RESEARCH REPORT
PORK SAFETY

Title: Impacts of growth promoting antibiotics on growth performance, economics, and the development and persistence of antibiotic resistance in nursery and finishing pigs – **NPB #05-195**

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Industry Summary

A study was conducted to evaluate the use of growth promoting antibiotics on growth performance of gilts (n=200) in the nursery and finishing phases, the economics of using growth promoting antibiotics and the development of antibiotic resistance. Pigs fed antibiotics in the nursery had increased ADG, ADFI, and GF one week after weaning compared to pigs fed no antibiotics. No improvements in growth were found during the remainder of the nursery phase, or during the finishing phase. Resistance of commensal bacteria to chlortetracycline and virginiamycin increased from week 1 to 5 of the nursery for all pigs. Resistance decreased from week 5 to 9 when the antibiotic growth promoter was switched, however increased from week 9 to the end of the trial. Commensal bacteria isolated from groundwater sampled from simulated water runoff events at the end of the nursery and finishing phases showed similar resistance patterns to that of fecal bacteria. Economic analysis based on weight gain, mortality, and feed consumption during the trials showed that relatively small differences in performance can produce economically important differences in cost of production. The group of pigs that received growth promoting antibiotics in the nursery and none in the finishing phase had calculated

costs that were $4 or more per head lower than the other groups in this experiment. The lack of statistical significance of differences in performance measures precludes statistically significant differences in calculated costs. Use of antibiotic growth promoters may not be beneficial in clean, isolated facilities with high labor inputs. Antibiotic resistant bacteria can develop and proliferate regardless of the usage of antibiotic growth promoters.

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III. Scientific Abstract

A 20-week study was conducted using gilts from a commercial source (n=200; initial BW = 6.2 ± 0.003 kg) to determine the effects of growth-promoting levels of antibiotics on growth performance of nursery and finishing pigs, as well as development and persistence of antibiotic resistant *E. coli* and *Enterococcus* isolated from fecal samples and groundwater samples after a simulated rainfall. Pigs were allotted by BW to one of four treatments in a 2 x 2 randomized complete factorial block design. A three phase nursery diet program (1.6, 1.4, and 1.24 % lysine) was used, with treatments consisting of feeding no antibiotics (CON) or chlortetracycline (ANTI). Pigs were weighed at the phase changes on week 1, 3, and 5. At the end of the nursery phase, one-half of the pigs receiving CON were switched to a diet containing antibiotic (Virginiamycin) and one-half of the pigs receiving ANTI were switched to CON for the remainder of the trial. Pigs were fed a four phase finishing diet program (1.05, 0.95, 0.85, and 0.75 % lysine) and were weighed at 4 week intervals at the phase changes. At the end of the trial, backfat and LMA were measured. Fecal samples were collected at phase changes in the nursery, two weeks after the nursery phase, and at phase changes in the finisher. Simulated water runoff trials were performed at the ends of the nursery and finishing phases. After one week, CON pigs weighed less and had lower ADG and ADFI than ANTI pigs ($P<0.05$). No performance differences were found at weeks 3 and 5 of the nursery, or for the overall nursery period. During the finishing period, no differences were found in ADG, ADFI or GF between pigs receiving CON or ANTI, respectively ($P>0.05$). Backfat and LMA measurements were not different between treatments ($P>0.05$). No carry-over effects of antibiotics in the nursery were apparent in the finishing period, and antibiotic supplementation did not affect performance during the finisher or overall growth trial. A significant time effect ($P<0.05$) and time x treatment interaction was noted for fecal coliform and *Enterococcus* resistance to CTC and VIR. Resistance decreased in the first week of the trial, then increased from week 1 to 5, when the antibiotic used in the diet was switched. Resistance to CTC and VIR then decreased in the two-week interval after the nursery, and increased throughout the remainder of the trial. Pigs fed CON had a lower percentage of *E. coli* resistant to CTC compared to ANTI fed pigs during the initial water sampling ($P<0.05$), but as the runoff event progressed, *E. coli* resistance from pigs fed CON increased while resistance from pigs fed ANTI decreased. A time x treatment interaction ($P<0.05$) was found for *E. coli* resistant to CTC and VIR isolated from water samples after the finishing phase, however, resistance neared 100 percent for both antibiotics. Antibiotic growth-promoters have little impact on growth performance in clean, isolated facilities with high labor inputs. Antibiotic resistance bacteria can develop and proliferate regardless of the usage of antibiotic growth promoters. Resistant bacteria from swine facilities have the capacity to persist in the environment. Economic analysis based on weight gain, mortality, and feed consumption during the trials showed that relatively small differences in performance can produce economically important differences in cost of production.

IV. Introduction

The use of antibiotics in swine feeds has come under serious scrutiny in the last few years due to concerns about their potential effects on antibiotic resistance in humans. This has led to a ban of growth-promoting antibiotics in Sweden in 1986, in Denmark in 1995 and 1999, and the decision by the EU to ban five antibiotics for growth promotion in 1999. These decisions were largely influenced by public and political opinions and the use of antibiotics for growth promotion in the U.S. will likely be influenced similarly. Particularly considering the export market, antibiotic-free pork (whether it was produced completely without antibiotics or without sub-therapeutic levels of antibiotics) is expected to be the norm rather than the exception. Therefore, it is critical to understand the maximal economic impact that antibiotic withdrawal may have.

Considering data collected from 1978 to 1985, Zimmerman (1986) reported an average improvement in daily gain of 15% in nursery pigs and 3.6% in finishing pigs when antibiotics were included in the feed. Feed efficiency was improved by 6.5% in nursery pigs and 2.4% in finishing pigs due to antibiotics. Effects may be different, depending on factors such as disease status of the herd, management, etc. Cromwell (2001) summarized that the improvements in daily gain and feed efficiency were much greater (more than 50%) in farm experiments compared to research station tests. In addition, mortality rate was reduced from 15.6% to 3.1% in field trials under high disease levels (4.3% to 2.0% in low disease conditions). Our previous research (See et al., 1997) showed an improvement of 1.8 and 2.8% in feed efficiency of finishing pigs in a clean environment when fed two different antibiotics.

The hazards associated with pathogens in land-applied animal wastes have long been recognized. Recently, a principal area of concern has been the increasing emergence of antibiotic resistance phenotypes in both clinically relevant strains and normal commensal microbiota. The concern over the use of antibiotics in agriculture, especially for prophylactic and growth-promoting purposes, has not been limited to the presumed role of antibiotics in selection of antibiotic-resistant bacteria (pathogenic or nonpathogenic) in the animal gut. The more debatable issue arising from chronic low-level exposure to antibiotics is whether this practice contributes significantly to increased gene frequencies and dissemination of resistance genes into other ecosystems. Management of risks associated with antibiotic resistance requires an understanding of sources,

concentrations and removal processes that may be used to treat the wastes and survival of the resistant microorganisms in the environment (Hutchinson et al., 2004; Cole et al., 1999).

IV. Objectives

The objectives of the proposed research are to:

1) Determine the effects of growth-promoting antibiotics on performance of nursery and finishing pigs obtained from a commercial source;
2) Evaluate the development and persistence of antibiotic resistance in pigs during the nursery and finisher stages;
3) Quantify percentages of antibiotic resistant bacteria that are found following a surface run-off event from soils fertilized with manure from experimental pigs;
4) Provide a comprehensive economic analysis of pig production using growth promoting antibiotics compared to antibiotic-free production.

VI. Materials and Methods

Female pigs selected from sow farms with known health status were purchased from a commercial swine production company in North Carolina and shipped to the Swine Evaluation Station in Clayton, NC. Selection of pigs from a commercial source allowed for testing similar to production in the swine industry. Therefore, the maximum potential economic benefit of the presence of antibiotic growth promoters (or conversely, the maximum loss due to their removal) could be evaluated. Gilts (n=200) were blocked by weight and randomly allocated to pen and dietary treatment within block. Pigs were housed five pigs per pen using 40 pens. A solid concrete wall separated pens of pigs receiving the same dietary treatment, and one empty pen as well as a concrete wall separated pens receiving different dietary treatments to prevent possible cross-contamination. In addition, gloves and boots were changed between every pen and coveralls were changed between every different treatment group during fecal sample collection. The same procedure was followed while weighing pigs, and a portable scale was brought to each pen, so pigs were never exposed to a common area of the barn.

Performance. During the nursery phase, gilts were assigned to one of two dietary treatments: 1) negative control diet without antibiotic or 2) diet containing growth-promoting levels of chlortetracycline (Table 1). The antibiotic treatment was selected based on its widespread use as a growth-promotant in the swine industry as reported by the Animal and Plant Health Inspection Service, USDA. Pigs were fed a three-phase dietary nursery program designed to be representative of diets used in the swine industry (1.6, 1.4, and 1.2% total lysine for the prestarter, starter I and starter II diets, respectively) and were provided in pellet form. Diets were not supplemented with growth-promoting levels of Cu and Zn in order to provide the greatest opportunity for antibiotics to work. Pig performance (body weight, feed intake, daily gain, and feed efficiency) was determined at each diet change. Morbidity and mortality was recorded.

