EFFECTS OF ADDING SODIUM BISULFATE TO WEANLING AND FINISHING PIG DIETS ON GROWTH PERFORMANCE, NUTRIENT EXCRETION, AND SLURRY CHARACTERISTICS

By

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TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

II. REVIEW OF LITERATURE

Acidifiers-description, characteristics 3
Challenges of the weaned pig 4
Topics of investigation in dietary acidification 5
Acidifiers vs. antibiotics 5
Acidification strategies 6
Acid type 7
Protein source 8
Feeding multiple additives 9
Modes of action 12
Proposed feeding strategies 15
Effects on slurry characteristics 16
Effects on gaseous emissions 18
Summary and justification 19

III. EFFECTS OF SODIUM BISULFATE ON GROWTH PERFORMACE OF WEANLING PIGS

Abstract 21
Introduction 22
Materials and Methods 23
Results 27
Discussion 34

IV. EFFECTS OF SODIUM BISULFATEON GROWTH PERFORMANCE, SLURRY CHARACTERISTICS, AND NUTRIENT EXCRETION OF FINISHING PIGS

Abstract 36
Introduction 37
Materials and Methods 38
Results 42
Discussion 56

V. CONCLUSION 60

REFERENCES 66

APPENDIX 64

LIST OF TABLES

Table Page

1. Diet composition by phase for both experiments……………………..…..……….26

2. Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ for Experiment 1……………………….……………………………..….29

3. Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ for Experiment 2…………………………………………………...…….30

4. Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ by Phase for both experiments……………………………………..…..31

5. Diet composition for all four phases (finisher)……………………..………...41

6. Mineral excretion averaged over the entire 100-d finishing period…………...54

7. Gaseous emissions from grow-finish pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period………………….…………………..…55

8. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 1……………………………...….66

9. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 1……………………..….67

10. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 1. ……………….……….…..….68

11. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 1……………..…....69

12. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 1……………………………...70

13. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 1. ……....………71

14. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for the entirety of Experiment 1 (Phases II – IV)……………………………………………………………………..72

15. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for the entirety of Experiment 1 (Phases II – IV) ……………………………………………………….…………73

16. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase I of Experiment 2. ……………………………….…74

17. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase I of Experiment 2…………….……75

18. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 2………………….…………...76

19. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 2. …………...……77

20. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 2……………………....78

21. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 2……………….…79

22. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 2………………………………80

23. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 2……………..…81

24. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases II – IV)…………………………………………………………………..82

25. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases II - IV) ……………………………………………………………………83

26. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases I – IV) …………………………………………………………….……84

27. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases I - IV)……… ………………………………………………….....…85

28. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs in Experiments 1 and 2 during Phase II…….….…..…86

29. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs in Experiments 1 and 2 during Phase II…..…87

30. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase III………......88

31. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase III.......89

32. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase IV..............90

33. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase IV.......91

34. Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phases II - IV.........92

35. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F)for weanling pigs over the entirety of Experiments 1 and 2 during Phases II -IV...93

36. Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase I. 94

37. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase I................................ 94

38. Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase II. 95

39. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase II. 95

40. Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase III. 96

41. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase III. 96

42. Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase IV. ……………………………………97

43. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase IV. …………………………...97

44. Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during the entirety to the experiment (Phases I – IV). ………………………………………………………………..…98

45. Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during the entirety to the experiment (Phases I – IV). …………………………………………….……98

46. Room means for pit pH, electrical conductivity and temperature for finishing pigs during Phase I. ………………………………………..……99

47. Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase I. ……………………………..…99

48. Room means for pit pH, electrical conductivity and temperature for finishing pigs during Phase II. …………………………………….…100

49. Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase II. …………………….....……100

50. Room means for pit pH, electrical conductivity and temperature for finishing pigs during Phase III. ………………………………………….101

51. Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase III. …………………..……101

52. Room means for pit pH, electrical conductivity, and temperature for finishing pigs during Phase IV……………………………………...102

53. Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase IV. ………………………..……102

54. Room means for pit pH, electrical conductivity, temperature, and pit volume for finishing pigs during the entirety of the experiment (Phases I – IV)……………………………………………103

55. Analysis of variance for pit pH, electrical conductivity, temperature, and pit volume for finishing pigs during the entirety of the experiment (Phases I – IV). ……………………………………………103

56. Room means for dry matter intake (DMI), dry matter excretion (DMEX), and dry matter excretion as a percentage of intake (DMEXPI) during the entire experiment (Phases I – IV). ……………………104

57. Analysis of variance for dry matter intake (DMI), dry matter excretion (DMEX), and dry matter excretion as a percentage of intake (DMEXPI) during the entire experiment (Phases I – IV). ……..…104

58. Room means for nitrogen intake (NI), nitrogen excretion (NEX), and nitrogen excretion as a percentage of intake (NEXPI) during the entire experiment (Phases I – IV). ………………...………………105

59. Analysis of variance for nitrogen intake (NI), nitrogen excretion (NEX), and nitrogen excretion as a percentage of intake (NEXPI) during the entire experiment (Phases I – IV). ………..…105

60. Room means for phosphorus intake (PI), phosphorus excretion (PEX), and phosphorus excretion as a percentage of intake (PEXPI) during the entire experiment (Phases I – IV). ………..…106

61. Analysis of variance for phosphorus intake (PI), phosphorus excretion (PEX), and phosphorus excretion as a percentage of intake (PEXPI) during the entire experiment (Phases I – IV). ………..…106

62. Room means for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) as a percentage of the slurry on a dry matter basis over the entire 100-day finishing period (Phases I – IV). ……………………………………………………107

63. Analysis of variance for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) as a percentage of the slurry on a dry matter basis over the entire 100-day finishing period (Phases I – IV). ……………………………………..107

64. Room means for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) nutrient concentration of the slurry over the entire 100-day finishing period (Phases I – IV)...……108

65. Analysis of variance for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) nutrient concentration of the slurry over the entire 100-day finishing period (Phases I – IV)………108

66. Room means for ammonia emitted on a mg/pig/d basis, ammonia concentration in ppm, ammonia concentration leaving the room per minute, ammonia emitted on a mg/kg/d basis, and ammonia emitted on a g/d/500 kg (AU) averaged over the entire 100-day finishing period (Phases I – IV). ……………………………..…109

67. Analysis of variance ammonia emitted on a mg/pig/d basis, ammonia concentration in ppm, ammonia concentration leaving the room per minute, ammonia emitted on a mg/kg/d basis, and ammonia emitted on a g/d/500 kg (AU) averaged over the entire 100-day finishing period (Phases I – IV). ………………………...……109

68. Room means for hydrogen sulfide emitted on a mg/pig/d basis, hydrogen sulfide, emitted on a µg/kg/d basis, hydrogen sulfide emitted on a mg/d/500 kg (AU), hydrogen sulfide emitted on a µg/m^3, and air flow (AFL) averaged over the entire 100-day finishing period (Phases I – IV). ………………………………...……110

69. Analysis of variance for hydrogen sulfide emitted on a mg/pig/d basis, hydrogen sulfide, emitted on a µg/kg/d basis, hydrogen sulfide emitted on a mg/d/500 kg (AU), hydrogen sulfide emitted on a µg/m^3, and air flow (AFL) averaged over the entire 100-day finishing period (Phases I – IV). ……………………………………………..…110

70. Room means for excretion of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), sulfur (S), and ammonium nitrogen (NH_4-N) averaged over the entire 100-day finishing period (Phases I – IV). ………………………………………………………...…111

71. Analysis of variance for excretion of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), sulfur (S), and ammonium nitrogen (NH_4-N) averaged over the entire 100-day finishing period (Phases I – IV). ………………………………………………..…………111

72. Room means for excretion of iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and nickel (Ni) averaged over the entire 100-day finishing period (Phases I – IV). ………………………………...……112

73. Analysis of variance for excretion of iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and nickel (Ni) averaged over the entire 100-day finishing period (Phases I – IV). ……………………...……112

LIST OF FIGURES

Figure Page

1. Growth performance for weanling pigs fed increasing levels of $NaHSO_4$ for both experiments during Phases 2-4……………………………..….32

2. Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ during all phases for both experiments………………………………….….33

3. Initial and final weights for pigs fed control versus $NaHSO_4$ over the entire 100-d finishing period…………………….……………..……..44

4. Growth performance for grow-finish pigs during the entire 100-d finishing period when fed control vs. $NaHSO_4$……………………………..…45

5. Nutrient concentration of the slurry averaged over the entire 100-d finishing period……………………………………………………………….46

6. Dry matter intake and excretion from pigs fed control vs. $NaHSO_4$ over the entire 100-d finishing period……..……………………………...47

7. Nitrogen intake and excretion of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period…………………………………………...48

8. Phosphorus intake and excretion of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period…………………………………….49

9. Sodium and sulfur excretion of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period…………………………………...50

10. Pit volume, electrical conductivity, and pH during the entire 100-d finishing period of pigs fed control vs. $NaHSO_4$……………… ……..51

11. Ammonia emissions of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period……………………….………………………52

12. Hydrogen sulfide emissions of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period…….…………….…………………53

CHAPTER I

INTRODUCTION

Public resistance to the day-to-day practices of food animal production systems has continued to become increasingly high and their concerns have played a role in the evolution of animal handling, feeding, and general management practices. Currently, one of the greatest points of contention is the addition of subtherapeutic antibiotics in food animal diets. Feeding subtherapeutic levels of antibiotics has shown to increase average daily gain (ADG) in pigs by 3.3 to 8.8% and gain to feed (G:F) by 2.5 to 7.0% (Doyle, 2001). Many alternatives to antibiotics have been and are currently being evaluated including, but not limited to, low protein diets, alternative cereal grains, feed restriction, specific functional proteins, liquid/fermented feeds (more specifically to weanling pigs), probiotics, prebiotics, essential oils, minerals, and acidifiers (Stein, 2007).

As of January 1, 2006, the European Union prohibits the feeding of antibiotics in livestock production. The concern is that the bacteria may become resistant to some commonly-fed antibiotics, and humans may become susceptible to these antibiotic resistant bacteria through improperly cooked meat (Union of Concerned Scientists, 2006). To help alleviate problems related to gastrointestinal health, upon removal of subtherapeutic antibiotics, these countries have resorted to the utilization of acidifiers in order to theoretically, keep the number of pathogenic bacteria in the gastrointestinal tract at a lower concentration than normally observed (NRC, 1998). To enhance performance without the addition of subtherapeutic antibiotics, three main areas need to be considered: 1) feeding the animal to maximize health of the intestinal environment, 2) directly manipulate the population of good and bad bacteria in the gastrointestinal tract, and 3) maximize immune function (Hardy, 2005). Acidifiers are proposed to impact all three areas.

Due to the lack of information on the mode of action that acidifiers have, many studies need to take place in order to determine the logistics of feeding them as an alternative to an antibiotic. Areas of proposed interest include, type of acid, dietary composition, stage of production, age at weaning, and percent inclusion. Of utmost importance, due to death loss, is to determine the efficacy of feeding an acidifier in the nursery period in direct comparison to various antibiotics and to evaluate the economic advantages and/or disadvantages to this feeding strategy.

The work in this thesis was conducted to determine the efficacy of feeding sodium bisulfate in the nursery period and to evaluate its effects on growth performance. Sodium bisulfate was also evaluated in the finishing period to determine whether dietary acidification would decrease slurry pH, in turn, reducing ammonia emissions, or have any other effects on nutrient excretion.

CHAPTER II

REVIEW OF LITERATURE

Acidifiers- description, characteristics

An acidifier is a non-nutritive feed additive that may enhance growth performance and general health. They may potentially provide beneficial effects in non-ruminant animals and more specifically immature pigs (NRC, 1998). There are many different acidifiers currently under investigation. In general, acidifiers fall into three main categories: organic acids, inorganic acids, and salts of acids. Salts of acids can be organic or inorganic and have an affiliation with a salt of some sort. Some examples include potassium diformate, sodium formate, calcium formate, and sodium bisulfate. Inorganic acids are typically very strong acids. They contain a nonmetallic portion and no carboxyl radical. Some well known inorganic acids include hydrochloric acid, nitric acid, phosphoric acid, and sulfuric acid; however, only a few of these are used as feed additives. Organic acids on the other hand contain at least one carboxyl radical. Some commonly fed organic acids are fumaric acid, citric acid, and formic acid.

Depending on various factors of diet composition and inclusion level, the acid in the diet may have very different effects due to factors such as bacterial interaction, pH of the acid, and dissociation (Stein, 2007).

Challenges of the weaned pig

Weanling pig health poses a big challenge for producers today. With a 7-10% death loss in the nursery, mainly attributed to diarrhea, and the need for an antibiotic alternative, it is important that the alternative has the capacity to alleviate the death loss that may ensue upon removal of an antibiotic. There are various suggested ideas that could help alleviate post-weaning scours outside of antibiotics, but none have had the growth-promoting effects typically observed with feeding antibiotics at a subtherapeutic level. The ability of the pig, especially at the fragile young age of weaning, to fight off pathogenic bacteria is low. Feeding acidifiers is thought to change the ratio of bacteria in the gastrointestinal tract, thus alleviating some disease problems (Stein, 2007), as well as providing some growth-promoting effects by altering gastric pH (NRC, 1998), possibly increasing the digestibility of the feed by increasing pepsin activation (Canibe et al., 2001).

In the pig, the placenta is incapable of transporting maternal immunoglobulins to the piglets. Therefore, their immune system does not begin to build until the first one to two days of life upon colostrum ingestion. Piglets in germ-free environments do not undergo the proper expansion and specialization in immune cell function as it relates to maintenance and regulation of mucosal tolerance (Lalles et al., 2007). Because of the immunological fragility of the piglet at birth, disease can easily make an impact in the early stages of the animal's life. Many problems that are observed post-weaning, especially in regards to early weaning, stem from not only the structural change of the gastrointestinal system, but also the adaptations of the enteric microbiota (Konstantinov et al., 2004). Due to the rapid changes of the microflora in the gastrointestinal system, care must be taken when feeding these young animals as to not shock their system and start them off as healthy as possible.

Topics of investigation in dietary acidification

Acidifiers vs. antibiotics

Addition of antibiotics to feed was a result of immunological challenges facing young pigs at weaning. Antibiotics were introduced to decrease the disease challenge that leads to death loss and decreased gain commonly associated with early-weaned pigs. In non-medicated swine production practices, disease problems were high and overall performance dropped (Stein, 2007). Even though antibiotics are routinely fed in swine diets, more specifically in nursery diets, the results of their effectiveness as a growth promoter are sometimes variable. The efficacy is also dependent upon the type of antibiotic fed and/or combination of antibiotics fed and results could be contingent upon inclusion of minerals in the same diet (Edmonds et al., 1984). Antibiotics (carbadox, tiamulin, chlorotetracyclin (CTC)) have been proven to alleviate diarrhea, to an extent, as well as mortality due to bacterial infections (Piva, 1998). Walsh et al. (2003) observed that carbadox provided the best average daily gain (ADG), feed efficiency (G:F), numerically, and gave rise to the heaviest pigs at the conclusion of the study compared with pigs fed the control and organic/inorganic acids. It is important to recognize that these conclusions were not present in the first seven days post-weaning. In fact, the exact opposite was true for week one.

Acidification strategies

Walsh et al. (2006) observed similar results with pigs fed carbadox. Average daily gain of pigs fed carbadox was greater than control or acid-fed pigs. These same animals had superior average daily feed intake (ADFI), but no difference in G:F. In this 3 by 2 factorial, water acidification was administered to the 3 diets (control, carbadox, organic/inorganic acid) to try to compare compounding effects of dietary and water acidification. This was an attempt to find alternative strategies to allow decreased stomach pH in order to more readily activate pepsin. In this case, carbadox-fed pigs had an increase in ADFI when the water was acidified and similar increases were reported with the control diet when compounded with water acidification. A following experiment by Walsh et al. (2006), a 3 by 2 factorial study was conducted to determine an effect, if any, on dietary acidification fed in conjunction with antibiotics. Carbadox with acid caused ADG to decrease, whereas acid fed in the control diet or with a diet containing Tiamulin + CTC, resulted in increased ADG in both instances in comparison to no dietary acids.

In these experiments (Walsh et al., 2003; 2006; 2007), microbial shedding was investigated to provide possible answers to the differences in growth performance in these trials. No *E. coli* shedding was observed in the water acidification trial; however, in the antibiotic-dietary acidification trial, differences were observed. Pigs fed carbadox without dietary acid had the lowest *E. coli* shedding. When comparing dietary acid to no dietary acid, the latter had lower *E. coli* shedding than pigs consuming dietary acid.

While Walsh et al. (2007) reported no improvements in microbial shedding upon dietary acidification, other research reported contradicting results. For example, Canibe et al. (2001) performed a trial using potassium diformate and measured the anaerobic bacteria, lactic acid bacteria, coliforms and yeast counts in the feces of piglets. This group reported a reduction in all 4 counts measured for piglets consuming the diet containing potassium diformate compared with the control. It is important to note that, no antibiotics were administered via feed in the control diet. Another important aspect to consider is that Canibe's group fed a primarily wheat and fishmeal diet whereas Walsh's study fed a primarily corn and soybean meal diet.

<u>Acid type</u>

Giesting and Easter (1985) reported that weanling pigs fed 2% propionate, fumarate, or citrate in a corn-soybean meal diet improved G:F by 8% and an improvement in G:F was observed with graded addition of fumarate; 16% was the greatest improvement observed when fumarate was fed at 3%. However, if feeding starter pigs 2% of propionic, fumaric or citric acid, it is important to note that ADG and ADFI were not different from control for fumaric and citric acid, but a decrease in ADG and ADFI was documented in the case of propionic acid. Nevertheless, G:F was improved for all three acids in relation to the control. Other experiments have reported a tendency to enhance feed efficiency with the addition of citric acid to the diet. A 13.5% improvement was reported with 1.5%

inclusion of citric acid over the control animals (Edmonds et al., 1984). However, this response only occurred in the presence of Aureo-Sulfa-Penicillin (Asp) and was not influenced by addition of copper.

Furthermore, studies in weanling pigs with organic acids and microbial phytase addition to a corn-soybean meal diet have reported improvements in apparent ileal digestibility of some amino acids, mainly histidine, isoleucine, and aspartic acid. In this same group of pigs, ADG was improved by 6.5% (Omogbenigum et al., 2003).

Protein source

It is a known fact that dietary composition will many times change the efficacy of a dietary acid depending upon the bulk of the ingredients. Giesting et al. (1991) evaluated the effect of fumaric acid in various diets. When a traditional corn and soybean meal diet was fed with either 2% or 3% inclusion of fumaric acid, G:F improved; however, if dried skim milk was added to the diet at 25%, the G:F improved even more drastically. Average daily gain was also improved, but this improvement, even with fumaric acid, was attributed solely to the dried skim milk inclusion. A following experiment tested this idea using casein and soy protein concentrate. Another added factor was that these diets were tested with the addition of sodium bicarbonate, which will be discussed later. Again improvements were reported to be greatest with an alternative protein source and statistically significant for G:F with an interaction of fumaric acid and protein source. The greatest improvement in G:F was recorded when sodium bicarbonate, casein, and fumaric acid were fed together. All three factors were statistically significant.

Following these results, Giesting and Easter (1991) set out to determine the effect of fumaric acid supplementation as well as protein source had on nutrient digestibility. They investigated fumaric acid supplementation on dry matter and nitrogen digestibility, as well as ADG, when added to a corn soybean meal diet versus a diet with 25% dried skim milk addition. Numerical differences were observed in both diets with fumaric acid addition in ADG, dry matter digestibility and nitrogen digestibility. All statistical improvements were a direct effect of dried skim milk inclusion and were observed in all three categories measured.

