 0.05$) ADG, ADFI, and G:F compared with pigs drinking control water. No dietary treatment main effects were observed for growth performance from d 8 to 24, but there was a trend ($P < 0.08$) for increasing zeolite to decrease ADFI.

For overall growth performance (d 0 to 21), water × dietary treatment interactions ($P < 0.03$) were observed for ADG and G:F because pigs fed the 1% HA diet had decreased ($P < 0.01$) ADG and G:F when drinking sodium sulfate water compared with other treatments but improved ADG and G:F when drinking control water. Pigs consuming the 1% HA diet had decreased ($P <$ 0.03) ADFI when drinking sodium sulfate water compared with pigs drinking control water. For main effects, pigs drinking sodium sulfate water had poorer ($P < 0.01$) ADG and G:F and tended ($P < 0.08$) to have lower ADFI than pigs drinking control water. Dietary treatment did not affect overall growth performance.

A water × day interaction was observed ($P < 0.01$; Table 8) for fecal moisture scores because fecal scores decreased over time for pigs drinking sodium sulfate water, but scores were consistent for pigs drinking control water throughout the length of the study. On d 5, there was a tendency for a water × dietary treatment interaction ($P < 0.10$) for fecal moisture scores because pigs eating the 1% HA diet had greater ($P < 0.01$) differences between control water and sodium sulfate water compared with other dietary treatments, and pigs eating 1%

**Table 5.** Effects of sodium sulfate water and dietary zeolite on fecal consistency scores[1,2,3,4]

| Water sodium sulfate, mg/L | Dietary zeolite, % | Day of collection 5 | 9 | 16 | 23 | Mean |
|---|---|---|---|---|---|---|
| 0 | 0 | 3.4 | 3.4 | 3.3 | 3.3 | 3.4 |
| | 0.25 | 3.3 | 3.3 | 3.0 | 3.2 | 3.2 |
| | 0.50 | 3.0 | 3.4 | 3.3 | 3.5 | 3.3 |
| | 1.00 | 3.2 | 3.3 | 3.2 | 3.2 | 3.2 |
| 3,000 | 0 | 4.1 | 4.0 | 3.6 | 3.7 | 3.9 |
| | 0.25 | 4.1 | 4.0 | 3.9 | 3.6 | 3.9 |
| | 0.50 | 4.1 | 4.4 | 3.5 | 3.6 | 3.9 |
| | 1.00 | 4.1 | 4.0 | 3.5 | 3.4 | 3.8 |
| SEM | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | | Probability, $P <$ | | | | |
| Interactions | | | | | | |
| Sodium sulfate × zeolite linear | | 0.58 | 0.68 | 0.44 | 0.50 | 0.23 |
| Sodium sulfate × zeolite quadratic | | 0.26 | 0.12 | 0.72 | 0.53 | 0.80 |
| Main effects | | | | | | |
| Sodium sulfate | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Zeolite linear | | 0.55 | 0.74 | 0.37 | 0.25 | 0.14 |
| Zeolite quadratic | | 0.38 | 0.18 | 0.79 | 0.64 | 0.75 |

[1]A total of 768 fecal samples were collected (192 per collection day; fecal samples were collected on d 5, 9, 16, and 23). Three samples were taken per pen and were scored by 5 trained individuals; those 15 scores were then averaged and reported as pen means for each collection day.

[2]Samples were collected from 3 random pigs per pen, and samples were scored on a numerical scale from 1 to 5 and were scored by 5 trained individuals.

[3]Scoring scale guidelines: 1 = dry firm pellet; 2 = firm formed stool; 3 = soft stool that retains shape; 4 = soft unformed stool that takes shape of container; and 5 = watery liquid that can be poured.

[4]Water × diet × day interaction ($P = 0.18$), water × day interaction ($P < 0.01$), diet × day interaction ($P = 0.51$), and day effect ($P < 0.01$).