Following the nursery phase of the experiment, pigs were maintained in their treatment groups and continued throughout the finishing phase. One-half of the pigs (10 pens) fed the antibiotic treatment during the nursery phase continued to be fed an antibiotic treatment (virginiamycin) throughout the finishing phase, while the other half fed antibiotics during the nursery phase was fed a diet with no antibiotics throughout the finisher phase. Similarly, one-half of the pigs that did not receive antibiotics in the nursery received an antibiotic treatment in the finisher while the other half remained antibiotic-free. Pigs were fed a four phase diet program during the finisher phase (1.05, 0.95, 0.85, and 0.75% total lysine for diet phase I to IV, respectively). Finishing pigs were weighed and feed intake was measured in 4 week intervals to coincide with the diet phase changes, which occurred as follows: the phase I diet was fed from approximately 50 to 100 lbs, phase II from 100 to 150 lbs, phase III from 150 to 200 lbs, and phase IV from 200 to 250 lbs (Table 1). Ultrasound measurements to determine backfat, loin eye area, percent lean and lean gain were taken at the end of the trial.

Sample Collection for Antibiotic resistance. Fecal samples were collected from each pen once every week during the nursery phase and once every two weeks during the finishing phase for the study period. Samples were analyzed for *E. coli* and *Enterococci* within 6 hrs of collection when possible, but no later than 12 hours after collection. *E. coli* and *Enterococci* were chosen for evaluation because these are the most common indicators of selective pressure of antibiotic usage (Anderson et al., 2003).

Isolation of E. coli and Enterococcus. Fecal samples were serially diluted and streaked on MacConkey and m- Enterococcus agar plates for the isolation of *E. coli* and *Enterococci*, respectively. The plates were incubated at 37°C for 24 h. A target number of forty-eight colonies of each bacterium representing each composite sample were selected and transferred to 96 microwell plates. Colonies that appeared purple on the MacConkey's agar were presumed to be *E. coli* and were transferred to microwells containing Colilert (Idexx, Westbrook, ME) for confirmation. After incubation for 24 hours, those microwells that turned yellow and fluoresced under UV light were confirmed as *E. coli*. Bacterial isolates that grew into a deep red color on m-Enterococcus agar were presumed to be *Enterococcus*. The deep red colonies were transferred to 96-microwell plates containing Enterococcosel broth. After incubation for 24 hours at 37°C, colonies that turned the broth black confirmed presence of enterococcus. All of the bacterial colonies were stored in the microwell trays at 4°C for the duration of the study.

Antibiotic Resistance Analysis. E. coli and *Enterococc*i isolates were transferred from the microwell trays and inoculated onto trypticase soy agar plates containing the antibiotics for resistance testing. The antibiotics used in this study were chlorotetracycline (CTC) and virginiamycin (VIR), for all sample periods. In addition, isolates were inoculated onto a control plate containing no antibiotic. The antibiotic plates contained a concentration of antibiotic comparable to what the pigs were exposed to. After inoculation, these plates were incubated for 24 hours at 37ºC. An isolate was considered resistant to a given concentration of antibiotic if growth of that isolate was comparable to the growth on the control plate.

Soil Runoff Study. Soil runoff boxes were constructed of wood (pine) and sealed with latex paint and a marine adhesive. Depth and sides of boxes measured 7.5 cm except the front which measured 5 cm. This allowed for 2.5 cm of freeboard to prevent any loss of applied materials due to splash from raindrop impact. Dimensions of the boxes were 20 cm wide x 100 cm long giving a total area of 0.2 m^2. Air dried soils were tamped to desired bulk densities in soil boxes in five separate layers of known and equal weight to avoid differing densities throughout the 5 cm of soil depth. Any foreign objects, including bits of gravel or organic materials, found in the soils were discarded.

A variable rate rainfall simulator delivered a rate of 7.5 cm hr^{-1} of water to soil runoff boxes located within the simulator using a size ½-HH-SS-30WSQ TeeJet® nozzle at 8.5 psi (Muirhead et al., 2005). Tarps encircling the simulator were used to minimize any effect of wind. To achieve similar rainfall rates for each of the four boxes a uniformity test was performed. Pre-weighed plastic cups were placed on a 20 cm x 20 cm grid within the simulator and rainfall was administered for 16.5 min and cups were weighed again to determine the weight of water. A coefficient of uniformity (C_u) of 0.814, was then calculated using the equation: $C_u = 1 –$ (absolute deviations from the mean/mean weight of water). Before each rainfall event, soil boxes were tamped with desired soil and placed in their predetermined area within the simulator on prefabricated 5% slope stands which were leveled to restrict runoff during pre-wetting.

Composite manure samples were collected from 8 sets of pens (giving 4 replicates per treatment) at the end of the nursery and applied to soil boxes. After applying the manure, rainfall followed immediately. For the finishing phase, 8 composite samples were again collected, which resulted in two replicates per treatment. Manure was applied evenly to surfaces of soil boxes and the boxes were left overnight before rainfall simulation the next morning. Only five boxes could be placed in the simulator, so two runs were performed, with each run containing a control box with no manure. Runoff was collected at the first sight of runoff, and from 5 to 10 min, 15-20 min and 30-35 minutes after first sight of runoff. A volume of runoff for each collection was determined. After collection, runoff samples were immediately transported to the laboratory where subsamples were taken to culture *E. coli* and *Enterococci* and to perform antibiotic resistance analysis on those isolates. The isolates were evaluated in the same manner as those collected directly from the pig feces. In addition, the antibiotic resistance assay used for the bacteria collected from water runoff were tested against Erythromycin (ERY).

Economics. Partial budgeting derived from full enterprise budgets for the nursery and finishing enterprises was used to calculate cost of production for each group of pigs. Recorded weights, average feed to gain ratio, and mortality in each period were used to calculate costs for each group. Actual diet composition and ingredient prices were used to calculate feed costs (Table 14.). Prices for weaned pigs and feeder pigs were assumed to be constant prices per kilogram. Prices and quantities of other inputs were assumed based on

previously developed worksheets. Variation exists in other costs per head marketed and per kilogram marketed due to differences between groups in mortality and in weight gain. The variation exists despite the fact that the same prices and quantities of other inputs were assumed per head capacity or per pig placed for all groups. No experimental data were included on costs of injectable antibiotics or condemnations and deductions at slaughter. Experimental data on carcass characteristics and antibiotic resistance were not utilized in the economic empirical analysis but are addressed in the discussion. Sensitivity of results to mortality rate was demonstrated by recalculating costs assuming constant mortality rates across all groups. Sensitivity of the results to other exogenous parameters (pig prices, feed and antibiotic prices, and carcass price) is discussed. Risk implications of antibiotic resistance are discussed in a probability framework including probability of losses due to morbidity and mortality at various levels of antibiotic resistance and value of those losses. Discussion is also provided regarding potential market level effects of (dis)adoption of antibiotics and to identify issues for further research.

Statistical Analysis. Performance data were analyzed as a randomized complete block design using the PROC GLM procedures of SAS (SAS Ins., Cary, NC). The model included block and treatment. Repeated measures in time were used for weight, ADG, ADFI, and G:F. Resistance data were analyzed as a complete randomized design using the PROC MIXED procedures of SAS. The model included treatment, level of antibiotic, time, and all appropriate interactions. Time was used as a repeated measure. Significance was declared at $P < 0.05$ for all variables measured.

VIII. Results

Performance. Performance data during the nursery phase are summarized in Table 2. After one week, pigs fed no antibiotics (CON) weighed less (7.09 vs. 7.29 kg) and had lower ADG (148.8 vs. 179.8 g/d) and ADFI (174.4 vs. 191.6 g/d) than pigs fed antibiotics (ANTI). No performance differences were found at weeks 3 and 5 of the nursery, or for the overall nursery period ($P> 0.05$). During the finishing period, no differences were found in ADG, ADFI or GF between any treatment groups (Table 3.). Backfat and LMA measurements were not different between treatments ($P>0.05$).