<u>Feeding multiple additives</u>

Other feed additives may have the ability to contribute to or hinder the growth performance improvements sometimes seen with the addition of dietary acid. Radcliffe et al. (1998), in a series of two experiments, set out to determine whether or not a synergistic effect was observed with citric acid and phytase addition in a corn and soybean meal diet. It was determined that a synergistic relationship did not occur; however citric acid addition, in one experiment, improved ADG, G:F, and calcium digestibility. In the second experiment, citric acid addition improved growth performance, but not calcium digestibility. The phytase addition improved calcium and phosphorous digestibility, but had no additive effects with the citric acid on growth performance.

Also Hahn et al. (1998) conducted a study leading to the conclusion that may be contradictory to Radcliffe et al (1998). Han et al. (1998) observed that when adding phytase to a diet with inclusion of 10% wheat middlings and 1.5% citric acid, an identical average daily gain was observed as compared to the control diet (0.2% inorganic phosphorus). Gain to feed ratio was greater in both diets containing either 10% or 15% wheat middlings, phytase and 1.5% citric acid, than pigs fed 15% wheat middlings with phytase and no citric acid as well as pigs fed the corn soybean meal control diet that contained 0.2% inorganic phosphorus.

Some speculation has been proposed in regards to acidifier function based on a drop in gastric pH, with the possibility that it may cause some metabolic shortcomings. Geisting et al. (1991) conducted a series of experiments investigating protein source, dietary acidification, and sodium bicarbonate addition. When sodium bicarbonate was added to a diet containing fumaric acid, ADG was improved; however, this improvement was attributed to the fumaric acid addition. With respect to G:F, it was determined that the recorded improvement with fumaric acid and sodium bicarbonate addition was a function of the fumaric acid as well as and more substantially to the sodium bicarbonate addition. It was hypothesized that this improvement observed with sodium bicarbonate inclusion and fumaric acid will alleviate some possible metabolic acidosis that occurs when drastically dropping gastric pH that occurs with 2.75 to 3.0% fumaric acid inclusion. As the diet becomes more acidic, metabolic acidosis will occur and can be attributed to decreases in feed consumption (Patience et al., 1987); however, this was not the driving factor in Geisting's study.

It has been reported that copper sulfate addition to weanling pig diets has a growth-promoting effect. Copper sulfate has been efficacious when fed in the presence of antibiotics. With addition of citric acid, G:F was improved; however, no statistical significance has been produced in some instances (Edmonds et al., 1985). In a following study by Edmonds et al. (1985), it was reported that copper sulfate had a more significant effect when fed in conjunction with 0.75% citric acid versus 1.50% citric acid. Week 3 post weaning has been reported as the time when the greatest improvement in growth performance can be observed and attributed to citric acid inclusion in combination with copper sulfate and antibiotics. Copper sulfate has helped to enhance dietary acid inclusion improvements when fed with antibiotics. With diets containing copper sulfate, antibiotics, and acid, a 5.3% average daily gain improvement has been documented as well as a 2.3% increase in feed efficiency as compared to animals fed control diets (Burnell et al., 1988). Dietary acid inclusion in weanling pig diets fed in conjunction with copper sulfate and antibiotics has a tendency to improve ADG and G:F (Edmonds et al., 1985; Burnell et al., 1988).

In summary, it has been reported that acidifiers positively impact growth performance when fed simultaneously with antibiotics, phytase, and various minerals. These studies also conclude that there is high variability of results when feeding organic acids. Enzyme addition, mineral addition, antibiotic addition and even diet composition can have a profound effect on the function of the acidifier in the animal's gastrointestinal tract. At this point, effects of acidifiers cannot be specifically defined (Stein, 2007). Because of this, an important area to focus is the growth performance effects of acidifiers.

Modes of action

Some proposed reasons for the beneficial effects that acidifiers have on weanling pig gastrointestinal health and growth performance are correlated with protein degradation and alteration in microbial populations. Supplementation of organic acids in the weanling pig diet has an effect on mucosal morphology. Bosi et al. (2006) determined that organic acids cause a decrease in parietal cells and an increase in somatostatin-producing cells, which actually suppress hydrochloric acid production. The speculation is that organic acid supplementation may be stifling the action of the parietal cells in the gastrointestinal tract rather than adding any benefits to the performance of the animal.

Other research has reported that it is very difficult to utilize organic acids to drop stomach pH for a significant period of time in order to produce beneficial effects in protein degradation. However, slight pH changes can have an effect on the microbial populations in the gastrointestinal tract. The dissociation of the acid may also have an effect on the interaction of the acid with the microbial population (Gauthier, 2002). Brul and Coote (1999) published modes of action for acids in food preservation and these ideas have been used as potential modes of action in the gastrointestinal tract of the animal. Weak organic acids tend to stay in a pH dependent equilibrium between their dissociated and undissociated states. They function optimally at a low pH. The modes of action include alteration of energy metabolism of the bacteria, disruption of the bacteria's cellular membrane, internal pH modification to the bacteria, fundamental metabolic function of the bacteria inhibited and bacteria may accumulate toxic anions. One proposal of action is that non-dissociated organic acids have the ability to go through the bacterium cell wall via passive diffusion, then dissociate once inside and cause the internal pH to plummet. This internal dissociation is triggered by an already lower than optimal pH and then subsequently contributes to the pH reduction once dissociated. In addition to this, certain bacteria have sensitivity to pH gradients across their cellular membrane. Some of these bacteria include highly pathogenic types; *E. coli*, *C. perfringens* and *Salmonella sp*. Bacteria that are not affected by this include *Lactobacillus sp*. and *Bifidobacterium sp*. (Gauthier, 2002). The pH gradient is usually maintained in affected bacteria across the plasma membrane. Diffusion will stop once the anion and hydrogen ion concentration in the cell becomes too high. This intracellular stress on homeostasis is a proposed reason as to why it is energetically expensive (Brul and Coote, 1999). If acid concentration in the diet becomes too high, a depression in growth may be observed because of the metabolic hardships.

Antibiotics have been shown effective in improving pig performance through many mechanisms. Most substantially, they have the ability to reduce the microbial load in the gastrointestinal tract which in turn allows more nutrients to be available to the animal for absorption (Hardy, 2005). Overland et al. (2000)

observed that potassium diformate gives rise to the same effects in reducing the microbial load in the gut, thus allowing an alteration in metabolism of the dietary components by increasing nutrient digestibility and absorption.

Upon weaning, it has been reported that the production of volatile fatty acids is decreased which in turn alters the pH of the gastrointestinal tract, more specifically the large intestine, and will have a profound effect on the balance of the beneficial and harmful bacteria. The volatile fatty acids are a source of energy for intestinal enterocytes. In addition to this, they help modulate the motility of the tract, and are an integral part in maintenance of the mucosa and its resistance to pathogenic bacteria (Hardy, 2005). When potassium diformate is fed in a primarily wheat and fishmeal diet, the short chain fatty acid content in the large intestines is not affected (i.e., no change in fermentable substrate in the large intestine). This gives rise to the implication that the acid does not effect short chain fatty acid production at day 29-postweaning; however, it is important to note that in the large intestine these short chain fatty acids are absorbed across the epithelium. It is possible upon measurement that no difference could be recorded in short chain fatty acid presence, but there may have been a difference in absorption (Canibe et al., 2001). One way to strategically feed to manipulate the pH is to reduce dietary fiber or feed different types of dietary fiber, which can alter the substrates available for the bacteria in the hind gut (Stein, 2007). When considering this in regard to acidifiers, function may be altered depending on dietary composition.

Since the impact of the pH throughout the intestinal tract is becoming better understood, acidifiers can now be scrutinized on how they directly influence pH in order to have a more strategic feeding regimen. Hardy (2005), as well as Brul and Coote (1999) and Guthier (2002), as discussed previously, proposed mechanisms of action of acidifiers. One mode is simply dissociation providing hydrogen ions in the intestines, which reduces the pH. However, some acids may not readily dissociate which leads to the second mode of action proposed. This resistance to initial dissociation allows the acid to pass through bacterial cell membranes and dissociate once inside. This may disrupt its cellular DNA formation which is detrimental to that population of bacteria in the gastrointestinal tract. Certain acids tend to act on certain bacterial populations. Continuing to find out more details about the bacterial populations that certain acids affect may give rise to superior acids to feed in order to ideally manipulate these populations.

Proposed feeding strategies

Feed ingredients also impact acid activity in the pig's gastrointestinal tract. In the United States, the majority of swine diets are comprised of corn and soybean meal. In Europe, a variety of feed ingredients are used in swine diets, such as wheat and barley. These grains have a much different function in the gastrointestinal tract than corn. For this reason, acidifiers should not be expected to and do not function in the same way in every feedstuff. High fiber diets tend to change microbial load and allow a different time frame for an acidifier to function (Stein, 2007). Beta-glucans are known to have a type of probiotic effect in swine, by the stimulation of lactic acid production, and can be found in barley. This also causes the increased production of short-chain fatty acids which can alter colonic pH and provide favorable conditions for the pathogenic bacteria that reside there (Montagne et al., 2003).

Feeding alternative feedstuffs in addition to inclusion of organic acids may have some additive effects, but may also differ from one feed to the next due to different fiber, crude protein and fat content and composition in each individual feedstuff. Upon weaning and introduction to solid feed, it has been reported that peristaltic rhythms did not change; however, amplification or severity did. These changes could be related to differences in the rates of gastric emptying (Liesnewska et al., 2000). This emptying rate is directly influenced by grain type in the diet. These rates can be tied to the water holding capacity of the grain fed (Boudry et al., 2004). If the gastric emptying rate is altered due to the grain fed, this will directly affect the acid activity in the diet which can be translated to growth performance.

It can be concluded that many physiological and chemical interactions play a role in the optimal function of a dietary acid. Potassium-diformate at this point seems to be an effective alternative to antibiotics in Europe; however, there are different cereal grains used in Europe as compared to the United States. Knowing that feed viscosity has an impact on the time spent in the various sections of the digestive tract, an optimally functional acidifier to be used in conjunction with a primarily corn-soybean meal diet needs to be determined.

Effects on slurry characteristics

In addition to the growth-promoting effects that acidifying swine diets have, there is a growing interest in research currently pertaining to the possibilities of acidifiers contributing to a decrease in emissions from animal production facilities. Sodium bisulfate ($NaHSO_4$) is currently used as a treatment for poultry litter. Blake and Hess (2001) reported that $NaHSO_4$, when used as a poultry litter treatment, allowed pH of the litter to remain below 7. This pH will allow a reduction in ammonia emissions. One reason for this reduction can be attributed to uric acid decomposition being favored at a pH above 7 (i.e., alkaline conditions).

Sodium bisulfate is also being used in dairy waste management strategies in the San Joaquin Valley in order to alleviate some of the volatile organic compounds (VOC) that are released. Sun et al. (2008) reported that the main sources of the VOCs are from the silage (fermented feed) and more importantly, the slurry. Shortly after urine excretion, upon mixing with feces, substantial amounts of ammonia are emitted (Lefcourt and Meisinger, 2001). Ammonia emissions from slurry are dependent upon factors like temperature, pH and slurry oxygenation. These things have an impact on the microbial processes that occur. For example, urease activity is regulated to some extent by temperature and pH (Monteny et al., 1998; Gay and Knowlton, 2005). Sodium bisulfate is a mineral (salt) acid. For the most part, mineral acids will release hydrogen ions upon dissociation which in turn will drop the pH in solution (Sun et al., 2008).

Sodium bisulfate dissolves into sodium (Na^+), hydrogen (H^+), and sulfate (SO_4^-) (Ullman et al., 2004). Pope and Cherry (2000) stated that the Na^+ as well as the H^+ have a negative impact on the bacterial populations in manure. Sun et al. (2008) attributed the decrease in ammonia emissions from topical application of $NaHSO_4$ to a decrease in slurry pH, due to the processes discussed above. These findings and the findings by Blake and Hess (2001) prove the efficacy of $NaHSO_4$ reducing ammonia emissions in scenarios when applied directly to the slurry or litter. However, it is unknown whether or not feeding $NaHSO_4$ to pigs will allow the pH of the slurry to decrease and possibly have some growth-promoting effects as commonly reported with dietary acidification in weanling pigs.

Effects on gaseous emissions

Interest in research pertaining to effectively managing nutrients into animal production systems is on the rise. Societal pressures in regards to environmental impact of animal feeding systems, as well as high feed costs, are forcing producers to more critically evaluate the nutrient balance of their operations. Typically swine diets consist of an exceedingly adequate amount of crude protein; however, this feeding strategy is being scrutinized due to NH_3 volatilization and nitrogen runoff leading to eutrophication of lakes and streams (Kornegay and Harper, 1997). As the amino acid requirements of swine become more completely understood, a reduction in crude protein in the diets can be made while still meeting amino acid requirements through the addition of crystalline amino acids. More closely matching these amino acid requirements, paying special attention to their relative ratios, can allow a reduced environmental impact that the overfeeding of nitrogen so commonly creates. In theory, feeding a dietary acidifier may allow more complete protein degradation in order to more maximally utilize the protein in the diet, thus reducing the amount required in the diet and reducing the amount excreted. Dietary acidification may allow the nitrogen excretion to be reduced (i.e., ammonia) as well as the necessity for elevated crude protein levels in the diet.

Summary and justification

The work contained in this thesis was conducted to determine the effects of $NaHSO_4$, when fed as a dietary acidifier, on growth performance during the nursery period. Antibiotics were included in the diet during all phases. Additionally, zinc oxide was included during Phases 1 to 3 and copper sulfate was included during Phase 4. Antibiotics, zinc oxide, and copper sulfate have all been proven to be growth-promoting agents in nursery pigs. It must be determined if ADG, ADFI, or G:F will improve with addition of antibiotics, zinc oxide, and copper sulfate in the diet and additionally, inclusion of $NaHSO_4$. Synergistic effects of antibiotics, copper sulfate and dietary acid (citric acid) inclusion have been reported (Edmonds et al., 1985; Burnell et al., 1988).

When including $NaHSO_4$ in growing and finishing pig diets, different results are expected. It has been reported that dietary acidification will lend a decrease in urinary pH; however, this pH reduction is drastically diminished once measured in the slurry (Brok et al., 1999). Slurry does have a high buffering capacity (Canh et al., 1998). The pH reduction of the urine is rarely maintained.

Usually only a slight reduction in slurry pH is observed as compared to the slurry from pigs fed non-acidified diets. If the pH remains at or below a pH of 7, ammonia emissions are reduced (Brok et al., 1999). This finishing pig experiment investigates the ability of $NaHSO_4$ addition to the diet to reduce slurry pH and, furthermore, reduce ammonia emissions. Nutrient excretion was also investigated for any effects $NaHSO_4$ may have.

CHAPTER III

EFFECTS OF SODIUM BISULFATE ON GROWTH PERFORMACE OF WEANLING PIGS

ABSTRACT

Two experiments were conducted to determine growth performance of weanling pigs fed sodium bisulfate ($NaHSO_4$), as a potential acidifier, at varying levels of inclusion. Pigs were stratified by sex, weight and ancestry and assigned to one of four dietary treatments containing 0, 0.2, 0.4, and 0.8% inclusion of $NaHSO_4$. All diets were formulated on a total lysine (1.60, 1.50, 1.35, and 1.20%) basis for a typical, 4 phase, nursery-feeding program. $NaHSO_4$ was added at the expense of sodium chloride. Pigs and feeders were weighed weekly to determine ADG, ADFI, and G:F. In Exp. 1, 200 pigs (5 pens/trt; 10 pigs/pen) were fed a common Phase 1 diet. Pigs were then allotted to one of four treatments for Phases 2 - 4. In Phase 2, there was no difference ($P > 0.10$) in ADG or ADFI among treatments, but G:F tended to improve (linear, $P < 0.07$) with increasing $NaHSO_4$. There were no differences ($P > 0.10$) in ADG, ADFI, or G:F for Phases 3 and 4. Overall in Exp. 1, there was no difference ($P > 0.10$) in ADFI; however, ADG ($P < 0.05$) and G:F ($P < 0.06$) improved quadratically as $NaHSO_4$ levels increased in the diet. In Exp. 2, 240 pigs (6 pens/trt;10 pigs/pen) were allotted at weaning in the same fashion to the four dietary treatments fed in

all four phases. During Phase 1, there was no effect ($P > 0.10$) of $NaHSO_4$ on ADG, ADFI, or G:F. In Phase 2, $NaHSO_4$ addition increased (linear, $P < 0.04$) ADG, and tended to improve G:F (linear, $P < 0.09$). No differences ($P > 0.10$) were observed in growth performance for Phase 3. During Phase 4, $NaHSO_4$ increased (linear, $P < 0.02$) ADG and tended to increase G:F (linear, $P < 0.07$). Overall, in Exp. 2, there was no effect ($P > 0.10$) of $NaHSO_4$ on ADFI or G:F, but increasing inclusion of $NaHSO_4$ tended to improve ADG (linear, $P < 0.07$). When combining results from both experiments (11 pens/trt) for Phases 2 - 4, ADG tended to increase (linear, $P < 0.06$) and G:F improved (quadratic, $P < 0.03$) for pigs fed $NaHSO_4$. These results suggest that feeding $NaHSO_4$ at 0.4 or 0.8% inclusion may improve growth performance in weanling pigs.

Introduction

Antibiotics have been used as growth promoters in animal feeding operations for upwards of 50 years. Emerging in the 1980's, concern of antibiotic resistant bacteria making it into the food supply started a trend focused on not feeding subtherapeutic levels of antibiotics in food animal production systems. Since January of 2000, Denmark has restricted the use of antimicrobials to solely prescription and only at therapeutic levels (Dibner and Richards, 2003). Beginning in January of 2006, the European Union (EU) also banned the feeding of subtheraputic antibiotics in food animal production systems. They have currently approved potassium diformate as an acidifier to use in place of subtheraputic antibiotics. Overland et al. (2000) reported that potassium diformate improves growth performance by an average of 11%, which is about equal to the growth enhancement observed by feeding antibiotics as growth promoters. The consistency of these improvements are mainly limited to commonly-fed European diets (i.e., wheat or barley).

With these restrictions well on their way to animal production systems in the United States, it is important for a sound alternative to antibiotics be identified for typical U.S. diets (i.e., corn and soybean meal). Many different acidifiers have been tested to determine which dietary acid has the most beneficial effects on growth performance. Some common acidifiers that have been investigated as feed additives for swine diets include citric acid, formic acid, fumaric acid and phosphoric acid. Sodium bisulfate ($NaHSO_4$) is a potential dietary acidifier currently being investigated as a possible feed additive for weanling pigs. It has been reported that $NaHSO_4$ reduces the pH of poultry litter and decreases ammonia volatilization (Blake and Hess, 2001). Since it is a feed grade acid, it has been speculated that it may have the ability to reduce gastric pH in weanling pigs, ideally initiating feed protein degradation in the stomach and small intestines.

The objectives of these experiments were to determine ADG, ADFI, and G:F for nursery pigs fed increasing levels of $NaHSO_4$ in diets containing antibiotics, zinc oxide or copper sulfate.

