Kansas Agricultural Experiment Station Research Reports

Volume 0
Issue 10 *Swine Day (1968-2014)*

Article 1266

2012

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J R. Flohr

Michael D. Tokach

Jim L. Nelssen

See next page for additional authors

Recommended Citation

Flohr, J R.; Tokach, Michael D.; Nelssen, Jim L.; DeRouchey, Joel M.; Goodband, Robert D.; and Dritz, Steven S. (2012) "An evaluation of dietary natural zeolite or humic acid substances and sulfate water on nursery pig performance (2012)," *Kansas Agricultural Experiment Station Research Reports*: Vol. 0: Iss. 10. https://doi.org/10.4148/2378-5977.7106

An evaluation of dietary natural zeolite or humic acid substances and sulfate water on nursery pig performance (2012)

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J R. Flohr, Michael D. Tokach, Jim L. Nelssen, Joel M. DeRouchey, Robert D. Goodband, and Steven S. Dritz

An Evaluation of Dietary Natural Zeolite or Humic Acid Substances and Sulfate Water on Nursery Pig Performance[1]

J. R. Flohr, M. D. Tokach, J. L. Nelssen, S. S. Dritz[2], J. M. DeRouchey, and R. D. Goodband

Summary

A total of 350 nursery pigs (PIC 1050 barrows, initially 21 d of age) were used in a 21-d study to determine the effects of high-sulfate water, dietary natural zeolite, and dietary humic substances on growth performance and fecal consistency of nursery pigs. Ten treatments were arranged as a 2 × 5 factorial with 2 water treatments (control or water with 2,000 ppm sodium sulfate) and 5 dietary treatments (control, 1 or 2% zeolite, 1% humic acid substance [HA], or 1% humic and fulvic acid blended substance [HFB]). Water treatments remained the same from d 0 to 21 and all diets were fed in 2 phases, with diets containing feed additives at the same inclusion rate in both phases. Phase 1 diets were fed in a pellet form from d 0 to 8 after weaning; Phase 2 diets were fed in meal form from d 8 to 21. Fecal samples were collected on d 5, 8, 15, and 21. These samples were visually assessed and scored on a scale of 1 to 5 to determine consistency of the fecal samples, then analyzed for DM.

Overall (d 0 to 21), a water source × diet interaction ($P < 0.03$) occurred for ADG and F/G. The interaction occurred because pigs fed 1% HA had poorer ($P < 0.01$) ADG and F/G than other treatments when drinking 2,000 ppm sodium sulfate water but improved ADG and F/G when drinking control water. Pigs drinking 2,000 ppm sodium sulfate water had poorer ($P = 0.01$) ADG and F/G and a tendency ($P = 0.08$) for lower ADFI than pigs drinking the control water. No significant main effects of diet were observed for growth performance criteria. Pigs drinking 2,000 ppm sodium sulfate water had more fluid fecal samples ($P < 0.01$) than pigs drinking control water. For fecal DM, pigs drinking 2,000 ppm sodium sulfate water had lower ($P < 0.01$) fecal DM on d 5 and 8 and lower overall mean fecal DM than pigs drinking control water.

Pigs drinking water with 2,000 ppm sodium sulfate had decreased ADG, poorer F/G, and tended to have lower ADFI for the overall trial than those drinking control water; they also had more watery feces on d 5 and 8 as measured by lower fecal DM compared with pigs drinking control water. The zeolite or humic acid products tested did not improve pig performance or alter fecal DM.

Key words: nursery pig, sulfate, water, zeolite, humic substances

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[1] The authors would like to thank St. Cloud Mining Co., Truth or Consequences, NM, for providing the zeolite used in this study and Humatech Inc., Houston, TX, for providing the humic acid products used in this study.

[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

Introduction

Signs of diarrhea and more fluid feces are many times associated with an infectious disease challenge and the stress that accompanies weaning. Other factors that can contribute to these signs are water quality and high-protein diets. High sulfate concentrations within groundwater supplies have been associated with more fluid fecal production and reductions in performance (Anderson et al., 1994[3]) when concentrations exceed 7,000 ppm. At concentrations less than 3,000 ppm, research has shown that sulfates act as a natural laxative and can cause less firm feces but do not affect growth performance (Patience et al., 2004[4]). A previous study conducted at K-State (Flohr et al., 2011[5]) showed that using a 3,000 ppm sodium sulfate challenge model decreased growth performance and increased the fecal moisture content and clinical diarrhea score of weaned pigs.