**Table 6.** Effects of sodium sulfate water and dietary zeolite on fecal DM[1,2,3]

| Water sodium sulfate, mg/L | Dietary zeolite, % | Day of collection 5 | 9 | 16 | 23 | Mean |
|---|---|---|---|---|---|---|
| 0 | 0 | 21.4 | 23.9 | 25.6 | 24.6 | 23.9 |
| | 0.25 | 21.0 | 25.0 | 26.4 | 25.8 | 24.6 |
| | 0.50 | 23.5 | 25.2 | 24.6 | 21.9 | 23.8 |
| | 1.00 | 23.1 | 26.2 | 26.0 | 25.7 | 25.3 |
| 3,000 | 0 | 13.5 | 19.0 | 25.6 | 21.9 | 20.0 |
| | 0.25 | 12.7 | 18.0 | 20.9 | 23.9 | 18.9 |
| | 0.50 | 14.0 | 17.0 | 24.4 | 24.3 | 19.9 |
| | 1.00 | 13.2 | 19.8 | 23.7 | 24.6 | 20.4 |
| SEM | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| | | Probability, $P <$ | | | | |
| Interactions | | | | | | |
| Sodium sulfate × zeolite linear | | 0.41 | 0.64 | 0.85 | 0.43 | 0.73 |
| Sodium sulfate × zeolite quadratic | | 0.87 | 0.24 | 0.61 | 0.14 | 0.86 |
| Main effects | | | | | | |
| Sodium sulfate | | 0.01 | 0.01 | 0.04 | 0.39 | 0.01 |
| Zeolite linear | | 0.39 | 0.22 | 0.88 | 0.27 | 0.13 |
| Zeolite quadratic | | 0.71 | 0.39 | 0.29 | 0.72 | 0.34 |

[1]A total of 768 fecal samples were collected (192 per collection day; fecal samples were collected on d 5, 9, 16, and 23).

[2]Samples were collected from 3 random pigs per pen.

[3]Water × diet × day Interaction ($P = 0.41$), water × day interaction ($P < 0.01$), diet × day interaction ($P = 0.60$), and day effect ($P < 0.01$).

zeolite tended ($P < 0.06$) to have greater differences in scores between control water and sodium sulfate water compared with other dietary treatments. On d 8, a water × dietary treatment interaction ($P < 0.01$) was observed because pigs eating diets containing 1 or 2% zeolite or 1% HFB had ($P < 0.03$) greater differences in fecal moisture scores between control water and sodium sulfate water compared with other dietary treatments. Mean fecal scores were lower ($P < 0.03$) for pigs fed diets containing 1 or 2% zeolite, 1% HA, or 1% HFB when drinking control water compared with drinking sodium sulfate water. Pigs drinking control water had ($P < 0.01$) lower fecal moisture scores and mean fecal moisture scores than pigs drinking sodium sulfate water on d 5 and 8. No main effects of dietary treatment were observed for fecal moisture scores, except for a trend (linear; $P < 0.09$) on d 8 for increasing zeolite to decrease fecal moisture score. These differences were most evident for pigs drinking control water (3.3, 2.8, and 2.7 for control and 1 and 2% zeolite treatments, respectively); however, pigs drinking sodium sulfate water were more variable in their respective fecal scores (3.3, 3.7, and 3.4 for control and 1 and 2% zeolite treatments, respectively).

A water × day interaction was observed ($P < 0.01$) for fecal DM because pigs drinking sodium sulfate water had increasing fecal DM over time, whereas pigs drinking control water had consistent fecal DM throughout the length of the study. Within d-5 fecal samples, pigs eating the diet with 1% HA had lower ($P < 0.03$) fecal DM when drinking sodium sulfate water compared with drinking control water (Table 9). On d 8, a water × dietary treatment interaction was observed ($P < 0.01$) because pigs consuming diets with 1 or 2% zeolite or 1% HFB had decreased ($P < 0.04$) fecal DM when drinking sodium sulfate water compared with other treatments but had higher fecal DM when drinking control water. For mean fecal DM, pigs eating diets containing 2% zeolite or 1% HA diets had decreased ($P < 0.03$) fecal DM when drinking sodium sulfate water compared with control water, and pigs consuming 1% zeolite tended ($P < 0.08$) to have lower fecal DM when drinking sodium sulfate water compared with control water. Nevertheless, pigs drinking sodium sulfate water had decreased ($P < 0.01$) fecal DM on d 5 and 8 and decreased mean fecal DM compared with pigs drinking control water. Within d 8, there was a trend (linear; $P < 0.08$) for increasing zeolite to increase fecal DM, which was mainly due to the magnitude of difference observed for pigs drinking control water (23.1, 26.7, and 28.7% DM for control and 1 and 2% zeolite, respectively); however, for pigs drinking sodium sulfate water (22.3, 18.8, and 22.1% DM for

**Table 7.** Influence of dietary natural zeolite or humic acid substance (HA) and humic and fulvic acid substance (HFB) and sodium sulfate water on nursery pig performance[1]