Antibiotic Resistance. While culturing bacteria samples, isolates that were selected from MacConkey's agar and thought to be *E. coli* did not always fluoresce under UV light after incubation in Colilert. We could not be sure that every isolate was, in fact, *E. coli*, therefore data are reported for fecal coliforms. Coliform resistance to CTC and VIR is shown in Tables 4 and 5. Samples collected at the beginning of the trial (week 0) showed that a large percentage of coliform bacteria isolated was already resistant to CTC and VIR, however, there were no differences in baseline percentage of resistant bacteria between treatments for either CTC or VIR. There was no effect of treatment on percent of fecal coliforms resistant to CTC and VIR throughout the trial ($P > 0.05$). As expected, there was an effect ($P < 0.05$) of antibiotic level used in the culture medium on percent of fecal coliforms resistant to CTC and VIR. As level of antibiotic increased, percent of resistant fecal coliforms was decreased. A significant effect of time ($P< 0.001$) and a treatment x time interaction ($P < 0.05$) was noted for percent of fecal coliforms resistant to CTC and VIR (Figures 1, 2). Percent of fecal coliforms resistant to CTC and VIR decreased after one week, and gradually increased to the end of the nursery phase, at which point antibiotic regimen was changed. Resistance to both antibiotics decreased from week 5 to week 7, then gradually increased to the end of the trial for all treatments. Enterococcus resistance data are shown in Tables 6 and 7. There was no effect of treatment on percent of Enterococcus resistant to either CTC or VIR throughout the trial ($P > 0.05$). There was an expected effect of antibiotic level in the culture medium ($P <0.001$) on percent of Enterococcus resistant to CTC and VIR. Increasing level of antibiotic decreased percentage of resistance. Percent of Enterococcus resistant to CTC and VIR also showed a significant effect of time ($P <0.001$) and a time x treatment interaction ($P <0.001$; Figures 4 and 5).

Water runoff event. The method used for detection of bacteria isolated from water runoff samples confirmed that all isolates were *E. coli*. Data for percentage of *E. coli* resistant to CTC, VIR, and ERY following the nursery phase are presented in Table 8. *E. coli* isolated from pigs fed CON had increased resistance to CTC compared to bacteria isolated from pigs fed ANTI ($P = 0.018$) during the nursery phase. However, a significant effect of time ($P = 0.009$) and a time x treatment interaction ($P = 0.011$) show that in the initial runoff, percent of bacteria resistant to CTC was lower for pigs fed CON compared to pigs fed ANTI. As the runoff event progressed, percent of *E. coli* resistant to CTC increased for CON fed pigs, while resistance decreased for pigs

fed ANTI. There were no effects of treatment, time, or level of antibiotic in the culture medium on percent of *E. coli* resistant to VIR during the nursery phase. There was a significant effect of time and a time x treatment interaction for percent of *E. coli* resistant to ERY as pigs fed CON had a lower percentage of *E. coli* resistance than pigs fed ANTI in the initial runoff. Percent of *E. coli* resistant to ERY decreased for both dietary treatments as the runoff event progressed. Percent of *Enterococcus* resistance during the nursery phase runoff event is presented in Table 9. There was no effect of dietary treatment on percent of *Enterococcus* resistant to any of the four antibiotics tested during the nursery phase. *E.coli* resistance to CTC, VIR, and ERY showed significant effects of time and time x treatment interactions ($P < 0.05$). *Enterococcus* isolated from pigs fed CON was less resistant to antibiotics than those isolated from ANTI fed pigs in the initial runoff, and decreased by the end of the runoff event for both treatment groups. Data for percent of *E. coli* resistance recovered from the water runoff event after the finishing phase are presented in Table 10. There was no effect of dietary treatment for any antibiotic tested. A significant time x treatment interaction ($P < 0.05$) was found for percent of *E. coli* resistant to CTC and VIR. While treatment differences were noted at different times throughout the runoff event, percent of resistant *E. coli* neared 100 % for all three antibiotics. Percent of *E. coli* resistant to ERY showed a significant time x treatment interaction ($P = 0.012$). Opposite of the resistance of other antibiotics, *E. coli* resistant to ERY recovered from the water runoff increased for AA, AC, and CA treatments as the event progressed, but decreased for the CC treatment group. Percent of *E. coli* resistant to ERY also showed a significant effect of level of antibiotic in the culture medium ($P = 0.006$), as level of ERY increased, resistance decreased for all treatment groups. *Enterococcus* resistance data for the finishing phase runoff event are presented in Table 11. Percent of *Enterococcus* resistant to CTC showed significant effects of treatment ($P= 0.017$), time ($P= 0.011$), and a time x treatment interaction ($P<0.001$). However, the only noticeable difference was apparent at the end of the runoff event (30 min), at which the percent resistant *Enterococcus* for the AA treatment was only 46.7%, while all other treatments showed 100% resistance. A time x treatment interaction ($P < 0.001$) was also apparent for percent of *Enterococcus* resistant to VIR during the finishing phase. Resistance was lower for the CC treatment compared to the CA, AC, and AA treatments during the initial runoff. However, resistance to VIR decreased for CA, AC, and AA treatments as the runoff event progressed,

but increased for the CC treatment. A treatment effect was found for percent of *Enterococcus* resistant to ERY during the finishing phase ($P < 0.001$). Pigs on the CA and AC had increased percent of *Enterococcus* resistant to ERY initially compared to pigs on AA and CC treatments ($P<0.05$). Similar to the resistance pattern for *E. coli*, percent of *Enterococcus* resistant to ERY decreased for pigs fed antibiotics as the runoff event progressed, but increased for pigs fed CON.

Economics. Nursery enterprise budgets were calculated using the average performance values for the pigs fed growth promoting levels of antibiotics and those that were not, using assumed prices for control and antibiotic diets (Table 12). The resulting cost estimates (Table 13) are presented in $ per pig marketed and in $ per kg of pig marketed. The calculated cost per pig marketed was 1.2% lower for the group that received antibiotics. Conversely, the cost per kg marketed was 2.4% lower for the control group reflecting the slightly heavier average market weight for nursery pigs in that group. Neither of these results are statistically significant given the lack of significant differences in the underlying performance measures. A few points are illustrated by the calculated costs. The cost of weaned pigs represents more than 70 percent of the total calculated cost in the nursery. The short residence time of the pigs in the nursery and the limited amount of feed consumed mean other costs are relatively low. The relative importance of weaned pig costs make the cost per pig marketed quite sensitive to mortality rate. Actual nursery mortality for the two groups is also presented in Table 13.

Finishing enterprise budgets were calculated for 4 groups: the pigs receiving growth promoting antibiotics in both the nursery and the finishing floor (AA), those receiving none in both phases (CC), and those that received antibiotics in one phase only (CA and AC). Calculated costs per hog marketed and per kilogram of hog marketed are summarized in Tables 14 and 15, respectively. Calculated costs per head finished are between $104 and $105 per head for all groups except the hogs that received growth promoting antibiotics in the nursery and none on the finishing floor (AC) which had a calculated cost of $100.07. The calculated cost per kilogram of hog finished ranges from $0.841 per kg (AC) to $0.886 per kg (AA). Again, none of the cost differences are statistically significant due to the lack of statistically significant differences in the underlying performance measures. The cost of feeder pigs represents about 44 percent of total calculated finishing cost per

kg. of hog marketed. Feed is the next largest cost component at about 39 percent of total cost per kg. As a result, finishing costs are less sensitive than nursery costs to mortality and more sensitive to feed cost.

The effect of mortality on cost estimates is illustrated in Table 16. Cost per head and per kg are recalculated for each group in the nursery and on the finishing floor using the average mortality rate for all pigs in the experiment. The range of nursery cost per head drops from $2.10 to $0.39 while the range of finishing cost per head increases slightly from $4.93 to $6.06. The range of cost per kg fell in both the nursery and the finishing floor. The control group CC had the highest mortality in both production phases and so exhibits reduced calculated costs when average mortality rates are assumed.

VIII. Discussion

While we were able to observe differences in performance during the first week of the trial, we were unable to detect differences in ADG, ADFI, and GF for the remainder of the nursery phase. Our results do not fully agree with previous research on the performance of pigs fed antibiotics compared to those fed no antibiotics during the nursery phase (Cromwell, 2002). It has been reported that improvements in growth performance of pigs is often greater in on-farm trials as compared to research station trials (Cromwell, 2002). It should also be noted that the growth rates of all pigs in this trial were very good for the nursery phase, and this reflects a high health status of the pigs. In this instance, we would not expect antibiotic growth promoters to have a large effect on growth performance, as it has been shown that growth promoting antibiotics are more likely to improve growth for pigs with a high level of immune activity (Hardy, 2002). We also found no impact of growth promoting antibiotics on performance of gilts during the finishing phase. Again, this result disagrees with previous research (See et al., 1997). However, Weber et al. (2001) showed no carry-over effects on growth of finishing pigs when fed growth promoting antibiotics in the nursery. Performance of all gilts during the finishing phase was also above average, which again confirms a high health status and good management of these animals.