A similar model is utilized at the University of Guelph to induce colitis in swine as a model for human Inflammatory Bowel Disease research. In this model, pigs are orally dosed with dextran sodium sulfate (DSS). Work conducted with the model has consistently shown that oral DSS administration results in clinical signs of pro-inflammatory cytokine activity that can inhibit ideal water balance and absorption. Ultimately, high sulfate concentrations in water supplies can increase production costs, either from antibiotic treatment of pigs displaying signs of enteric disease (diarrhea) or from reductions in performance.

Zeolites are microporous aluminosilicate minerals composed of alkali and alkaline earth cations along with small amounts of other elements. The zeolite molecules are arranged in 3-dimensional structures that create interconnected channels capable of trapping molecules of proper dimensions similar to that of a sieve. Zeolite molecules can also bind and release specific molecules by adsorption or ion exchange. In industrial operations, zeolites have been used as detergents because of their ability to bind with water and other molecules. In agriculture, zeolites frequently have been used to reduce odor because of their ability to bind with ammonia. Flohr et al. (2011) showed that adding up to 1% zeolite to the diet of nursery pigs following weaning resulted in a linear increase in feed intake, but no changes in scour score were associated with increasing the amount of zeolite added to the diet.

Humic substances, another natural feed additive, have been used in nursery diets to decrease the incidence and severity of diarrhea. Humic substances can include most of the organic matter found in many soils, but its largest constituents include humic acid, fulvic acid, and humin. These substances can include several other minerals such as iron, manganese, copper, and zinc. Ji et al. (2006[6]) reported improved ADG and F/G for 2 specialized humic substances with varying concentrations of humic and fulvic acid.

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[3] Anderson, J. S., D.M. Anderson, and J.M. Murphy. 1994. The effect of water quality on nutrient availability for grower/finisher pigs. Can. J. Anim. Sci. 74:141–148.
[4] Patience J. F., A. D. Beaulieu, and D. A. Gillis. 2004. The impact of ground water high in sulfates on the growth performance, nutrient utilization, and tissue mineral levels of pigs housed under commercial conditions. J. Swine Health Prod. 12(5):228–236.
[5] Flohr et al., Swine Day 2011, Report of Progress 1056, pp. 46–56.
[6] F. Ji, J. J. Mcglone, and S. W. Kim. 2006. Effects of dietary humic substances on pig growth performance, carcass characteristics, and ammonia emission. J. Anim. Sci. 84:2482–2490.

The objectives of this study were to determine if adding natural zeolite (clinoptilolite) and humic and fulvic acid substances to the diet might mitigate the incidence and severity of diarrhea caused by adding 2,000 ppm sodium sulfate to the water supply of weaned pigs.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the K-State Segregated Early Weaning Facility in Manhattan, KS.

A total of 350 nursery pigs (PIC 1050 barrows, initially 12.5 lb and 21 d of age) were allotted to 1 of 10 treatments arranged in a 2 × 5 factorial with main effects of water source (control or water containing 2,000 ppm sodium sulfate) and dietary regimen (control [no added zeolite or humic substances], 1% zeolite [clinoptilolite], 2% zeolite [clinoptilolite], 1% HA, and 1% HFB. There were 5 pigs per pen and 7 pens per treatment. Pigs were provided unlimited access to feed and water through a 4-hole dry self-feeder and a cup waterer in each pen (5 ft × 5 ft).

Chemical composition of the natural zeolite (clinoptilolite) and the humic substances used in the experiment are shown in Table 1. All diets were fed in 2 phases (Table 2), and the dietary experimental feed additive additions were the same in both phases. Phase 1 diets were fed in a pellet form from d 0 to 8 after weaning. Phase 2 diets were fed in a meal form from d 8 to 21. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 5, 8, 15, and 21.

For the sodium sulfate water treatment, sodium sulfate was mixed in a stock solution and administered in the water supply (Manhattan, KS, municipal water source) of the corresponding pens by a medicator (Dosatron; Dosatron International Inc., Clearwater, FL) at the rate of 1:10 to provide 2,000 ppm of sodium sulfate. Two water samples were collected from both the control water and 2,000 ppm sodium sulfate treatments: the first was collected on d 8, and the second sample was taken on d 21. Samples were analyzed by Servi-Tech Laboratories, Dodge City, KS, for sodium, sulfate, total dissolved solids, pH, and several other minerals (Table 3).

