THESIS

THE EFFECT OF FEED ADDITIVE PROGRAM IN STEAM-FLAKED CORN DIETS CONTAINING WET DISTILLER'S GRAINS ON PERFORMANCE AND CARCASS MERIT IN YEARLING FEEDLOT STEERS.

Submitted by

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ABSTRACT

THE EFFECT OF FEED ADDITIVE PROGRAM IN STEAM-FLAKED CORN DIETS CONTAINING WET DISTILLER'S GRAINS ON PERFORMANCE AND CARCASS MERIT IN YEARLING FEEDLOT STEERS.

Crossbred yearling steers (432, BW = 329 ± 10.5 kg) were used in an unbalanced randomized block design to examine the effect of feed additives on performance and carcass merit. Treatment factors were arranged as a 2 x 2 factorial and included ionophore and antibiotic [Rumensin/Tylan (R/T) or Cattlyst/Aureomycin (C/A)] and dietary S (constant or variable). High S diets were fed on random days to the variable (VAR) treatment. Low S diets were fed to the VAR treatment on remaining days and to the constant (CON) treatment all days. From d 0 through 35, the high S diet was achieved by using a high S granular supplement; however, since S concentration in wet distillers grains (WDG) is associated with distillers solubles (DS) added to WDG and H_2SO_4 added to the DS, the high S diet was achieved from d 36 through 159 by using a DS based liquid supplement with 2.35% S while the low S diet was achieved using a 0.99% S DS based liquid supplement. Cause of cattle death for study steers was verified by necropsy. No interaction between S and additive treatments existed for feedlot performance; therefore, only main effects are presented. Most of the sulfur comparisons from this study will be addressed in another manuscript. Feedlot performance and

carcass merit were similar for feed additive treatments. The S by feed additive interaction was significant ($P < 0.05$) for dressing percentage indicating that S treatment had no effect on dressing percentage if R/T was fed but when steers were fed C/A, dressing percentage was reduced by 0.72 % ($P < 0.02$) if VAR diets were fed. The results of this study indicate that performance and carcass characteristics for cattle fed Cattlyst and Aureomycin are similar to performance and carcass characteristics for cattle fed Rumensin and Tylan.

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Introduction

Throughout the 20th century in the United States, an increase in demand for animal products and advances in agronomy allowed animal industry to examine alternative methods for animal production. One of the outcomes of this trend was a shift from forage and grazing based diets for livestock to grain based diets as well as confined production practices. Though many economic benefits can be seen, the system is not without flaw.

When feeding high levels of concentrate feeds to ruminants, there is a shift in the proportions of volatile fatty acids (VFA) in the rumen. An increase in propionate production and decrease in acetate production are normal responses (Richardson et al., 1976). When done correctly, this should not create issues for the animal. However, unexpected circumstances such as weather, equipment breakdown, or illness coupled with high concentrate diets can fuel digestive upsets (Pritchard and Bruns, 2003). Many lactate producing, starch-utilizing strains of bacteria thrive in the high concentrate environments. When lactate utilizing bacteria cannot compensate, lactic acid accumulates in the rumen, reducing pH and disturbing normal digestive function (Dennis et al., 1981).

In the latter half of the century, the poultry industry began commonly using ionophores to combat coccidiostats. In 1967, one of these products, monensin (Figure 1.1), was found to have properties which inhibit gram-positive bacteria and mycobacteria (Haney and Hoehn, 1968), which could be applied to ruminant animal production. Further research showed positive effects in terms of acidosis, feed efficiency, and methanogenesis among others (Owens, 1987, As cited by Bauer et al., (1995); Goodrich et al., 1984;Van Nevel and Demeyer, 1977). Ionophores gained FDA approval in 1975 as a feed additive for ruminants (Goodrich et al., 1984).

Rumen Microbiology

The fauna composites of the rumen depend greatly on the diet of the animal. As explained by Russell and Strobel (1989) in a minireview on ruminal fermentation, protozoa, fungi, and bacteria generally present in the rumen as both facultative and obligate anaerobes are all assets to the fermentation process. Though not required for feed digestion, protozoa make up approximately half of the biomass in the rumen. Fungi make up 8% of the microbial mass. Fungi seem to play a role in lignified fiber digestion and have been found to have some proteolytic properties (Wallace and Joblin, 1985). High and diverse bacterial counts are necessary characteristics for efficient feed digestion (Russell and Strobel, 1989).

Proton motive force can be considered the basis of prokaryotic metabolism. Transport of amino acids, sugars, and other ions as well as adenosine triphosphate (ATP) synthesis are dependent upon on this system. As discussed by Mitchell (1967), proton motive force is a result of a difference in electron potential and pH values across

microbial membranes. It can be expressed by the following equation

$$\Delta P = \frac{F\Delta\Psi - 2.3RT\Delta pH}{F}$$ with P = proton motive force, F = faraday, R = gas content, T = temperature in Kelvin units, Ψ = electrical gradient, and pH = chemical gradient of protons. Changes in electrical and chemical gradient exert a force that pulls protons in or out of the cell.

Bergen and Bates (1984) reviewed the mode of action for ionophores. The following section is a brief summary of that review. Proton motive force is maintained in an anaerobic environment by proton extrusion and/or electron transport. Proton extrusion generally consists of a membrane bound ATPase, such as F1 F0 ATP synthase. This protein has a hydrophobic section that acts as a proton channel and a section that catalyzes or hydrolyzes ATP. In the presence of a proton gradient, ATP is synthesized, while in the absence of a proton gradient, the energy from ATP hydrolysis is expended on proton extrusion. Electron transport allows for more energy efficient maintenance of the proton gradient and does not require as much intracellular ATP as proton extrusion. Electron transport in anaerobes is similar to oxidative phosphorylation except the electron acceptors that are most common are sulfate, nitrate, and sulfur. Both electron transport and proton extrusion are considered to be primary transport systems. The purpose of these systems is to convert chemical energy to electrosmotic energy. The electrosmotic energy can then activate secondary active transport systems.

Secondary active transport systems include symport, uniport, and antiport. Transport of nutrients is actively facilitated against the concentration gradient by electrosmotic energy. Symporters are carriers that will transport two unrelated ions across

the membrane at the expense of one solute flowing against the gradient. Uniport transport either involves diffusion for single uncharged solutes or is gradient potential dependent for charged substrates. Antiporters translocate two substrates across a membrane in opposite directions. This mechanism is the preferred method for creating a sodium gradient in place of a proton gradient for halophiles, which are abundant in the rumen..

In anaerobic environments, fumarate reductase is the enzyme responsible for metabolizing fumarate to succinate, which is easily converted to propionate. This enzyme has higher activity in gram negative enzymes than in gram positive enzymes. This contributes to higher levels of oxidative phosphorylation and greater ATP production.

Effects of Ionophores on Ruminal Microbes

When a carboxylic polyether ionophore is added to a ruminant diet, it impacts the rumen microbial environment and may also have effects on the host animal. Kadner and Bassford (1978; As cited by Bergen and Bates, 1984) discuss that gram negative bacteria seem to maintain populations in the rumen while gram positive bacteria tend to be negatively affected. Gram negative microbes have three layers: an outer membrane, a peptidoglycan layer, and a plasma membrane. The outer membrane protects the proton gradient from ionophore activity. However, gram positive bacteria lack the outer membrane. The difference in structure influences the organisms' abilities to cope in the presence of ionophores. Gram positive bacteria lack the protection of an outer membrane. Therefore, gram positive bacteria do not thrive in an environment containing ionophores. *Butyrivibrio fibrisolvens*, a bacterium that stains and is considered gram

negative, also displays properties of gram positive bacteria in the membrane structure and is also inhibited by ionophores (Cheng and Costerton 1977).

In addition to differences in membrane structure, gram positive and negative bacteria vary in ATP production. Gram negative bacteria rely heavily on fumarate reductase, while gram positive negative depend on alternative methods. Fumarate reductase, in addition to contributing to higher levels of intracellular ATP, contributes to the shift in ruminal VFAs (Kroger, 1977; As cited by Bergen and Bates, 1984). As gram positive bacteria counts are depleted, gram negative can continue to proliferate causing a higher presence of fumarate reductase and therefore increasing the proportion of propionate in the rumen (Bergen and Bates, 1984).

One of the results of a diet including ionophores is a decrease in ruminal methanogenesis. About 12% of feed energy loss is from methane production, which is eventually eructated. Feeding ionophores allows for 30% of this energy to be retained (Russell and Strobel, 1989). This reduction is not due to the inhibition of methanogens, but rather a decrease in free protons. Van Nevel and Demeyer (1977) confirmed this in vitro when infusing hydrogen gas reactivated methanogenesis.

Pressman (1976) reviewed the structure and activation of ionophores that is briefly summarized here. Ionophores can be absorbed and/or activated throughout the digestive tract. When activated, it takes an acyclic ionic form. The acyclic formation of the ionophore allows for stability in bimolecular lipid membranes and aids in cationic transport across cell membranes. The negative charge on the carboxyl terminus or at other points in the structure permits an ionic bond with metals. When the binding takes

place the structure takes a cyclic formation with lipophilic properties. Eventually, the formation will interact with the polar aspects of the internal side and will disrupt the stability of the ionic bond. This causes the structure to revert to its acyclic form.

As the antiport mechanism of the ionophore take place in the rumen, the proton motive force can be disrupted. This causes an influx of hydrogen ions into the cells. In order to counteract this disturbance, the cells must expend ATP to maintain pH and electrical gradients across the cell membranes. As explained by Jolliffe et al. (1981; As cited by Bergen and Bates, 1984) gram positive bacteria have difficulty as their main source of stability is proton extrusion that requires the use of intracellular ATP. Once the store of ATP is depleted, the cell cannot survive. Gram negative bacteria have more success because of higher use of electron transport. As a result, feeding ionophores causes an increase in population of gram negative bacteria and inhibits gram positive bacteria. Many lactate and acetate producing bacteria are gram positive, and many propionate producing, lactate utilizing bacteria are gram negative. This contributes to the change in VFA ratio and the decreased prevalence of lactic acidosis (Newbold and Wallace, 1988).

Though most ionophores have similar stoichiometric properties, their likeness is not consistent in terms of cationic affinity. Monensin has a strong predilection for Na^+. Following Na^+ is K^+ with an affinity ten times lower (Bergen and Bates, 1984; Pressman, 1976). Lysocellin is similar to monensin in preference (Kegley, 1991). Other ionophores have distinct tendencies. Lasalocid has a preference for K^+, but will still bind with Na^+ and Ca^{++}. Tetronasin binds strictly with divalent ions. The literature regarding the

mechanisms of ionophores laidlomycin (Figure 1.2) and narasin is sparse (Russell and Strobel, 1989).