| Water sodium sulfate, mg/L | Dietary regimen | d 0 to 8 | | | d 8 to 21 | | | d 0 to 21 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ADG, g | ADFI, g | G:F | ADG, g | ADFI, g | G:F | ADG, g | ADFI, g | G:F |
| 0 | Control | 128 | 136 | 0.92 | 360 | 529 | 0.68 | 268 | 374 | 0.72 |
| | 1% zeolite | 140 | 140 | 1.00 | 356 | 514 | 0.69 | 274 | 372 | 0.74 |
| | 2% zeolite | 121 | 122 | 0.97 | 328 | 488 | 0.67 | 248 | 347 | 0.71 |
| | 1% HA | 157 | 128 | 1.29 | 389 | 545 | 0.71 | 300 | 386 | 0.78 |
| | 1% HFB | 142 | 147 | 0.96 | 357 | 521 | 0.69 | 274 | 377 | 0.73 |
| 2,000 | Control | 150 | 142 | 1.06 | 338 | 514 | 0.65 | 264 | 369 | 0.71 |
| | 1% zeolite | 142 | 135 | 1.04 | 317 | 494 | 0.64 | 249 | 353 | 0.70 |
| | 2% zeolite | 134 | 131 | 0.99 | 340 | 491 | 0.70 | 262 | 354 | 0.74 |
| | 1% HA | 102 | 130 | 0.80 | 307 | 473 | 0.65 | 229 | 342 | 0.67 |
| | 1% HFB | 119 | 142 | 0.84 | 344 | 507 | 0.68 | 255 | 363 | 0.70 |
| SEM | | 15 | 12 | 0.10 | 19 | 19 | 0.02 | 13 | 14 | 0.02 |
| Interactions | | | | | | Probability, *P* < | | | | |
| Sodium sulfate × diet | | 0.06 | 0.90 | 0.01 | 0.11 | 0.33 | 0.25 | 0.02 | 0.41 | 0.02 |
| Sodium sulfate within control | | 0.26 | 0.66 | 0.27 | 0.37 | 0.56 | 0.33 | 0.80 | 0.76 | 0.91 |
| Sodium sulfate within 1% zeolite | | 0.95 | 0.67 | 0.72 | 0.12 | 0.44 | 0.09 | 0.16 | 0.31 | 0.22 |
| Sodium sulfate within 2% zeolite | | 0.52 | 0.49 | 0.86 | 0.60 | 0.91 | 0.43 | 0.43 | 0.70 | 0.33 |
| Sodium sulfate within 1% HA | | 0.01 | 0.85 | 0.01 | 0.01 | 0.01 | 0.04 | 0.01 | 0.03 | 0.01 |
| Sodium sulfate within 1% HFB | | 0.24 | 0.68 | 0.31 | 0.59 | 0.61 | 0.75 | 0.28 | 0.45 | 0.32 |
| Main effects | | | | | | | | | | |
| Sodium sulfate | | 0.35 | 0.83 | 0.15 | 0.01 | 0.05 | 0.05 | 0.01 | 0.08 | 0.02 |
| Diet | | 0.81 | 0.34 | 0.57 | 0.82 | 0.48 | 0.86 | 0.91 | 0.54 | 0.95 |
| Dietary comparisons | | | | | | | | | | |
| Zeolite linear | | 0.40 | 0.21 | 0.97 | 0.40 | 0.08 | 0.40 | 0.37 | 0.12 | 0.50 |
| Zeolite quadratic | | 0.52 | 0.58 | 0.67 | 0.75 | 0.92 | 0.63 | 0.94 | 0.90 | 0.95 |
| Control vs. 1% HA | | 0.49 | 0.31 | 0.54 | 0.97 | 0.49 | 0.51 | 0.92 | 0.59 | 0.70 |
| Control vs. 1% HFB | | 0.53 | 0.58 | 0.33 | 0.93 | 0.68 | 0.50 | 0.88 | 0.90 | 0.98 |
| 1% zeolite vs. 1% HA | | 0.41 | 0.39 | 0.79 | 0.52 | 0.80 | 0.51 | 0.78 | 0.90 | 0.91 |
| 1% zeolite vs. 1% HFB | | 0.44 | 0.48 | 0.19 | 0.43 | 0.58 | 0.50 | 0.81 | 0.58 | 0.76 |
| 1% HA vs. 1% HFB | | 0.94 | 0.12 | 0.12 | 0.90 | 0.77 | 0.99 | 0.96 | 0.67 | 0.69 |

[1]A total of 350 weanling pigs (PIC 1050 barrows, initially 5.7 kg and 21 d of age) were used with 5 pigs per pen and 7 pens per treatment.

control and 1 and 2% zeolite, respectively) treatment differences were not as evident. For mean fecal scores, a diet effect ($P < 0.02$) was observed because increasing zeolite increased (linear; $P < 0.01$) fecal DM; again, these differences were most evident for pigs drinking control water (23.1, 24.3, and 26.4% DM for control and 1 and 2% zeolite, respectively) compared with those drinking sodium sulfate water (22.7, 22.5, and 23.7% DM for control and 1 and 2% zeolite). In addition, pigs fed the 1% HFB diet had higher ($P < 0.01$) and tended to have higher ($P < 0.06$) fecal DM than pigs fed control and 1% zeolite diets, respectively.