Materials and Methods

A series of two experiments were conducted with a total of 440 pigs to determine growth performance when fed varying levels of $NaHSO_4$. In both experiments, pigs were housed in one of two rooms of an environmentally-controlled nursery building. There were 12 pens/room that each contained a 5-hole self-feeder and one nipple waterer. Feed and water were provided *ad libitum*. Pigs were stratified based on sex and ancestry and blocked by body weight then randomly allotted to one of four dietary treatments. Dietary treatments consisted of a control diet and three treatment diets containing 0.2, 0.4 or 0.8% $NaHSO_4$. Diets were formulated in a 4-phase (Table 1) nursery program and balanced for lysine. Early phases included dried whey, lactose, fishmeal, spray dried plasma, and soy protein concentrate. As phases progressed, diet complexity decreased. $NaHSO_4$ was added at the expense of sodium chloride in order to balance for sodium content. Pigs were weighed and feed disappearance was obtained weekly to calculate ADG, ADFI, and G:F.

Exp. 1 utilized 200 pigs weaned at 21± 3 days of age for a total of 43 days. These pigs were fed a common Phase1 diet for one week and then allotted to treatments as described previously. Pigs in Exp. 1 were fed Phase 4 for a total of 21 days rather than the typical 14 days. This experiment contained 5 pens/treatment and 10 pigs/pen.

Experiment 2 utilized 240 pigs weaned and started on a 41 day experiment at 21± 3 days of age. This experiment contained 6 pens/treatment and utilized 10 pigs/pen.

<u>Statistical Analysis</u>

Data were analyzed as a randomized complete block design (Freund and Wilson, 2003). The model included the effect of block, treatment, and block x treatment (error). Orthogonal polynomial contrasts were used to test the effects of increasing $NaHSO_4$. The pen was considered the experimental unit for all response criteria.

Table 1. Diet composition by phase for both experiments.

Ingredient	Phase I	Phase II	Phase III	Phase IV
Corn	29.97	52.14	52.25	64.01
Soybean meal, 47.5%	10.65	15.72	27.16	29.26
Whey dried	25.0	15.0	10.0	-
Lactose	10.0	-	-	-
Plasma, spray dried	6.0	3.0	-	-
Fish meal	5.0	5.0	4.5	-
Soy protein conc.	4.0	3.0	-	-
Soybean oil	5.0	3.0	3.0	3.0
Dicalcium phosphate	0.92	0.66	0.57	1.42
Limestone, ground	0.78	0.54	0.71	0.88
Sodium chloride[a]	0.96	0.50	0.50	0.50
Mineral mix	0.15	0.15	0.15	0.15
Vitamin mix	0.25	0.25	0.25	0.25
Zinc oxide	0.28	0.28	0.21	-
Copper sulfate	-	-	-	0.08
Antibiotic	0.50	0.50	0.50	0.10
L-Lysine HCl	0.20	0.11	0.10	0.19
L-Threonine	0.11	0.10	0.04	0.05
DL-Methionine	0.19	0.05	0.06	0.02
L-Tryptophan	0.03	-	-	-

[a]$NaHSO_4$ was added to the basal diet in each phase at the expense of NaCl to provide 0.2, 0.4, and 0.8%.

Results

When evaluating Exp. 1 by phase, there were a few differences observed (Table 2). During Phase 2, there were no differences ($P > 0.10$) in ADFI or ADG among treatments; however G:F tended to improve linearly ($P < 0.07$) as inclusion of $NaHSO_4$ increased. For both Phases 3 and 4, no differences ($P > 0.10$) were observed in ADG, ADFI or G:F upon treatment comparison. When combining the results over the entirety of Exp. 1, no difference ($P > 0.10$) was determined in ADFI, but ADG improved ($P < 0.05$) and G:F tended to increase ($P < 0.07$) quadratically as $NaHSO_4$ inclusion increased in the diet.

Upon evaluation of Exp. 2 alone, results vary depending on phase and treatment (Table 3). During Phase 1, there was no improvement ($P > 0.10$) in ADG or ADFI regardless of level of $NaHSO_4$ in the diet; however, G:F had a tendency to decrease (Linear, $P < 0.09$) as $NaHSO_4$ inclusion in the diet increased. There was no improvement ($P > 0.10$) in ADFI during Phase 2 as $NaHSO_4$ in the diet increased; however, ADG improved linearly ($P < 0.04$) in Phase 2 and G:F had a tendency to improve ($P < 0.10$). No improvements ($P > 0.10$) were recorded in any growth performance category during Phase 3. Improvements during Phase 4 were similar to those in Phase 2. A linear increase in ADG ($P < 0.02$) and a tendency to improve G:F ($P < 0.10$) as $NaHSO_4$ levels in the diet increased. Overall in Exp. 2, ADG tended to improve linearly ($P < 0.07$) as addition of $NaHSO_4$ increased in the diet.

When Exp. 1 and Exp. 2 results were combined for the common Phases 2, 3 and 4 (Table 4 and Figure 1), ADG tended to improve linearly ($P < 0.06$) and

G:F improved quadratically ($P < 0.03$) as the pigs were fed increasing levels of $NaHSO_4$. When including Phase 1 feeding of Exp. 2 to the results (Figure 2), ADG had a tendency to improve (Linear, $P < 0.07$) as $NaHSO_4$ addition increased. These results suggest feeding $NaHSO_4$ during all nursery phases can be beneficial, but most improvements were observed during Phases 2-4. Sodium bisulfate inclusion in the diet improved ADG and G:F and had no impact on ADFI.

Table 2. Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ for Experiment 1.[a]

	$NaHSO_4$, %					
Growth Trait	Control, 0	0.2	0.4	0.8	SE	P-value[b]
Phase II						
ADG, kg	0.315	0.308	0.347	0.319	0.011	0.52
ADFI, kg	0.423	0.391	0.442	0.398	0.016	0.04C
G:F	0.747	0.787	0.783	0.807	0.020	0.07L
Phase III						
ADG, kg	0.477	0.491	0.580	0.469	0.015	0.57
ADFI, kg	0.752	0.703	0.736	0.710	0.021	0.35
G:F	0.635	0.711	0.663	0.656	0.032	0.98
Phase IV						
ADG, kg	0.569	0.579	0.581	0.658	0.009	0.75
ADFI, kg	1.006	1.014	1.015	1.022	0.011	0.38
G:F	0.567	0.572	0.574	0.557	0.007	0.24
Overall						
ADG, kg	0.492	0.500	0.505	0.489	0.006	0.05Q
ADFI, kg	0.815	0.791	0.799	0.801	0.014	0.68
G:F	0.605	0.634	0.633	0.612	0.012	0.07Q

[a] Least square means for 5 pens/trt.
[b] L (linear), Q (quadratic), and C (cubic) effect of increasing $NaHSO_4$ in the diet.

Table 3. Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ for Experiment 2.[a]

	$NaHSO_4$, %					
Growth Trait	Control, 0	0.2	0.4	0.8	SE	P-value[b]
Phase I						
ADG, kg	0.156	0.143	0.147	0.133	0.016	0.38
ADFI, kg	0.164	0.172	0.160	0.164	0.013	0.86
G:F	0.967	0.805	0.905	0.763	0.066	0.09L
Phase II						
ADG, kg	0.357	0.375	0.378	0.406	0.015	0.04L
ADFI, kg	0.431	0.422	0.464	0.450	0.018	0.30
G:F	0.828	0.886	0.816	0.907	0.025	0.10L
Phase III						
ADG, kg	0.411	0.419	0.432	0.431	0.012	0.24
ADFI, kg	0.691	0.684	0.700	0.708	0.015	0.32
G:F	0.595	0.613	0.619	0.613	0.013	0.40
Phase IV						
ADG, kg	0.521	0.523	0.530	0.562	0.012	0.02L
ADFI, kg	0.936	0.904	0.919	0.962	0.023	0.26
G:F	0.560	0.579	0.576	0.585	0.009	0.10L
Overall						
ADG, kg	0.397	0.401	0.409	0.422	0.009	0.07L
ADFI, kg	0.648	0.634	0.651	0.665	0.014	0.24
G:F	0.612	0.634	0.630	0.635	0.009	0.14

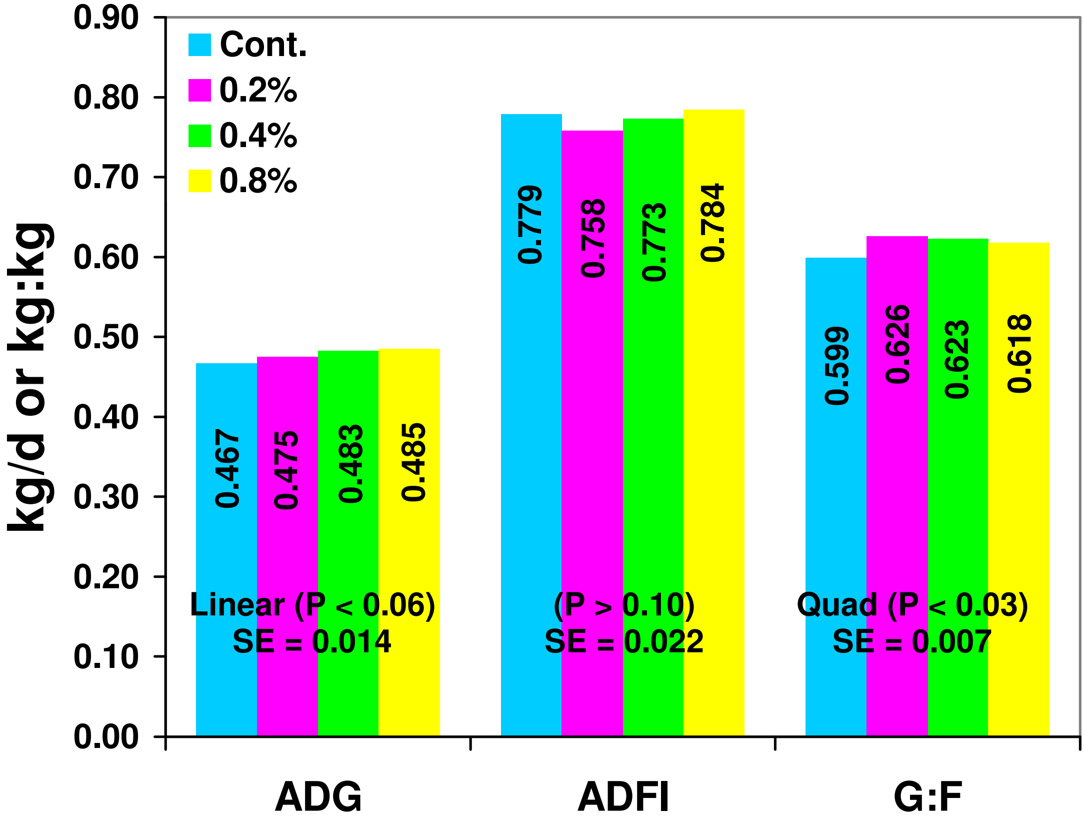
[a] Least square means for 6 pens/trt.
[b] L (linear), Q (quadratic), and C (cubic) effect of increasing $NaHSO_4$ in the diet.

Table 4. Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ by Phase for both experiments.[a]

	$NaHSO_4$, %					
Growth Trait	Control, 0	0.2	0.4	0.8	SE	P-value[b]
Phase I						
ADG, kg	0.156	0.143	0.147	0.133	0.016	0.38
ADFI, kg	0.164	0.172	0.160	0.164	0.013	0.86
G:F	0.967	0.805	0.905	0.763	0.066	0.09L
Phase II						
ADG, kg	0.338	0.345	0.364	0.366	0.010	0.04L
ADFI, kg	0.427	0.408	0.454	0.426	0.012	0.59
G:F	0.796	0.846	0.706	0.867	0.020	0.05L
Phase III						
ADG, kg	0.441	0.452	0.459	0.448	0.009	0.64
ADFI, kg	0.719	0.692	0.716	0.709	0.013	0.95
G:F	0.605	0.649	0.631	0.624	0.017	0.08Q
Phase IV						
ADG, kg	0.543	0.548	0.553	0.565	0.008	0.07L
ADFI, kg	0.968	0.955	0.964	0.991	0.014	0.16
G:F	0.566	0.579	0.578	0.575	0.006	0.50

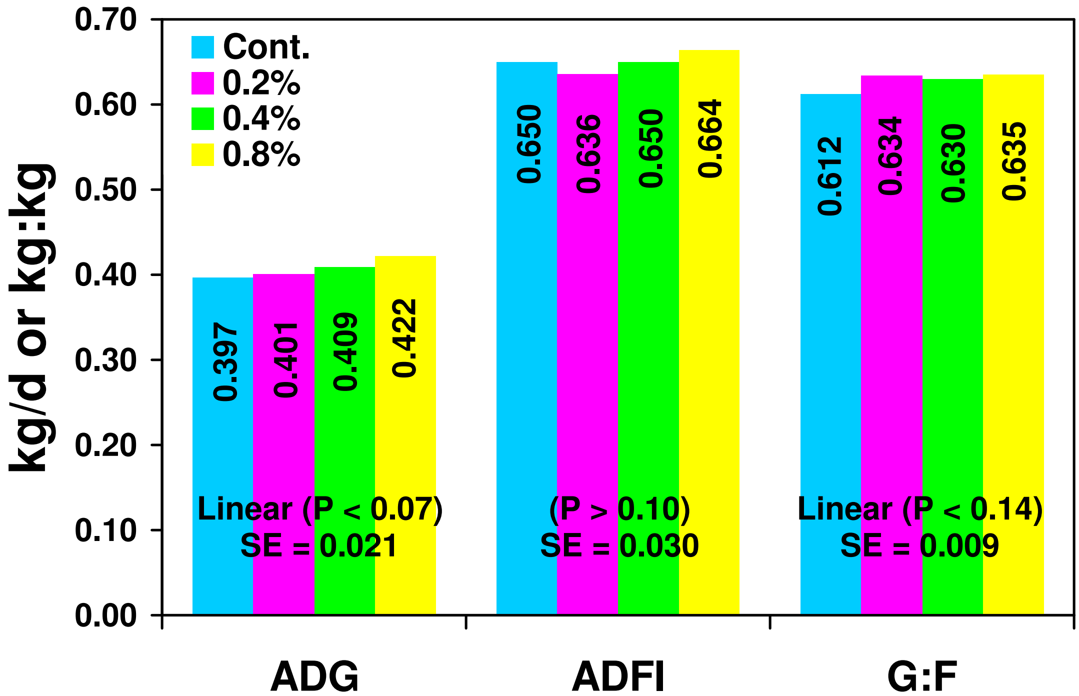
[a] Least square means for 11 pens/trt.
[b] L (linear), Q (quadratic), and C (cubic) effect of increasing $NaHSO_4$ in the diet.

Figure 1. Growth performance for weanling pigs fed increasing levels of $NaHSO_4$ for both experiments during Phases 2-4.



Control: Fortified corn-soybean meal diet
0.2%: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
0.4%: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
0.8%: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Figure 2: Growth performance of weanling pigs fed increasing levels of $NaHSO_4$ during all phases for both experiments.



Control: Fortified corn-soybean meal diet
0.2%: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
0.4%: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
0.8%: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Discussion

An acidifier is a non-nutritive feed additive that may have the ability to enhance growth performance in weanling pigs (NRC, 1998); however, the exact mechanism of action of acidifiers has not yet been elucidated. The purpose of this study was to determine the efficacy of $NaHSO_4$ as a growth promoting agent when fed to pigs upon weaning and throughout their time in the nursery. Previous studies using various acidifiers have had inconsistent results between studies. An improvement in ADG (Geisting et al., 1991; Overland et al., 2000; Radcliffe et al., 1998; Walsh et al., 2007;) and feed efficiency (Overland et al., 2000; Radcliffe et al., 1998) have been observed in some studies, whereas others have reported no improvement in gain or nutrient digestibility (Geisting and Easter, 1991) upon dietary acidification. The variability in these results may be attributed to many different factors. Some possible explanations include type of dietary acid, protein source, concurrent feeding of antibiotics, copper sulfate, phytase, age at weaning and fiber level, to name a few. All of these factors may interact in some way on the ability of the acid to take effect in the stomach and/or other areas of the gastrointestinal tract. Gastric emptying rate and buffering capacity of the feed are two additional ways that the factors listed above may interact with the mode of action of the dietary acid. Stein (2007) proposed that dietary acidification may change the ratio of bacteria in the gastrointestinal tract; therefore, possibly alleviating some disease problems that are many times observed in nursery pigs. In addition to this, the enhanced growth performance sometimes observed may also be attributed to gastric pH alteration (NRC, 1998), perhaps allowing enhanced nutrient digestibility.

In experiments reported here, ADG tended to improve linearly and G:F quadratically; however, in these two experiments zinc oxide or copper sulfate and antibiotics were present. Growth performance effects of $NaHSO_4$ were not evaluated without the addition of antibiotics at subtherapeutic levels or without copper sulfate. Our experiments report the compounding effects that are experienced above and beyond the addition of antibiotics and copper sulfate alone. These data suggests that improvements in ADG and G:F can be achieved through $NaHSO_4$ addition to weanling pig diets.

Furthermore, ADG and G:F improvement in animals fed $NaHSO_4$ at 0.2, 0.4 and 0.8% of the diet suggests that the possibility of $NaHSO_4$ improving protein digestibility, in a corn soybean meal diet, is present. It is unknown to what extent gastric pH is altered to have the ability to initiate protein digestibility and give rise to an enhancement in growth performance when feeding $NaHSO_4$. To further validate the scope of pig performance that $NaHSO_4$ has more research needs to be conducted. Expanded trials should include measurement of pH in various segments of the gastrointestinal tract, possibly feeding without antibiotics or copper sulfate and adding different types of feed ingredients to determine the extent of the efficacy that $NaHSO_4$ has as a growth promoting agent in weanling pigs.

CHAPTER IV

EFFECTS OF SODIUM BISULFATE ON GROWTH PERFORMANCE, SLURRY CHARACTERISTICS, AND NUTRIENT EXCRETION OF FINISHING PIGS

ABSTRACT

Sodium bisulfate ($NaHSO_4$) is a strong acid that has been used in the poultry industry as a litter additive to reduce pH and ammonia emissions. Little is known about the effects of $NaHSO_4$ in swine slurry when administered as a feed additive. A total of 80 crossbred [D x (Y x L)] pigs were used to determine the effects of $NaHSO_4$ addition to a traditional corn-soybean meal diet on growth performance, slurry pH and electrical conductivity, and DM, N, and P excretion during a 100-d finishing period. Pigs were blocked by BW, sex, and ancestry and allotted to one of two dietary treatments. The control was a fortified corn-soybean meal diet and the treatment diet consisted of the control diet + 0.30% $NaHSO_4$. Diets were fed in four phases (40 to 62, 62 to 90, 90 to 108, 108 to 128 kg) and formulated on true digestible lysine (0.92, 0.79, 0.65, 0.56%). $NaHSO_4$ was added at the expense of sodium chloride to maintain sodium levels. Pigs were housed in 4 identical, environmentally-controlled rooms equipped with a shallow pit, pull-plug system (20 pigs/room, 2 rooms/trt). Feed intake, pig weight, pit volume, and slurry pH and electrical conductivity were measured on a weekly basis. Feed and slurry samples were collected weekly and analyzed for DM, N, and P. During the100-d finishing period, there was no difference ($P > 0.10$) in

ADG (0.79 vs. 0.81kg), ADFI (2.11 vs. 2.19 kg), or G:F (0.37 vs. 0.37). Also, no difference ($P > 0.10$) was observed in pit pH (7.15 vs. 7.20). However, electrical conductivity (8.22 vs. 9.18 mS) of the slurry tended to increase ($P < 0.09$) for pigs fed $NaHSO_4$. There was no difference ($P > 0.10$) in daily DM (230.4 vs. 236.9 g), N (33.7 vs. 31.4 g) or P (6.0 vs. 6.2 g) excretion between the 2 groups. $NaHSO_4$ addition did not affect ($P > 0.10$) excretion of sodium or ammonium-N. Sulfur excretion (2.41 vs. 4.0 g) tended to increase ($P < 0.09$) in pigs fed $NaHSO_4$. These results suggest that dietary addition of $NaHSO_4$ does not affect growth performance, pit characteristics, or DM, N or P excretion of finishing pigs.