Effects of Ionophores on Host Physiology

The changes in the rumen when ionophores are fed are significant; however, the amount of improvement in performance and carcass characteristics cannot be accounted for solely by contributions from changes in ruminal fermentation (Raun et al., 1976). Bergen and Bates (1984) offer the solutions of lower heat increment and protein sparing as additional factors. The lower heat increment of propionate compared with acetate requires less energy for metabolism; however, inconsistency exists in the research. Also, Ionophores are known to alter nitrogen metabolism. The decrease in overall cell yield or the tolerance of gram negative versus positive bacteria (Van Nevel and Demeyer, 1977) may influence the protein sparing effect leaving protein for intestinal degradation.

Monensin

Monensin was the first ionophore approved for ruminants by the FDA and is still the most widely used in the feedlot industry (Russell and Strobel 1989). This ionophore is produced by a strain of *Streptomyces cinnamonensis* (Haney and Hoehn, 1968). Commonly seen effects of monensin when added to ruminant diets are improved gain and feed efficiency. Richardson et al. (1976) reported a 50% increase in propionic acid production *in vitro* with reduction ($P < 0.05$) in butyric acid at dosages as little as 0.5 mg/kg DM monensin. A decrease in acetate was not detected until the dosage increased to 25 ppm. An even higher increase of 76% propionate production and decreases of 16% and 14% for acetic and butyric acids, respectively, was detected by Perry et al. (1976) for

steers fed 33 ppm monensin. Propionate is the most gluconeogenic VFA and could contribute to the increased efficiency. Goodrich et al. (1984) summarized 228 studies utilizing monensin in cattle with the outcome of 1.6% greater average daily gain and a 6.4% decrease in dry matter intake. Dry matter intake is commonly depressed when feeding monensin (Baile et al., 1979; Bergen and Bates, 1984; Galyean et al., 1992). Feed efficiency was found to be optimum at a metabolizable energy concentration of 2.9 Mcal/kg DM (Goodrich et al, 1984). However, other research shows monensin palatability influencing a decrease in intake while maintaining gains (Gill et al., 1976; Perry et al., 1976). This palatability issue was investigated further by Baile et al. (1979) by comparing Rumensin (Elanco Animal Health) with monensin sodium salt. Dry matter intakes between cattle receiving the control diet and cattle receiving monensin sodium were similar leading to the possibility that a component of the Rumensin premix is causing the decrease in intake not the monensin itself.

Digestive disorders are estimated to effect 1.9% of calves after arrival at the feedlot (USDA, 2000). Monensin has been linked to improved cattle health in the feedlot. By reducing intake variation (Stock et al., 1995), digestive disorders can be reduced. Monensin is known to inhibit many lactate producing bacteria without hindering lactate utilizing bacteria (Dennis et al., 1981). The ionophore also was successful at combating experimentally induced acidosis (Naragaja et al., 1981); however, Stock et al. (1990) concluded monensin helps reduce the likelihood of acidotic animal, but does not prevent occurrence. Erickson et al. (2003) supported this with reporting a decrease in meal size and increase in number of meals when cattle are fed monensin may contribute to a decrease in lactic acidosis when clean bunk management is used.

Another production disease found in feedlot is grain (feedlot) bloat. This condition can arise when feeding high concentrate diets. *Streptococcus bovis*, a common gram positive lactate producing bacteria, is known to produce large mucoid colonies as a fermentation product (Niven et al., 1941). This polysaccharide product has been attributed to the formation of the froth in both feedlot and legume bloat (Hungate et al., 1954). Because monensin is known to have detrimental effects on *S. bovis,* research has taken place to determine the reliability of feeding monensin to prevent grain bloat. Bartley et al. (1983) found at a dose of 1.32 mg of monensin/kg BW reduced bloat 64%.

The effects of monensin are not limited to rumen microflora and the higher ruminal propionate production does not account for the entire feed efficiency increase (Raun et al., 1976). Thirty-six to 40% of monensin is absorbed by a calf (Davison, 1984). By intravenous administration of 18 g monensin, Armstrong and Spears (1988) found concentrations of free fatty acids and glucose were elevated and K, Mg, and P concentrations were reduced for heifers receiving monensin treatments. A study done by Starnes et al. (1984) concluded that monensin increased absorption of Na, Mg, and P. Absorption of K and Ca were not affected by monensin.

Serum concentrations of macrominerals were not affected, though serum Zn and Cu concentrations were elevated. It should be noted that despite different cationic affinities, mineral metabolism responds to different ionophores in a similar manner (Spears, 1990).

Laidlomycin Propionate

Laidlomycin propionate was developed in the 1970s by Japanese scientists as a polyether ionophore with antimycoplasmic properties. This antibiotic is produced from a

strain of *Streptomyces* that was originally found in soil at Lake Saiko, Yamanshi Prefecture, Japan. These bacteria have similar properties to *Streptomyces eurocidus* var. *asterocidicus*. The stoichiometry of laidlomycin differs by the presence of a propionyl group in place of the methoxy group of monensin. This difference seems to influence the characteristics of this ionophore by increasing molecular weight and lowering the nuclear magnetic resonance (Kitame et al., 1974).

In a study comparing laidlomycin and its derivatives, it was found that compounds with straight chain acyl groups were more effective in reducing lactic acid production when the groups had two to twelve carbons. Laidlomycin butyrate was found to surpass both monensin and laidlomycin for lactic acid inhibition, while improving the environment for propionate producers more efficiently than laidlomycin. However, inadequate statistical power associated with the study prevented performance differences between these products (Spires and Algeo, 1983).

In a summary of six experiments in various locations in the United States, Spires et al. (1990) concluded that laidlomycin propionate was effective for increasing average daily gain and feed efficiency in both steers and heifers. The dosage found to maximize benefits was 6 to 12 mg/kg; however, differences existed between these dosages. Six mg/kg maximized average daily gain, but feed efficiency progressed until 12 mg/kg (Spires et al., 1990). Diets fed consisted of 1.08 to 1.49 Mcal/kg for NE_g and decreases in average daily gain could be seen as energy density increased. Increases in longissimus area, internal kidney, pelvic, and heart fat, yield and quality grade, back fat, and marbling score could be seen in the laidlomycin diets; however, utilizing carcass weight as a

covariate eliminated these differences (Spires et al., 1990). It should be noted that cattle used in these trials were not implanted.

Galyean et al. (1992) reported increased dry matter intake for a dosage of 6 mg/kg laidlomycin treatment compared to control, 12 mg/kg laidlomycin, and monensin plus tylosin; however, average daily gain was similar for all treatments. It is suggested that the differences between this study and previous studies may be due to the presence of implants and a NE_g equal to 1.42, which is on the higher end of the range studied in past experiments.

Effects of laidlomycin propionate on ruminal fermentation have varied. Laidlomycin has been reported to have no influence on ruminal VFA concentration (Galyean et al., 1992; Quinn et al., 2009). In contrast, Laidlomycin was concluded at 6 mg/kg, but not at 12 mg/kg level to increase total VFA production (Bauer et al. 1995) as well as reducing ruminal lactate (Bauer et al., 1995; Gaylean et al., 1992; Spires and Algeo, 1983). Laidlomycin has been found to be an effective *S. bovis* inhibitor, though not to the extent of monensin, which would attribute to the decrease in ruminal lactate (Wampler et al., 1998). Propionate concentration has been found to increase while acetate:propionate decreases in both in vitro and feedlot experiments (Bohnert et al., 2000; Spires and Algeo, 1983). Though Domescik and Martin (1999) found laidlomycin to decrease acetate:propionate, concentrations of propionate were suppressed in vitro. Campbell et al. (1997) reported laidlomycin had no effect on ruminal fermentation or performance.

Though inconsistency exists regarding laidlomycin research, Zinn et al. (1996) suggest an explanation. It was reported that 76% of the variation in feed efficiency for laidlomycin propionate could be associated with Ca:Mg ratio (Zinn et al., 1996). This is further supported by a metabolism trial showing Mg by laidlomycin interactions. Decreased proportions of acetate and increased proportions of propionate were found at higher Mg (0.32%) levels when feeding laidlomycin. Laidlomycin also increased intake at lower Mg levels, while decreasing intake at higher Mg levels (Zinn et al., 1996). Similar comparisons were made in vitro with Mg and K when examining other polyether ionophores by Chirase et al (1987). In addition, rumen pH is generally reported unaffected by laidlomycin (Bauer et al, 1995; Bohnert et al., 2000; Domescik and Martin, 1999; Galyean et al., 1992), however an interaction between Mg and laidlomycin concentrations shows an increase in pH with low Mg (0.18%) diets and decrease in pH on high Mg (0.32%) diets when laidlomycin was included in the diet (Zinn et al., 1996). Quinn et al. (2009) also reported when S was added to an in vitro culture system at approximately 0.42%, no difference was found in ionophore treatments which included laidlomycin, in acetate:propionate and propionate concentration when compared with the control. However, when no S was added acetate:propionate was decreased and propionate concentration was increased in ionophore treatment (Quinn et al., 2009). These data lead to the recommendation of further research for the effects of laidlomycin on ruminal fermentation and overall performance especially in respect to nutrient interactions with the ionophore.

Monensin vs. Laidlomycin Propionate

In 1983, an in vitro study showed though both laidlomycin and monensin increased propionic acid concentration, decreased lactic acid accumulation, monensin was more effective (Spires and Algeo 1983). Similarly, Domescik and Martin (1999) reported reductions in lactate production, methane concentration, and acetate:propionate ratio when conducting an in vitro experiment with ground corn, trypticase and alfalfa; however, only monensin increased final pH and in vitro dry matter disappearance. Contrary to Spires and Algeo (1983), concentrations of ruminal VFA were depressed by both laidlomycin and monensin. Despite the similar effects of monensin and laidlomycin, laidlomycin was less potent. The lack in ruminal pH decrease for laidlomycin found by Domescik and Martin (1999) agrees with research done at the University of Nebraska on ruminal acidosis (Bauer et al., 1995). This study concluded laidlomycin propionate was not effective at preventing ruminal acidosis, but did improve feed efficiency. Monensin was also found to be effective at controlling acidosis with higher pH by Burrin and Britton (1986). When comparing cell growth and glucose utilization of gram-positive and gram negative bacteria, though both products decreased opticial density, glucose utilization, and lactate production in gram-positive, monensin was the more potent inhibitor.

Feedlot studies done directly comparing laidlomycin and monensin are few. In 1992, New Mexico State University found monensin and laidlomycin to be equally effective regarding average daily gain and feed:gain, but monensin had lower intakes (Galyean et al., 1992). Bohnert et al. (2000) reported feedlot performance to be indistinguishable between treatments. Both these studies agree with an in vitro study with

sulfur components by Quinn et al. (2009) which conveyed lack of difference between monensin and laidlomycin in gas production and in vitro dry matter disappearance. The contradiction between the majority of the in vitro studies and the performance studies suggests that monensin and laidlomycin propionate may have an influence on host physiology that is difficult to replicate in culture.