Escherichia coli are the predominant isolate in the fecal microflora of animals, and have the ability to transfer antibiotic resistance genes to other species (Anderson et al., 2003). Our data showed an unexpected high level of *E. coli* resistant to CTC, and VIR at the beginning of the trial. These pigs received no antibiotic treatments before weaning and came from a farrowing facility in which antibiotics were not fed to the sows. By

the first week in the nursery, *E. coli* resistant to CTC and VIR decreased for all treatment groups. While CC pigs showed the lowest level, CA and AC treatments showed the highest level of resistant *E. coli*. This was also unexpected, since CA pigs were fed no antibiotic growth promoters during this time period. *E. coli* resistant to CTC and VIR were not different between treatments at weeks 3 and 5 of the nursery period. At the end of the nursery phase, the growth promoter used in the diet switched from CTC to VIR. When measured two weeks after the switch (week 7), resistance to CTC and VIR decreased for all treatment groups except CC. Research has shown that when use of one antibiotic decreases, resistance may also decline (Salyers, 2002). *E. coli* resistance to CTC and VIR gradually increased from week 7 to the end of the trial for all treatment groups. Salyers (2002) also reported that a change in antibiotic regimen may only decrease resistance to a low level, and when an organism is exposed to an antibiotic, resistance can increase quickly. While we expected resistance to be prevalent in pigs fed an antibiotic regimen treatment (CA, AC, AA), reasons for the high incidence of antibiotic resistance for CC fed pigs is unclear. Strict biosecurity practices were enforced during all aspects of data collection. NARMS has established the minimum inhibitory concentration breakpoints for tetracycline resistance in E. coli to be greater than 16 μg/mL, although a breakpoint for chlortetracycline has not been evaluated (CDC, 2007). We tested much higher concentrations of chlortetracycline in the current study (60, 80, and 100 μg/mL) and still observed high levels of fecal coliforms resistant to these levels.

The commensal bacteria, *Enterococci*, are able to serve as a reservoir of resistance genes (Jackson et al., 2004). Similar to *E. coli*, *Enterococcus* isolated from pigs at the beginning of the trial showed an unexpected high level of resistance to CTC and VIR. Incidence of resistance remained high throughout the nursery until week 5, at which time pigs receiving the AA treatment had a higher level of resistance to both antibiotics than pigs receiving the CC treatment. A study by Aarestrup et al. (2001) reported *Enterococcus* resistant to VIR was between 40-60 % for pigs and 30-70% for broilers fed VIR during a three year time period. Resistance to both CTC and VIR decreased for all treatment groups from week 5 to week 9, when CTC was removed and VIR was included as the growth promoting antibiotic. *Enterococcus* resistance to both CTC and VIR then increased from week 9 to the end of the trial. This was also unexpected, as the CC treatment received no antibiotics throughout the trial. However, *Enterococcus faecilis* is intrinsically resistant to VIR (Aarestrup et al., 2001),

and our culture media could not select between different species of *Enterococcus*. Therefore, it is possible that the noted decrease in resistance was due to a decrease in *Enterococcus* species susceptible to VIR, and by 9 weeks *E. faecilis* may have proliferated in the gut of the pigs and caused the noticeable increase in resistance. NARMS lists the minimum inhibitory concentration breakpoint for *Enterococcus* resistance to tetracyclines as being greater than 16 μg/mL, and for streptogramins as greater than 4 μg/mL (CDC, 2007). The antibiotic levels used to test and classify *Enterococcus* resistance in the current study were greater than these reported levels.

Resistant bacteria have been isolated from non-selective environments, such as soil, and resistant bacteria originating from animals have been identified in groundwater (Newman and Scheuren-Portocarrero, 2006). To our knowledge, this is the first simulated water runoff trial that measured antibiotic resistant bacteria. Therefore, comparisons with other similar trials are not possible. Neither *E. coli* nor *Enterococcus* was isolated from water runoff samples taken from the control boxes in which no manure was applied. Therefore, it is reasonable to assume that all bacteria isolated originated from the swine manure. *E. coli* isolated from the simulated runoff event showed resistance patterns similar to that isolated from fecal samples. Levels of resistance in *E. coli* isolated from water runoff were over 70% to CTC and VIR regardless of dietary treatment. McKeon et al. (1995) reported 87% of fecal coliforms isolated from groundwater sampled near swine facilities were resistant to one antibiotic while 60% were resistant to multiple antibiotics. In the same trial, 34% of *E. coli* isolated was resistant to tetracycline. In the current trial, *E. coli* resistance to ERY was increased for pigs fed antibiotics compared to control fed pigs in water runoff during the first five minutes, but similar at all other time points. Gallert et al. (2005) sampled groundwater from multiple wells near a sewage treatment plant and found *E. coli* with 94-100% resistance to ERY, but no resistance to tetracycline. NARMS indicates that the minimum inhibitory concentration breakpoint for *E. coli* resistance to ERY as greater than 32 μg/mL, while the breakpoint for *Enterococcus* resistance to ERY is greater than 8 μg/mL (CDC, 2007). The levels of ERY for testing resistance in the current trial were much higher than those indicated by NARMS.

The lack of statistically significant differences in performance parameters means that no statistically significant differences in average cost and returns estimates can be expected. However, the results of the partial

budgeting analysis in this study suggest that relatively small differences in performance parameters can have important economic effects. For example, if the $4 per market hog lower cost of the AC feeding regimen could be sustained in a commercial setting over many more replications, it would have a very significant economic impact on the industry. The dataset in this study is simply not large enough or heterogeneous enough to detect systematic differences of this small magnitude. Sensitivity of cost results to performance parameters was illustrated by replacing actual group mortality with broad average mortality. Nursery costs per feeder pig marketed were shown to vary inversely with small changes in mortality reflecting the fact that weaned pig costs were over 70% of feeder pig costs per head in this model. Feeder pig costs at about 44% and feed costs at about 39% were the largest components of market hog cost. The AC group exhibited the lowest calculated cost per hog and per kg marketed from the finishing floor while the AA group had the highest calculated finishing costs.

Important dimensions of the effects of feeding growth promoting antibiotics are not measured in this study. Costs and returns of feeding antibiotics are expected to vary through time and across farms. The data reported here arise from one site observed for one time period from weaning to market hog. Carcass composition and quality is another factor that was not included in this economic analysis. If significant differences in carcass composition and quality arose from the different feeding regimens, then hog producer revenue differences could be calculated using each packer's pricing schedule for carcass characteristics. Revenue differences could be as important as cost differences in measuring the costs and benefits of feeding antibiotics.

This economic analysis does not address the broad policy issue associated with feeding growth promoting antibiotics. The data collected in this study may provide an indication of one part of the analysis required to support market analysis and policy-making. Market-driven product differentiation may occur if some consumers of pork are willing to pay more for pork from pigs that were not fed antibiotics. The price of the differentiated pork must cover the costs of certifying the antibiotic-free status of the pigs and maintaining their segregation through the marketing, processing, and retailing channels. The price difference must also offset any differences in the costs and returns (carcass characteristics, condemnations, and deductions) of the pigs that were not fed antibiotics.

A more general policy question is whether or not to restrict feeding of growth promoting antibiotics. The economics version of the question is whether or not such restrictions would lead to a general improvement in human welfare. The purported benefits of such restrictions are that they would reduce the rate of proliferation of antibiotic resistant human pathogens and hence reduce the physical effect and cost of treating those pathogens. In order to make a rational policy decision, information is needed about the effect of feeding antibiotics on proliferation of antibiotic resistant organisms in swine facilities, on the transmission of such organisms off of the swine farm, on the impact of emitted organisms on the population of human pathogens, and on the effect of changed levels of resistant organisms on human health and the costs and efficacy of treatments. Any increased costs in human health and treatment of disease would be compared to the costs of restricting feeding of growth promoting antibiotics on pig producers, pork processors and distributors, and costumers.

Potential market level effects of dis-adoption of growth promoting antibiotics include increased costs and reduced net returns distributed unevenly across producers and over time, eventual reduction in the number and size and ownership of pig farms with some producers exiting the business, Increased costs of pig production would result in a reduction of the quantity of pork supplied at any price. A new market equilibrium would occur with reduced quantity supplied, higher prices, reduced exports, and increased foreign production of pork. Transitional effects would include losses to existing pig producers and associated sectors of the economy as well as to manufacturers of antibiotics fed as growth promotants to pigs. Consumers of pork would experience reduced welfare by having to pay more for pigs while increased welfare would be experienced by health care consumers and particularly those that would have suffered effects of resistant pathogens but did not. Almost none of the data required to analyze and quantify these effects is available.

Implications

Results of this trial showed that the use of antibiotic growth promoters in clean, well-managed facilities will not improve growth performance of growing and finishing pigs. However, we did see an effect of growth promoting antibiotics in the first week after weaning, a time of high stress for pigs. Understanding difference scenarios in which antibiotics improve growth will help determine their usefulness. Antibiotic resistant bacteria develop and persist over time regardless of the use of antibiotic growth promoters. The antibiotic resistant

bacteria may also enter environmental waters as a result of land application. Strategies of antibiotic growth promoter usage may need to be evaluated in order to maintain their effectiveness of improving growth. Future economic research could include comparisons of existing commercial pig production systems to examine the effects of different antibiotic feeding regimes on performance and costs and the emission of resistant organisms. Similar studies could examine the correlation between pig production and the general incidence of various types of resistant organisms in surrounding areas and populations and the effect of different antibiotic feeding regimens on that correlation through time and location.