Introduction

It is known that reducing the pH of swine slurry will reduce ammonia emissions by allowing conversion of ammonia (NH_3) to ammonium (NH_4^+) (Canh, 1998). Reduction of ammonia emissions allows for decrease in the environmental impact of swine production systems as well as for a higher nitrogen (N) content of the slurry. This would give rise to an increased value of the slurry as an applied manure product. Van Kempen (2001) reported that dietary adipic acid at 1% inclusion resulted in a reduction of 93% of NH_3 emission as compared to control at 1 h. At 46 h, a 39% reduction in NH_3 emissions was obtained. This supports that feeding adipic acid reduces urinary pH; however, this pH reduction may not hold true once mixed with feces. Canh and others (1998) established that feces have a strong buffering capacity. This buffering capacity, in a shallow pit pull plug system, may not support a reduction in slurry pH upon dietary acidification. In another study by Canh et al. (1998), feedig acidified diets resulted in a very small change in slurry pH can have a drastic effect on ammonia emissions.

Sodium bisulfate ($NaHSO_4$) is used as an additive to poultry litter to reduce pH and therefore reduce ammonia volatilization (Blake and Hess, 2001). Growth performance studies upon feeding acidifiers to weanling pigs have reported improvements. These two ideas lead to the proposed feeding of $NaHSO_4$ to grow-finish pigs to investigate if similar effects on growth performance and slurry characteristics would occur. The purpose of this study was to examine $NaHSO_4$ as a feed additive in growing and finishing pigs in order to determine the effects on growth performance, slurry characteristics, and gaseous emissions.

Materials and Methods

A total of eighty crossbred [Duroc x (Yorkshire x Landrace)] pigs (40 kg initial weight) were used in a 100-day finishing period (128 kg final weight). Pigs were randomly allotted to one of two dietary treatments after being blocked by body weight and stratified by sex and ancestry. The barn used for this experiment contained 4 identical environmentally controlled rooms each equipped with a shallow pit, pull-plug system containing 20 pigs per room and 2 rooms per treatment. Each room contained two nipple waterers and 4 two-hole feeders. Feed and water were provided on an *ad libitum* basis. Diets were formulated in a 4-phase feeding program. Phases progressed based on average weights. Phases 1 and 4 were 3 weeks each, while Phases 2 and 3 each lasted 4 weeks. Diets were corn and soybean meal based. $NaHSO_4$ was added at 0.3% for Phase 1 and 2, 0.5% for Phase 3 and 1.0% of the diet for Phase 4. Diets for each phase were formulated on a true digestible lysine basis and balanced for sodium. $NaHSO_4$ was added at the expense of sodium chloride (Table 5).

Pigs were weighed and feed and water consumption was recorded weekly. Slurry samples for each room were obtained weekly after measuring pit volume. In order to homogenize the pit, the fecal material above the pit was scraped into the pit. Slurry was then mixed using a submersible pump. Pit scrapers were also used to aid in pit homogenization. Once the slurry was thoroughly mixed, the plug was removed and a continuous sample was taken as the slurry left the room using the submersible pump. Once the sample was obtained, pH, electrical conductivity, and temperature were measured and subsamples were acquired and taken to the lab for nutrient analysis. The pit was then refilled with fresh water. Weekly slurry and feed samples were analyzed for DM, N, and P content using approved methods by AOAC (1998).

Sludge samples were taken at the conclusion of each phase after contents of the pit were weighed and pH, electrical conductivity, and temperature were measured. These samples were also analyzed for DM, N, and P again using methods by AOAC (1998).

In each room, exhaust airflow was measured and analyzed for ammonia and hydrogen sulfide emissions. Ammonia concentration was quantified using a

TEI model 17C chemiluminescence ammonia analyzer (Thermo Electron Corporation, Waltham, MA). Hydrogen sulfide concentrations were quantified using 450C H_2S – SO_2 Analyzer, Trace level (Thermo Electron Corporation, Waltham, MA). These measurements were analyzed every 20 minutes in 80 minute cycles. Determination of NH_3 and H_2S emissions were calculated by multiplying concentration of the gas leaving the room by air flow from the room.

Data were analyzed in a randomized complete block design (Freund and Wilson, 2003). The model included block, treatment and block x treatment (error). The room served as the experimental unit.

Table 5. Diet composition for all four phases.

Ingredient, %	Phase I	Phase II	Phase III	Phase IV
Corn	65.72	71.25	76.70	80.32
Soybean meal, 47.5	29.11	23.67	18.30	14.58
Soybean oil	3.00	3.00	3.00	3.00
Dicalcium phosphate	0.60	0.54	0.47	0.39
Limestone, ground	0.97	0.94	0.93	0.90
Sodium chloride[a]	0.25/ 0.12	0.25/ 0.12	0.25/ 0.04	0.47 /0.05
Trace mineral mix	0.10	0.10	0.10	0.10
Vitamin mix	0.15	0.15	0.15	0.15
Antibiotic	0.10	0.10	0.10	0.10
$NaHSO_4$[a]	0.00/ 0.30	0.00/ 0.30	0.00/ 0.50	0.00/ 1.00
Lysine, TID %	0.92	0.79	0.65	0.56
Ca, %	0.60	0.56	0.52	0.48
P, %	0.50	0.46	0.43	0.40
Na, %	0.10	0.12	0.12	0.21

[a]$NaHSO_4$ was added at the expense of NaCl in order to maintain sodium level.

Results

Over the entire 100-day finishing period (40 kg – 128 kg) (Figure 3), no difference ($P > 0.10$) was observed in ADG, ADFI, or G:F (Figure 4). Pen weights at the beginning and end of each phase were similar ($P > 0.10$).

Nutrient concentration of the slurry were analyzed and expressed in mg/L. Concentration of nitrogen, ammonium-nitrogen, phosphorus, and sodium in the slurry were not different ($P > 0.10$) for pigs fed $NaHSO_4$ as compared to control. However, sulfur concentration of the slurry was increased ($P < 0.01$) for pigs fed $NaHSO_4$ when contrasted to pigs fed the control diet (Figure 5).

$NaHSO_4$ had no affect ($P > 0.10$) on DM (Figure 6), N (Figure 7), or P (Figure 8) intake or excretion during the 100-day finishing period on a cumulative or a g/pig/day basis. However, there was a tendency ($P < 0.09$) for sulfur excretion to be greater for pigs fed $NaHSO_4$ (Figure 9). Furthermore, no difference ($P > 0.10$) was observed for excretion of calcium, potassium, magnesium, sodium, iron, zinc, copper, manganese, nickel, or ammonium-nitrogen (Table 6).

Pit volume and slurry pH were also not affected ($P > 0.10$) for pigs fed $NaHSO_4$ as compared to slurry for pigs fed the control diet. However, electrical conductivity of the slurry had a tendency to be greater ($P < 0.09$) for pigs fed $NaHSO_4$ (Figure 10).

Air flow (Table 7) in the rooms was determined to be similar ($P > 0.10$). Upon determination of air flow equality from all rooms, concentrations of gaseous emissions could be compared. No difference ($P > 0.10$) was observed in concentration of ammonia leaving rooms with pigs being fed $NaHSO_4$ compared with rooms containing pigs fed the control diet on a mg/m^3, mg/min, or mg/kg of body weight basis. Also, on a concentration basis, µg/m^3 and µg/ kg of body weight, dietary treatment did not affect ($P > 0.10$) hydrogen sulfide emissions. Ammonia emissions (Figure 11) from rooms with pigs fed $NaHSO_4$ were numerically greater ($P = 0.13$) from the rooms with pigs fed the control diet on a basis of g/pig/day. Furthermore, hydrogen sulfide (Figure 12) emissions from rooms with pigs fed $NaHSO_4$ were also numerically greater ($P = 0.13$) than those for rooms fed control on a basis of mg/pig/day.

Figure 3. Initial and final weights for pigs fed control versus $NaHSO_4$ over the entire 100-d finishing period.

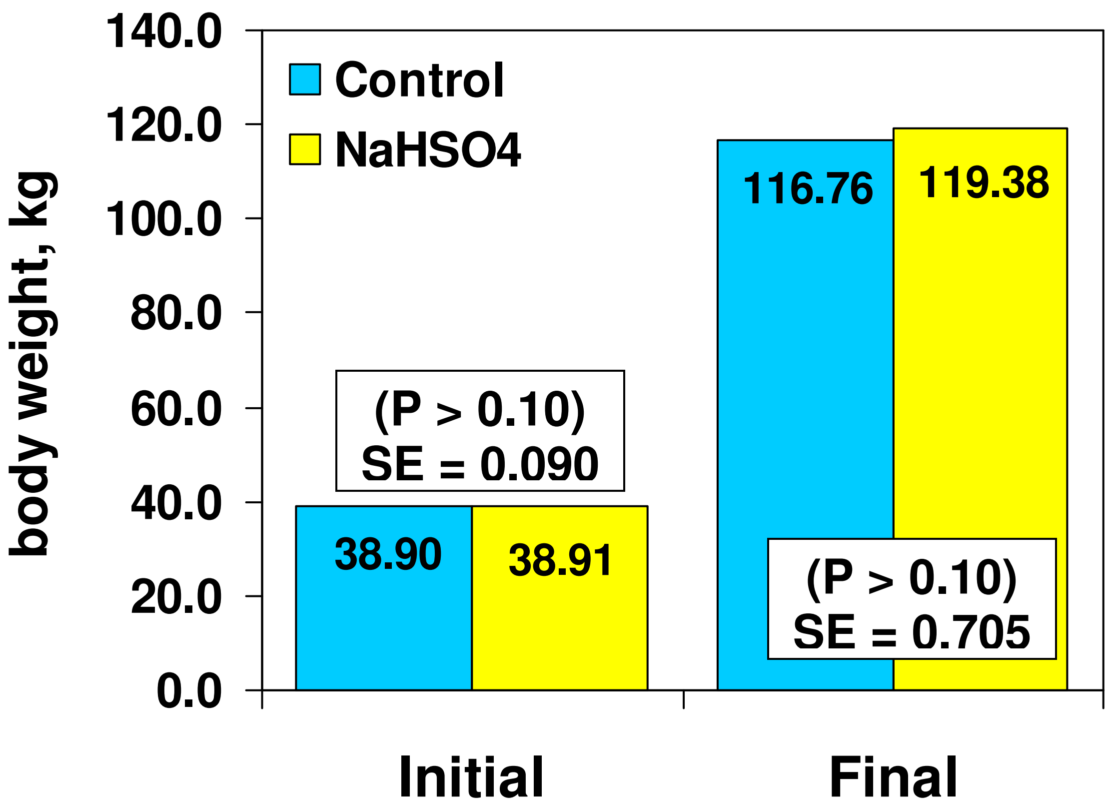
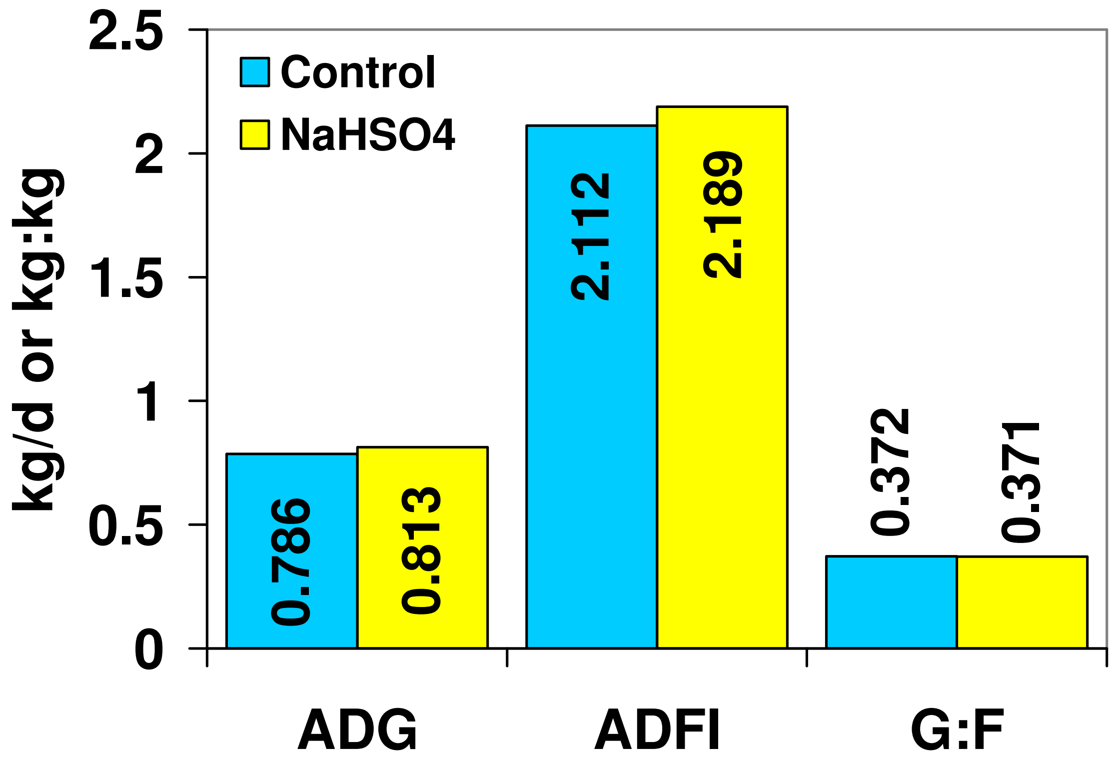


Figure 4. Growth performance for grow-finish pigs during the entire 100-d finishing period when fed control vs. $NaHSO_4$.



Control vs. $NaHSO_4$	ADG ($P > 0.10$) SE 0.006
ADFI ($P > 0.10$) SE 0.034	G:F ($P > 0.10$) SE 0.023

Figure 5. Nutrient concentration of the slurry averaged over the entire 100-d finishing period.

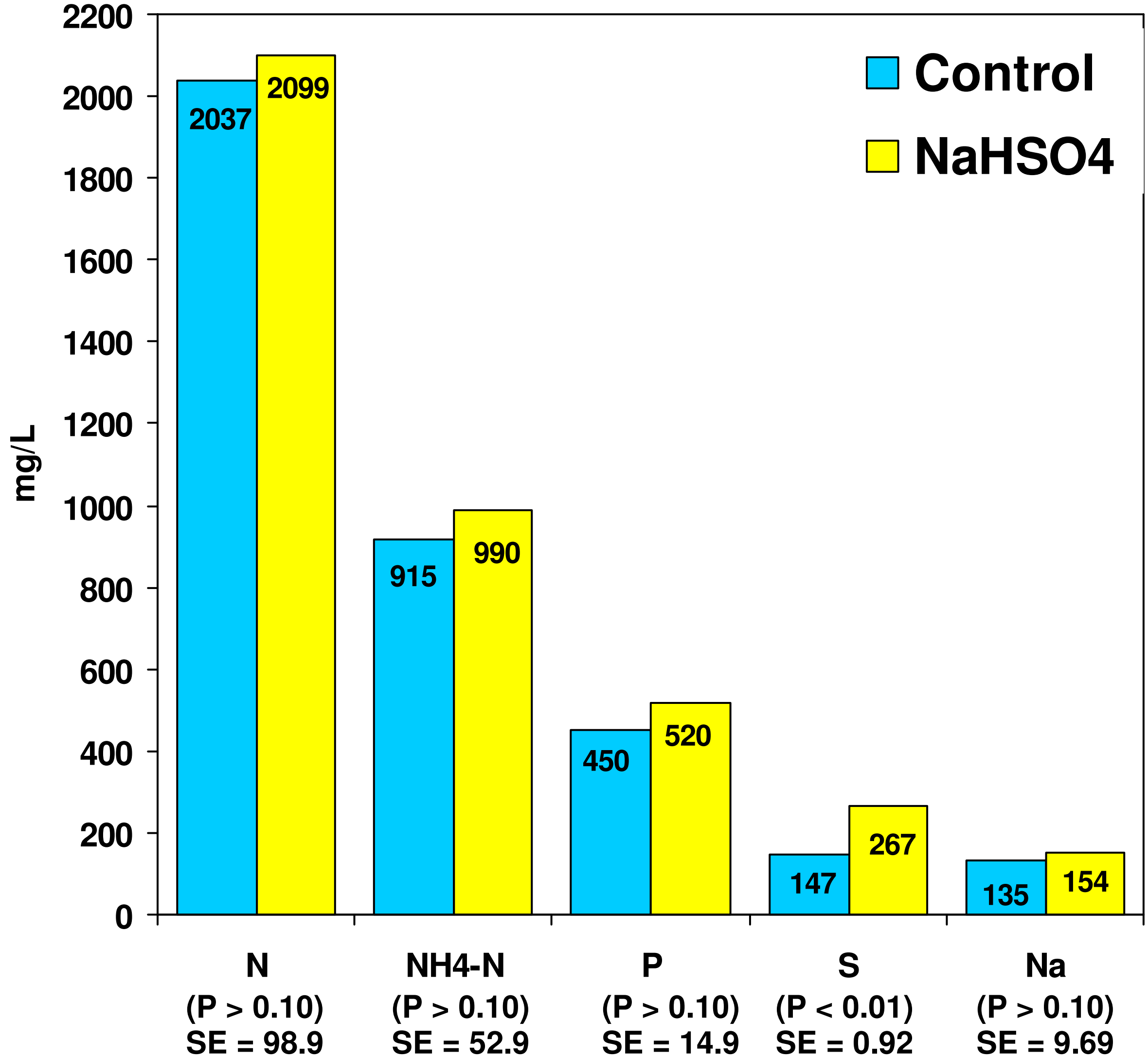


Figure 6. Dry matter intake and excretion from pigs fed control vs. $NaHSO_4$ over the entire 100-d finishing period.