Sub-therapeutic Antibiotics

Though antibiotics were originally designed to cure infectious diseases, feeding antibiotics to livestock at sub-therapeutic levels produces growth enhancing effects and has become common practice in the last 50 years. The mode of action behind these advantages is unclear. Many hypotheses revolve around microorganisms in the gastrointestinal tract. These hypotheses suggest that proliferation of microorganisms increase nutrient absorption or metabolism or inhibition of microbes depress growth (Visek, 1978). In addition, antibiotics have been attributed to the efficacy of *Fusobacterium necrophorum* inhibition, a major bacteria in the rumen and contributor to the development of liver abscesses (Nagaraja and Chengappa, 1998). The products that will be described in more detail are tylosin and chlortetracycline.

Tylosin

Tylosin is known to be the most commonly used sub-therapeutic antibiotic. Tylosin can be fed in conjunction with monensin, ractopamine or zilpaterol, and melengesterol acetate. Potter et al. (1985) analyzed fourteen trials to gain clarity about previous ambiguous results of the effects of tylosin on feedlot performance and carcass merit. Authors reported faster gain, no effect on feed intake, and an increase by 1.64% on

feed efficiency. Tylosin also decreased incidence of liver abscess from 27% in controls to 9% in supplemented cattle. This contributes to the conclusion made by Nagaraja and Chengappa (1998) of tylosin being the most effective antibiotic for liver abscesses. Bacterial resistance to tylosin has also been investigated with the conclusion that feeding tylosin is not inducing antibiotic resistance (Nagaraja et al., 1999). Interactions between tylosin and monensin have not been found, however additive effects were validated (Potter et al., 1985).

Chlortetracycline

Chlortetracycline is a broad spectrum antibiotic approved for use with products such as lasalocid and laidlomycin. Though the mode of action of chlortetracycline has not been well defined, it is known to improve feed efficiency, decrease incidence of bovine respiratory disease, and reduce liver abscesses. In addition to the idea of promotion or inhibition of enhancing or antigrowth bacteria, respectively, Rumsey et al. (1999) found changes in the levels of growth hormone and thyroid stimulating hormone when steers were fed diets top dressed with chlortetracycline (350 mg/hd/d). This is hypothesized to be influenced by an alteration of pituitary performance which could modify metabolism and deposition of tissues (Rumsey et al., 1999). In combined analysis of two studies done at Purdue University and Kansas State University on shipping fever, during the first 28 days steers receiving chlortetracycline gained more ($P < 0.05$) and were more feed efficient ($P < 0.05$) than controls.

When chlortetracycline is fed continuously, it has been found to be an effective moderator for reducing the incidence of liver abscesses. Brown et al. (1975) reported a

reduction in liver condemnation from 56.2% to 44.2% in cattle fed chlortetracycline (70 mg/hd/d) in medium to high concentrate rations; however, the chlortetracycline treatment was not as successful as the tylosin treatment in which liver condemnation was 18.6% (Brown et al., 1975). These authors suggest that the mode of action of antibiotics may be the reduction of liver abscesses (Brown et al., 1975), which are known to account for decreases in feed efficiency (Brink et al., 1990).

Changes in Industry

Throughout ionophore research, there has been decreasing efficacy as noted by DiLorenzo and Galyean (2010). It is hypothesized that the trend of including distiller's co-products in diets may have an influence. Products such as wet and dry distiller's grains are high in fat. Clary et al. (1993) examined level of fat and ionophore type, finding that fat supplementation did have negative effects on ionophore productivity. It also should be noted that since the beginning of ionophore supplementation, the amount of roughage in the diet has decreased, decreasing acetate:propionate and methane production. This shift to higher concentrate diets may be responsible for the observed decrease in efficacy (DiLorenzo and Galyean, 2010).

Another prominent change in feedlot industry is the concern of the public as well as the scientific community about creating bacterial resistance to antibiotics. This apprehension has led to research examining impact of ionophores on food safety. *Escherichia coli* O157:H7 is a gram negative bacteria, which is not discouraged by ionophores. In a study by Edrington et al. (2003), sheep fed a variety of ionophores were inoculated with *E. coli* O157:H7 and *Salmonella typhimurium.* No differences were

reported for fecal shedding and isolates did not differ in antimicrobial resistance. A review by Callaway et al. (2003) also supported the conclusion that ionophores do not stimulate microbial resistance to antibiotics and thus ionophores will continue to be utilized in food production.

Economics

Rumensin (monensin), Cattylst (laidlomycin propionate), and Bovatec (lasalocid) have a combined yearly sales of over $150 million and the cost to benefit ratio of ionophores is estimated to save the cattle industry one billion dollars per year (Callaway et al., 2003). By previous publications in feedlot trials no difference has been detected in feed efficiency between monensin and laidlomycin (Galyean et al., 1992; Bohnert et al., 2000) though differences in dry matter intake ($P < 0.01$) can exist (Galyean et al., 1992). With the price of Rumensin is 685/cwt and the price of Cattlyst is 1352/cwt and at 33 g/ton monensin and 11 g/ton laidlomycin with an intake of approximately 9.6 and 10.0 kg (Galyean et al., 1992), the cost of per head per day is $0.0053 and $0.0036, respectively (Table 1.1). Assuming similar performance and using the prices from February 2011, it would take a simultaneous 19% price increase of Cattlyst and decrease of Rumensin to arrive at a point of ambivalence ($0.0043).

Conclusion

Ionophores are commonly used and very beneficial to beef production. Though significant research has taken place on monensin, research on laidlomycin propionate has yet to discover the mode of action and physiological effects on the host. A similar statement could be made about the sub-therapeutic antibiotics, tylosin and

chlortetracycline. It appears that both monensin and laidlomycin have comparable effects in feedlot performance; however dry matter intake is suppressed when cattle are fed monensin. Monensin seems to be a more proficient inhibitor of lactate and acetate producing microorganisms *in vitro*. It is recommended that additional research take place to further the understanding of these beneficial products.

Figure 1.1. Structure of Monensin; Adapted from Day et al. (1973).

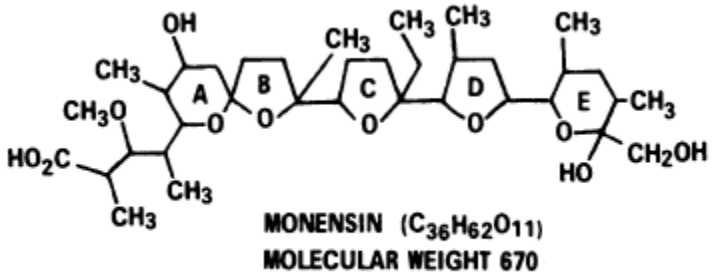

FIG. 1. *Structure of monensin.*

Figure 1.2 Structure of Liadlomycin; Adapted from Spires and Algeo (1983).

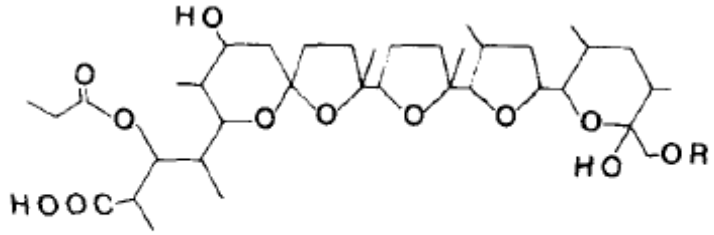

Figure 1. Planar representation of the structure of laidlomycin and its derivatives. R=H in the parent compound.

Table 1.1 Cost Sensitivity			Rumensin[b]						
	% of Current Price[c]		80	81	90	95	100	105	110
		$/cwt	479.50	554.85	616.50	650.75	685.00	691.85	719.25
	90	1216.80	0.0037 0.0033	0.0043 0.0033	0.0047 0.0033	0.0050 0.0033	0.0053 0.0033	0.0053 0.0033	0.0055 0.0033
	95	1284.40	0.0037 0.0034	0.0043 0.0034	0.0047 0.0034	0.0050 0.0034	0.0053 0.0034	0.0053 0.0034	0.0055 0.0034
	100	1352.00	0.0037 0.0036	0.0043 0.0036	0.0047 0.0036	0.0050 0.0036	0.0053 0.0036	0.0053 0.0036	0.0055 0.0036
Cattlyst[a]	105	1419.60	0.0037 0.0038	0.0043 0.0038	0.0047 0.0038	0.0050 0.0038	0.0053 0.0038	0.0053 0.0038	0.0055 0.0038
	110	1487.20	0.0037 0.0040	0.0043 0.0040	0.0047 0.0040	0.0050 0.0040	0.0053 0.0040	0.0053 0.0040	0.0055 0.0040
	119	1608.88	0.0037 0.0043	0.0043 0.0043	0.0047 0.0043	0.0050 0.0043	0.0053 0.0043	0.0053 0.0043	0.0055 0.0043
	120	1622.40	0.0037 0.0043	0.0043 0.0043	0.0047 0.0043	0.0050 0.0043	0.0053 0.0043	0.0053 0.0043	0.0055 0.0043
	125	1690.00	0.0037 0.0045	0.0043 0.0045	0.0047 0.0045	0.0050 0.0045	0.0053 0.0045	0.0053 0.0045	0.0055 0.0045

[a]Cost/hd/d calculated using DMI of 10.0 kg/hd/d (Galyean et al., 1992) and dosage of 11 g/ton. Expressed in lower number of cost comparison.

[b]Cost/hd/d calculated using DMI of 9.6 kg/hd/d (Galyean et al., 1992) and dosage of 33 g/ton. Expressed in upper number of cost comparison.

[c]Price as of February 2011

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CHAPTER II

THE EFFECT OF FEED ADDITIVE PROGRAM IN STEAM-FLAKED CORN DIETS CONTAINING WET DISTILLER'S GRAINS ON PERFORMANCE AND CARCASS MERIT IN YEARLING FEEDLOT STEERS.

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Abstract

Crossbred yearling steers (432, BW = 329 ± 10.5 kg) were used in an unbalanced randomized block design to examine the effect of feed additives on performance and carcass merit. Treatment factors were arranged as a 2 x 2 factorial and included ionophore and antibiotic [Rumensin/Tylan (R/T) or Cattlyst/Aureomycin (C/A)] and dietary S (constant or variable). High S diets were fed on random days to the variable (VAR) treatment. Low S diets were fed to the VAR treatment on remaining days and to the constant (CON) treatment all days. From d 0 through 35 the high S diet was achieved by using a granular high S supplement; however, since S concentration in wet distillers grains (WDG) is associated with distillers solubles (DS) added to WDG and H_2SO_4 added to the DS, the high S diet was achieved from d 36 through 159 by using a 2.35% S DS based liquid supplement while the low S diet was achieved by using a 0.99% S DS

based liquid supplement. Cause of death was verified by necropsy for steers that died during the study. No interaction between S and additive treatments existed for feedlot performance; therefore, only main effects are presented. Most of the sulfur results associated with this study will be addressed in another manuscript. Feedlot performance and carcass merit were similar for feed additive treatments. The S by feed additive interaction was significant ($P < 0.05$) for dressing percentage indicating that S treatment had no effect on dressing percentage if R/T was fed but when steers were fed C/A, dressing percentage was reduced by 0.72 % ($P < 0.02$) if VAR diets were fed. These data indicate that performance and carcass characteristics for steers fed Cattlyst and Aureomycin are similar to that observed for steers fed Rumensin and Tylan.