Fecal scoring techniques used in these experiments were used as a quick tool to determine visual fecal moisture. We were interested in whether they were as effective at predicting differences as typical DM techniques. Based on correlations, scoring was an effective predictor of fecal moisture content (as measured by fecal DM) during collections conducted in the first feeding phase (d 5 and 9 in Exp. 1 and d 5 and 8 in Exp. 2), but they were not accurate predictors in the second phase (d 16 and 23 in Exp. 1 and d 15 and 21 in Exp. 2; Fig. 1 and 2).

## DISCUSSION

Maximum recommended water sulfate levels by the NRC (1998) for livestock are 1,000 mg/L. Water analysis conducted for the current studies showed sulfate levels of 2,000 (Exp. 1) and 1,700 mg/L (Exp. 2) for experimental treatments when sodium sulfate was added to the water supply at rates of 3,000 and 2,000 mg/L, respectively, and control water concentrations were approximately 80 mg/L sulfate in both trials. Estimated dissolved solids in the trials were 2,800 and 1,770 for Exp. 1 and 2, respectively, which are under the recommended maximum level of 3,000 mg/L. Work by Anderson and Stothers (1978) concluded that water with the same total dissolved solids (**TDS**) but containing chloride rather than sulfate did not cause excessive diarrhea; therefore, sulfates are a better estimating compound compared to TDS alone.

**Table 8.** Influence of dietary natural zeolite or humic acid substance (HA) and humic and fulvic acid substance (HFB) and sodium sulfate water on nursery pig fecal consistency[1,2,3]

| Water sodium sulfate, mg/L | Dietary regimen | Day of collection 5 | 8 | 15 | 21 | Mean |
|---|---|---|---|---|---|---|
| 0 | Control | 3.4 | 3.3 | 3.4 | 3.4 | 3.4 |
| | 1% zeolite | 3.4 | 2.8 | 3.3 | 3.4 | 3.2 |
| | 2% zeolite | 3.5 | 2.7 | 3.1 | 3.4 | 3.2 |
| | 1% HA | 3.3 | 3.1 | 3.3 | 3.4 | 3.3 |
| | 1% HFB | 3.4 | 3.1 | 3.2 | 3.4 | 3.3 |
| 2,000 | Control | 3.7 | 3.3 | 3.3 | 3.4 | 3.4 |
| | 1% zeolite | 3.8 | 3.7 | 3.4 | 3.4 | 3.6 |
| | 2% zeolite | 3.7 | 3.4 | 3.4 | 3.3 | 3.4 |
| | 1% HA | 3.8 | 3.3 | 3.3 | 3.5 | 3.5 |
| | 1% HFB | 3.6 | 3.5 | 3.4 | 3.6 | 3.5 |
| SEM | | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 |
| | | Probability, $P <$ | | | | |
| Interactions | | | | | | |
| Sodium sulfate × diet | | 0.10 | 0.01 | 0.83 | 0.97 | 0.23 |
| Sodium sulfate within control | | 0.13 | 0.83 | 0.42 | 0.69 | 0.78 |
| Sodium sulfate within 1% zeolite | | 0.06 | 0.01 | 0.65 | 0.96 | 0.01 |
| Sodium sulfate within 2% zeolite | | 0.28 | 0.01 | 0.23 | 0.71 | 0.01 |
| Sodium sulfate within 1% HA | | 0.01 | 0.21 | 0.93 | 0.74 | 0.03 |
| Sodium sulfate within 1% HFB | | 0.30 | 0.03 | 0.16 | 0.28 | 0.01 |
| Main effects | | | | | | |
| Sodium sulfate | | 0.01 | 0.01 | 0.30 | 0.79 | 0.01 |
| Diet | | 0.99 | 0.40 | 0.95 | 0.88 | 0.58 |
| Diet comparisons | | | | | | |
| Zeolite linear | | 0.85 | 0.09 | 0.48 | 0.73 | 0.20 |
| Zeolite quadratic | | 0.82 | 0.43 | 0.65 | 0.63 | 0.33 |
| Control vs. 1% HA | | 0.98 | 0.55 | 0.76 | 0.64 | 0.81 |
| Control vs. 1% HFB | | 0.88 | 0.94 | 0.76 | 0.52 | 0.96 |
| 1% zeolite vs. 1% HA | | 0.76 | 0.66 | 0.73 | 0.82 | 0.67 |
| 1% zeolite vs. 1% HFB | | 0.66 | 0.92 | 0.73 | 0.69 | 0.89 |
| 1% HA vs. 1% HFB | | 0.90 | 0.59 | 0.99 | 0.87 | 0.77 |

[1]A total of 560 fecal samples were collected (140 per collection day; fecal samples were collected on d 5, 8, 15, and 21). Two samples were taken per pen and scored by 5 trained individuals. The 10 scores were then averaged and reported as pen means for each collection day.