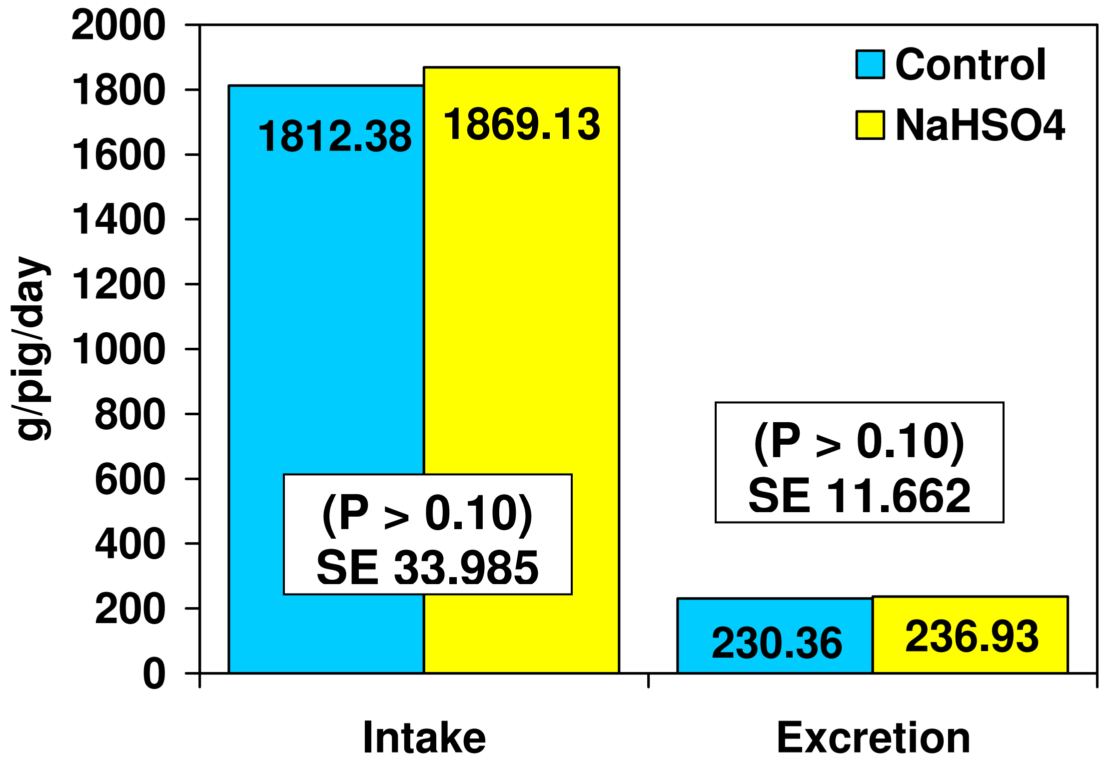


Figure 7. Nitrogen intake and excretion of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period.

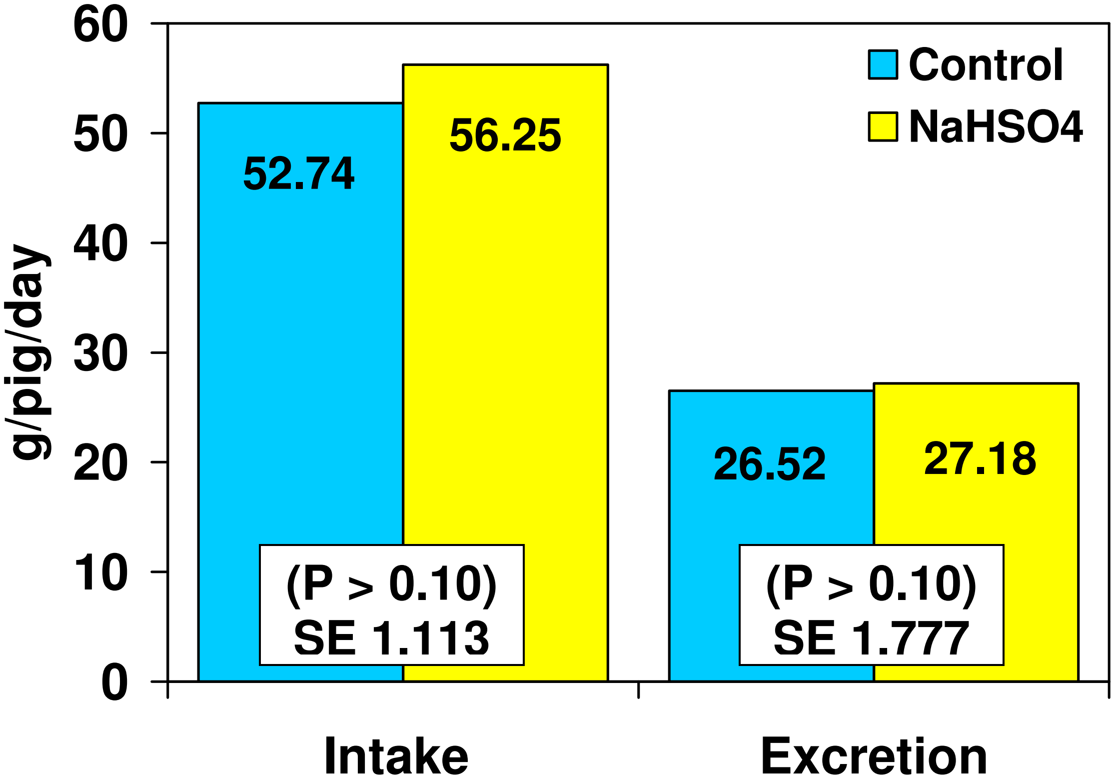


Figure 8. Phosphorus intake and excretion of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period.

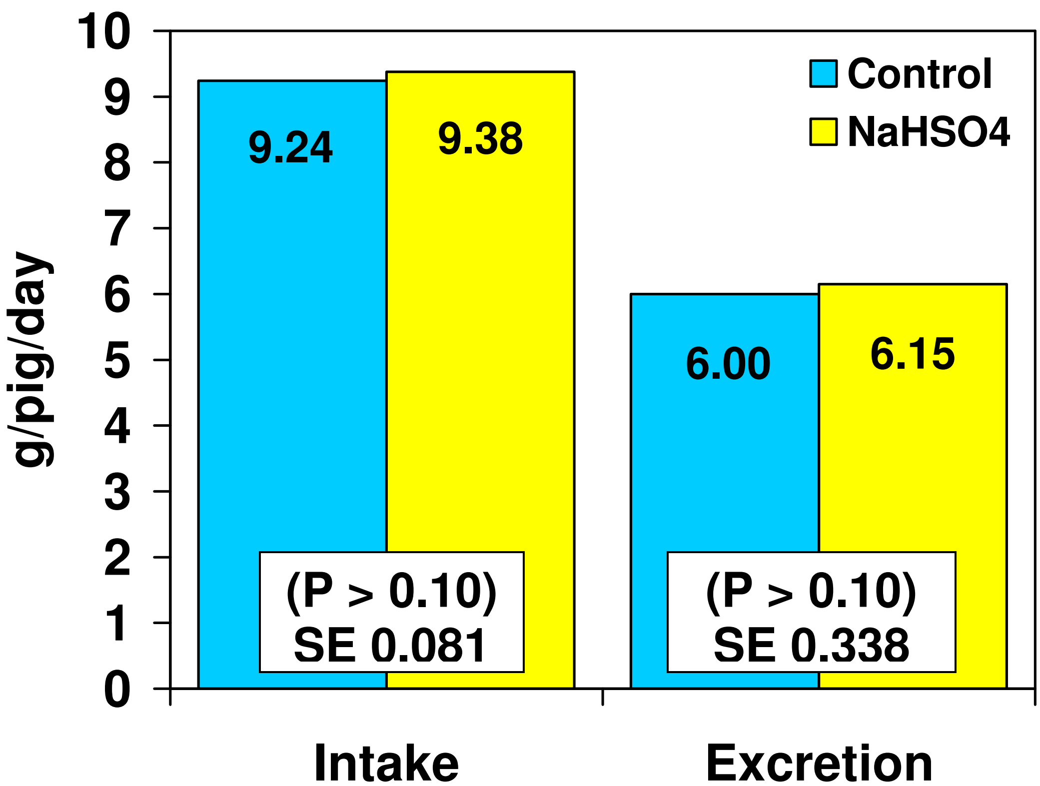


Figure 9. Sodium and sulfur excretion of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period.

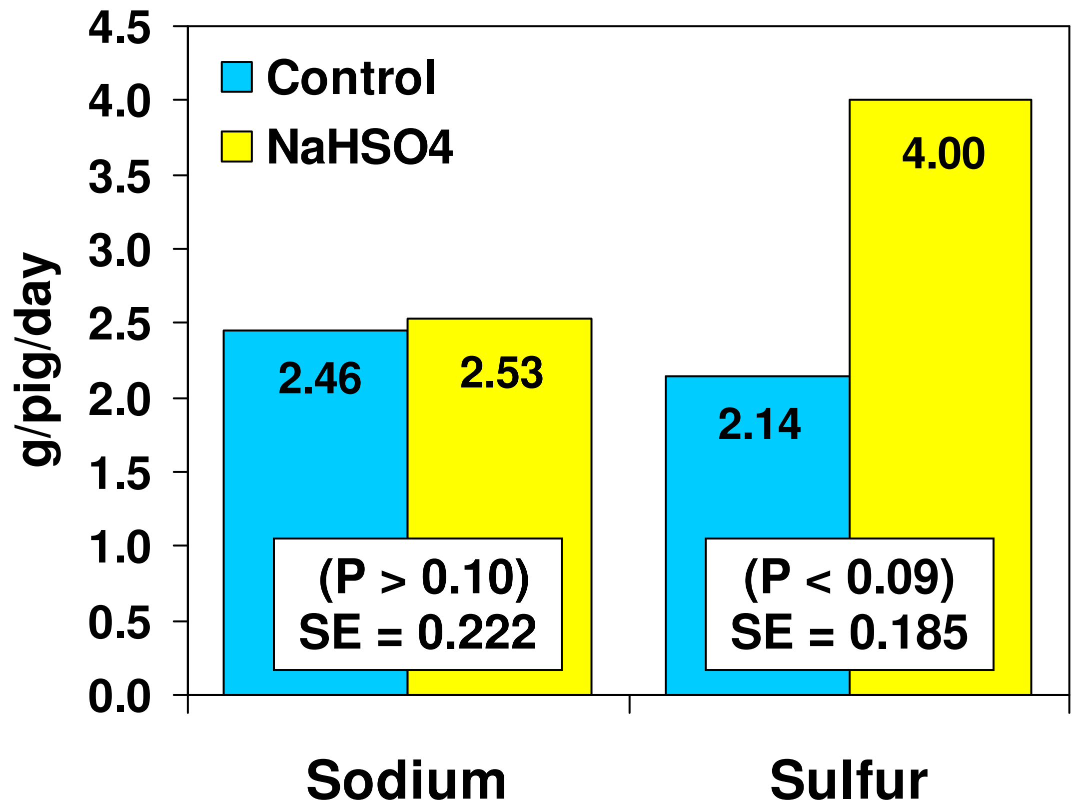


Figure 10. Pit volume, electrical conductivity, and pH during the entire 100-d finishing period of pigs fed control vs. $NaHSO_4$.

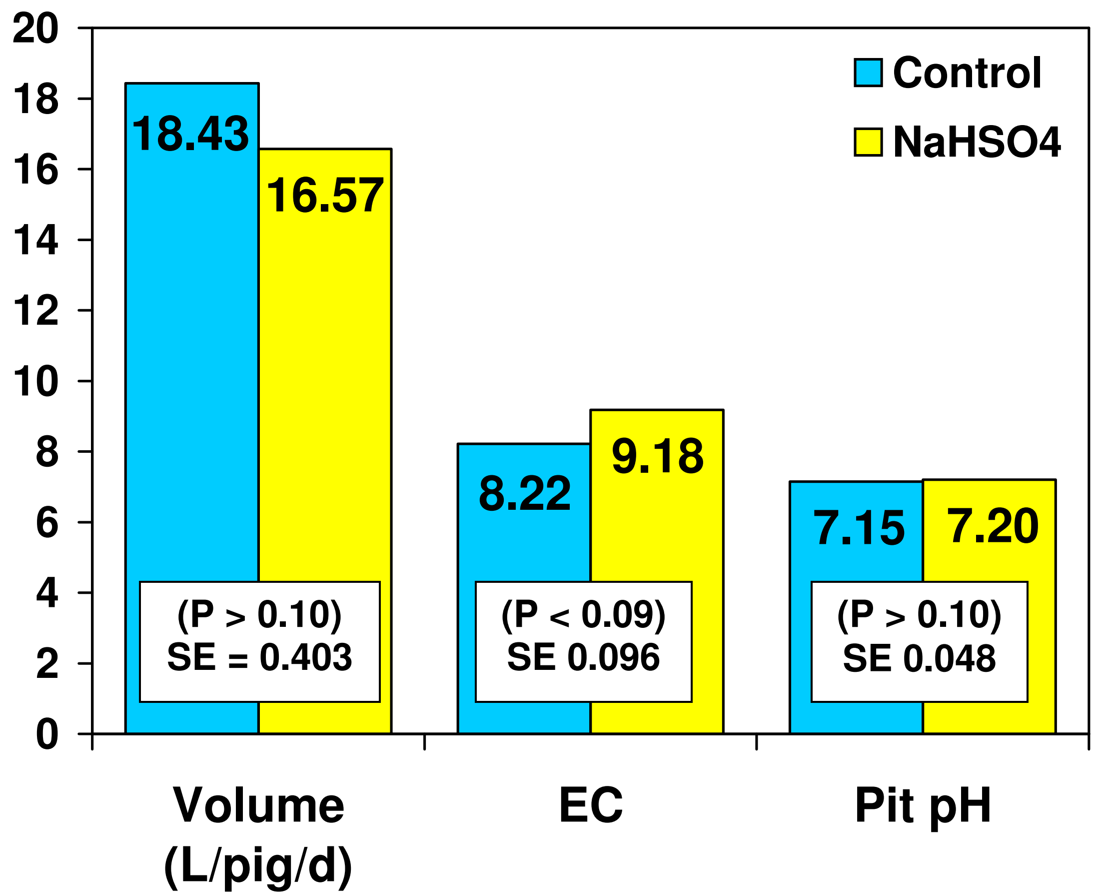


Figure 11. Ammonia emissions of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period.

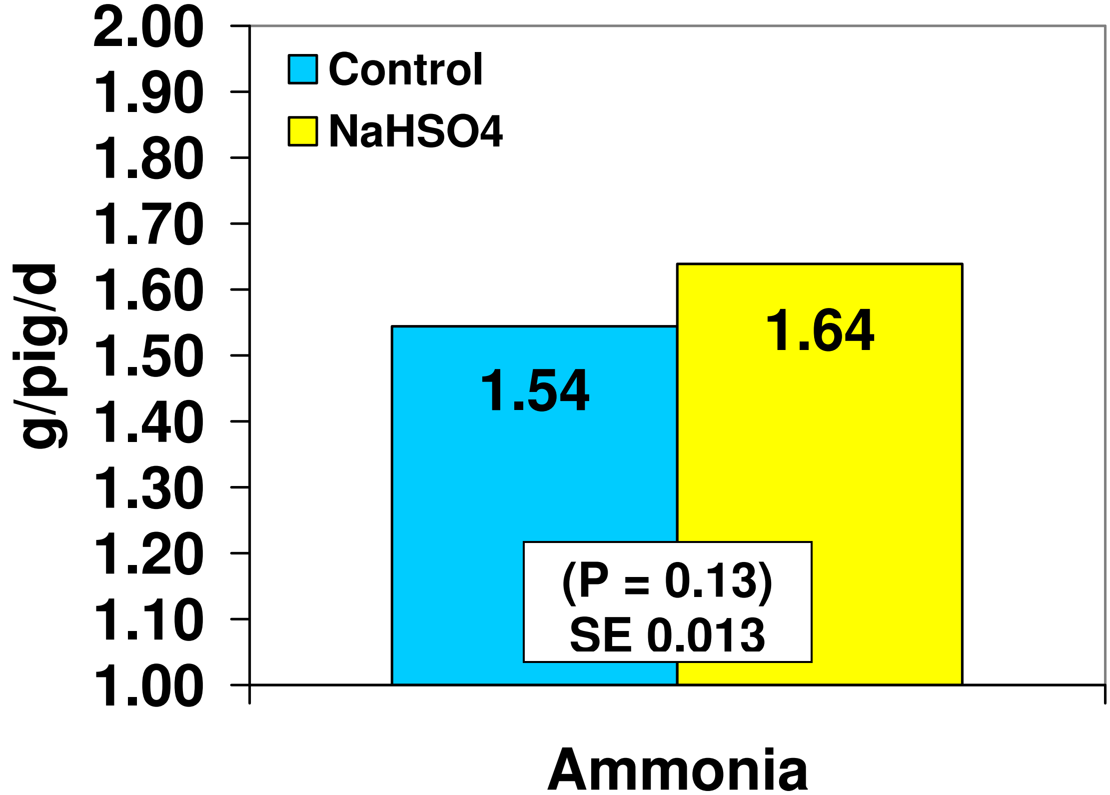


Figure 12. Hydrogen sulfide emissions of pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period.

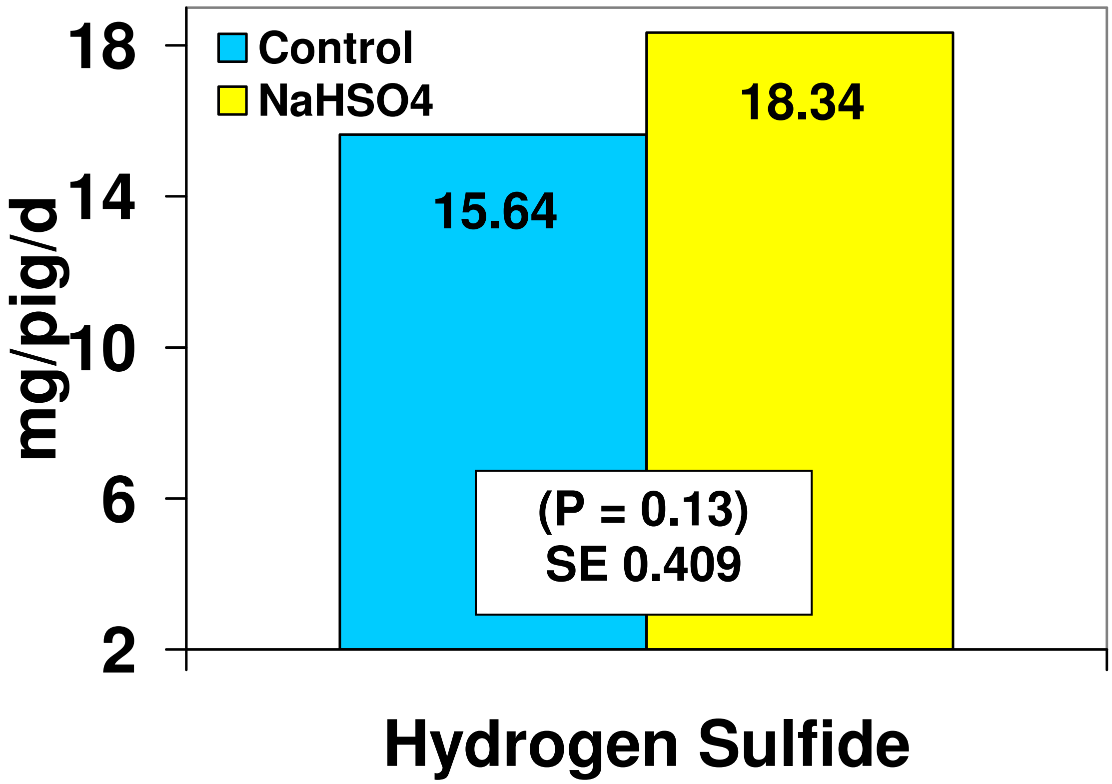


Table 6. Mineral excretion averaged over the entire 100-d finishing period.[a]

Diet	Ca g/d	K g/d	Mg g/d	Na g/d	S g/d	Fe mg/d	Zn mg/d	Cu mg/d	Mn mg/d	Ni mg/d	NH_4 g/d
Control	6.07	13.9	2.41	2.46	2.14	393	267	33.8	77.0	3.96	18.5
$NaHSO_4$	6.60	13.9	2.41	2.53	4.00	396	272	36.2	77.7	4.49	19.3
SE	0.35	1.43	0.24	0.22	0.19	33.7	30.0	1.99	7.94	0.74	1.42
P-value	0.48	0.99	0.99	0.86	0.09	0.96	0.94	0.55	0.96	0.70	0.76

[a] Least square means for 2 rooms/trt.