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Table 1. Composition of diets fed throughout the trial.

	Pre-starter	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Time (weeks)	0-1	1-3	3-5	5-9	9-13	13-17	17-20
Ingredient							
Corn	29.30	54.22	50.94	59.29	63.35	66.75	69.78
SBM	16.00	25.00	28.04	23.26	19.27	15.94	12.94
Wheat Midds	-	-	10.00	10.00	10.00	10.00	10.00
Dried Whey	17.17	0.26	-	-	-	-	-
Oatmeal	10.00	-	-	-	-	-	-
Whey Permeate	7.72	8.32	-	-	-	-	-
Spray Dried Animal Plasma	4.00	-	-	-	-	-	-
Poultry Meal	3.38	3.60	-	-	-	-	-
Fat	4.33	3.33	5.56	4.71	4.56	4.45	4.38
Soy protein conc.	2.66	-	-	-	-	-	-
Fish Meal	2.50	2.40	2.50	-	-	-	-
Dical. Phos.	1.12	0.78	1.15	0.83	0.86	0.90	0.97
Calcium Carb.	0.83	0.83	1.00	1..00	1.00	1.01	1.00
Salt	0.40	0.40	0.40	0.50	0.50	0.50	0.50
Lysine	0.22	0.38	0.17	0.27	0.31	0.30	0.28
DL-meth.	0.15	0.16	0.04	-	-	-	-
Se Premix[a]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Trace Min.[b]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vit. Pack[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Starter Vit.[c]	0.02	0.02	0.02	-	-	-	-
Choline Chloride	0.02	0.02	-	-	-	-	-
L-Trp	0.01	0.03	-	-	-	-	-
L-Thr	0.01	0.09	0.03	-	-	-	-
Vit. E	0.01	0.01	-	-	-	-	-
Aureomycin 90*[d]	0.03	0.03	0.03	-	-	-	-
Stafac*[e]				0.05	0.05	0.05	0.05
Ferric oxide*	0.01	0.01	0.01	0.01	0.01	0.01	0.01

* Included in antibiotic containing diets only. Ferric oxide was used to identify the anitibiotic containing diets.

[a] provided 0.3 ppm Se

[b] provided 20 ppm Cu, 0.75 ppm I, 70 ppm Fe, 50 ppm Mn, and 90 ppm Zn

[c] vitamin premixes provided 3.0 TIU/lb Vit. A, 0.5 TIU/lb Vit D, 50 IU/lb Vit. E, 4.4 ppm Menadione, 0.22 ppm Biotin, 1.25 ppm Folic acid, 43 ppm Niacin, 21.5 ppm pantothenic acid, 0.1 ppm pyridoxine, 0.033 ppm Vit. B12

[d] provided 90 g chlortetracycline per ton

[e] provided 10 g virginiamycin per ton

Table 2. Effect of antibiotic growth-promoters on performance of gilts during the nursery phase[1].

	Treatment		
	Control	Antibiotic	SE
Weight (kg)			
Start	6.19	6.19	0.003
Wk 1	7.09[a]	7.29[b]	0.047
Wk 3	12.4	12.5	0.213
Wk 5	21.9	21.1	0.441
ADG			
Wk 0-1	0.15[a]	0.18[b]	0.008
Wk 1-3	0.38	0.37	0.014
Wk 3-5	0.67	0.62	0.026
ADFI			
Wk 0-1	0.17[a]	0.19[b]	0.005
Wk 1-3	0.48	0.48	0.014
Wk 3-5	0.80	0.76	0.019
G:F			
Wk 0-1	0.85[c]	0.94[d]	0.036
Wk 1-3	0.79	0.76	0.017
Wk 3-5	0.85	0.82	0.033

[1] Values are means of 20 pens with 5 pigs per pen.
[a,b] means differ ($P < 0.05$)
[c,d] means differ ($P = 0.065$)

Table 3. Effect of antibiotic growth promoter regimen on performance of gilts during the finishing phase[1].

[1] Values are means of 10 pens with 5 pigs per pen. No differences between treatments for any measure (P > 0.05)

	Treatment				
	CC	CA	AC	AA	SE
Weight (kg)					
Wk 4	40.1	41.6	39.8	40.3	1.17
Wk 8	67.1	70.2	66.3	67.5	1.47
Wk 12	95.5	97.1	94.8	95.2	1.81
Wk 15	119.6	120.7	118.9	118.5	1.81
ADG					
Wk 4	0.67	0.70	0.70	0.68	0.033
Wk 8	0.95	0.97	0.93	0.92	0.022
Wk 12	1.03	1.02	1.01	1.03	0.035
Wk 15	1.12	1.10	1.12	1.08	0.034
ADFI					
Wk 4	1.39	1.46	1.36	1.40	0.044
Wk 8	1.99	2.07	1.97	1.98	0.046
Wk 12	2.55	2.57	2.49	2.54	0.049
Wk 15	2.90	2.88	2.90	2.88	0.054
G:F					
Wk 4	0.48	0.48	0.51	0.49	0.017
Wk 8	0.48	0.47	0.47	0.47	0.008
Wk 12	0.41	0.40	0.41	0.40	0.012
Wk 15	0.38	0.38	0.39	0.38	0.013
Backfat (cm)	1.88	1.99	1.83	1.87	0.069
LMA (cm^2)	46.3	46.6	46.9	46.2	0.766

Table 4. Percent of fecal coliforms resistant to chlortetracycline added to the culture medium at three levels[a].

	Treatment											
	CC			**CA**			**AC**			**AA**		
Level (µg/L)	60	80	100	60	80	100	60	80	100	60	80	100
Week:												
0	67.7	65.9	56.1	69.6	64.3	63.3	79.1	75.3	65.9	73.8	69.2	64.1
1	22.0	19.1	17.7	48.1	45.9	42.0	47.7	45.6	41.4	32.9	30.4	25.9
3	57.5	57.5	43.3	81.3	88.3	66.9	49.6	44.1	37.8	66.3	61.1	55.2
5	65.0	63.2	60.9	59.9	62.4	58.9	75.1	71.5	66.7	82.1	78.7	68.7
7	76.7	71.0	69.2	61.8	56.4	52.1	65.9	63.7	60.0	57.5	55.9	49.0
9	82.8	78.1	76.8	81.7	80.7	71.3	86.2	84.0	85.6	70.6	64.7	57.5
13	75.8	72.8	75.0	81.9	74.1	71.3	92.3	90.0	83.9	82.0	80.6	74.4
17	90.5	87.1	87.1	100.	99.7	95.7	87.6	86.8	82.7	92.1	91.1	89.5
19	91.2	88.9	85.9	95.4	95.4	92.6	92.1	85.5	86.2	88.8	88.7	88.2
Mean	69.9	67.1	63.6	75.5	74.1	68.2	75.1	71.8	67.8	77.8	68.9	63.6

SEM = 10.97

[a] Values are means of 10 pens with 5 pigs per pen. CC = pigs fed control in the nursery and finishing, CA = pigs fed control in the nursery and antibiotic in finishing, AC = pigs fed antibiotic in the nursery and control in finishing, AA = pigs fed antibiotics in the nursery and finishing.

1.) Treatment (P = 0.147)
2.) Level (P= 0.015)
3.) Time (P< 0.001)
4.) Treatment x Level interaction (P = 0.999)
5.) Treatment x Time interaction (P = 0.004)
6.) Time x Level interaction (P = 1.000)
7.) Treatment x Time x Level interaction (P= 1.000)

Table 5. Percent of fecal coliforms resistant to virginiamycin added to the culture medium at three levels[a].

		Treatment											
		CC			CA			AC			AA		
Level (µg/L)		8	16	32	8	16	32	8	16	32	8	16	32
Week:													
0		76.6	73.1	50.5	73.5	67.2	67.2	76.5	72.8	69.4	86.4	85.0	80.4
1		27.7	26.0	20.5	58.4	54.3	44.1	50.0	47.7	45.6	42.9	38.7	36.7
3		80.0	80.0	78.0	86.1	92.3	69.9	76.6	70.0	68.5	94.3	79.3	73.4
5		71.9	70.6	66.2	72.3	69.5	64.2	76.6	73.7	71.8	88.6	83.0	79.7
7		78.2	71.3	69.6	73.3	61.2	53.9	68.3	65.4	60.6	60.8	49.7	35.7
9		84.0	84.0	84.0	82.2	75.6	81.0	88.5	88.2	86.4	72.8	71.1	67.2
13		75.2	76.6	76.6	81.4	73.2	73.2	89.4	88.2	85.5	84.3	82.7	75.5
17		86.7	90.5	86.7	100.	100.	98.4	89.1	88.3	88.3	92.4	91.9	87.9
19		98.4	98.8	98.4	94.8	94.7	96.1	92.8	91.9	90.4	98.2	98.2	96.1
Mean		75.4	74.5	70.1	80.2	76.4	72.0	78.6	76.3	74.1	80.1	75.5	70.3

SEM = 10.65

[a] Values are means of 10 pens with 5 pigs per pen. CC = pigs fed control in the nursery and finishing, CA = pigs fed control in the nursery and antibiotic in finishing, AC = pigs fed antibiotic in the nursery and control in finishing, AA = pigs fed antibiotics in the nursery and finishing.