Fecal samples were collected on d 5, 8, 15, and 21. The samples were collected from 2 randomly selected pigs per pen for a total of 14 samples per treatment. Immediately after collection, the samples were individually scored by 5 individuals trained to determine fecal consistency. In this way, 10 fecal consistency scores were determined for each pen, and an average score was reported for the pen. The scale used for assessing fecal consistency was based on a numerical scale from 1 to 5, where 1 represented a hard, dry fecal pellet; 2 represented a firmly formed feces; 3 represented soft, moist feces that retained its shape; 4 represented soft, unformed feces that assumed the shape of its container; and 5 represented a watery liquid that could be poured. After scoring, samples were analyzed for DM using a 2-stage DM procedure. The first stage consisted of drying the complete sample in a 122°F oven for 24 h. Afterward, the samples were cooled and ground into a powder. In the second stage, 1 g of the ground sample was placed in a crucible and dried in a 212°F oven for 24 h. The initial DM value was then multiplied by the second to determine a total percentage DM.

Nursery pig growth performance was analyzed as a 2 × 5 factorial with main effects of water and dietary treatment using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was designated as the experimental unit, and contrast statements were used to determine effects of water and dietary treatments and their interactions along with linear and quadratic effects of dietary zeolite. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

For fecal scores and fecal DM, repeated measures over time analysis was conducted using the MIXED procedure of SAS. Pen was the experimental unit and the fixed effects were water and dietary treatment. Contrast statements were used to evaluate: (1) linear and quadratic effects of increasing zeolite, (2) linear and quadratic effects over time (collection days), (3) water × day interactions, (4) diet × day interactions, and (5) water × diet × day interactions. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

For overall growth performance (d 0 to 21), a water source × diet interaction ($P < 0.01$) was observed for ADG and F/G (Table 4). The interaction occurred because pigs fed 1% HA had poorer ($P < 0.01$) ADG and F/G when drinking 2,000 ppm sodium sulfate water but improved ADG and F/G when drinking control water. Pigs consuming 1% HA also had decreased ($P = 0.03$) ADFI when drinking 2,000 ppm sodium sulfate water compared with control water. For main effects, pigs drinking 2,000 ppm sodium sulfate water had poorer ($P = 0.01$) ADG and F/G and a tendency ($P = 0.08$) for lower ADFI compared with pigs drinking control water. Dietary treatment did not affect growth performance criteria.

A water × day interaction was observed ($P < 0.01$) for fecal consistency scores because fecal scores decreased over time for pigs drinking 2,000 ppm sodium sulfate water (Table 5). This observation indicates that their feces became firmer over time compared with pigs drinking control water that had similar fecal scores throughout the length of the study.

We observed a tendency ($P = 0.10$) for a water × diet interaction for d 5 fecal scores because of the greater difference between fecal scores on control and high-sulfate water for pigs eating the diet with 1% HA compared with pigs consuming other diets. We observed a water × diet ($P < 0.01$) interaction on d 8, because pigs eating diets containing 1 or 2 % zeolite and 1% HFB had looser fecal samples ($P < 0.03$) if they were drinking 2,000 ppm sodium sulfate water compared with pigs on these same treatments drinking control water. Pigs drinking 2,000 ppm sodium sulfate had less firm ($P < 0.01$) fecal samples than pigs drinking control water. Diet did not influence ($P > 0.40$) overall fecal consistency scores.

A water × day interaction ($P < 0.01$) was observed for fecal DM (Table 6). Fecal DM increased over time for pigs drinking 2,000 ppm sodium sulfate water but remained similar throughout the study for pigs drinking control water.

A water × diet interaction was observed ($P < 0.01$) on d 8, because pigs that ate diets with 1 or 2% zeolite or 1% HFB had lower ($P < 0.04$) fecal DM if they drank 2,000 ppm sodium sulfate water than pigs eating the same diets and drinking control water. Pigs on the control diet had similar fecal DM on both water sources. For main effects, pigs drinking 2,000 ppm sodium sulfate water had lower fecal DM ($P < 0.01$) on d 5, d 8, and for overall mean fecal DM. For diet effects, average fecal DM increased (linear, $P < 0.01$) with increasing zeolite inclusion, and pigs on control diets or 1% zeolite had lower ($P < 0.01$) or tended to have lower ($P = 0.06$) fecal DM than pigs consuming diets with 1% HFB.

Adding 2,000 ppm sodium sulfate within the water source had effects on fecal consistency similar to 3,000 ppm sodium sulfate in previous work. A significant impact on growth performance was observed at 2,000 ppm. This study agrees with Flohr et al. (2011), indicating that when providing high-sulfate containing water to newly weaned pigs, the largest detrimental effects occur within the first wk to 10 d after weaning.