Key words: ionophore, monensin, laidlomycin, antibiotic, tylosin, chlortetracycline.

Introduction

Ionophores are regularly used feed additives in feedlot diets. The first to gain FDA approval was Rumensin® (monensin, Elanco Animal Health, Greenfield, IN) in 1976. Within a few years ionophores became commonplace and the improvement in feed efficiency was reported to be 7.5% (Goodrich et al., 1984). The improvement in productivity is ascribed to the mode of action of ionophores. Ionophores disturb the proton motive force of ruminal fauna. Gram-positive bacteria, many of which are lactate and acetate producers, lack the membrane structure to adjust to the new environment, which attributes to the changes in ruminal VFA concentrations (Bergen and Bates, 1984). When feeding ionophores, a shift in volatile fatty acid (VFA) production is noted with

increase in propionate and a decrease in acetate production (Newbold and Wallace, 1988). Propionate is known to be highly gluconeogenic, which can indirectly stimulate growth and increased productivity in terms of feedlot performance and carcass merit.

Increases in productivity have led to other ionophores being marketed. In 2003, the FDA approved Cattlyst® (laidlomycin propionate, Alpharma Animal Health, Bridgewater, NJ). Monensin and laidlomycin, though similar in structure, have been found to have different cationic affinities (Bergen and Bates, 1984) and potencies against gram positive bacteria (Wampler et al., 1998). Bauer et al. (1995) reported a 5.6% increase in feed efficiency for laidlomycin, which is 1.9% less than monensin. However in more direct comparison, evidence has been presented showing similar performance between ionophore compounds (Bohnert et al., 2000; Galyean 1992).

With changes in the industry and the introduction of ethanol co-products such as wer distillers grains (WDG) and corn gluten feed into feedlot diets, energy, roughage, and sulfur concentrations have fluctuated leaving questions about how to most effectively apply traditional techniques to the modern feedlot (DiLorenzo and Galyean, 2010). Though data exists on both these ionophores alone, there are limited studies evaluating them by direct comparison. Thus, the objective of this study was to examine the effects of Rumensin and Tylan as compared with Cattlyst and Aureomycin on feedlot performance and carcass characteristics in yearling feedlot steers in steam-flaked corn based diets containing WDG.

Materials and Methods

This study was conducted at the Southeast Colorado Research Center (SECRC) near Lamar, CO from December 2009 to May 2010. Care, handling, and management of steers described herein were approved by the Colorado State University Animal Care and Use Committee. This study was part of a larger study designed to evaluate the effect of dietary sulfur on feedlot performance, carcass merit, and rumen hydrogen sulfide production by yearling steers.

Five hundred twenty-eight crossbred yearling steers from 5 different locations in Kansas arrived at Colorado Beef, JBS Five Rivers Cattle Feeding by December 6 (Table 2.1). Upon arrival, long-stem grass hay and water were available ad libitum. On December 7, all steers were trailed to SECRC and fed a common diet. Steers were individually weighed, assigned a breed score, and processed on December 9. Processing procedures included application of lot tags and electronic identification tags, vaccination with Express 3 (Boehringer Ingelheim, St. Joseph, MO), injection with Noromectin (Norboork Laboratories Limitd, Newry, Co. Down, Northern Ireland), back pouring with Permectin CDS (KMG Bernuth Inc., Houston, TX), and drenching with Safe-Guard (Fenbendazole, Intervet/Schering-Plough, Overland Park, KS) to control internal parasites, and implanting with Revalor-XS delayed release implant (200 mg of trenbolone acetate and 40 mg estradiol, Intervet/Schering-Plough).

After data collection from processing, steers were ranked by weight. Any individuals that were outside ±2 standard deviations from the mean were eliminated, as well as steers with health issues or breed scores suggesting high Brahman, Longhorn, or Dairy influence. The remaining individuals were randomly assigned a number from 1 to

1000 using Microsoft® Excel 2007 (Microsoft Inc., Redmond, WA). Then, the steers with the lowest random numbers were removed from consideration until 432 steers were remaining. These steers were divided within breed type into 8 weight block replicates. Within each breed type by weight block, each successive group of 6 ranked steer were assigned to treatments 1-6, using the lowest to highest random number, respectively. On December 10 (d 0), steers were individually weighed and tagged with identifying study number, treatment, weight block replicate and the individual steer number within the pen, then sorted into correlating pens. Forty-eight pens of 9 steers each began the study.

Due to mechanical failure and cold weather, the evaluation of the impact of S from water source was not possible. Pens originally allocated to the water treatments were reassigned to the constant S treatments changing the study design to an unbalanced randomized block with a 2 × 2 factorial arrangement of treatments with 2 treatments with 8 replicates and 2 treatments with 16 replicates. Treatments consisted of: 1) Constant S (CST) with Rumensin/Tylan (RT; 16 replicates; Elanco Animal Health, Greenfield, IN); 2) Variable S (VAR) with RT (8 replicates); 3) CST with Cattlyst/Aureomycin (CA; 16 replicates; Alpharma Animal Health, Bridgewater, NJ); and 4) VAR S with CA (8 replicates).

The variable treatment was intended to simulate the use of random loads of wet distiller's grains (WDG). Often the S concentration in these loads varies widely. The variation in S concentration in the WDG is driven by the rate of inclusion and the S concentration in distiller's solubles (DS). The S concentration in the DS is driven by the use of sulfuric acid to cleanse the production equipment. For the first 35 days, the VAR S intake was achieved by addition of S flowers (100% elemental S) to a granular mineral

supplement. From d 36 to harvest, the VAR S intake was controlled by addition of H_2SO_4 to a distiller's solubles (DS) based liquid supplement. Random numbers were generated for each d of the study. Diets containing the high S were fed to the VAR treatment on days associated with even numbers. Low S diets were fed to the CST treatment on all days of the study and to the VAR treatment only on days associated with odd numbers. Table 2.2 shows the results of the randomization for the feeding schedule. Table 2.3 describes the 2 DS based liquid supplements that were utilized to create the constant versus variable S intake treatments.

These treatments were provided within a high concentrate diet and mixed in a stationary auger mixer in SECRC feedmill. At 0630 and 1600 h, feedbunks were assessed for remaining feed with the goal of just crumbs in the morning hour. If a bunk was found slick two consecutive mornings, DM intake was increase 0.2 kg per animal in the pen. Diets were manufactured immediately prior and fed twice daily at 0700 and 1130 h.

A starter and series of step-up diets were used to acclimate the steers to steam-flaked corn (Table 2.4). The starter diet was fed to all cattle prior to the initiation of treatments on d 0. Step- up diets were fed starting with d 0 through the round 1 feeding on d 6 though the round 1 feeding on d 17, and step-up 3 diets were fed starting with round 2 feeding on d 17 through the round 2 feeding on d 35. Step ups occurred simultaneously for all treatments until d 36 when all treatments were receiving the respective finishing diet (Table 2.4).

Diets were formulated to meet or exceed the requirements for all nutrients listed by NRC (2000). Finishing diets were formulated to contain 2% crude protein equivalent from non-protein nitrogen, 4% neutral detergent fiber solely from corn silage as the roughage source in the diet, 1000 IU per lb DM vitamin A, and 15 IU per lb DM vitamin E. Because of the concentration of WDG in the finishing diets, CP concentration exceeded requirements listed by NRC (2000). Finishing diets for the Rumensin/Tylan treatments contained 33 mg/kg DM monensin and 11 mg/kg DM tylosin. Finishing diets for the Cattlyst/Aureomycin treatments contained 12.1 mg/kg DM laidlomycin and 36.4 mg/kg DM chlortetracycline (target of 350 mg chlortetracycline per head daily). Vitamins, minerals, urea, and feed additives were added to each diet in the form of a meal supplement (Table 2.5, 2.6, and 2.7).

Weekly samples were taken of all commodities and diets. Approximately 100 g of each sample were evaluated for DM content at SECRC using a forced-air drying oven at 60ºC for 48 h. The remaining sample was frozen and composited monthly. The monthly composite divided into two parts with one being sent in for laboratory analysis (SDK Laboratories, Hutchinson, KS) and the other frozen and stored at SECRC as a backup. In the event of feed refusal, feed was collected, weighed, and samples were stored for DM analysis in order to calculate accurate DMI.

Weekly samples of water were also obtained. Table 2.8 displays the average water sulfate concentration for all months for the trial. Water sulfate concentration averaged 1712 ± 131 mg/L throughout the study. Sulfate is approximately 33.4% elemental S; therefore, average S concentration in the water was approximately 572 ± 44 mg/L. If water consumption averaged 25 L per steer during the study, S intake from water was

about 14.3 g per steers daily. To consider the added S from water as a percentage of dry matter intakes, 0.17% needs to be added to the diet S concentration.

Interim individual weights were collected throughout the study on d 21, d 34-35, d 69-70, and d104-105. A four percent pencil shrink was applied to all weights prior to analysis. Final weights were obtained on two consecutive mornings prior to the day of slaughter. Steers were slaughtered on d 160 at a commercial abattoir (JBS, Greeley, CO) where HCW and liver scores were recorded on the day of slaughter. After a 36 h chill, fat thickness, REA, % KPH, marbling score, USDA quality grade, and USDA yield grade data were collected.

Net energy requirements for maintenance (NEm) and gain (NEg) for each pen of steers from d 0 through slaughter were calculated using equations for large-framed steer calves published by NRC (2000). Equations incorporating the Standard Reference Weight concept as described by NRC (2000) were used to calculate retained energy. Net energy for maintenance and NEg derived from the diet for each pen were calculated from pen performance and pen requirements for NEm and NEg using the quadratic equation derivation of the energy equations (Appendix A; further described by Zinn, 1992).

The days that PEM steers were found dead or initially removed from the home pen were examined with regard to S treatment on the day of death or removal and for the previous 3 days. No patterns associated with the S diet fed during this 4 day period were found. Of the 11 PEM cases, 3 steers were fed the high S diet for 3, 3 steers were fed the high S diet for 2, 4 steers were fed the high S diet for 1, and 1 steer was fed the high S diet for 0 of the 4 days examined.