[2]Scoring scale guidelines: 1 = dry, firm pellet; 2 = firmly formed stool; 3 = soft stool that retains shape; 4 = soft, unformed stool that takes shape of container; 5 = watery liquid that can be poured.

[3]Water × diet × day interaction ($P = 0.45$), water × day interaction ($P < 0.01$), diet × day ($P = 0.99$), and day effect ($P < 0.01$).

**Table 9.** Influence of dietary natural zeolite or humic acid substance (HA) and humic and fulvic acid substance (HFB) and sodium sulfate water on nursery pig fecal DM[1,2,3]

| Water sodium sulfate, mg/L | Dietary regimen | Day of collection 5 | 8 | 15 | 21 | Mean |
|---|---|---|---|---|---|---|
| 0 | Control | 20.5 | 23.1 | 22.7 | 26.0 | 23.1 |
| | 1% zeolite | 21.6 | 26.7 | 23.8 | 25.2 | 24.3 |
| | 2% zeolite | 23.1 | 28.7 | 26.7 | 27.1 | 26.4 |
| | 1% HA | 23.2 | 25.6 | 24.6 | 27.5 | 25.2 |
| | 1% HFB | 22.7 | 26.5 | 26.9 | 26.8 | 25.7 |
| 2,000 | Control | 18.3 | 22.3 | 23.8 | 26.5 | 22.7 |
| | 1% zeolite | 19.4 | 18.8 | 24.6 | 27.0 | 22.5 |
| | 2% zeolite | 20.5 | 22.1 | 24.8 | 27.4 | 23.7 |
| | 1% HA | 18.3 | 22.7 | 25.1 | 25.3 | 22.8 |
| | 1% HFB | 20.7 | 22.0 | 24.9 | 28.3 | 24.0 |
| SEM | | 1.7 | 1.7 | 1.7 | 1.7 | 0.9 |
| | | Probability, $P <$ | | | | |
| Interactions | | | | | | |
| Sodium sulfate × diet | | 0.19 | 0.01 | 0.73 | 0.93 | 0.60 |
| Sodium sulfate within control | | 0.32 | 0.70 | 0.63 | 0.82 | 0.74 |
| Sodium sulfate within 1% zeolite | | 0.30 | 0.01 | 0.69 | 0.42 | 0.08 |
| Sodium sulfate within 2% zeolite | | 0.24 | 0.01 | 0.38 | 0.88 | 0.01 |
| Sodium sulfate within 1% HA | | 0.03 | 0.19 | 0.83 | 0.32 | 0.03 |
| Sodium sulfate within 1% HFB | | 0.35 | 0.04 | 0.36 | 0.48 | 0.11 |
| Main effects | | | | | | |
| Sodium sulfate | | 0.01 | 0.01 | 0.76 | 0.70 | 0.01 |
| Diet | | 0.50 | 0.35 | 0.40 | 0.84 | 0.02 |
| Diet comparisons | | | | | | |
| Zeolite linear | | 0.12 | 0.08 | 0.11 | 0.52 | 0.01 |
| Zeolite quadratic | | 0.94 | 0.34 | 0.83 | 0.61 | 0.38 |
| Control vs. 1% HA | | 0.38 | 0.36 | 0.31 | 0.93 | 0.15 |
| Control vs. 1% HFB | | 0.13 | 0.31 | 0.09 | 0.40 | 0.01 |
| 1% zeolite vs. 1% HA | | 0.86 | 0.39 | 0.68 | 0.84 | 0.41 |
| 1% zeolite vs. 1% HFB | | 0.42 | 0.34 | 0.28 | 0.34 | 0.06 |
| 1% HA vs. 1% HFB | | 0.54 | 0.95 | 0.51 | 0.46 | 0.30 |

[1]A total of 560 fecal samples were collected (140 per collection day; fecal samples were collected on d 5, 8, 15, and 21). Two samples were taken per pen and were scored by 5 trained individuals. The 10 scores were then averaged and reported as pen means for each collection day.

[2]Scoring scale guidelines: 1 = dry, firm pellet; 2 = firmly formed stool; 3 = soft stool that retains shape; 4 = soft, unformed stool that takes shape of container; 5 = watery liquid that can be poured.

[3]Water × diet × day interaction ($P = 0.69$), water × day interaction ($P < 0.01$), diet × day ($P = 0.99$), and day main effect ($P < 0.01$).