Table 7. Gaseous emissions from grow-finish pigs fed control vs. $NaHSO_4$ during the entire 100-d finishing period.[a]

Diet	NH_3 (mg/m^3)	NH_3 (mg/min)	NH_3 (mg/kg BW)	H_2S ($\mu g/m^3$)	H_2S (µg/kg BW)	Air Flow (L/sec)
Control	0.363	21.3	19.8	28.5	183.0	970.22
$NaHSO_4$	0.350	22.6	20.7	33.4	211.0	1048.66
SE	0.009	0.449	0.236	1.819	5.431	47.001
P-value	0.473	0.296	0.236	0.313	0.175	0.448

[a] Least square means for 2 rooms/trt.

Discussion

Many studies report dietary acidification for growing and finishing pigs will lend a reduction in urinary pH and sometimes slurry pH, translating to a reduction in NH_3 emissions from the slurry. Van Kempen (2001) conducted a study involving 1% adipic acid addition to diets of growing and finishing pigs to determine effects on urinary pH and NH_3 emissions. At 1 h post urine collection, van Kempen (2001) reported a 93% diminution in NH_3 emissions for pigs fed adipic acid as compared to control. In a second experiment van Kempen (2001) reported a 25% reduction in NH_3 emissions over a two week period in a pit recharge system. This suggests that more volatilization would occur in a deep pit system. It can be deduced that a reduction in urinary pH may delay ammonia emission, but because of the high buffering capacity of the feces (Canh et al., 1998), the volatilization will not cease indefinitely since the pH will not remain at a low enough level over time.

Temperature and pH are 2 main factors affecting NH_3 emissions. An equation created by Zhang et al. (1994) suggests that for every 1ºC increase in temperature, a 7-9% increase in NH_3 emissions will occur. Also, a 1 unit increase in pH will lend a 10 fold increase in NH_3 volatilization based on that same equation (increases will vary depending on initial temperature and pH).

Brok et al. (1999) investigated urinary pH and slurry pH from growing and finishing pigs fed an organic acid blend, primarily comprised of benzoic acid. This group reported a reduction in urinary pH of 7.5 to 5.69 for growing phases and 7.48 and 5.02 for finishing phases for control as compared to acidified diets, respectively. Trends for slurry pH were similar; although, not as drastic; 7.76 and 7.28 for growing phases and 7.82 and 7.04 for finishing phases for control vs. acidified diets, respectively. These results suggest a 40% reduction in NH_3 emissions for acid fed pigs compared to control. Due to this research and others concluding that dietary acidification can lead to an improvement in growth performance in nursery pigs, the idea that dietary acidification in grow-finish pigs may improve growth performance characteristics and translate some pH reductions in the gut to the slurry is proposed.

There are a variety of acids that have been utilized to reduce the pH of animal waste, but problems with some of these products have arisen (i.e., corrosiveness, high cost, and hazards to animal and human health; Rotz, 2004). Studies on $NaHSO_4$ as a poultry litter amendment have reported a reduction in ammonia volatilization (Blake and Hess, 2001). This reduction in NH_3 volatilization could be attributed to a diminished amount of NH_3 -generating bacteria that stem from a pH reduction (Terzich et al., 1998). Sun et al. (2008) stated that $NaHSO_4$ has an effect on the mitigation of NH_3 emissions as well as alcohol emissions from fresh dairy slurry. $NaHSO_4$ reduces NH_3 emissions via pH reduction. Free ammonium ions will form ammonium sulfate. Furthermore, excess sodium will bond to a phosphate (Terzich et al., 1998).

The present experiment did not result in a pH reduction in the slurry when using $NaHSO_4$ as a feed additive; therefore, NH_3 emissions were not reduced, but values were consistent with those reported by Lachmann et al. (2008) and Bundy et al. (2008). However, hydrogen sulfide emissions did have a numerical increase in rooms with pigs fed $NaHSO_4$. Confined Livestock Air Quality Committee (2000) stated that a main concern in regards to carbon fuels and combustion engines stem from the released sulfur compounds. These sulfur compounds react with NH_3 and form a large portion of the particulate matter of 2.5µ which is a major concern for public health. With this information, it is important when going forward with research in dietary acids in regards to mitigating environmental impact, that sulfur emissions are investigated in addition to NH_3 emissions.

CHAPTER V

CONCLUSION

Feeding acidifiers to weanling pigs has become an increasingly common practice especially in the European Union because of their use of acidifiers as an antibiotic substitute. In addition, dietary acidification during the nursery period has been reported to have growth-promoting effects. As legislation on feeding subtherapeutic antibiotics continues to become more stringent, the need for acidifiers as an antibiotic substitute will become increasingly pertinent. Sodium bisulfate, when fed to weanling pigs, led to improved average daily gain and feed efficiency; however, its effects on growth performance fed in the absence of subtherapeutic antibiotics are currently unknown.

Dietary acidification is also a strategy utilized during the growing and finishing phases of swine production in order to decrease slurry pH, in turn reducing ammonia volatilization. Many dietary acidifiers drastically reduce urinary pH and slightly reduce slurry pH, or sometimes not at all. The buffering capacity of the slurry many times may allow a decreased urinary pH to become negligible once in the pit. Sodium bisulfate addition to growing and finishing pig diets did not alter growth performance or any pit characteristics. Because slurry pH was not affected, ammonia volatilization was also not reduced for pigs fed $NaHSO_4$.

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APPENDIX

Appendix Table 8

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 1.

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	9.245	11.845	0.327	0.450	0.724
1	2	8.495	11.436	0.368	0.482	0.762
1	3	6.227	8.564	0.291	0.414	0.706
1	4	7.545	10.318	0.345	0.450	0.770
1	5	5.864	7.836	0.245	0.318	0.771
2	1	9.336	12.336	0.377	0.482	0.780
2	2	8.036	10.891	0.359	0.486	0.732
2	3	6.255	8.136	0.236	0.323	0.726
2	4	7.136	9.555	0.305	0.327	0.920
2	5	5.755	7.845	0.264	0.336	0.776
3	1	9.382	12.536	0.395	0.509	0.772
3	2	8.118	11.445	0.418	0.491	0.844
3	3	6.282	8.795	0.314	0.441	0.715
3	4	7.645	10.545	0.364	0.445	0.818
3	5	5.900	7.873	0.245	0.323	0.765
4	1	9.055	12.118	0.382	0.477	0.805
4	2	8.336	11.191	0.359	0.473	0.754
4	3	6.073	8.155	0.259	0.368	0.706
4	4	7.555	10.059	0.314	0.332	0.949
4	5	6.109	8.364	0.282	0.341	0.829

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 9

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 1.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	7	21.657	36.465	0.035	0.054	0.008
Rep	4	37.788	63.096	0.056	0.085	0.012
Trt	3	0.151	0.957	0.007	0.013	0.003
Linear	1	0.001	0.104	0.001	0.002	0.008
Quad	1	0.042	0.169	0.007	0.003	0.001
Cubic	1	0.410	2.597	0.013	0.034	0.001
Error	12	0.140	0.375	0.003	0.007	0.002
CV%		2.294	2.785	7.675	8.892	5.835

Appendix Table 10

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 1.

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	11.845	19.673	0.559	0.918	0.906
1	2	11.436	19.691	0.591	0.877	0.671
1	3	8.564	14.891	0.450	0.682	0.663
1	4	10.318	16.218	0.423	0.714	0.592
1	5	7.836	12.918	0.364	0.568	0.640
2	1	12.336	20.127	0.555	0.859	0.648
2	2	10.891	18.555	0.545	0.795	0.688
2	3	8.136	15.945	0.559	0.568	0.985
2	4	9.555	15.036	0.391	0.659	0.595
2	5	7.845	13.491	0.405	0.632	0.639
3	1	12.536	20.877	0.595	0.882	0.676
3	2	11.445	19.782	0.595	0.859	0.692
3	3	8.795	15.300	0.464	0.682	0.682
3	4	10.545	16.564	0.432	0.727	0.593
3	5	7.873	12.923	0.814	0.532	0.670
4	1	12.118	20.191	0.577	0.864	0.667
4	2	11.191	19.127	0.568	0.850	0.669
4	3	8.155	14.555	0.459	0.664	0.689
4	4	10.059	15.059	0.359	0.573	0.621
4	5	8.364	13.682	0.382	0.600	0.634

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 11

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 1.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	7	36.465	95.511	0.096	0.193	0.010
Rep	4	63.096	166.063	0.165	0.329	0.013
Trt	3	0.957	1.441	0.003	0.013	0.005
Linear	1	0.104	0.126	0.002	0.010	0.000
Quad	1	0.169	2.281	0.006	0.002	0.006
Cubic	1	2.597	1.915	0.000	0.026	0.010
Error	12	0.375	1.723	0.005	0.011	0.005
CV%		2.785	3.556	6.948	6.565	10.615

Appendix Table 12

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 1.

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	19.673	32.755	0.623	1.118	0.557
1	2	19.691	33.227	0.645	1.164	0.555
1	3	14.891	26.773	0.564	0.973	0.581
1	4	16.218	27.718	0.545	0.955	0.575
1	5	12.918	22.745	0.468	0.823	0.569
2	1	20.127	33.336	0.627	1.109	0.567
2	2	18.555	32.336	0.655	1.145	0.573
2	3	15.945	28.423	0.595	1.055	0.563
2	4	15.036	26.391	0.541	0.923	0.585
2	5	13.491	23.518	0.477	0.836	0.572
3	1	20.877	34.173	0.632	1.136	0.557
3	2	19.782	33.027	0.632	1.127	0.559
3	3	15.300	28.000	0.605	1.041	0.581
3	4	16.564	27.736	0.532	0.923	0.576
3	5	12.882	23.445	0.505	0.845	0.596
4	1	20.191	33.655	0.641	1.150	0.557
4	2	19.127	31.627	0.595	1.141	0.522
4	3	14.555	26.991	0.591	1.000	0.593
4	4	15.059	26.941	0.564	0.982	0.577
4	5	13.682	23.073	0.900	0.836	0.535

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 13

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 1.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	7	95.511	199.155	0.049	0.185	0.000
Rep	4	166.063	346.290	0.085	0.323	0.000
Trt	3	1.441	2.974	0.001	0.001	0.001
Linear	1	0.126	0.397	0.000	0.003	0.000
Quad	1	2.281	6.892	0.003	0.000	0.000
Cubic	1	1.915	1.633	0.000	0.000	0.000
Error	12	1.713	1.751	0.002	0.003	0.000
CV%		3.556	2.089	3.466	2.549	2.792

Appendix Table 14

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for the entirety of Experiment 1 (Phases II – IV).

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	9.245	32.755	0.545	0.927	0.588
1	2	8.495	33.227	0.577	0.945	0.610
1	3	6.227	26.773	0.477	0.773	0.617
1	4	7.545	27.718	0.468	0.782	0.601
1	5	5.864	22.745	0.391	0.645	0.608
2	1	9.336	33.336	0.559	0.909	0.613
2	2	8.036	32.336	0.564	0.909	0.622
2	3	6.255	28.423	0.514	0.732	0.706
2	4	7.136	26.391	0.450	0.727	0.616
2	5	5.755	23.518	0.414	0.677	0.611
3	1	9.382	34.173	0.577	0.845	0.684
3	2	8.118	33.027	0.577	0.923	0.628
3	3	6.282	28.000	0.505	0.814	0.622
3	4	7.645	27.455	0.459	0.768	0.599
3	5	5.900	23.445	0.409	0.645	0.632
4	1	9.055	33.655	0.573	0.932	0.614
4	2	8.336	31.627	0.541	0.923	0.588
4	3	6.073	26.991	0.486	0.764	0.638
4	4	7.555	26.941	0.450	0.718	0.628
4	5	6.109	23.073	0.395	0.668	0.592

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 15

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for the entirety of Experiment 1 (Phases II – IV).

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	7	21.657	199.609	0.055	0.138	0.001
Rep	4	37.788	347.399	0.095	0.240	0.001
Trt	3	0.151	2.555	0.001	0.002	0.001
Linear	1	0.001	0.428	0.000	0.001	0.000
Quad	1	0.042	5.986	0.004	0.003	0.003
Cubic	1	0.410	1.253	0.000	0.003	0.000
Error	12	0.140	1.757	0.001	0.004	0.001
CV%		2.294	2.093	2.640	3.790	4.477

Appendix Table 16

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase I of Experiment 2.

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	6	7.545	8.545	0.141	0.141	1.01
1	7	6.545	7.600	0.150	0.168	0.90
1	8	5.618	6.282	0.095	0.091	1.06
1	9	7.145	8.391	0.177	0.223	0.78
1	10	5.764	7.100	0.191	0.191	0.74
1	11	4.668	5.927	0.182	0.173	0.63
2	6	7.573	8.236	0.095	0.123	0.88
2	7	6.509	7.482	0.141	0.186	0.90
2	8	5.591	6.018	0.059	0.095	1.04
2	9	7.100	7.864	0.109	0.186	0.32
2	10	5.791	7.282	0.214	0.214	0.80
2	11	4.695	6.395	0.241	0.227	0.90
3	6	7.491	8.500	0.145	0.164	0.80
3	7	6.509	7.464	0.136	0.150	1.00
3	8	5.618	6.682	0.150	0.145	1.03
3	9	7.136	7.900	0.109	0.150	0.59
3	10	5.764	6.545	0.114	0.159	1.01
3	11	4.759	6.345	0.227	0.191	1.08
4	6	7.555	7.764	0.032	0.095	0.73
4	7	6.564	7.364	0.114	0.141	0.70
4	8	5.655	6.509	0.123	0.136	1.08
4	9	7.118	7.918	0.114	0.145	0.79
4	10	5.755	7.273	0.218	0.236	0.91
4	11	4.777	6.182	0.200	0.232	0.86

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 17

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase I of Experiment 2.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	8	13.214	8.625	0.024	0.016	0.053
Rep	5	21.140	13.741	0.037	0.025	0.053
Trt	3	0.005	0.099	0.003	0.001	0.052
Linear	1	0.010	0.224	0.006	0.000	0.085
Quad	1	0.004	0.010	0.000	0.000	0.001
Cubic	1	0.000	0.63	0.001	0.002	0.069
Error	15	0.005	0.414	0.008	0.005	0.026
CV%		0.511	4.042	27.910	19.279	18.895

Appendix Table 18

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 2.

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	6	8.545	10.682	0.427	0.532	0.805
1	7	7.600	9.445	0.368	0.464	0.796
1	8	6.282	7.845	0.314	0.400	0.778
1	9	8.391	10.964	0.427	0.455	0.926
1	10	7.100	9.045	0.323	0.386	0.751
1	11	5.927	7.627	0.282	0.350	0.836
2	6	8.236	10.409	0.436	0.468	0.823
2	7	7.482	8.964	0.295	0.395	0.708
2	8	6.018	7.691	0.336	0.400	0.809
2	9	7.864	10.318	0.409	0.414	0.955
2	10	7.282	9.464	0.364	0.432	0.912
2	11	6.395	8.836	0.409	0.423	0.863
3	6	8.500	10.445	0.391	0.473	0.943
3	7	7.464	9.009	0.309	0.436	0.836
3	8	6.682	8.718	0.409	0.505	0.812
3	9	7.900	10.745	0.473	0.573	0.993
3	10	6.545	8.627	0.345	0.386	0.842
3	11	6.345	8.382	0.341	0.409	0.968
4	6	7.764	9.909	0.427	0.450	0.828
4	7	7.364	9.255	0.377	0.414	0.895
4	8	6.509	8.400	0.377	0.436	0.835
4	9	7.918	10.600	0.445	0.541	0.829
4	10	7.273	9.800	0.423	0.436	0.965
4	11	6.182	8.505	0.386	0.423	0.916

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 19

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase II of Experiment 2.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	8	8.625	12.641	0.024	0.021	0.009
Rep	5	13.741	20.152	0.032	0.028	0.007
Trt	3	0.099	0.122	0.012	0.010	0.012
Linear	1	0.224	0.353	0.035	0.011	0.012
Quad	1	0.010	0.011	0.000	0.003	0.003
Cubic	1	0.063	0.002	0.001	0.016	0.020
Error	15	0.414	0.923	0.007	0.010	0.004
CV%		4.042	4.685	9.979	10.067	7.127

Appendix Table 20

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 2.

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	6	10.682	16.473	0.386	0.645	0.600
1	7	9.445	15.909	0.432	0.655	0.656
1	8	7.845	13.682	0.391	0.627	0.622
1	9	10.964	17.509	0.468	0.786	0.665
1	10	9.045	14.891	0.418	0.686	0.590
1	11	7.627	12.777	0.368	0.745	0.631
2	6	10.409	17.045	0.441	0.664	0.620
2	7	8.964	14.400	0.364	0.614	0.690
2	8	7.691	14.264	0.436	0.695	0.671
2	9	10.318	16.164	0.418	0.700	0.653
2	10	9.464	15.982	0.464	0.714	0.671
2	11	8.836	14.332	0.391	0.718	0.665
3	6	10.445	16.573	0.409	0.659	0.595
3	7	9.009	15.827	0.455	0.659	0.607
3	8	8.718	15.482	0.450	0.673	0.492
3	9	10.745	17.536	0.486	0.850	0.595
3	10	8.627	13.923	0.377	0.623	0.652
3	11	8.382	14.150	0.414	0.736	0.545
4	6	9.909	16.355	0.432	0.659	0.569
4	7	9.255	15.800	0.436	0.650	0.606
4	8	8.400	14.909	0.432	0.655	0.560
4	9	10.600	17.055	0.459	0.823	0.561
4	10	9.800	15.718	0.423	0.723	0.585
4	11	8.505	14.164	0.405	0.741	0.544

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 21

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase III of Experiment 2.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	8	12.641	18.276	0.006	0.040	0.005
Rep	5	20.152	28.482	0.008	0.061	0.008
Trt	3	0.122	1.265	0.003	0.003	0.001
Linear	1	0.353	3.387	0.007	0.007	0.001
Quad	1	0.011	0.334	0.002	0.000	0.001
Cubic	1	0.002	0.074	0.000	0.002	0.000
Error	15	0.923	2.672	0.005	0.007	0.001
CV%		4.685	4.808	7.229	5.414	5.036

Appendix Table 22

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 2.

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	6	16.473	23.800	0.523	1.009	0.519
1	7	15.909	23.309	0.527	0.995	0.532
1	8	13.682	20.718	0.505	0.964	0.521
1	9	17.509	25.155	0.545	0.955	0.524
1	10	14.891	22.236	0.523	0.873	0.542
1	11	12.777	19.818	0.505	0.818	0.595
2	6	17.045	24.127	0.505	0.964	0.535
2	7	14.400	21.773	0.527	0.973	0.561
2	8	14.264	21.818	0.541	0.909	0.576
2	9	16.164	23.009	0.491	0.800	0.548
2	10	15.982	23.018	0.505	0.868	0.594
2	11	14.332	22.273	0.568	0.909	0.572
3	6	16.573	23.173	0.473	0.882	0.572
3	7	15.827	22.600	0.482	0.864	0.600
3	8	15.482	23.536	0.577	1.000	0.615
3	9	17.536	25.318	0.555	0.968	0.612
3	10	13.923	21.309	0.527	0.868	0.578
3	11	14.150	22.032	0.564	0.932	0.625
4	6	16.355	24.227	0.564	1.027	0.573
4	7	15.800	23.809	0.573	0.964	0.608
4	8	14.909	22.545	0.545	0.955	0.603
4	9	17.055	25.182	0.582	0.950	0.612
4	10	15.718	23.736	0.573	0.950	0.603
4	11	14.164	21.677	0.536	0.927	0.578

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 23

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over Phase IV of Experiment 2.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	8	18.276	18.547	0.005	0.020	0.002
Rep	5	28.482	26.126	0.002	0.022	0.003
Trt	3	1.265	5.915	0.011	0.018	0.001
Linear	1	3.387	17.591	0.029	0.021	0.001
Quad	1	0.334	0.058	0.003	0.029	0.000
Cubic	1	0.074	0.095	0.000	0.004	0.000
Error	15	2.672	4.605	0.005	0.015	0.000
CV%		4.808	4.255	5.715	6.078	3.761

Appendix Table 24

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases II - IV).