Statistical Analysis:

The feedlot performance data were analyzed as a randomized complete block design with repeated measures using PROC MIXED of SAS (Statistical Analysis System, version 9.2, Cary, NC). Pen served as the experimental unit. The model included sulfur treatment (S), feed additive treatment (TRT), TRT × S interaction, period (PER), PER × TRT, PER × TRT × S as fixed variables. Random variables in the model included weight block replicate (REP), TRT × REP, and S × REP. All variables were considered classification variables. The subject of the repeated statement was REP × TRT × S, autoregressive (AR1) covariance structure was used, and Kenward-Roger degrees of freedom were computed.

Net energy recovery, hot carcass weight (HCW), dressing percentage, fat depth, ribeye area (REA), internal fat (KPH), marbling score, and calculated yield grade (YG) were analyzed as a randomized complete block design using PROC MIXED. In the model as fixed variables were feed additive treatment (TRT), sulfur treatment (S), and the TRT × S interaction. Random variables included weight block replicate (REP), TRT × REP, and S × REP. All variables were considered class variables. Kenward-Roger degrees of freedom were computed.

USDA quality grade, USDA yield grade, and liver abscess data were evaluated as categorical data using PROC GLIMMIX of SAS. The model used the same random and fixed variables as the rest of the carcass data. A binomial distribution was assumed for categorical data and the LINK = LOGIT option was used. The ILINK option of the least

square means statement was used to calculate the likelihood that an individual carcass or liver qualified for a specific category.

For all analyses, pen was used as the experimental unit. Differences between treatment means were detected using the PDIFF option of the LSMEANS statement. Significance was declared at $P \leq 0.05$.

Results and Discussion

Most interactions between S and feed additive treatment were not significant. Therefore, only the main effects of feed additive are presented in this manuscript for most variables evaluated. Sulfur results associated with this study will be addressed in another manuscript.

Feed Analysis: Feed analysis results for the finishing diets are displayed by proposed sulfur concentration and feed additive treatment in Table 2.9. Analyzed results for most nutrients were reasonably close to theoretical values for all treatment finishing diets. Analyzed diet dry matter and neutral detergent fiber concentrations were slightly lower than theoretical values. Analyzed diet CP, NPN, ether extract, calcium, and sulfur were slightly higher than analyzed values. The target sulfur concentration for the finishing diets was 0.34 and 0.50% as compared with 0.48 and approximately 0.60% for the analyzed sulfur concentration for the low and high sulfur diets, respectively. The theoretical difference in sulfur concentration between the low and high sulfur diets was targeted at 0.16%. The analyzed differential was approximately 0.12%. Other analyzed nutrient concentrations were similar between the high and low S concentration diets.

Analyzed nutrient concentrations for the Rumensin and Tylan diets were similar to analyzed values for the Cattlyst and Aureomycin diets.

Feedlot performance:

Raw means and standard errors for feedlot performance measurements are displayed by treatment in Appendix B.

Live Weight: The effects of treatment and weigh day on live body weight (BW) are shown in Table 2.10. There were no interactions between weigh day and feed additive ($P > 0.76$); therefore only main effects of feed additive treatment are shown at each weigh day. As expected, BW increased with each successive weigh day ($P < 0.0001$). There were no feed additive treatment effects on BW ($P > 0.83$).

Average Daily Gain: The effects of treatment and period on average daily gain (ADG) are shown in Table 2.11. There were no interactions between period and feed additive ($P > 0.17$); therefore main effects of feed additive are shown for each period. The higher ADG was observed from d 35 through d 69 while the lowest ADG was observed from d 70 through d 104. The effects of feed additive program on ADG were not different ($P > 0.61$). Body weight and ADG results are similar to those described by Galyean et al. (1992) where no differences in performance measurements were observed in feedlot cattle receiving Rumensin and Cattlyst throughout a 161 d trial period. These results could be attributed to the NE_g of 1.41 Mcal/kg DM. Spires et al. (1990) found ionophores were less effective with higher energy diets.

Daily dry matter intake: Treatment and period effects on daily dry matter intake (DMI) are shown in Table 2.12. Interactions between period and feed additive treatment

were not significant ($P > 0.17$). Period was a significant ($P > 0.0001$) source of variation describing DMI. No differences are reported between treatments for feed additive ($P > 0.44$). Though statistical differences were not detected, the Rumensin/Tylan supplemented steers had numerically lower intakes throughout the trial. This agrees with studies done by (Bohnert et al., 2000; Galyean 1992; Gill et al., 1976; Perry et. al., 1976) and could be attributed to the known palatability issues with monensin (Baile et al., 1979).

Feed efficiency: Treatment and period effects on feed efficiency expressed as feed to gain ratio (FG) and gain to feed ratio (GF) are shown in Tables 2.13 and 2.14 respectively. Interactions between period and feed additive treatment were not significant ($P > 0.36$). Feed additive treatment was not significant ($P > 0.41$). This contradicts past studies where improvement in feed efficiency has been greater for monensin than laidlomycin (Bauer et al., 1995; Goodrich et al., 1984). Although DMI for d 34 through d 69 was similar to DMI from d 70 through d 104, reduced gain and poorer efficiency observed for d 70 through d 104 as compared with d 34 through d 69 was likely the result of poorer pen conditions from February 18 through March 24, 2010 as compared with January 13 through February 17, 2010. From d 34 through d 69, the average daily temperature at the SECRC weather station was below freezing at -0.5ºC and ranged from a low of -15.9 to a high of 18.1ºC. During this time period a total of 1.57 cm of precipitation were recorded. From d70 through d104, the average daily temperature at SECRC was 3.4ºC and ranged from -9.4 to 21.8ºC. Total precipitation during this time period was 4.19 cm. The additional cm of rain and above freezing temperatures resulted in muddy pen conditions. Poor pen conditions are known to increase energy requirements

for beef cattle (NRC, 2005) and with similar dry matter intake, it is expected that depression in gain would result.

Net energy recovery: Net energy for maintenance (NEm) and net energy for gain (NEg) recovered from the diet dry matter as calculated from performance and NRC (2000) equations are shown in Table 2.15. Feed additive treatment resulted in a trend for increased NEm or NEg recovery ($P > 0.13$) for Rumensin/Tylan when compared with Cattlyst/Aureomycin. This confirms research showing increased feed efficiency and decreased dry matter intake (Goodrich et al., 1984) for monensin as animals were shown to have similar performance on less feed.

Cattle Health: Health problems encountered during the trial are listed in Table 2.16. Of 11 steers that were treated for respiratory issues during the study; 8 recovered while 3 ultimately died. One of these deaths was confirmed as atypical interstitial pneumonia (AIP). Two of the steers initially diagnosed as respiratory disease that subsequently died were confirmed to have brain lesions characteristic of polioencephalomalacia (PEM). One additional respiratory dead was found in its home pen. Including the 2 steers initially diagnosed with respiratory disease, 9 steers died, 1 steer was euthanized, and 1 steer was sold for salvage due to PEM.

Polioencephalomalacia was confirmed by the diagnostic lab in 9 of the 11 PEM cases. The brain tissue was not sent to the laboratory for 1 of the PEM deads and brain tissue was not recovered from the steer that was sold for salvage. Two dead steers were initially diagnosed as feedlot bloat; however, 1 of these steers was ultimately found to

have brain lesions characteristic of PEM. This steer initially diagnosed as bloat was also included in the PEM statistics discussed above.

Table 2.17 summarizes the health data. No interactions were found between S and feed additive treatment; therefore, only the main effects are shown. No treatment differences for respiratory pulls, total pulls, or total deads were found. Feed additive treatment were not significant sources of variation describing PEM deaths. It is interesting to note that 1, 6, 1, 1, 0, 2, and 0 PEM cases first appeared on Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday, respectively. Eight of the 11 PEM cases occurred on Sunday through Tuesday suggesting that the incidence of PEM may be related to events that may have happened on Saturday and Sunday. At SECRC, a smaller crew feeds and cares for the cattle over the weekend. In addition, the work day generally ends a couple of hours earlier on the weekend, especially on Sunday, as compared with the rest of the week. Though ionophores are known to improve cattle health compared with diets without ionophores (Cheng et al., 1998; Owens et al., 1998), these data did not document a difference in cattle health between feed additive treatments. This also contradicts research done by Brown et al. (1975), which reported lower liver condemnation 18.6% for tylosin compared to 44.2% for chlortetracycline; however, research comparing steam-flaked corn diets with and without WDG reported no impact on liver abscess severity when tylosin was fed with (Depenbusch et al., 2008). As the diets used in this study contained 30% WDG on a dry matter basis, this may have influenced the lack of difference between treatment for cattle health.

Carcass merit

Raw means and standard errors showing the effect of treatment on carcass measurements are displayed in Appendix C. Table 2.18 displays least squares means describing the effects feed additive treatment on carcass merit. The only carcass effect detected was an interaction between S and feed additive treatment for dressing percentage ($P < 0.05$). The effect of feed additive ($P > 0.19$) and S by feed additive interaction ($P > 0.12$) for all other measurements were not different.

The dressing percentage interaction is shown in Figure 2.1. From Figure 2.1, it appears as if S treatment had no effect ($P > 0.81$) on dressing percentage if steers received Rumensin and Tylan. However, for steers receiving Cattlyst and Aureomycin, dressing percentage was reduced by 0.73 percentage units ($P < 0.02$) if S concentration varied randomly in the diet. Reasons for the dressing percentage interactions are unknown. The treatment with the lowest DMI from d 105 through slaughter, and as a result, perhaps the lowest gut fill wand predictably the highest percentage, was the variable sulfur with Rumensin and Tylan treatment. The dressing percentage for this treatment (62.62%) was essentially the same as the average dressing percentage for the entire study (62.64%). The lack of difference found between feed additive treatments supports the previous research where no differences between the various ionophores on carcass merit were detected (Goodrich et al., 1984; Potter et al., 1976; Spires et al., 1990).

Conclusion

Performance and carcass merit were similar for yearling feedlot steers fed laidlomycin and chlortetracycline as compared with monensin and tylosin indicating that

the use of Cattlyst and Aureomycin is an acceptable alternative to the use of Rumensin and Tylan in feedlot diets. These results support the findings of other research (Bohnert et al., 2000; Galyean 1992) conducted with growing and feedlot steers. Feed additive did not affect final weight or improve ADG. The effect of feed additive on carcass merit was negligible. Further research is needed to determine the impact of feeding monensin and laidlomycin on host physiology and with ethanol co-products.

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Figure 2.1. Interaction between feed additive program and sulfur treatment for dressing percentage.