The weaning process triggers distinct changes in the digestive tract of young pigs (Boudry et al., 2004). Postweaning diarrhea may be the result of these gastrointestinal alterations, but it can be exacerbated by other stressors (Pluske et al., 1997). Sulfates are transported across the intestinal epithelium via a sodium dependent transporter and a sodium dependent anion exchanger (Markovich, 2001). Resecretion of the sulfate in the lower intestine causes osmotic pull of water into the lumen resulting in increased incidence of diarrhea. In the current studies, sodium sulfate exacerbated diarrhea up to 16 d after weaning as measured by fecal DM in Exp. 1, but visual scoring suggested higher moisture content on all fecal collection days (d 5, 9, 15, and 23). In Exp. 2, decreased fecal DM and increased fecal moisture scores were observed up to 8 d postweaning. Similar results have been found in previous studies (Anderson and Stothers, 1978; Paterson et al., 1979; McLeese et al., 1992), which show that weaned pigs experience increased diarrhea initially but the negative effects of high water sulfates decrease over time. This may be the result of the young pig's gastrointestinal maturity and ability to adapt to high sodium

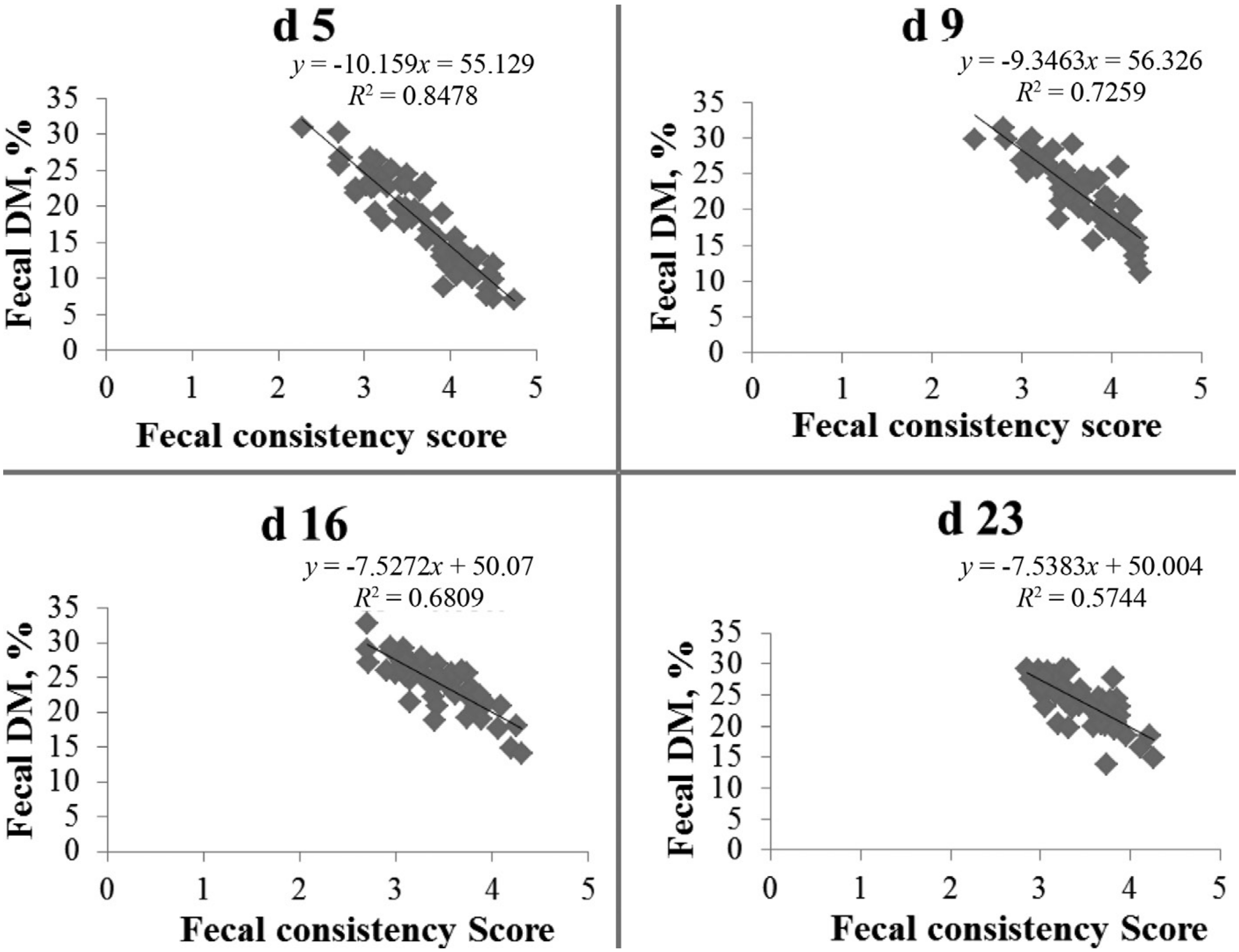


**Figure 1.** Correlation of fecal score to fecal DM, Exp. 1.

sulfate levels. Paterson et al. (1979) and Anderson et al. (1994) have shown that sows and finishing pigs are able to tolerate higher levels of sulfates than weaned pigs with no influence on performance or diarrhea. Based on the fecal moisture scores from the current studies, it could be concluded that pigs adapted faster to sodium sulfate levels supplied in Exp. 2 than in Exp. 1.