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	6	8.545	23.800	0.450	0.777	0.577
1	7	7.600	23.309	0.464	0.768	0.602
1	8	6.282	20.718	0.423	0.732	0.580
1	9	8.391	25.155	0.491	0.795	0.615
1	10	7.100	22.236	0.445	0.714	0.577
1	11	5.927	19.818	0.409	0.705	0.634
2	6	8.236	24.127	0.468	0.759	0.597
2	7	7.482	21.773	0.418	0.727	0.627
2	8	6.018	21.818	0.464	0.732	0.634
2	9	7.864	23.009	0.445	0.691	0.622
2	10	7.282	23.018	0.464	0.727	0.654
2	11	6.395	22.273	0.468	0.745	0.633
3	6	8.500	23.173	0.432	0.723	0.619
3	7	7.464	22.600	0.445	0.709	0.625
3	8	6.682	23.536	0.495	0.782	0.578
3	9	7.900	25.318	0.514	0.850	0.645
3	10	6.545	21.309	0.436	0.682	0.636
3	11	6.345	22.032	0.464	0.759	0.627
4	6	7.764	24.227	0.486	0.777	0.602
4	7	7.364	23.809	0.482	0.741	0.636
4	8	6.509	22.545	0.473	0.745	0.608
4	9	7.918	25.182	0.509	0.823	0.616
4	10	7.273	23.736	0.486	0.764	0.632
4	11	6.182	21.677	0.455	0.764	0.597

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 25

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases II - IV).

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	8	8.620	18.547	0.005	0.009	0.001
Rep	5	13.741	26.126	0.004	0.010	0.001
Trt	3	0.099	5.915	0.007	0.007	0.001
Linear	1	0.224	17.591	0.020	0.012	0.002
Quad	1	0.010	0.058	0.000	0.005	0.001
Cubic	1	0.063	0.095	0.000	0.005	0.001
Error	15	0.414	4.605	0.003	0.007	0.000
CV%		4.042	4.255	5.340	5.010	3.236

Appendix Table 26

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases I - IV).

Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	6	7.545	23.800	0.395	0.668	0.593
1	7	6.545	23.309	0.409	0.664	0.615
1	8	5.618	20.718	0.368	0.623	0.592
1	9	7.145	25.155	0.441	0.700	0.620
1	10	5.764	22.236	0.400	0.623	0.585
1	11	4.668	19.818	0.368	0.614	0.643
2	6	7.573	24.127	0.405	0.650	0.609
2	7	6.509	21.773	0.373	0.636	0.638
2	8	5.591	21.818	0.395	0.618	0.649
2	9	7.100	23.009	0.386	0.605	0.614
2	10	5.791	23.018	0.418	0.641	0.668
2	11	4.695	22.273	0.427	0.655	0.643
3	6	7.491	23.173	0.382	0.627	0.628
3	7	6.509	22.600	0.391	0.614	0.645
3	8	5.618	23.536	0.436	0.673	0.600
3	9	7.136	25.318	0.445	0.732	0.642
3	10	5.764	21.309	0.377	0.595	0.657
3	11	4.759	22.032	0.423	0.664	0.654
4	6	7.555	24.227	0.405	0.664	0.606
4	7	6.564	23.809	0.423	0.627	0.639
4	8	5.655	22.545	0.414	0.641	0.636
4	9	7.118	25.182	0.441	0.709	0.622
4	10	5.755	23.736	0.436	0.677	0.649
4	11	4.777	21.677	0.414	0.673	0.613

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 27

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiment 2 (Phases I - IV).

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	8	13.214	18.547	0.003	0.006	0.001
Rep	5	21.140	26.126	0.003	0.007	0.001
Trt	3	0.005	5.915	0.004	0.005	0.000
Linear	1	0.010	17.591	0.011	0.008	0.001
Quad	1	0.004	0.058	0.000	0.003	0.000
Cubic	1	0.000	0.095	0.000	0.003	0.000
Error	15	0.005	4.605	0.003	0.005	0.000
CV%		0.511	4.255	5.862	5.077	3.402

Appendix Table 28

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs in Experiments 1 and 2 during Phase II.

Exp	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	1	9.245	11.845	0.327	0.450	0.724
1	1	2	8.495	11.436	0.368	0.482	0.762
1	1	3	6.227	8.564	0.291	0.414	0.706
1	1	4	7.545	10.318	0.345	0.450	0.770
1	1	5	5.864	7.836	0.245	0.318	0.771
1	2	1	9.336	12.336	0.377	0.482	0.780
1	2	2	8.036	10.891	0.359	0.486	0.732
1	2	3	6.255	8.136	0.236	0.323	0.726
1	2	4	7.136	9.555	0.305	0.327	0.920
1	2	5	5.755	7.845	0.264	0.336	0.776
1	3	1	9.382	12.536	0.395	0.509	0.772
1	3	2	8.118	11.445	0.418	0.491	0.844
1	3	3	6.282	8.795	0.314	0.441	0.715
1	3	4	7.645	10.545	0.364	0.445	0.818
1	3	5	5.900	7.873	0.245	0.323	0.765
1	4	1	9.055	12.118	0.382	0.477	0.805
1	4	2	8.336	11.191	0.359	0.473	0.754
1	4	3	6.073	8.155	0.259	0.368	0.706
1	4	4	7.555	10.059	0.314	0.332	0.949
1	4	5	6.109	8.364	0.282	0.341	0.829
2	1	6	8.545	10.682	0.427	0.532	0.805
2	1	7	7.600	9.445	0.368	0.464	0.796
2	1	8	6.282	7.845	0.314	0.400	0.778
2	1	9	8.391	10.964	0.427	0.455	0.943
2	1	10	7.100	9.045	0.323	0.386	0.836
2	1	11	5.927	7.627	0.282	0.350	0.812
2	2	6	8.236	10.409	0.436	0.468	0.926
2	2	7	7.482	8.964	0.295	0.395	0.751
2	2	8	6.018	7.691	0.336	0.400	0.836
2	2	9	7.864	10.318	0.409	0.414	0.993
2	2	10	7.282	9.464	0.364	0.432	0.842
2	2	11	6.395	8.836	0.409	0.423	0.968
2	3	6	8.500	10.445	0.391	0.473	0.823
2	3	7	7.464	9.009	0.309	0.436	0.708
2	3	8	6.682	8.718	0.409	0.505	0.809
2	3	9	7.900	10.745	0.473	0.573	0.828
2	3	10	6.545	8.627	0.345	0.386	0.895
2	3	11	6.345	8.382	0.341	0.409	0.835
2	4	6	7.764	9.909	0.427	0.450	0.955

2	4	7	7.364	9.255	0.377	0.414	0.912
2	4	8	6.509	8.400	0.377	0.436	0.863
2	4	9	7.918	10.600	0.445	0.541	0.829
2	4	10	7.273	9.800	0.423	0.436	0.965
2	4	11	6.182	8.505	0.386	0.423	0.916

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 29

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs in Experiments 1 and 2 during Phase II.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	13	17.093	29.131	0.045	0.045	0.015
Rep	10	22.167	37.700	0.055	0.052	0.016
Trt	3	0.179	0.572	0.011	0.019	0.012
Linear	1	0.111	0.431	0.026	0.002	0.020
Quad	1	0.045	0.040	0.003	0.007	0.000
Cubic	1	0.380	1.245	0.003	0.048	0.017
Error	30	0.270	0.662	0.005	0.008	0.005
CV%		3.228	3.842	9.537	9.386	8.156

Appendix Table 30

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase III.

Exp	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	1	11.845	19.673	0.559	0.918	0.609
1	1	2	11.436	19.691	0.591	0.877	0.671
1	1	3	8.564	14.891	0.450	0.682	0.663
1	1	4	10.318	16.218	0.423	0.714	0.592
1	1	5	7.836	12.918	0.364	0.568	0.640
1	2	1	12.336	20.127	0.555	0.859	0.648
1	2	2	10.891	18.555	0.545	0.795	0.688
1	2	3	8.136	15.945	0.559	0.568	0.985
1	2	4	9.555	15.036	0.391	0.659	0.595
1	2	5	7.845	13.491	0.405	0.632	0.639
1	3	1	12.536	20.877	0.595	0.882	0.676
1	3	2	11.445	19.782	0.595	0.859	0.692
1	3	3	8.795	15.300	0.464	0.682	0.682
1	3	4	10.545	16.564	0.432	0.727	0.593
1	3	5	7.873	12.923	0.814	0.532	0.670
1	4	1	12.118	20.191	0.577	0.864	0.667
1	4	2	11.191	19.127	0.568	0.850	0.669
1	4	3	8.155	14.555	0.459	0.664	0.689
1	4	4	10.059	15.059	0.359	0.573	0.621
1	4	5	8.364	13.682	0.382	0.600	0.634
2	1	6	10.682	16.473	0.386	0.645	0.600
2	1	7	9.445	15.909	0.432	0.655	0.656
2	1	8	7.845	13.682	0.391	0.627	0.622
2	1	9	10.964	17.509	0.468	0.786	0.595
2	1	10	9.045	14.891	0.418	0.686	0.607
2	1	11	7.627	12.777	0.368	0.745	0.492
2	2	6	10.409	17.045	0.441	0.664	0.665
2	2	7	8.964	14.400	0.364	0.614	0.590
2	2	8	7.691	14.264	0.436	0.695	0.631
2	2	9	10.318	16.164	0.418	0.700	0.595
2	2	10	9.464	15.982	0.464	0.714	0.652
2	2	11	8.836	14.332	0.391	0.718	0.545
2	3	6	10.445	16.573	0.409	0.659	0.620
2	3	7	9.009	15.827	0.455	0.659	0.690
2	3	8	8.718	15.482	0.450	0.673	0.671
2	3	9	10.745	17.536	0.486	0.850	0.569
2	3	10	8.627	13.923	0.377	0.623	0.606
2	3	11	8.382	14.150	0.414	0.736	0.560
2	4	6	9.909	16.355	0.432	0.659	0.653

2	4	7	9.255	15.800	0.436	0.650	0.671
2	4	8	8.400	14.909	0.432	0.655	0.665
2	4	9	10.600	17.055	0.459	0.823	0.561
2	4	10	9.800	15.718	0.423	0.723	0.585
2	4	11	8.505	14.164	0.405	0.741	0.544

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 31

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase III.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	13	29.131	68.992	0.069	0.130	0.014
Rep	10	37.700	89.226	0.088	0.167	0.020
Trt	3	0.572	1.543	0.003	0.007	0.003
Linear	1	0.431	1.254	0.001	0.000	0.000
Quad	1	0.040	2.088	0.007	0.002	0.006
Cubic	1	1.245	1.286	0.000	0.020	0.005
Error	30	0.662	2.138	0.005	0.009	0.003
CV%		3.842	4.145	6.949	5.968	8.773

Appendix Table 32

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase IV.

Exp	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	1	19.673	32.755	0.623	1.118	0.557
1	1	2	19.691	33.227	0.645	1.164	0.555
1	1	3	14.891	26.773	0.564	0.973	0.581
1	1	4	16.218	27.718	0.545	0.955	0.575
1	1	5	12.918	22.745	0.468	0.823	0.569
1	2	1	20.127	33.336	0.627	1.109	0.567
1	2	2	18.555	32.336	0.655	1.145	0.573
1	2	3	15.945	28.423	0.595	1.055	0.563
1	2	4	15.036	26.391	0.541	0.923	0.585
1	2	5	13.491	23.518	0.477	0.836	0.572
1	3	1	20.877	34.173	0.632	1.136	0.557
1	3	2	19.782	33.027	0.632	1.127	0.559
1	3	3	15.300	28.000	0.605	1.041	0.581
1	3	4	16.564	27.736	0.532	0.923	0.576
1	3	5	12.882	23.445	0.505	0.845	0.596
1	4	1	20.191	33.655	0.641	1.150	0.557
1	4	2	19.127	31.627	0.595	1.141	0.522
1	4	3	14.555	26.991	0.591	1.000	0.593
1	4	4	15.059	26.941	0.564	0.982	0.577
1	4	5	13.682	23.073	0.900	0.836	0.535
2	1	6	16.473	23.800	0.523	1.009	0.519
2	1	7	15.909	23.309	0.527	0.995	0.532
2	1	8	13.682	20.718	0.505	0.964	0.521
2	1	9	17.509	25.155	0.545	0.955	0.572
2	1	10	14.891	22.236	0.523	0.873	0.600
2	1	11	12.777	19.818	0.505	0.818	0.615
2	2	6	17.045	24.127	0.505	0.964	0.524
2	2	7	14.400	21.773	0.527	0.973	0.542
2	2	8	14.264	21.818	0.541	0.909	0.595
2	2	9	16.164	23.009	0.491	0.800	0.612
2	2	10	15.982	23.018	0.505	0.868	0.578
2	2	11	14.332	22.273	0.568	0.909	0.625
2	3	6	16.573	23.173	0.473	0.882	0.535
2	3	7	15.827	22.600	0.482	0.864	0.561
2	3	8	15.482	23.536	0.577	1.000	0.576
2	3	9	17.536	25.318	0.555	0.968	0.573
2	3	10	13.923	21.309	0.527	0.868	0.608
2	3	11	14.150	22.032	0.564	0.932	0.603
2	4	6	16.355	24.227	0.564	1.027	0.548

2	4	7	15.800	23.809	0.573	0.964	0.594
2	4	8	14.909	22.545	0.545	0.955	0.572
2	4	9	17.055	25.182	0.582	0.950	0.612
2	4	10	15.718	23.736	0.573	0.950	0.603
2	4	11	14.164	21.677	0.536	0.927	0.578

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 33

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phase IV.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	13	68.992	257.361	0.035	0.139	0.002
Rep	10	89.226	333.483	0.044	0.177	0.003
Trt	3	1.543	3.621	0.004	0.012	0.000
Linear	1	1.254	7.143	0.013	0.020	0.000
Quad	1	2.088	2.536	0.000	0.015	0.001
Cubic	1	1.286	1.186	0.000	0.002	0.000
Error	30	2.138	3.529	0.004	0.010	0.000
CV%		4.145	3.337	5.045	4.628	3.732

Appendix Table 34

Pen means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs for Experiments 1 and 2 during Phases II - IV.

Exp	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	1	1	9.245	32.755	0.545	0.927	0.588
1	1	2	8.495	33.227	0.577	0.945	0.610
1	1	3	6.227	26.773	0.477	0.773	0.617
1	1	4	7.545	27.718	0.468	0.782	0.601
1	1	5	5.864	22.745	0.391	0.645	0.608
1	2	1	9.336	33.336	0.559	0.909	0.613
1	2	2	8.036	32.336	0.564	0.909	0.622
1	2	3	6.255	28.423	0.514	0.732	0.706
1	2	4	7.136	26.391	0.450	0.727	0.616
1	2	5	5.755	23.518	0.414	0.677	0.611
1	3	1	9.382	34.173	0.577	0.845	0.684
1	3	2	8.118	33.027	0.577	0.923	0.628
1	3	3	6.282	28.000	0.505	0.814	0.622
1	3	4	7.645	27.455	0.459	0.768	0.599
1	3	5	5.900	23.445	0.409	0.645	0.632
1	4	1	9.055	33.655	0.573	0.932	0.614
1	4	2	8.336	31.627	0.541	0.923	0.588
1	4	3	6.073	26.991	0.486	0.764	0.638
1	4	4	7.555	26.941	0.450	0.718	0.628
1	4	5	6.109	23.073	0.395	0.668	0.592
2	1	6	8.545	23.800	0.450	0.777	0.577
2	1	7	7.600	23.309	0.464	0.768	0.602
2	1	8	6.282	20.718	0.423	0.732	0.580
2	1	9	8.391	25.155	0.491	0.795	0.619
2	1	10	7.100	22.236	0.445	0.714	0.625
2	1	11	5.927	19.818	0.409	0.705	0.578
2	2	6	8.236	24.127	0.468	0.759	0.615
2	2	7	7.482	21.773	0.418	0.727	0.577
2	2	8	6.018	21.818	0.464	0.732	0.634
2	2	9	7.864	23.009	0.445	0.691	0.645
2	2	10	7.282	23.018	0.464	0.727	0.636
2	2	11	6.395	22.273	0.468	0.745	0.627
2	3	6	8.500	23.173	0.432	0.723	0.597
2	3	7	7.464	22.600	0.445	0.709	0.627
2	3	8	6.682	23.536	0.495	0.782	0.634
2	3	9	7.900	25.318	0.514	0.850	0.602
2	3	10	6.545	21.309	0.436	0.682	0.636
2	3	11	6.345	22.032	0.464	0.759	0.608
2	4	6	7.764	24.227	0.486	0.777	0.622

2	4	7	7.364	23.809	0.482	0.741	0.654
2	4	8	6.509	22.545	0.473	0.745	0.633
2	4	9	7.918	25.182	0.509	0.823	0.616
2	4	10	7.273	23.736	0.486	0.764	0.632
2	4	11	6.182	21.677	0.455	0.764	0.597

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.2% $NaHSO_4$
Trt 3: Fortified corn-soybean meal diet with 0.4% $NaHSO_4$
Trt 4: Fortified corn-soybean meal diet with 0.8% $NaHSO_4$

Appendix Table 35

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for weanling pigs over the entirety of Experiments 1 and 2 during Phases II -IV.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	13	17.093	256.980	0.036	0.090	0.001
Rep	10	22.167	333.055	0.046	0.116	0.001
Trt	3	0.179	3.396	0.003	0.007	0.002
Linear	1	0.111	7.059	0.009	0.004	0.001
Quad	1	0.045	2.166	0.002	0.008	0.003
Cubic	1	0.380	0.964	0.000	0.008	0.001
Error	30	0.270	3.512	0.002	0.006	0.001
CV%		3.228	3.330	4.514	4.360	3.869

Appendix Table 36

Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase I.

Room	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	2	1	40.617	56.429	0.753	1.657	0.454
2	1	1	40.730	56.361	0.744	1.617	0.460
3	2	2	37.202	52.528	0.730	1.503	0.485
4	1	2	37.061	50.896	0.659	1.459	0.451

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.3% $NaHSO_4$

Appendix Table 37

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase I.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	2	6.273	11.326	0.002	0.013	0.003
Rep	1	12.546	21.930	0.003	0.024	0.002
Trt	1	0.000	0.723	0.002	0.002	0.004
Error	1	0.016	0.612	0.001	0.000	0.008
CV%		0.326	1.447	4.297	0.128	4.232

Appendix Table 38

Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase II.

Room	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	2	1	56.429	81.667	0.841	2.163	0.389
2	1	1	56.361	81.451	0.836	2.147	0.390
3	2	2	52.528	77.551	0.834	2.153	0.387
4	1	2	50.896	77.503	0.864	2.084	0.415

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.3% $NaHSO_4$

Appendix Table 39

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase II.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	2	11.326	8.137	0.000	0.002	0.006
Rep	1	21.930	16.257	0.000	0.001	0.005
Trt	1	0.723	0.017	0.000	0.002	0.008
Error	1	0.612	0.007	0.000	0.001	0.007
CV%		1.447	0.106	2.074	1.240	3.277

Appendix Table 40

Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase III.