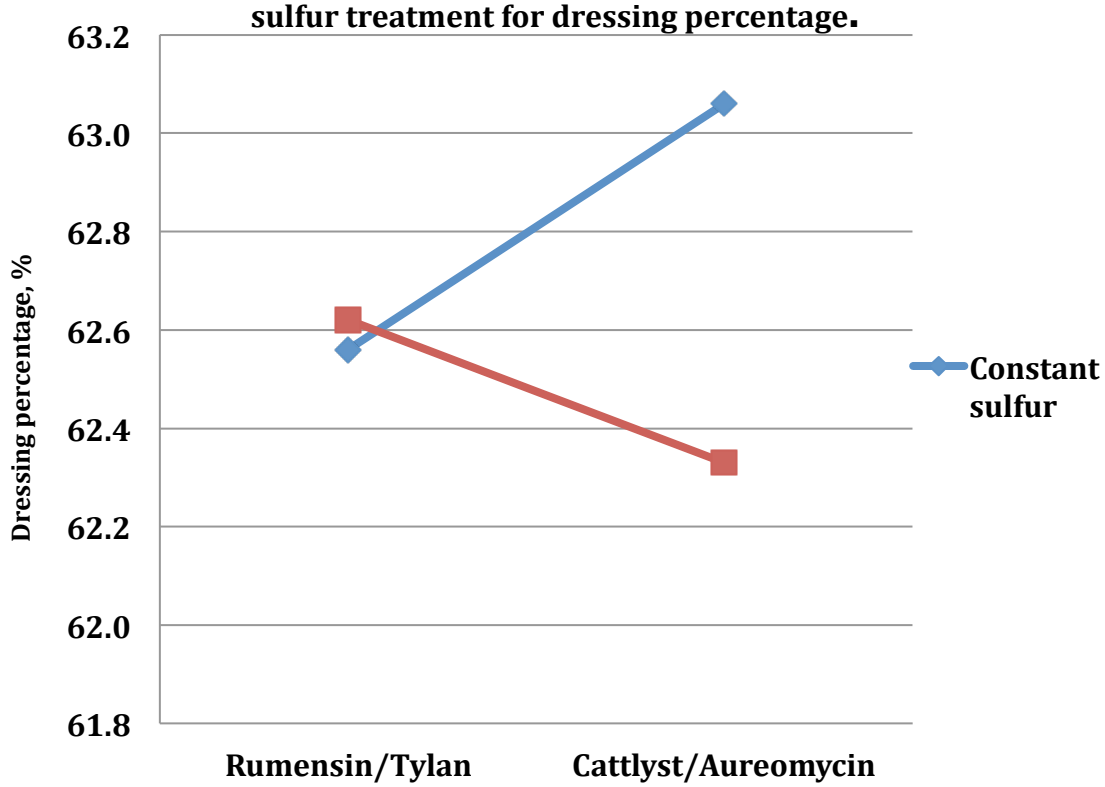

Table 2.1. Sources of steers used for the feed additive program and dietary sulfur study.

Head	Arrival Date	Off-truck Weight, Lb	Average O-T Weight, lb	Pay-weight, lb	Average Pay-weight, lb	Shrink, %	Origin
76	12/04/2009	54,460	717	57,210	753	4.81	Coffeeville, KS
124	12/04/2009	99,780	805	101,440	818	1.64	Anthony, KS
133	12/05/2009	100,880	758	102,907	774	1.97	Syracuse, KS
134	12/06/2009	101,600	758	103,285	771	1.63	Oakley, KS
61	12/06/2009	47,480	778	49,015	804	3.13	Fort Scott, KS
528		404,200	765	413,857	784	2.34	

Table 2.2. Randomized feeding schedule results for the low and high sulfur diets.

Consecutive Days Fed	Low Sulfur Diet Episodes	Total Days	High Sulfur Diet Episodes	Total Days
1	20	20	25	25
2	13	26	10	20
3	7	21	4	12
4	1	4	3	12
5	1	5	0	0
6	0	0	0	0
7	1	7	1	7
Sum		83		76

Table 2.3. As-fed ingredient composition and dry matter nutrient composition of the liquid supplements used to establish the low and high sulfur diets used from d36 through slaughter.

Item	Low Sulfur	High Sulfur
Ingredient, % of as-fed		
Condensed corn distiller's soluble[a]	85.5500	83.5360
Crude glycerin[b]	12.5000	12.5000
Dry urea[c]	1.9500	1.9903
Sulfuric acid		1.9731
Nutrient[d]		
Dry Matter, % of as-fed[e]	42.96 ± 0.92	43.85 ± 0.41
Crude protein	25.42 ± 0.43	26.89 ± 0.57
Non-protein nitrogen[f]	14.21 ± 0.33	8.02 ± 1.83[g]
Neutral detergent fiber	3.62 ± 0.36	3.03 ± 0.32
Fat[h]	11.52 ± 0.26	11.92 ± 1.11
Calcium	0.27 ± 0.02	0.21 ± 0.01
Phosphorus	1.29 ± 0.03	1.28 ± 0.03
Potassium	1.98 ± 0.03	2.02 ± 0.05
Magnesium	0.61 ± 0.01	0.56 ± 0.01
Sulfur	0.99 ± 0.02	2.35 ± 0.06

[a] Quality Distiller's Grains, Hereford, TX.
[b] Added to improve flow rate during winter.
[c] Needed in the high sulfur liquid to help maintain pH above 2 facilitating transport of the product.
[d] Percentage of dry matter ± standard error of the mean unless stated otherwise.
[e] As-received moisture determined by Karl-Fischer methodology. DM = 100 – moisture.
[f] Crude protein equivalent.
[g] Non-protein nitrogen averaged 16.25 ± 0.14 for January and February and only averaged 2.53 ± 0.64 for March, April, and May.
[h] Fat was determined by acid hydrolysis.

Table 2.4. Ingredient and theoretical nutrient concentration for the starter, step-up, and finishing diets used for the feed additive and dietary sulfur study.

Item[a]	Starter	Step-one	Step-two	Step-three	Finish
Ingredient					
Corn silage	36.917	20.716	15.066	9.416	9.978
Steam-flaked corn	28.173	27.497	42.648	57.610	45.598
Alfalfa hay	20.000	20.000	10.000		
DDG[b]	10.646				
WDG[c]		30.000	30.000	30.000	30.000
Yellow grease/tallow[d]					0.383
Corn steep liquor	3.000				
Liquid supplement[e]					11.839
Supplement[f]	1.264	1.787	2.286	2.974	2.202
Nutrient					
Dry matter, % of as-fed	50.714	47.225	49.821	52.738	49.241
Crude protein	14.000	18.073	17.204	16.298	17.422
Non-protein nitrogen	1.000	1.000	1.000	1.000	2.000
Acid detergent fiber	19.682	19.349	14.868	10.377	10.524
Neutral detergent fiber	30.412	31.380	25.745	20.075	20.086
Effective NDF	19.706	15.643	9.980	4.313	4.256
Crude fiber	16.862	14.627	10.837	7.039	7.069
Forage NDF[h]	24.000	18.000	11.000	4.000	4.000
NEm, Mcal/kg DM	1.81	1.74	1.87	1.98	2.04
NEg, Mcal/kg DM	1.16	1.14	1.26	1.37	1.41
Ether extract	4.650	6.142	6.562	6.967	7.500
Calcium	0.700	0.700	0.700	0.700	0.700
Phosphorus	0.310	0.421	0.431	0.440	0.553
Potassium	1.146	0.994	0.818	0.700	0.866
Magnesium	0.250	0.261	0.250	0.250	0.257
Sulfur[g]	0.216	0.31/0.50	0.29/0.50	0.30/0.50	0.34/0.50
Vitamin A, IU/kg DM	22.05	22.05	22.05	22.05	22.05
Vitamin E, IU/kg DM	0.33	0.33	0.33	0.33	0.33

[a] Percentage of dry matter unless stated otherwise.
[b] Dried distiller's grains.
[c] Wet distiller's grains.
[d] Yellow grease fed through March, 2010. Tallow fed during April and May, 2010.
Crude protein equivalent.
[d] Neutral detergent fiber from the forage components of the diet.
[e] Refer to Table 2.3 for the ingredient and analyzed nutrient concentration for the liquid supplement.
[f] Refer to Tables 2.5 and 2.6 for the ingredient composition of the step-one, step-two, and step-three supplements and Table 2.7 for the starter and finishing diet supplements.
[g] First number in a column refers to the constant S treatments. The second number refers to the high S diets.

Table 2.5. As-fed composition of supplements used to establish low and high sulfur diets for treatments containing Rumensin and Tylan from d 0 through d 35 of the study.

	Step-one Diets		Step-two Diets		Step-three Diets	
Ingredient[a]	Low S	High S	Low S	High S	Low S	High S
Urea	19.209	19.209	15.045	15.056	11.667	11.679
Limestone	47.914	47.914	52.587	52.555	49.706	49.756
Salt	13.782	13.782	10.795	10.803	8.372	8.380
Mineral oil	2.000	2.000	2.001	2.003	2.000	2.002
Min-Ad[b]			5.279	5.406	12.461	12.473
KCl[c]					3.998	4.002
Ground corn	10.864		9.223		7.697	
Sulfur flowers[d]		10.864		9.230		7.705
Rumensin 80[e]	0.517	0.517	0.594	0.594	0.628	0.629
Tylan 100[f]	0.275	0.275	0.216	0.216	0.168	0.067
TM premix[g]	4.410	4.410	3.455	3.457	2.679	2.682
Vit. A premix[h]	0.110	0.110	0.087	0.087	0.067	0.067
Vit. E premix[i]	0.919	0.919	0.719	0.594	0.558	0.559

[a] Percentage of as-fed.
[b] Min Ad Inc., Amarillo, TX. (21.45% calcium and 11.68% magnesium, DM basis).
[c] Potassium Chloride.
[d] Elemental sulfur, 100%.
[e] Monensin, 176. 4 g/kg.
[f] Tylosin, 220.5 g/kg.
[g] Trace mineral premix: Cobalt, 500 mg/kg; Copper, 2.5%; Manganese, 6.25%; Zinc, 18.75%; Iodine, 630 mg/kg; and Selenium, 300 mg/kg.
[h] 110,250,000 IU vitamin A activity per kg.
[i] 198,450 IU vitamin E activity per kg.

Table 2.6. As-fed composition of supplements used to establish low and high sulfur diets for treatments containing Cattlyst and Aureomycin from d0 through d35 of the study.