Dietary regimen appeared to have no direct impact on growth performance regardless of which additive was used. The interactions between water and diet were mainly driven by the 1% HA diet, because these pigs had more fluid feces and poorer growth performance when supplemental sulfate was provided in the water treatment. A linear improvement in fecal DM was observed with increasing dietary zeolite, but there was no indication that these feed additives improved growth performance or led to firmer feces with less signs of diarrhea. This study contrasts with the previous work (Flohr et al., 2011), which showed that increasing zeolite up to 1% increased ADG and ADFI in nursery pigs.

Because of the variable responses found in studies conducted with zeolite, this additive may not be beneficial for growth performance in swine diets. Humic substances appeared to have no direct effect on growth performance or fecal consistency in this study, and some evidence indicated that they may be detrimental, which could be due to the fact that 1% may be above the optimal inclusion rate in swine diets. Research with other nutritional therapies in sulfate challenges may lead to effective practices to reduce scouring in early nursery pigs.

Table 1. Analyzed composition of feed additives

Item	Zeolite[1]	Humic acid[2]	Humic fulvic blend[3]
Element			
Ca, %	2.40	0.47	0.63
P, %	0.01	0.02	0.03
K, %	1.20	0.07	0.36
Na, %	0.10	0.20	0.42
Zn, ppm	59	101	72
Cu, ppm	10	20	16
Mn, ppm	---	14	166
Fe, ppm	6,000	6,000	14,000
Mg, ppm	9,000	600	2,500
Al, ppm	31,000	125,000	384,000
Si, ppm	329,000	---	---
Humic acid, %	---	55.70	26.80

[1] Chemical composition was performed by use of x-ray fluorescence and conducted at St. Cloud Mining Co., Truth or Consequences, NM.

[2] DPX 5800, Humatech Inc., Houston, TX. Analysis conducted by A & L Agricultural Laboratories Inc. Lubbock, TX (values reported on DM basis).

[3] DPX 9902, Humatech Inc., Houston, TX. Analysis conducted by A & L Western Agricultural Laboratories Inc., Modesto, CA (values reported on DM basis).

Table 2. Diet composition (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
DPS 50[3]	3.00	---
Soybean oil	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	0.15	0.15
Vitamin premix	0.25	0.25
L-lysine HCl	0.20	0.25
DL-methionine	0.13	0.13
L-threonine	0.08	0.11
Phytase[4]	0.13	0.17
Acidifier[5]	0.20	---
Vitamin E, 20,000 IU	0.05	---
Choline chloride 60%	0.04	---
Zeolite (clinoptilolite)[6]	---	---
Humic acid[7]	---	---
Humic and fulvic acid blend[8]	---	---
Total	100	100

continued

Table 2. Diet composition (as-fed basis)

Item	Phase 1[1]	Phase 2[2]
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.35	1.30
Isoleucine:lysine	54	61
Leucine:lysine	132	127
Methionine:lysine	30	35
Met & Cys:lysine	57	59
Threonine:lysine	65	63
Tryptophan:lysine	18	17
Valine:lysine	72	68
Total lysine, %	1.51	1.43
CP, %	21.6	21.3
ME, kcal/lb	1,552	1,505
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, ppm[9]		
Zn	2,973	1,965
Fe[10]	165	165
Mn	40	40
Cu	17	17
I	0.30	0.30
Se	0.30	0.30

[1] Phase 1 diets were fed in pellet form from d 0 to 8.
[2] Phase 2 diets were fed in meal form from d 8 to 21.
[3] Nutra-Flo Company, Souix City, IA.
[4] Natuphos 600, BASF, Florham Park, NJ. Provided 354 and 446 phytase units (FTU)/lb of diet, respectively.
[5] Kem-gest, Kemin Industries Inc., Des Moines, IA.
[6] Zeolite, St Cloud Mining Company, Truth or Consequences, NM. Replaced corn to provide 1 and 2% zeolite.
[7] DPX 5800, Humatech Inc., Houston, TX.
[8] DPX 9902, Humatech Inc., Houston, TX.
[9] Total supplemental trace mineral content from feed additive and trace mineral premix was calculated within each respective dietary regimen.
[10] Added iron levels were 165, 6,165, 12,330, 6,165, and 14,165 ppm for control, 1 or 2% zeolite, 1% HA, and 1% HFB, respectively.

Table 3. Water analysis[1,2]

Item, ppm	Control water	2,000 ppm sodium sulfate
Total dissolved solids	233	1,770
Sulfate (SO_4)	77	1,700
Sulfate Sulfur (SO_4-S)	26	565
Chloride (Cl)	51	39
Sodium (Na)	34	565
Calcium (Ca)	13	14
Magnesium (Mg)	10	10
Potassium (K)	6	6
Iron (Fe)	0.1	0.1
Manganese (Mn)	0.01	0.01
pH, units	8.8	8.7

[1] Samples collected on d 8 and 21 were analyzed and the average values were reported.
[2] Water analysis performed by Servi-Tech Laboratories, Dodge City, KS.