Room	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	2	1	81.667	104.069	0.838	2.516	0.333
2	1	1	81.451	104.320	0.880	2.473	0.356
3	2	2	77.551	98.537	0.807	2.350	0.343
4	1	2	77.503	96.229	0.720	2.176	0.331

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 41

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase III.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	2	8.137	23.727	0.005	0.033	0.003
Rep	1	16.257	46.397	0.009	0.053	0.004
Trt	1	0.017	1.058	0.001	0.012	0.002
Error	1	0.007	1.637	0.004	0.004	0.022
CV%		0.106	1.269	7.951	2.753	5.092

Appendix Table 42

Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase IV.

Room	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	2	1	104.069	122.916	0.857	2.622	0.327
2	1	1	104.320	121.291	0.771	2.560	0.301
3	2	2	98.537	115.839	0.786	2.503	0.314
4	1	2	96.229	112.221	0.727	2.308	0.315

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 1.0% $NaHSO_4$

Appendix Table 43

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during Phase IV.

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	2	23.727	36.027	0.004	0.025	0.008
Rep	1	46.397	65.181	0.003	0.034	0.000
Trt	1	1.058	6.872	0.005	0.017	0.016
Error	1	1.637	0.993	0.000	0.004	0.018
CV%		1.269	0.844	1.719	2.662	4.176

Appendix Table 44

Room means for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during the entirety to the experiment (Phases I – IV).

Room	Trt	Rep	Initial Wt. (kg)	Final Wt. (kg)	ADG (kg/pig/d)	ADFI (kg/pig/d)	G:F (kg)
1	2	1	40.617	122.916	0.831	2.232	0.372
2	1	1	40.730	121.291	0.814	2.204	0.369
3	2	2	37.202	115.839	0.794	2.145	0.370
4	1	2	37.061	112.221	0.759	2.020	0.376

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 45

Analysis of variance for initial weight, final weight, average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for finishing pigs during the entirety to the experiment (Phases I – IV).

		Mean Squares				
Source	Df	Initial Wt	Final Wt	ADG	ADFI	G:F
Total	2	6.273	36.027	0.001	0.012	0.000
Rep	1	12.546	65.181	0.002	0.018	0.000
Trt	1	0.000	6.872	0.001	0.006	0.000
Error	1	0.016	0.993	0.000	0.002	0.001
CV%		0.326	0.844	1.126	2.256	1.190

Appendix Table 46

Room means for pit pH, electrical conductivity and temperature for finishing pigs during Phase I.

Room	Trt	Rep	pH	EC (mS)	Temp (˚C)
1	2	1	7.483	10.547	21.067
2	1	1	7.247	9.363	21.333
3	2	2	7.277	8.770	20.600
4	1	2	7.323	8.027	20.867

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.3% $NaHSO_4$

Appendix Table 47

Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase I.

		Mean Squares		
Source	Df	pH	EC	Temp
Total	2	0.007	1.676	0.144
Rep	1	0.004	2.423	0.218
Trt	1	0.009	0.928	0.071
Error	1	0.020	0.049	0.000
CV%		1.923	2.403	0.002

Appendix Table 48

Room means for pit pH, electrical conductivity and temperature for finishing pigs during Phase II.

Room	Trt	Rep	pH	EC (mS)	Temp (˚C)
1	2	1	7.335	11.555	24.175
2	1	1	7.138	10.750	24.025
3	2	2	7.215	10.688	23.700
4	1	2	7.233	8.725	23.950

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.3% $NaHSO_4$

Appendix Table 49

Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase II.

		Mean Squares		
Source	Df	pH	EC	Temp
Total	2	0.004	2.003	0.039
Rep	1	0.000	2.091	0.076
Trt	1	0.008	1.915	0.003
Error	1	0.012	0.335	0.040
CV%		1.487	5.552	0.835

Appendix Table 50

Room means for pit pH, electrical conductivity and temperature for finishing pigs during Phase III.

Room	Trt	Rep	pH	EC (mS)	Temp (˚C)
1	2	1	7.105	7.748	24.000
2	1	1	7.018	6.161	23.900
3	2	2	7.145	6.133	23.475
4	1	2	7.163	6.583	23.600

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 51

Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase III.

		Mean Squares		
Source	Df	pH	EC	Temp
Total	2	0.005	0.340	0.085
Rep	1	0.009	0.356	0.170
Trt	1	0.001	0.323	0.000
Error	1	0.003	1.037	0.013
CV%		0.739	15.301	0.474

Appendix Table 52

Room means for pit pH, electrical conductivity and temperature for finishing pigs during Phase IV.

Room	Trt	Rep	pH	EC (mS)	Temp (˚C)
1	2	1	7.027	9.243	25.200
2	1	1	7.083	9.767	25.100
3	2	2	7.040	8.997	24.900
4	1	2	7.020	6.637	25.333

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 1.0% $NaHSO_4$

Appendix Table 53

Analysis of variance for pit pH, electrical conductivity and temperature for finishing pigs during Phase IV.

		Mean Squares		
Source	Df	pH	EC	Temp
Total	2	0.000	1.846	0.014
Rep	1	0.001	2.849	0.001
Trt	1	0.000	0.843	0.028
Error	1	0.001	2.079	0.071
CV%		0.540	16.650	1.060

Appendix Table 54

Room means for pit pH, electrical conductivity, temperature, and pit volume for finishing pigs during the entirety of the experiment (Phases I – IV).

Room	Trt	Rep	pH	EC (mS)	Temp (˚C)	Pit Volume (L)
1	2	1	7.235	9.756	23.679	31795.82
2	1	1	7.115	8.931	23.643	36652.37
3	2	2	7.171	8.613	23.229	34496.36
4	1	2	7.186	7.516	23.486	37073.12

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 55

Analysis of variance for pit pH, electrical conductivity, temperature, and pit volume for finishing pigs during the entirety of the experiment (Phases I – IV).

		Mean Squares			
Source	Df	pH	EC	Temp	Pit Volume
Total	2	0.001	1.280	0.052	8124568.6
Rep	1	0.000	1.636	0.092	2435612.8
Trt	1	0.003	0.924	0.012	13813524.4
Error	1	0.005	0.018	0.021	1299360.6
CV%		0.941	1.563	0.623	3.3

Appendix Table 56

Room means for dry matter intake (DMI), dry matter excretion (DMEX), and dry matter excretion as a percentage of intake (DMEXPI) during the entire experiment (Phases I – IV).

Room	Trt	Rep	DMI (g/d)	DMEX (g/d)	DMEXPI (%)
1	2	1	1899.48	250.216	13.17
2	1	1	1890.80	260.142	13.76
3	2	2	1838.77	223.633	12.16
4	1	2	1733.96	200.575	11.57

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 57

Analysis of variance for dry matter intake (DMI), dry matter excretion (DMEX), and dry matter excretion as a percentage of intake (DMEXPI) during the entire experiment (Phases I – IV).

		Mean Squares		
Source	Df	DMI	DMEX	DMEXPI
Total	2	7525.641	949.298	1.280
Rep	1	11831.029	1855.480	2.560
Trt	1	3220.254	43.116	0.000
Error	1	2309.901	271.996	0.348
CV%		2.611	7.059	4.659

Appendix Table 58

Room means for nitrogen intake (NI), nitrogen excretion (NEX), and nitrogen excretion as a percentage of intake (NEXPI) during the entire experiment (Phases I – IV).

Room	Trt	Rep	NI (g/d)	NEX (g/d)	NEXPI (%)
1	2	1	57.232	28.339	49.52
2	1	1	55.296	30.192	54.60
3	2	2	55.272	26.021	47.08
4	1	2	50.189	22.846	45.52

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 59

Analysis of variance for nitrogen intake (NI), nitrogen excretion (NEX), and nitrogen excretion as a percentage of intake (NEXPI) during the entire experiment (Phases I – IV).

		Mean Squares		
Source	Df	NI	NEX	NEXPI
Total	2	12.402	11.894	18.138
Rep	1	12.487	23.350	33.178
Trt	1	12.317	0.437	3.098
Error	1	2.477	6.318	11.022
CV%		2.888	9.362	6.751

Appendix Table 60

Room means for phosphorus intake (PI), phosphorus excretion (PEX), and phosphorus excretion as a percentage of intake (PEXPI) during the entire experiment (Phases I – IV).

Room	Trt	Rep	PI (g/d)	PEX (g/d)	PEXPI (%)
1	2	1	9.590	6.510	67.88
2	1	1	9.567	6.834	71.43
3	2	2	9.174	5.797	63.18
4	1	2	8.922	5.166	57.90

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 61

Analysis of variance for phosphorus intake (PI), phosphorus excretion (PEX), and phosphorus excretion as a percentage of intake (PEXPI) during the entire experiment (Phases I – IV).

		Mean Squares		
Source	Df	PI	PEX	PEXPI
Total	2	0.150	0.721	41.916
Rep	1	0.281	1.418	83.083
Trt	1	0.019	0.024	0.748
Error	1	0.013	0.228	19.492
CV%		1.234	7.856	6.782

Appendix Table 62

Room means for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) as a percentage of the slurry on a dry matter basis over the entire 100-day finishing period (Phases I – IV).

Room	Trt	Rep	N	P	Na	S	NH_4-N
1	2	1	11.77	2.24	0.958	1.585	7.903
2	1	1	13.28	2.38	1.015	0.912	8.067
3	2	2	14.83	2.39	1.187	1.802	8.456
4	1	2	16.45	2.22	1.133	0.955	8.027

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 63

Analysis of variance for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) as a percentage of the slurry on a dry matter basis over the entire 100-day finishing period (Phases I – IV).

		Mean Squares				
Source	Df	N	P	Na	S	NH_4-N
Total	2	2.400	0.009	0.009	0.299	0.083
Rep	1	2.350	0.017	0.018	0.020	0.149
Trt	1	2.450	0.000	0.000	0.578	0.018
Error	1	7.356	0.007	0.015	0.005	0.005
CV%		19.260	3.595	11.307	5.168	0.870

Appendix Table 64

Room means for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) nutrient concentration of the slurry over the entire 100-day finishing period (Phases I – IV).

Room	Trt	Rep	N ppm	P ppm	Na ppm	S ppm	NH_4-N ppm
1	2	1	2023.2	537.4	150.8	277.3	967.7
2	1	1	2100.4	488.6	145.1	155.6	968.0
3	2	2	2175.2	501.9	158.0	156.5	1011.9
4	1	2	1972.8	411.0	124.9	137.4	862.5

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 65

Analysis of variance for nitrogen (N), phosphorus (P), sodium (Na), sulfur (S), and ammonium-nitrogen (NH_4-N) nutrient concentration of the slurry over the entire 100-day finishing period (Phases I – IV).

		Mean Squares				
Source	Df	N	P	Na	S	NH_4-N
Total	2	2033.80	4038.46	209.31	7438.21	3248.56
Rep	1	148.84	3197.90	42.25	380.25	939.42
Trt	1	3918.76	4879.02	376.36	14496.16	5557.70
Error	1	19544.04	443.10	187.69	1.69	5602.52
CV%		6.76	4.34	9.47	0.63	7.86

Appendix Table 66

Room means for ammonia emitted on a mg/pig/d basis, ammonia concentration in ppm, ammonia concentration leaving the room per minute, ammonia emitted on a mg/kg/d basis, and ammonia emitted on a g/d/500 kg (AU) averaged over the entire 100-day finishing period (Phases I – IV).

Room	Trt	Rep	NH_3 mg/pig/d	NH_3 ppm	NH_3 mg/min	NH_3 mg/kg/d	NH_3 g/d/AU
1	2	1	1789.92	0.504	23.86	21.89	10.95
2	1	1	1676.63	0.505	23.23	20.70	10.35
3	2	2	1487.51	0.501	21.27	19.44	9.72
4	1	2	1411.74	0.538	19.37	18.91	9.46

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 67

Analysis of variance ammonia emitted on a mg/pig/d basis, ammonia concentration in ppm, ammonia concentration leaving the room per minute, ammonia emitted on a mg/kg/d basis, and ammonia emitted on a g/d/500 kg (AU) averaged over the entire 100-day finishing period (Phases I – IV).

		Mean Squares				
Source	Df	NH_3 mg/pig/d	NH_3 ppm	NH_3 mg/min	NH_3 mg/kg/d	NH_3 g/d/AU
Total	2	44697.70	0.000	6.018	2.611	0.656
Rep	1	80459.28	0.000	10.438	4.482	1.120
Trt	1	8936.11	0.000	1.598	0.740	0.185
Error	1	352.05	0.000	0.403	0.112	0.028
CV%		1.18	3.452	2.893	1.652	1.682

Appendix Table 68

Room means for hydrogen sulfide emitted on a mg/pig/d basis, hydrogen sulfide, emitted on a µg/kg/d basis, hydrogen sulfide emitted on a mg/d/500 kg (AU), hydrogen sulfide emitted on a µg/m^3, and air flow (AFL) averaged over the entire 100-day finishing period (Phases I – IV).

Room	Trt	Rep	H_2S mg/pig/d	H_2S µg/kg/d	H_2S mg/d/AU	H_2S µg/m^3	AFL L/sec
1	2	1	19.567	218.205	109.103	32.207	1095.11
2	1	1	16.286	183.352	91.676	24.834	1083.13
3	2	2	17.115	203.310	101.655	34.525	1002.22
4	1	2	14.992	183.817	91.908	32.270	857.31

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 69

Analysis of variance for hydrogen sulfide emitted on a mg/pig/d basis, hydrogen sulfide, emitted on a µg/kg/d basis, hydrogen sulfide emitted on a mg/d/500 kg (AU), hydrogen sulfide emitted on a µg/m^3, and air flow (AFL) averaged over the entire 100-day finishing period (Phases I – IV).

		Mean Squares				
		H_2S	H_2S	H_2S	H_2S	AFL
Source	Df	mg/pig/d	µg/kg/d	mg/d/AU	µg/m^3	L/sec
Total	2	5.405	395.217	98.804	23.479	15773.72
Rep	1	3.509	52.062	13.015	23.911	25393.89
Trt	1	7.301	738.371	184.593	23.046	6153.55
Error	1	0.335	58.982	14.745	6.615	4418.21
CV%		3.405	3.895	3.895	8.306	6.59

Appendix Table 70

Room means for excretion of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), sulfur (S), and ammonium nitrogen (NH_4-N) averaged over the entire 100-day finishing period (Phases I – IV).

Room	Trt	Rep	Ca g/d	K g/d	Mg g/d	Na g/d	S g/d	NH_4-N g/d
1	2	1	6.91	13.91	2.42	2.40	3.97	19.78
2	1	1	6.87	15.93	2.76	2.64	2.37	20.99
3	2	2	6.30	13.91	2.40	2.65	4.03	18.91
4	1	2	5.28	11.87	2.06	2.27	1.92	16.10

Trt 1: Fortified corn-soybean meal diet
Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 71

Analysis of variance for excretion of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), sulfur (S), and ammonium nitrogen (NH_4-N) averaged over the entire 100-day finishing period (Phases I – IV).

		Mean Squares					
Source	Df	Ca g/d	K g/d	Mg g/d	Na g/d	S g/d	NH_4-N g/d
Total	2	0.745	2.068	0.063	0.004	1.738	4.454
Rep	1	1.209	4.135	0.127	0.003	0.038	8.266
Trt	1	0.281	0.000	0.000	0.005	3.437	0.641
Error	1	0.241	4.107	0.116	0.098	0.069	4.042
CV%		7.741	14.575	14.164	12.587	8.531	10.614

Appendix Table 72

Room means for excretion of iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and nickel (Ni) averaged over the entire 100-day finishing period (Phases I – IV).

Room	Trt	Rep	Fe mg/d	Zn mg/d	Cu mg/d	Mn mg/d	Ni mg/d
1	2	1	409.86	272.08	37.75	79.07	7.19
2	1	1	454.85	310.17	38.17	89.64	4.69
3	2	2	383.19	272.37	34.67	76.30	4.80
4	1	2	332.14	225.60	29.47	64.42	3.23

Trt 1: Fortified corn-soybean meal diet

Trt 2: Fortified corn-soybean meal diet with 0.5% $NaHSO_4$

Appendix Table 73

Analysis of variance for excretion of iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and nickel (Ni) averaged over the entire 100-day finishing period (Phases I – IV).

		Mean Squares				
Source	Df	Fe mg/d	Zn mg/d	Cu mg/d	Mn mg/d	Ni mg/d
Total	2	2794.05	897.29	20.21	98.20	0.233
Rep	1	5578.89	1775.74	34.73	195.96	0.184
Trt	1	9.21	18.85	5.70	0.44	0.282
Error	1	2305.92	1800.35	7.91	126.06	1.081
CV%		12.16	15.71	8.03	14.51	24.599

VITA

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Thesis: EFFECTS OF ADDING SODIUM BISULFATE TO WEANLING AND FINISHING PIG DIETS ON GROWTH PERFORMANCE, NUTRIENT EXCRETION AND SLURRY CHARACTERISTICS

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Title of Study: EFFECTS OF ADDING SODIUM BISULFATE TO WEANLING AND FINISHING PIG DIETS ON GROWTH PERFORMANCE, NUTRIENT EXCRETION AND SLURRY CHARACTERISTICS

Pages in Study: 112 Candidate for the Degree of Master of Science

Major Field: Animal Science

Scope and Method of Study/ Findings and Conclusions:

Two experiments were conducted to determine growth performance of weanling pigs fed sodium bisulfate ($NaHSO_4$), as a potential acidifier. Pigs were stratified by sex, weight and ancestry and assigned to one of four diets containing 0, 0.2, 0.4, and 0.8% inclusion of $NaHSO_4$. $NaHSO_4$ was added at the expense of sodium chloride. Pigs and feeders were weighed weekly to determine growth performance. In Exp. 1, 200 pigs were allotted to one of four dietary treatments for Phases 2 - 4. Overall in Exp. 1, there was no difference in ADFI; however, ADG and G:F improved as $NaHSO_4$ levels increased in the diet. In Exp. 2, 240 pigs were allotted at weaning to the four dietary treatments fed in all four phases. Overall, in Exp. 2, increasing inclusion of $NaHSO_4$ tended to improve ADG. When combining results from both experiments for Phases 2 - 4, ADG (tendency) and G:F improved for pigs fed $NaHSO_4$. These results suggest that feeding $NaHSO_4$ at 0.4 or 0.8% inclusion may improve growth performance in weanling pigs.

$NaHSO_4$ is a strong acid that has been used in the poultry industry as a litter additive to reduce pH and ammonia emissions. Little is known about the effects of $NaHSO_4$ in swine slurry when administered as a feed additive. 80 crossbred pigs were used to determine the effects of $NaHSO_4$ addition to the diet on growth performance and slurry characteristics during a 100-d finishing period. Pigs were allotted by BW, sex, and ancestry to one of two treatments. The control was a fortified corn-soybean meal diet. The treatment diet was the control diet + 0.30% $NaHSO_4$. Feed intake, pig weight, pit volume, pH and EC were measured weekly. Feed and slurry samples were collected and analyzed for DM, N, and P. No difference in ADG, ADFI, G:F, pit pH or daily DM, N, P, Na or NH_4-N excretion was observed. However, EC of the slurry as well as sulfur excretion tended to increase for pigs fed $NaHSO_4$. These results suggest that dietary addition of $NaHSO_4$ does not affect growth performance or slurry characteristics of finishing pigs.

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