	Step-one Diets		Step-two Diets		Step-three Diets	
Ingredient[a]	Low S	High S	Low S	High S	Low S	High S
Urea	18.978	18.978	14.949	14.941	11.641	11.641
Limestone	47.342	47.342	52.249	52.152	49.596	49.596
Salt	13.618	13.618	10.727	10.720	8.353	8.353
Mineral oil	2.000	2.000	2.001	2.000	2.000	2.000
Min-Ad[b]			5.252	5.373	12.436	12.436
KCl[c]					3.991	3.991
Ground corn	10.735		9.165		7.681	
Sulfur flowers[d]		10.735		9.160		7.681
Cattlyst 50[e]	0.631	0.631	0.497	0.497	0.387	0.387
Aureomycin 90[f]	1.324	1.324	0.927	0.927	0.619	0.619
TM premix[g]	4.357	4.357	3.433	3.430	2.673	2.673
Vit. A premix[h]	0.108	0.108	0.086	0.086	0.067	0.067
Vit. E premix[i]	0.908	0.908	0.715	0.714	0.557	0.557

[a] Percentage of as-fed.
[b] Min Ad Inc., Amarillo, TX. (21.45% calcium and 11.68% magnesium, DM basis).
[c] Potassium Chloride.
[d] Elemental sulfur, 100%.
[e] Laidlomycin, 110.25 g per kg.
[f] Chlortetracycline, 198.45 g per kg.
[g] Trace mineral premix: Cobalt, 500 mg/kg; Copper, 2.5%; Manganese, 6.25%; Zinc, 18.75%; Iodine, 630 mg/kg; and Selenium, 300 mg/kg.
[h] 110,250,000 IU vitamin A activity per kg.
[i] 198,450 IU vitamin E activity per kg.

Table 2.7. As-fed ingredient composition of the starter and finishing diet supplements used for the feed additive and sulfur study.

Ingredient[a]	Starter Diet	Rumensin/Tylan Finish Diet	Cattlyst/Aureomycin Finish Diet
Urea	21.683	2.273	2.272
Limestone	47.927	78.555	78.556
Salt	17.979	11.334	11.334
Mineral oil	1.999	2.001	2.001
Min-Ad[b]	3.529		
Ground corn		0.288	
Rumensin 80[c]		0.850	
Tylan 100[d]		0.226	
Cattlyst 50[e]			0.525
Aureomycin 90[f]			0.840
TM premix[g]	5.539	3.627	3.627
Vit. A premix[h]	0.144	0.090	0.090
Vit. E premix[i]	1.199	0.756	0.756

[a] Percentage of as-fed.
[b] Min Ad Inc., Amarillo, TX. (21.45% calcium and 11.68% magnesium, DM basis).
[c] Monensin, 176.4 g per kg. Finish diet contained 33.1 g per ton of dry matter.
[d] Tylosin, 220.5 g per kg. Finish diet contained 11.0 g per ton of dry matter.
[e] Laidlomycin, 110.3 g per kg. Finish diet contained 12.1 g per ton of dry matter.
[f] Chlortetracycline, 198.5 g per kg. Finish diet contained 36.7 g per ton dry matter to provide for 350 mg per head daily.
[g] Trace mineral premix: Cobalt, 500 mg/kg; Copper, 2.5%; Manganese, 6.25%; Zinc, 18.75%; iodine, 630 mg/kg; and Selenium, 300 mg/kg.
[h] 110,250,000 IU vitamin A activity per kg.
[i] 198,450 IU vitamin E activity per kg.

Table 2.8. Sulfate concentration (mg/L) in water consumed during the feed additive and dietary sulfur study.

Date of sample	400 Alley	600 Alley	Average
January 6, 2010	1690	1660	1675
January 13, 2010	1340	1300	1320
January 20, 2010	1190	1310	1250
January 27, 2010	1660	1810	1735
February 3, 2010	2050	1870	1960
February 10, 2010	1900	2130	2015
February 17, 2010	2050	1940	1995
February 24, 2010	1840	1850	1845
March 3, 2010	2325	2475	2400
March 10, 2010	1875	1975	1925
March 17, 2010	1775	2125	1950
March 24, 2010	1925	788	1357
March 31, 2010	6	2350	1178
April 7, 2010	2300	2100	2200
April 14, 2010	2525	2350	2438
April 21, 2010	60	25	42
April 28, 2010	2350	2525	2438
May 5, 2010	1400	1400	1400
May 12, 2010	1430	1400	1415
Average	1668	1757	1712
Standard error	156	142	131

Table 2.9. Dry matter nutrient concentration in finishing diets as determined by laboratory analysis.

	Low Sulfur		High Sulfur	
Item[a]	R/T	C/A	R/T	C/A
Dry matter[b]	46.99 ± 0.39	46.90 ± 0.25	48.08 ± 0.59	48.44 ± 0.60
Crude protein	18.74 ± 0.28	18.48 ± 0.18	18.41 ± 0.34	18.08 ± 0.50
Non-protein nitrogen	2.33 ± 0.06	2.36 ± 0.05	2.29 ± 0.09	2.20 ± 0.14
Neutral detergent fiber	18.04 ± 0.25	17.84 ± 0.27	17.79 ± 0.24	18.53 ± 0.87
Ether extract	8.65 ± 0.18	8.58 ± 0.15	8.23 ± 0.37	7.82 ± 0.42
Calcium	0.91 ± 0.05	0.90 ± 0.03	0.83 ± 0.03	0.89 ± 0.05
Phosphorus	0.57 ± 0.008	0.57 ± 0.005	0.53 ± 0.02	0.49 ± 0.03
Potassium	0.89 ± 0.01	0.88 ± 0.009	0.86 ± 0.01	0.86 ± 0.03
Magnesium	0.28 ± 0.004	0.27 ± 0.002	0.27 ± 0.004	0.26 ± 0.007
Sulfur	0.48 ± 0.007	0.48 ± 0.005	0.62 ± 0.02	0.58 ± 0.03

[a] Raw mean ± standard error of the mean. Dry matter basis unless stated otherwise.
[b] As-fed basis.

Table 2.10. Least squares means showing the effects of weigh day and feed additive treatment on body weight (lb/hd).

	Feed Additive[b]		
Day of study[a]	R/T[c]	C/A[d]	SEM
0	328.8	328.3	10.5
21	375.4	376.8	10.5
34 or 35	396.1	395.0	10.5
69 or 70	454.8	456.9	10.5
104 or 105	497.0	497.3	10.5
Slaughter	584.5	584.6	10.5

[a] Day of study, $P < 0.0001$; Day of study by feed additive, $P > 0.76$.
[b] Feed additive, $P > 0.83$.
[c] Rumensin and Tylan.
[d] Cattlyst and Aureomycin.

Table 2.11. Least squares means showing the effects of period and feed additive treatment on average daily gain (kg/hd/d).

	Feed Additive[bd]		
Period[a]	R/T[e]	C/A[f]	SEM
d0 – 20	2.20	2.27	0.07
d21 – 34	1.57	1.38	0.07
d35 – 69	1.63	1.71	0.07
d70 – 104	1.24	1.19	0.07
d105 – slaughter	1.56	1.56	0.07
d0 – slaughter	1.64	1.62	0.04

[a] Period, $P < 0.0001$; Period by feed additive, $P > 0.17$.
[b] Feed additive, $P > 0.61$.
[c] Rumensin and Tylan.
[d] Cattlyst and Aureomycin.

Table 2.12. Least squares means showing the effects of period and feed additive treatment on average daily dry matter intake (kg/hd/d).

	Feed Additive[b]		
Period[a]	R/T[c]	C/A[d]	SEM
d0 – 20	7.74	7.76	0.12
d21 – 34	8.10	7.89	0.12
d35 – 69	8.63	8.76	0.12
d70 – 104	8.59	8.82	0.12
d105 – slaughter	8.73	8.93	0.12
d0 – slaughter	8.36	8.43	0.09

[a] Period, $P < 0.0001$.
[b] Feed additive, $P > 0.44$.
[c] Rumensin and Tylan.
[d] Cattlyst and Aureomycin.

Table 2.13. Least squares means showing the effects of period and feed additive treatment on feed to gain ratio.

	Feed Additive[b]		
Period[a]	R/T[c]	C/A[d]	SEM
d0 – 20	3.59	3.45	0.32
d21 – 34	5.50	6.23	0.32
d35 – 69	5.65	5.21	0.32
d70 – 104	7.22	7.68	0.32
d105 – slaughter	5.63	5.80	0.32
d0 – slaughter	5.52	5.67	0.17

[a] Period, $P < 0.0001$.
[b] Feed additive, $P > 0.41$.
[c] Rumensin and Tylan.
[d] Cattlyst and Aureomycin.

Table 2.14. Least squares means showing the effects of period and feed additive treatment on gain to feed ratio

	Feed Additive[b]		
Period[a]	R/T[c]	C/A[d]	SEM
d0 – 20	0.29	0.30	0.01
d21 – 34	0.20	0.18	0.01
d35 – 69	0.19	0.20	0.01
d70 – 104	0.14	0.13	0.01
d105 – slaughter	0.18	0.17	0.01
d0 – slaughter	0.20	0.20	0.01

[a] Period, $P < 0.0001$.
[b] Feed additive, $P > 0.50$.
[c] Rumensin and Tylan.
[d] Cattlyst and Aureomycin.

Table 2.15. Least squares means showing the effects of feed additive treatment on net energy recovery (Mcal/kg DM).

	Feed Additive		
Item	R/T[a]	C/A[b]	SEM
d0 – slaughter[c]			
NEm	2.23	2.20	0.02
NEg	1.55	1.52	0.02
d21 – slaughter[d]			
NEm	2.20	2.16	0.02
NEg	1.52	1.49	0.02

[a] Rumensin and Tylan.
[b] Cattlyst and Aureomycin.
[c] Feed additive, $P > 0.26$.
[d] Feed additive, $P > 0.13$.

Table 2.16. Cattle health summary for the feed additive program and dietary sulfur study.

Date	Steer	Pen	Trt[a]	ºC	SC[b]	Diagnosis +[c]	Outcome
12/10/09	4117	125	1	39.9	7	Respiratory	Dead in pen 12/15/09
12/11/09	4586	424	4	39.8	7	Respiratory	Recovered
12/11/09	4629	610	2	39.8	7	Respiratory	Recovered
12/11/09	4616	608	2	39.9	7	Respiratory	Recovered
12/11/09	4263	414	3	39.8	7	Respiratory	Recovered
12/15/09	4117	125	1			AIP	Found dead in pen
12/17/09	4678	620	2	39.8	6	Respiratory	Recovered
12/17/09	4661	618	2	39.7	6	Respiratory	Retreated 02/12/10
12/27/10	4364	617	1			AIP +	Found dead in pen
02/01/10	4331	611	1	39.8	6	Respiratory	Retreated 02/08/10
02/08/10	4331	611	1	39.8	7	Respiratory	Recovered
02/08/10	4639	612	2	39.8	6	Respiratory	Dead in pen 02/12/10
02/08/10	4266	414	3	40.1	7	Respiratory +	Dead in Pen 02/17/10
02/10/10	4256	410	3	40.0	7	Respiratory	Recovered
02/12/10	4661	618	2	39.9	7	Respiratory	Recovered
02/12/10	4533	404	4			PEM +	Found dead in pen
02/12/10	4639	612	2			PEM +	Found dead in pen
03/08/10	4582	424	4			PEM +	Found dead in pen
03/08/10	4584	424	4			PEM +	Found dead in pen
03/22/10	4282	422	3			PEM	Found dead in pen
03/22/10	4248	406	3			PEM +	Found dead in pen
03/23/10	4558	412	4			PEM +	Euthanized
04/21/10	4567	416	4			Bloat +	Found dead in pen
05/14/10	4574	420	4			Bloat	Found dead in pen
05/17/10	4429	427	2			PEM	Railized[d]

[a] Trt (Treatment Codes): (1) Rumensin/Tylan CON; (2) Cattlyst/ Aureomycin CON; (3) Rumensin/Tylan VAR (4) Cattlyst/Aureomycin VAR.