Overall, growth performance was negatively influenced with increased sulfate concentrations in both experiments. Average daily gain decreased by 11 and 8%, ADFI decreased 6 and 4%, and G:F was 4% lower in both Exp. 1 and 2, respectively. Anderson and Stothers (1978) observed tendencies for increased ADG for control pigs compared to pigs receiving high saline water, but these differences were not significant, perhaps due to small sample sizes. McLeese et al. (1992) observed decreases in ADG and G:F in weaned pigs drinking 2,650 mg/L sulfate water, but when medications were introduced into the diet, growth performance was not affected. A potential explanation of this response to antibiotics may be due to a reduction in mucosal lining damage and immune activation that has been found with increased concentrations of sulfate in the lower bowel (Argenzio and Whipp, 1980) or a decrease in pathogenic bacteria proliferation. Interestingly, diarrhea was observed even with medication in the diet, which shows that antibiotics did not compensate for osmotic imbalances resulting in decreased electrolyte and water absorption. Patience et al. (2004) found no effect of poor-quality water with high sulfate concentrations on growth performance of weaned pigs raised in commercial settings; however, diarrhea occurrences were not measured, and complete diet compositions were not provided.

Variations in results have been found in swine growth studies when zeolite is added to the diet of swine (Shurson et al., 1984). Mumpton and Fishman (1977) described zeolite's growth-promoting level to be based on its properties, source, and the amount supplemented in the diet. Like other clay-based feed additives, zeolite has been shown to adsorb aflatoxins and mitigate the effects of contaminated feeds (Ramos et al., 1996). In the current studies, we used a single source of natural zeolite at