1.) Treatment (P = 0.714)
2.) Level (P=0.025)
3.) Time (P<0.001)
4.) Treatment x Time interaction (P = 0.035)
5.) Treatment x Level interaction (P= 0.993)
6.) Time x Level interaction (P=0.9924)
7.) Treatment x Time x Level interaction (P= 1.000)

Table 6. Percent of Enterococcus resistant to chlortetracycline added to the culture medium[a].

	Treatment											
	CC			**CA**			**AC**			**AA**		
Level (µg/L)	60	80	100	60	80	100	60	80	100	60	80	100
Week:												
0	75.6	74.3	72.1	92.9	75.8	70.2	88.6	76.4	54.1	74.4	73.0	73.5
1	92.7	94.5	90.9	97.5	97.6	81.5	99.0	99.8	95.7	98.7	91.8	80.0
3	94.9	92.3	89.1	99.1	97.8	89.8	96.1	92.5	84.9	93.8	89.1	85.9
5	78.6	77.8	72.3	90.1	88.5	87.3	92.1	91.0	85.6	99.6	100.	98.2
7	66.7	52.4	46.4	93.7	82.3	72.0	82.3	72.6	66.9	83.3	74.2	71.6
9	22.9	14.7	7.9	66.0	43.8	21.3	58.4	34.4	11.6	42.5	35.2	14.2
13	99.2	92.1	85.6	74.0	64.3	50.0	85.3	79.8	70.8	76.4	72.4	54.0
17	68.6	58.0	18.0	43.4	34.8	33.7	65.9	44.8	25.9	65.4	50.8	22.2
19	86.8	85.2	64.5	65.1	53.6	35.1	73.7	68.9	61.4	63.4	49.4	41.5
Mean	76.2	71.3	60.7	80.2	70.9	60.1	82.4	73.4	61.9	77.5	70.7	60.1

SEM = 10.09

[a] Values are means of 10 pens with 5 pigs per pen. CC = pigs fed control in the nursery and finishing, CA = pigs fed control in the nursery and antibiotic in finishing, AC = pigs fed antibiotic in the nursery and control in finishing, AA = pigs fed antibiotics in the nursery and finishing.

1.) Treatment ($P = 0.562$)
2.) Level ($P < 0.001$)
3.) Time ($P<0.001$)
4.) Treatment x Time interaction ($P< 0.001$)
5.) Treatment x Level interaction ($P = 0.986$)
6.) Time x Level interaction ($P = 0.11$)
7.) Treatment x Time x Level interaction ($P = 1.000$)

Table 7. Percent of Enterococcus resistant to virginiamycin added to the culture medium at three levels[a].

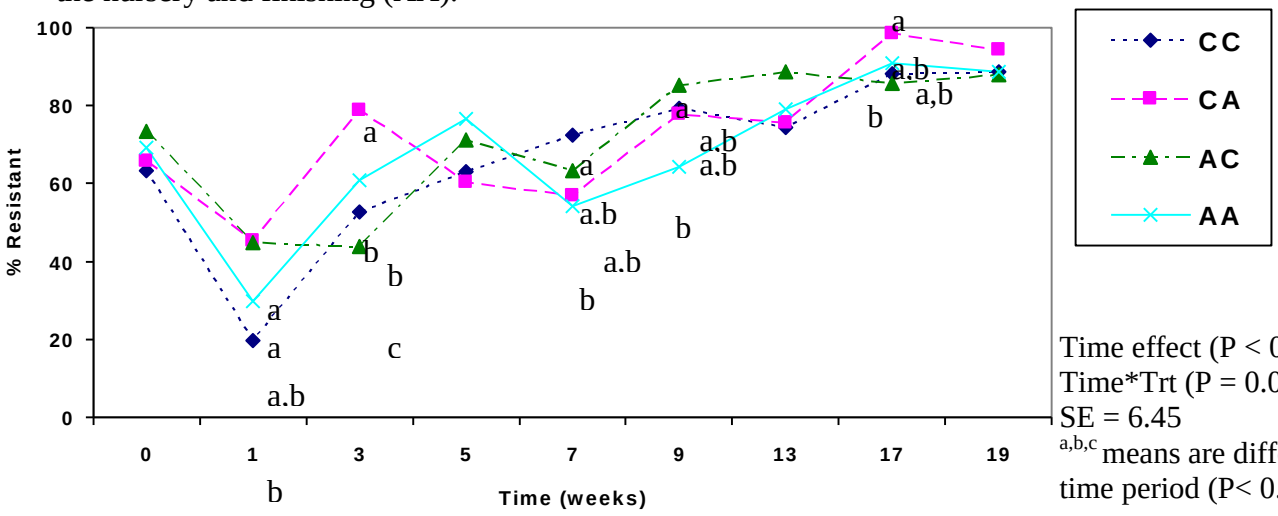
	Treatment											
	CC			**CA**			**AC**			**AA**		
Level (µg/L)	8	16	32	8	16	32	8	16	32	8	16	32
Week:												
0	76.7	72.2	52.8	89.9	69.3	46.5	87.7	82.4	55.2	86.1	79.0	57.4
1	99.7	90.0	88.2	95.3	83.5	87.1	95.1	95.1	89.7	88.7	83.9	80.9
3	91.7	89.4	86.1	97.3	87.8	86.4	94.8	87.1	86.2	94.7	89.8	85.8
5	81.4	79.7	75.0	90.6	90.8	81.9	97.5	96.9	91.7	97.8	97.6	96.6
7	75.6	58.3	43.0	83.2	71.4	67.1	77.0	72.6	63.0	83.6	80.2	73.8
9	27.2	15.8	11.0	55.2	47.7	27.6	49.7	35.1	21.3	61.4	36.9	21.5
13	99.6	94.9	83.0	73.8	62.0	50.5	91.4	87.8	78.9	71.3	58.3	45.0
17	68.9	49.4	16.2	50.8	44.5	35.9	61.2	51.8	39.8	71.1	51.3	21.5
19	74.6	65.9	55.1	91.8	69.8	28.3	76.4	65.3	61.0	74.8	59.8	46.6
Mean	77.3	68.4	56.7	80.9	69.7	56.8	81.2	74.9	65.2	81.1	70.8	58.8

SEM = 10.17

[a] Values are means of 10 pens with 5 pigs per pen. CC = pigs fed control in the nursery and finishing, CA = pigs fed control in the nursery and antibiotic in finishing, AC = pigs fed antibiotic in the nursery and control in finishing, AA = pigs fed antibiotics in the nursery and finishing.

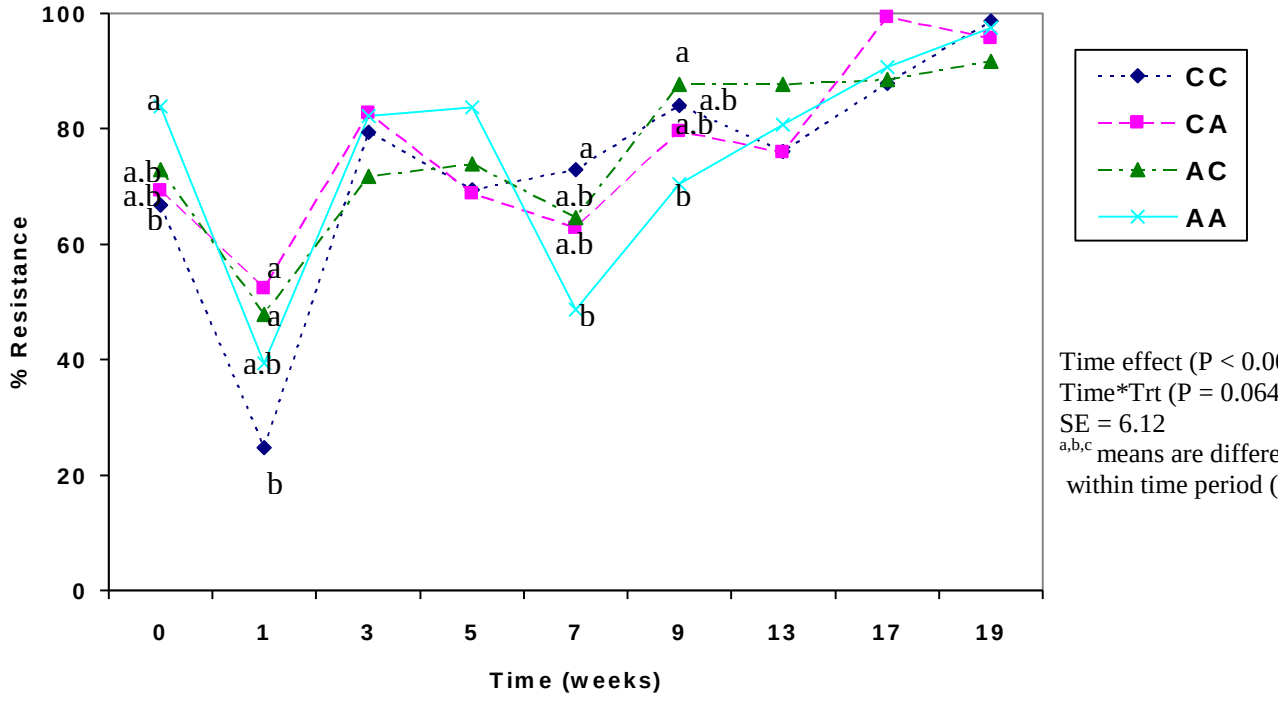
1.) Treatment ($P = 0.105$)
2.) Level ($P < 0.001$)
3.) Time ($P < 0.001$)
4.) Treatment x Time interaction ($P = 0.001$)
5.) Treatment x Level interaction ($P = 0.942$)
6.) Time x Level interaction ($P= 0.087$)
7.) Treatment x Time x Level interaction ($P = 1.000$)