Table 4. Influence of dietary natural zeolite or humic acid substances (HA and HFB) and high-sulfate water on nursery pig performance[1,2]

		d 0 to 21			Weight	
Water sodium sulfate, ppm	Dietary regimen	ADG, lb	ADFI, lb	F/G	Initial	Final
0	Control	0.59	0.82	1.4	12.5	25.4
	1% zeolite	0.60	0.82	1.36	12.5	25.2
	2% zeolite	0.55	0.77	1.4	12.5	24.2
	1% HA	0.66	0.85	1.29	12.5	26.5
	1% HFB	0.6	0.83	1.38	12.5	25.4
2,000	Control	0.58	0.81	1.41	12.5	25.3
	1% zeolite	0.55	0.78	1.44	12.5	24.3
	2% zeolite	0.58	0.78	1.36	12.5	24.7
	1% HA	0.51	0.75	1.51	12.6	23.2
	1% HFB	0.56	0.80	1.44	12.5	24.7
SEM		0.030	0.031	0.043	---	0.63
		Probability, *P*<				
Interactions						
Sulfate × diet		0.02	0.41	0.03	---	0.03
Sulfate within control		0.80	0.76	0.82	---	0.91
Sulfate within 1% zeolite		0.16	0.31	0.20	---	0.27
Sulfate within 2% zeolite		0.43	0.70	0.44	---	0.57
Sulfate within 1% HA		0.01	0.03	0.01	---	0.01
Sulfate within 1% HFB		0.28	0.45	0.32	---	0.40
Main effects						
Sulfate		0.01	0.08	0.01	---	0.02
Diet		0.91	0.54	0.95	---	0.64
Diet comparisons						
Zeolite linear		0.37	0.12	0.48	---	0.14
Zeolite quadratic		0.94	0.90	0.88	---	0.84
Control vs. 1% HA		0.92	0.59	0.84	---	0.41
Control vs. 1% HFB		0.88	0.90	0.99	---	0.69
1% zeolite vs. 1% HA		0.78	0.90	0.99	---	0.95
1% zeolite vs. 1% HFB		0.81	0.58	0.82	---	0.61
1% HA vs. 1% HFB		0.96	0.67	0.83	---	0.67

[1] A total of 350 weanling pigs (PIC 1050 barrows, initially 12.5 lb and 21 d of age) were used with 5 pigs per pen and 7 pens per treatment.

[2] Overall interactions of water and diet were analyzed and contrast statements were used to compare water treatment means within each dietary treatment.

Table 5. Influence of dietary natural zeolite or humic acid substances (HA and HFB) and high-sulfate water on nursery pig fecal consistency[1,2,3]

		Day of collection				
Water sodium sulfate, ppm	Dietary regimen	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		0.15	0.15	0.15	0.15	0.08
		Probability, *P*<				
Interactions						
Sulfate × diet		0.10	0.01	0.83	0.97	0.23
Sulfate within control		0.13	0.83	0.42	0.69	0.78
Sulfate within 1% zeolite		0.06	0.01	0.65	0.96	0.01
Sulfate within 2% zeolite		0.28	0.01	0.23	0.71	0.01
Sulfate within 1% HA		0.01	0.21	0.93	0.74	0.03
Sulfate within 1% HFB		0.30	0.03	0.16	0.28	0.01
Main effects						
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; those 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 ($P = 0.99$), day effect ($P < 0.01$).

Table 6. Influence of dietary natural zeolite or humic acid substances (HA and HFB) and high-sulfate water on nursery pig fecal DM[1,2,3]

		Day of collection				
Water sodium sulfate, ppm	Dietary regimen	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		1.70	1.70	1.70	1.70	0.92
		Probability, *P*<				
Interactions						
Sulfate × diet		0.19	0.01	0.73	0.93	0.60
Sulfate within control		0.32	0.70	0.63	0.82	0.74
Sulfate within 1% zeolite		0.30	0.01	0.69	0.42	0.08
Sulfate within 2% zeolite		0.24	0.01	0.38	0.88	0.01
Sulfate within 1% HA		0.03	0.19	0.83	0.32	0.03
Sulfate within 1% HFB		0.35	0.04	0.36	0.48	0.11
Main effects						
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; those 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 ($P = 0.99$), day effect ($P < 0.01$).