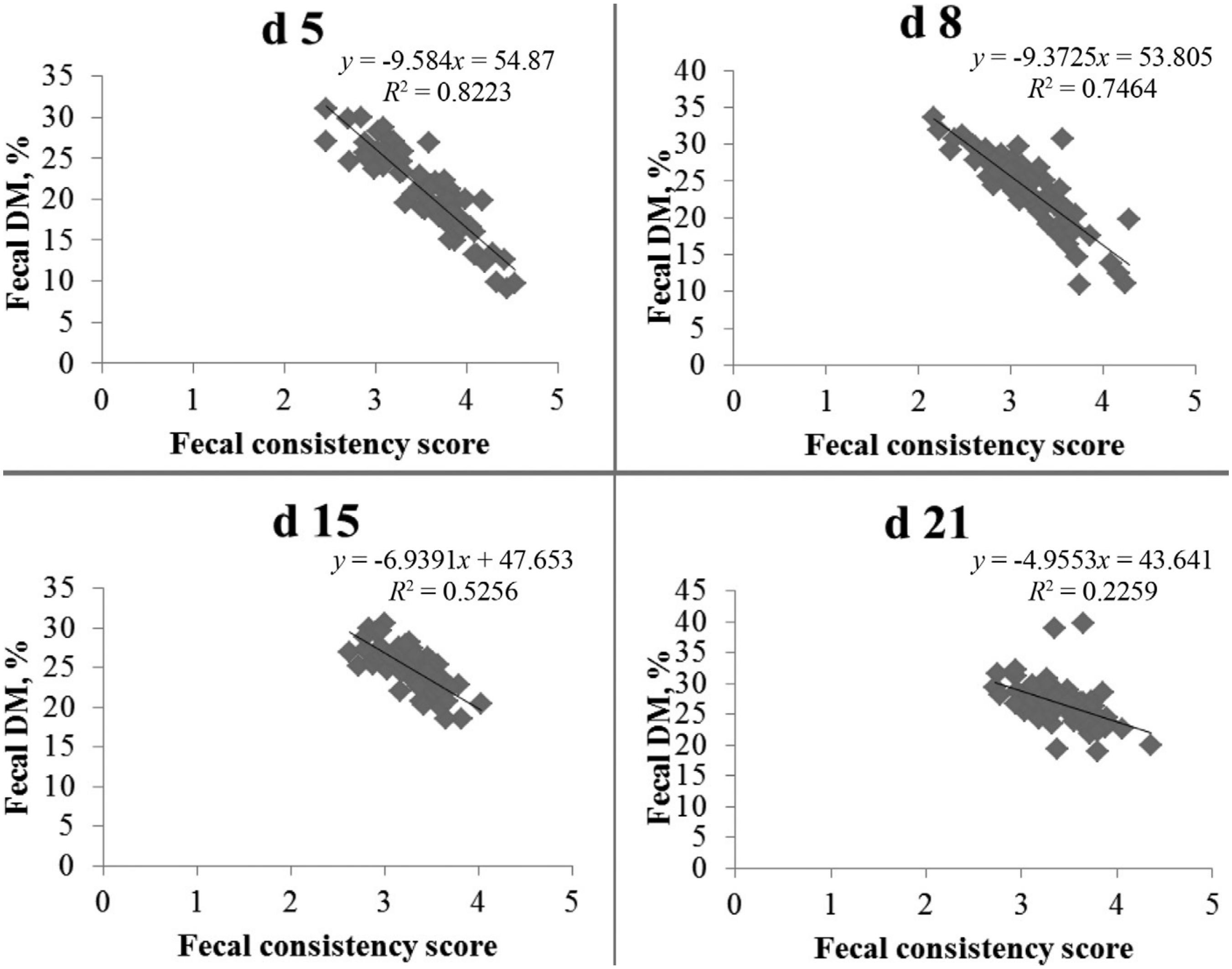


**Figure 2.** Correlation of fecal score to fecal DM, Exp. 2.

different levels in the diets. For Exp. 1, we observed a linear increase in ADG and ADFI when levels of up to 1% zeolite were fed. As a followup, levels of zeolite to be tested in the second experiment were set at 1 and 2% of the diet, which showed no differences in growth performance criteria. In both studies, zeolites proved to be ineffective in improving fecal consistency scores, but in Exp. 2, fecal DM increased with increasing zeolite inclusion. Based on the magnitude of differences, however, greater improvements were observed in pigs drinking control water than in those consuming sodium sulfate water (3.4 vs. 1.0% in control water and sodium sulfate water, respectively, for mean fecal DM scores). Our objective was to test whether the water adsorption capabilities of zeolite could alleviate scouring resulting from increased osmotic pull from sodium sulfate in the lower intestine. The variation in growth responses and the inability of natural zeolite to improve fecal consistency suggest that when weaned pigs are in normal conditions and provided poor-quality water, dietary zeolite are chemically not suited to alter osmotic diarrhea resulting from high sodium sulfate. Research examining the effect of modified zeolites that act as anionic exchangers may be useful to test in the future given their ability to preferentially bind anions rather than zeolites, which are known for their cation exchange capabilities.

Two forms of humic substances (peat) were used in Exp. 2. The first substance was high in humic acid, and the second was a blended product with both humic and fulvic acid. Different sources of humic substances can result in a variety of compositions, which are typically a result of their humic:fulvic acid ratios, humin content, and mineral content. For classification, humic acids within these substances are defined as aromatic polyfunctional compounds with medium to high molecular weight. Fulvic acids are similar to humic acids in composition but have lower molecular weights (Janoš, 2003). Because of the hydrophilic nature of peat, it was believed to help reduce litter buildup when included in turkey feed (Enueme et al., 1987). Interestingly, ADG decreased (12% compared with the control diet) in Exp. 2 for pigs consuming 1%

HA diets and drinking 2,000 mg/L sodium sulfate, but ADG improved (11% compared with control diet) when pigs were drinking control water and fed the same diet. Inclusion of 1% of the humic and fulvic acid blended product did not affect growth performance. In contrast, Ji et al. (2006)observed improvements in ADG and G:F with 2 humic substances similar in composition to the humic and fulvic acid blended product used in this study, but these advantages were observed with inclusion rates of 0.5% in diets and when pigs were in finishing phases of production.

Fecal consistency scores observed in the current study were not improved with the inclusion of either humic substance compared with the control diets, but again, statistical interactions of sulfate and humic substances were observed for mean fecal scores and in some fecal collection days. Fecal DM was inconsistently affected by the inclusion of humic substances based on interactions associated with collection day or with water treatments. The inability of the humic and fulvic acid blended product to increase growth performance and inability to consistently improve fecal scores or DM of weaned pigs suggest that it is not an effective additive at a 1% inclusion rate. The same can be said for the HA that was tested and the negative interactions observed with the sulfate water treatment. Because little published work looking at the effects of humic substances as additives in swine diets has been conducted, it may be an area in need of further research, not only evaluating ideal inclusion rates but also determining production periods in which its inclusion is beneficial.

In conclusion, water high in sodium sulfate caused decreased performance and increased diarrhea compared with control water when supplied to weaned pigs. The use of nonnutritive adsorbent ingredients (natural zeolite and humic substances) for pigs receiving sodium sulfate water was ineffective in mitigating the negative responses observed from sodium sulfate water; however, more work testing nutritional therapies in a sodium sulfate challenge model used in the present experiments may help identify beneficial ingredients that can improve osmotic diarrhea and growth performance in the weaned pig.

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