Figure 1. Percentage of chlortetracycline resistant fecal coliforms isolated from pigs fed control in the nursery and finishing (CC), control in nursery and antibiotics in the finishing (CA), antibiotics in the nursery, control in the finishing (AC), or antibiotics in the nursery and finishing (AA).



Time effect (P < 0.001)
Time*Trt (P = 0.0092)
SE = 6.45
[a,b,c] means are different within time period (P< 0.05)

Figure 2. Percentage of virginiamycin resistant fecal coliforms isolated from pigs fed control in the nursery and finishing (CC), control in nursery and antibiotics in the finishing (CA), antibiotics in the nursery, control in the finishing (AC), or antibiotics in the nursery and finishing (AA).



Time effect (P < 0.001)
Time*Trt (P = 0.0641)
SE = 6.12
[a,b,c] means are different within time period (P< 0.05)

Figure 4. Percentage of chlortetracycline resistant enterococcus isolated from pigs fed control in the nursery and finishing (CC), control in nursery and antibiotics in the finishing (CA), antibiotics in the nursery, control in the finishing (AC), or antibiotics in the nursery and finishing (AA).

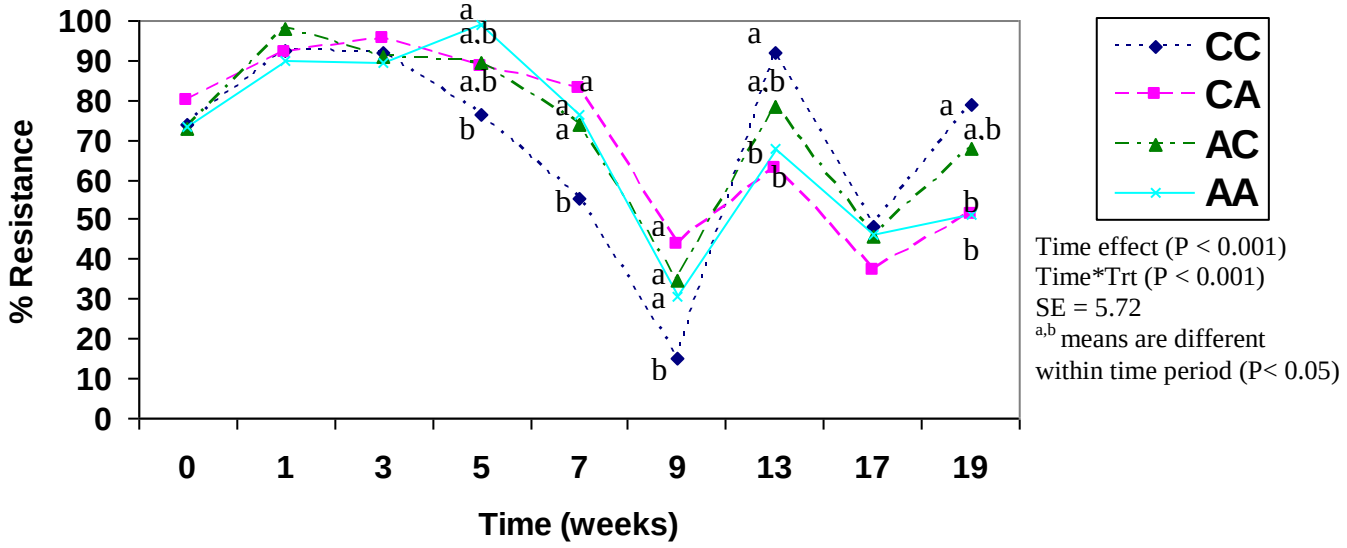


Figure 5. Percentage of virginiamycin resistant enterococcus isolated from pigs fed control in the nursery and finishing (CC), control in nursery and antibiotics in the finishing (CA), antibiotics in the nursery, control in the finishing (AC), or antibiotics in the nursery and finishing (AA).

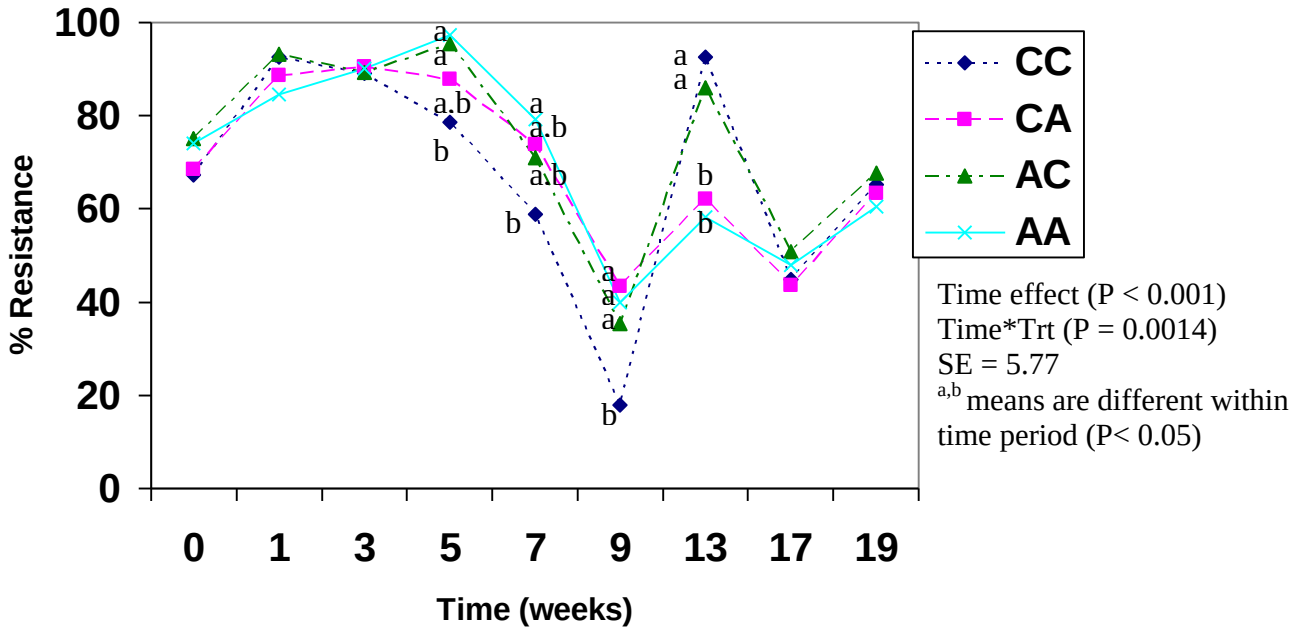


Table 8. Percent of resistant E. coli recovered during a simulated water runoff event following the nursery phase.

	Treatment		SE	P-value
	Control	Antibiotic		
Antibiotic	Chlortetracycline[a,b,c]			
Time:				
Initial runoff	72.1	93.7	10.11	0.040
5 min	81.0	68.7	8.99	0.181
15 min	71.5	78.8	10.11	0.470
30 min	82.2	15.6	16.65	>0.001
Antibiotic	Virginiamycin			
Time:				
Initial runoff	99.8	99.9	2.82	0.992
5 min	95.8	96.5	2.44	0.748
15 min	99.1	95.7	2.82	0.235
30 min	100.	100.	4.87	0.939
Antibiotic	Erythromycin[b,c]			
Time:				
Initial runoff	28.7	56.8	11.97	0.024
5 min	27.2	3.98	10.37	0.031
15 min	27.4	29.3	11.97	0.872
30 min	0.67	0.26	20.73	0.984

[a] treatment effect ($P < 0.05$)
[b] time effect ($P < 0.05$)
[c] time x treatment effect ($P < 0.05$)

Table 9. Percent of resistant Enterococcus recovered during a simulated water runoff event following the nursery phase.