[b] Respiratory score – 1 point for each of the following symptoms: eye discharge, nasal discharge, depression, cough, and rapid breathing.

[c] Initial Diagnosis: Rows with a "+ " had PEM brain lesions confirmed by Colorado State University Diagnostic Laboratory.

[d] Steer not in condition to ship; sold for salvage

Table 2.17. The effect of feed additive treatment on steer health.

	Feed Additive		
Item	R/T[a]	C/A[b]	SEM
Total pulls[c]	2.42	2.42	1.28
Resp. pulls[d]	2.42	2.20	1.19
PEM pulls[e]	0.00	0.46	--
Repulls[f]	19.0	19.0	--
Total deads[g]	2.42	2.46	1.31
Resp. deads[h]	0.93	0.00	--
PEM deads[i]	1.65	2.15	1.25
PEM conf.[j]	1.38	2.21	1.24
Other deads[k]	0.00	0.46	--
Realizers[l]	0.00	0.46	--

[a] Rumensin and Tylan.
[b] Cattlyst and Aureomycin.
[c] Percentage likelihood that an individual steer within each pen was pulled from the pen for any reason. Feed additive, P = 1.00.
[d] Percentage likelihood that an individual steer within each pen was pulled from the pen for respiratory issues. Feed additive, P > 0.91.
[e] Convergence criteria not met using PROC GLIMMIX. Results shown as the percentage of individual steers for each treatment that were pulled for PEM symptoms.
[f] Convergence criteria not met using PROC GLIMMIX. Results shown as the percentage of total pulls for each treatment that were pulled a second time for any reason.
[g] Percentage likelihood that an individual steer within each pen died from all causes. Feed additive, P > 0.98.
[h] Convergence criteria not met using PROC GLIMMIX. Results shown as the percentage of individual steers for each treatment that died due to respiratory disease.
[i] Percentage likelihood that an individual steer within each pen died from PEM. Feed additive, P > 0.73.
[j] Percentage likelihood that an individual steer within each pen died from a confirmed case of PEM. Feed additive, P > 0.56.
[k] Convergence criteria not met using PROC GLIMMIX. Results shown as the percentage of individual steers for each treatment that died due to other feedlot causes.
[l] Convergence criteria not met using PROC GLIMMIX. Results shown as the percentage of individual steers for each treatment that were realized.

Table 2.18. Least squares means showing the effects of sulfur and feed additive treatment on carcass merit.

	Sulfur			Feed Additive		
Item[a]	Constant	Variable	SEM	R/T[b]	C/A[c]	SEM
HCW, kg[d]	365.0	367.3	2.22	365.5	366.9	2.18
Carcass weight distribution[e]						
< 600 lb[f]	1.41	1.49		1.90	0.97	
600 – 949 lb	96.13	97.09	1.84	95.20	97.66	2.10
950 – 999 lb	1.62	1.84	1.41	2.11	1.42	1.38
≥ 1000 lb[f]	0.71	0.00		0.48	0.48	
DP, %[g]	62.81	62.48	0.19	62.59	62.69	0.19
FAT, cm	1.13	1.08	0.03	1.08	1.13	0.03
REA, sq. cm[h]	91.03	92.13	1.03	91.94	91.23	0.97
REA/HCW[h]	1.76	1.77	0.02	1.77	1.75	0.02
KPH, %	2.07	2.06	0.02	2.06	2.07	0.02
Calc. YG, units	2.58	2.50	0.08	2.49	2.59	0.07
USDA YG distribution[e]						
YG 1 and 2	67.48	72.43	3.87	74.48	65.14	3.62
YG 3	30.02	23.88	3.68	23.74	30.19	3.54
YG 4 and 5[f]	1.43	1.53		0.96	1.97	
MARB, units	413	411	7.8	410	414	7.1
MARB/FAT	103.6	101.9	3.4	105.4	100.1	3.0
USDA QG distribution[e]						
≥ Low CH	48.41	48.51	4.32	47.86	49.06	3.73
Select	43.78	42.48	4.52	43.44	42.82	3.97
Standard	6.68	6.32	2.23	7.45	5.66	2.00
Liver abscesses[i]	16.58	10.36	2.65	12.57	13.77	2.64
Pale livers[j]	2.47	0.00		0.95	2.42	

[a] HCW = Hot carcass weight; DP = Dressing percentage; FAT = 12th rib fat depth; REA = Ribeye area; REA/HCW = REA per cwt HCW; KPH = Kidney, pelvic, and heart fat; Calc. YG = Yield grade calculated from carcass measurements; YG = Yield grade; MARB = Marbling score, 400 = Small^{00}, 500 = Modest^{00}; MARB/FAT = MARB per 0.1 inches FAT; CH = Choice.
[b] Rumensin and Tylan.
[c] Cattlyst and Aureomycin.
[d] Initial weight was used as a covariant in the analysis of HCW.
[e] Percentage likelihood that an individual carcass within each pen qualified for each specific weight, quality grade, or yield grade category.
[f] Convergence criteria not met using PROC GLIMMIX. Results are shown as the percentage of individual carcasses the qualified for each weight or yield grade category.
[g] Feed additive by sulfur treatment interaction, $P < 0.05$. See Figures 2.1 for an explanation of the interaction.
[h] Initial weight was used in the analysis of ribeye area and ribeye area per unit HCW.
[i] Percentage likelihood that individual livers within a pen showed symptoms of liver abscesses.
[j] Convergence criteria not met using PROC GLIMMIX. Results are shown as the percentage of individual livers that appeared pale upon a subjective assessment of color.

APPENDIX A:

Energy Recovery. Net energy values for each diet were calculated from estimates of energy expended for maintenance (EM, Mcal/d) and energy retained (EG, Mcal/d) derived from BW, actual growth performance data, and DMI using the following equations for large-framed yearling steers (NRC, 2000):

EM = 0.077 × mean shrunk $BW^{0.75}$ (kg), where mean shrunk BW (SBW) = full mean BW × 0.96;

EG = (0.0635 × ($EQEBW^{0.75}$) × ($EBG^{1.097}$)), where EQEBW = 0.891 * [SBW * (Standard Reference Weight/final shrunk body weight, kg)], Standard Reference Weight (SRW) at a Small degree of marbling = 478 kg, and EBG = 0.956 * daily shrunk weight gain (kg/d).

The NEm and NEg values of the diets were then calculated using the solution for the quadratic equation:

NEm (Mcal/kg DM) = $((-b + \sqrt{(b^2-4ac)}) / 2a)$, where

a = 0.877 × DMI,

b = (-0.877 × EM) - (0.41* DMI) - EG, and

c = 0.41 × EM

NEg (Mcal/kg DM) = 0.877 x NEm - 0.41.

APPENDIX B:

The effect of additive program and dietary sulfur on feedlot performance (Raw means).

	Rumensin/Tylan		Cattlyst/Aureomycin	
Item	Constant	Variable	Constant	Variable
N	16	8	16	8
Initial weight, lb	330.2 ± 8.2	328.3 ± 11.3	329.3 ± 8.16	329.7 ± 11.8
Final weight, lb	581.4 ± 7.26	587.6 ± 9.07	581.0 ± 6.35	587.8 ± 10.9
Average daily gain, lb	1.57 ± 0.02	1.62 ± 0.03	1.57 ± 0.03	1.61 ± 0.03
Dry matter intake, lb	8.44 ± 0.08	8.57 ± 0.07	8.61 ± 0.09	8.6 ± 0.14
Feed/gain	5.40 ± 0.11	5.30 ± 0.07	5.50 ± 0.09	5.36 ± 0.13
Gain/feed, kg/kg DM	0.19 ± 0.005	0.19 ± 0.003	0.18 ± 0.003	0.19 ± 0.005
NEm[a]	2.23 ± 0.03	2.23 ± 0.02	2.19 ± 0.02	2.22 ± 0.03
NEg[b]	1.54 ± 0.03	1.55 ± 0.02	1.51 ± 0.15	1.53 ± 0.03

[a] Net energy for maintenance, Mcal/cwt dry matter.
[b] Net energy for gain, Mcal/cwt dry matter.

APPENDIX C:

The effect of additive program and dietary sulfur on carcass merit (Raw means).

	Rumensin/Tylan		Cattlyst/Aureomycin	
Item[a]	Constant	Variable	Constant	Variable
N	16	8	16	8
HCW, lb	363.8 ± 4.08	367.4 ± 6.35	366.6 ± 3.63	366.8 ± 2.72
Weight category[b]				
< 272 kg	1.41	2.94	1.42	0.0
272 – 430 kg	95.77	92.65	95.04	98.48
431 – 453 lb	2.11	4.41	2.84	1.52
≥ 454 kg	0.70	0.0	0.71	0.0
Dressing percent	62.56 ± 0.16	62.62 ± 0.23	63.06 ± 0.19	62.33 ± 0.26
Fat depth, cm	1.1 ± 0.03	1.05 ± 0.05	1.13 ± 0.03	1.13 ± 0.05
Ribeye area, cm^2	91.94 ± 1.10	91.87 ± 1.03	90.19 ± 0.90	92.32 ± 2.13
REA/kg HCW	0.25 ± 0.001	0.25 ± 0.003	0.25 ± 0.003	0.25 ± 0.006
Calculated YG, units	2.50 ± 0.05	2.48 ± 0.07	2.65 ± 0.08	2.52 ± 0.14
Calc. YG Category[b]				
YG12	74.47	76.12	61.15	71.88
YG3	24.11	23.88	37.41	25.00
YG45	1.42	0.0	1.44	3.13
Marbling score, units	411 ± 8	410 ± 9	415 ± 8	412 ± 12
Marb./cm fat	314 ± 13.6	424 ± 20.4	410 ± 11.4	391.2 ± 14.0
USDA QG Category[b]				
≥Low Choice	47.52	49.25	50.36	50.00
Select	46.10	41.79	7.19	45.31
Standard	6.38	8.96	42.45	4.69
Abscessed Livers[c]	17.86	8.96	15.60	12.12
Pale Livers[c]	1.41	0.0	3.55	0.0

[a] HCW = Hot carcass weight; YG = Yield Grade; QG = Quality Grade.
[b] Percentage of individual carcasses.
[c] Percentage of individual livers exhibiting signs of abscesses.