	Treatment		SE	P-value
	Control	Antibiotic		
Antibiotic	Chlortetracycline[a,b]			
Time:				
First flush	64.6	90.06	12.96	0.054
5 min	89.8	88.57	12.79	0.923
15 min	90.6	87.20	12.47	0.786
30 min	63.1	80.28	12.47	0.173
Antibiotic	Virginiamycin[a,b]			
Time:				
First flush	88.2	100.0	10.12	0.141
5 min	95.4	87.4	10.00	0.429
15 min	81.2	87.2	9.81	0.545
30 min	64.2	78.5	9.81	0.150
Antibiotic	Erythromycin[a,b]			
Time:				
First flush	66.5	74.2	13.76	0.579
5 min	69.8	82.9	13.60	0.341
15 min	90.6	87.2	13.35	0.800
30 min	40.3	57.9	13.35	0.191

[a] time effect ($P < 0.05$)
[b] time x treatment effect ($P < 0.05$)
[c] level effect ($P = 0.0127$)

Table 10. Percent of resistant E. coli recovered during a simulated water runoff event following the finishing phase.

	Treatment				SE
	CC	CA	AC	AA	
Antibiotic	Chlortetracycline [a]				
Time:					
Initial Runoff	100.0^{x}	100.0^{x}	98.4^{y}	100.0^{x}	0.194
5 min	100.0	100.0	100.0	100.0	0.194
15 min	100.0^{x}	100.0^{x}	100.0^{x}	98.5^{y}	0.173
30 min	100.0	100.0	99.6	100.0	0.173
Antibiotic	Virginiamycin[a]				
Time:					
Initial Runoff	100.0	100.0	88.1	100.0	2.540
5 min	100.0^{x}	100^{x}	78.3^{y}	100.0^{x}	2.493
15 min	100.0	89.3	97.9	98.9	2.286
30 min	100.0^{x}	85.7^{y}	100.0^{x}	100.0^{x}	2.286
Antibiotic	Erythromycin[a,b]				
Time:					
Initial Runoff	75.7^{y}	29.2^{x}	31.7^{x}	40.0^{x}	6.311
5 min	70.4^{y}	29.5^{x}	33.8^{x}	32.4^{x}	6.217
15 min	48.5^{x}	56.9^{x,y}	43.7^{x}	87.2^{y}	5.663
30 min	50.0	47.1	50.7	75.9	5.663

[a] time x treatment interaction ($P < 0.05$)

[b] level effect ($P < 0.05$)

[x,y] treatment means within a row differ ($P < 0.05$)

Table 11. Percent of resistant Enterococcus recovered during a simulated water runoff event following the finishing phase.

	Treatment				SE
	CC	CA	AC	AA	
Antibiotic	Chlortetracycline [a,b,c]				
Time:					
Initial Runoff	100.0	100.0	96.3	100.0	2.850
5 min	100.0	100.0	99.6	100.0	3.186
15 min	100.0	95.0	100.0	100.0	2.850
30 min	100.0[x]	100.0[x]	100.0[x]	46.7[y]	3.186
Antibiotic	Virginiamycin[c]				
Time:					
Initial Runoff	61.5[y]	100.0[x]	100.0[x]	100.0[x]	4.828
5 min	52.0[y]	100.0[x]	92.2	100.0[x]	5.278
15 min	100.0[x]	100.0[x]	71.2[y]	100.0[x]	4.828
30 min	100.0[x]	85.7[x]	84.6[x]	50.0[y]	5.331
Antibiotic	Erythromycin [a]				
Time:					
Initial Runoff	67.4[x,y]	93.7[x]	72.2[x]	37.5[y]	5.473
5 min	60.6[x]	100.0[y]	48.7[x]	34.5[x]	6.051
15 min	100.0[x]	100.0[x]	45.4[y]	31.8[y]	5.473
30 min	100.0[x]	72.6[x,y]	53.9[y]	18.2[z]	6.083

[a] treatment effect ($P < 0.05$)
[b] time effect ($P < 0.05$)
[c] time x treatment interaction ($P < 0.05$)
[x,y,z] treatment means within a row differ ($P < 0.05$)

Table 12. Assumed prices for control and antibiotic diets ($/kg feed)

	Pre-starter	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Control	0.6304	0.3500	0.2452	0.1804	0.1765	0.1731	0.1626
Antibiotic	0.6343	0.3543	0.2496	0.1835	0.1812	0.1782	0.1676
Antibiotic as percentage of Control	100.63	101.23	101.80	101.71	102.66	102.93	103.08

Table 13. Effect of antibiotic growth-promoters on calculated costs of production of gilts during the nursery phase

	Treatment			
	Control	Antibiotic	Control	Antibiotic
	$/pig marketed	$/pig marketed	$/kg marketed	$/kg marketed
Cost Category				
Weaned Pigs Purchased	30.957	30.612	1.415	1.451
Pre-starter	0.685	0.740	0.031	0.035
Starter 1	2.430	2.420	0.111	0.115
Starter 2	2.766	2.629	0.126	0.125
Other Operating	4.303	4.255	0.197	0.202
Facilities	1.481	1.465	0.068	0.069
Total	42.622	42.121	1.948	1.996
Mortality	percent of pigs placed			
Wk 0-1	0	0	0	0
Wk 1-3	1	2	1	2
Wk 3-5	2	0	2	0

Table 14. Effect of antibiotic growth-promoters on calculated costs of production of gilts during the finishing phase ($/pig marketed)

	Treatment			
	CC	AC	CA	AA
	$/pig marketed	$/pig marketed	$/pig marketed	$/pig marketed
Cost Category				
Feeder Pigs Purchased	46.50	43.16	46.07	46.02
Grower 1 Feed	7.36	6.91	7.38	7.32
Grower 2 Feed	10.05	10.14	11.06	11.02
Finisher 1 Feed	12.12	12.22	12.13	12.46
Finisher 2 Feed	10.14	10.16	10.40	10.34
Other Operating	11.73	11.40	11.38	11.62
Facilities	6.351	6.092	5.970	6.218
Total	104.26	100.07	104.38	105.00
Mortality	percent of pigs placed			
Wk 6-9	4	0	0	0
Wk 10-13	2	0	0	0
Wk 14-17	0	2	0	4
Wk 18-20	0	0	0	0

Table 15. Effect of antibiotic growth-promoters on calculated costs of production of gilts during the finishing phase ($/kg marketed)

	Treatment			
	CC	AC	CA	AA
	$/kg marketed	$/kg marketed	$/kg marketed	$/kg marketed
Cost Category				
Feeder Pigs Purchased	0.389	0.363	0.382	0.388
Grower 1 Feed	0.06	0.06	0.06	0.06
Grower 2 Feed	0.08	0.09	0.09	0.09
Finisher 1 Feed	0.10	0.10	0.10	0.11
Finisher 2 Feed	0.08	0.09	0.09	0.09
Other Operating	0.098	0.096	0.094	0.098
Facilities	0.053	0.051	0.049	0.052
Total	0.872	0.841	0.865	0.886
Mortality	percent of pigs placed			
Wk 6-9	4	0	0	0
Wk 10-13	2	0	0	0
Wk 14-17	0	2	0	4
Wk 18-20	0	0	0	0

Table 16. Effect of Eliminating Mortality differences on the effect of antibiotic growth-promoters on calculated costs of production of gilts during the nursery an finishing phases

	Treatment			
	CC	AC	CA	AA
Nursery Phase				
	$ Cost per Nursery pig marketed			
With Actual Mortality	43.67	42.02	41.57	42.22
With Average Mortality	42.17	42.25	42.56	42.44
	$ Cost per Nursery kg marketed			
With Actual Mortality	2.047	2.035	1.848	1.957
With Average Mortality	1.976	2.046	1.892	1.968
	CC	AC	CA	AA
Finishing Phase				
	$ Cost per Finished Hog marketed			
With Actual Mortality	104.26	100.07	104.38	105.00
With Average Mortality	102.45	100.63	106.69	103.86
	$ Cost per Finished kg marketed			
With Actual Mortality	0.872	0.841	0.865	0.886
With Average Mortality	0.857	0.846	0.884	0.876

1. Average mortality for the nursery phase is: week 0 – 1: 0.0%, week 1 – 3: 1.5%, and week 3 – 5: 2.0%.
2. Average mortality for the finishing phase is: week 6 – 9: 1.0%, week 10 – 13: 0.5%, week 14 – 17: 1.5%, and week 18 – 20: 0.0%.
3. See previous tables for the actual mortality rates in the nursery and finishing phases.