EFFECT OF IONOPHORES ON PERFORMANCE AND DIGESTION BY LIVESTOCK

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Bachelor of Science in Agriculture

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1980

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1983

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DIGESTION BY LIVESTOCK

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ACKNOWLEDGMENTS

The writer would like to recognize several key people whose guidance and assistance were instrumental in furthering his education as well as conducting and completing this study.

Sincere appreciation is expressed to Dr. F. N. Owens for his guidance and invaluable assistance in the course of this study and preparation of this manuscript. Appreciation is also extended to Dr. D. R. Gill and Dr. W. A. Phillips for helpful suggestions and evaluation in preparation of this manuscript. The advice and guidance they gave is gratefully acknowledged.

Further appreciation is extended to fellow graduate students for their constant assistance and helpful suggestions. Special recognition is extended to Kevin Milliner for feeding and care of animals plus assistance in sample collection. Many thanks goes to Dr. Bob Teeter for assistance in completing the chick studies. A special thanks to Debbie Phelps and Joan Summers for assistance in laboratory analysis.

Last and most important, the writer would like to express gratitude and love to his parents, Robert and Martha Ferrell; and his sister, Lisa, for their support, encouragement and sacrifice throughout the course of this study.

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CHAPTER I

INTRODUCTION

Constantly increasing costs of production of livestock have caused producers to attempt to increase returns by employing new methods of production. This has been accomplished by improving the breeds of livestock, using growth stimulants, and employing a wide variety of other techniques. In cattle production, improving the efficiency of feed use is one way for the producer to increase returns.

Manipulating rumen fermentation of feedstuffs to increase overall production of the ruminant is the basis of much research. There is a possibility to greatly improve return from ruminants by increasing the efficiency with which diets are utilized through adjusting nutrient breakdown in the rumen and altering the composition of the material entering the small intestine.

Ionophores are a class of feed additives which can increase the efficiency of feed use by ruminant animals. The first ionophore to be approved for feeding of cattle was monensin. Monensin was approved by the Food and Drug Administration (FDA) for feeding to feedlot cattle in 1976. By 1978, over 80 percent of the

cattle in feedlots in the United States were being feed monensin (Owens, 1980). This rapid acceptance has stimulated testing of other ionophores. Lasalocid was the second ionophore to be approved for use in cattle feeding and a third ionophore, salinomycin, has recently been approved for field testing trials. Salinomycin was used in two feeding trials described in this thesis to determine its effect on rate and efficiency of gain by steers and heifers. These trials tested various dose levels to help to determine the optimal concentration in feedlot diets. In the first trial, steers were fed levels of 0, 5.5, 11, 22 or 33 ppm. In the second trial, both steers and heifers were fed levels of 0, 5.5, 11, 16.5, and 22 ppm. In both trials, feed intake and rate of gain were measured to determine the effectiveness of the ionophores at various levels. Carcass characteristics also were measured to determine effects on the carcass.

Ionophores in some studies will increase the digestion of various dietary components, probably through altering ruminal fermentation of the feedstuffs. Retention time for digestion of feedstuffs may be increased when ionophores are fed. This may increase the extent of digestion of certain dietary components. The effects of ionophores on digestibility are not universally observed. Monensin addition at 33 ppm to a 90 percent concentrate feedlot diet had no effect on apparent digestibility of dry matter, gross energy, or starch in a recent trial by Muntifering (1980a) though digestibility of crude protein tended to increase with the addition of monensin. Digestibility of sorghum-based feedlot diets was also tested by Muntifering (1980b) and again monensin improved

apparent digestibility of crude protein but not the digestibility of dry matter or gross energy of the diet. More study of the effect of the several ionophores on digestibility of the various dietary components is needed. An alteration in the ratios of volatile fatty acids (VFAs) in the rumen has been associated with monensin feeding. Monensin increases the acetate to propionate ratio (Richardson, et al., 1976; Van Nevel and Demeyer, 1977; Chalupa et al., 1980; and Whetstone, 1980) and effects of lasalocid on VFA ratios appear to be similar. An increase in the propionate to acetate plus butyrate ratio conserves energy since formation of both acetate or butyrate result in an excess of electons which are usually shunted to methane, a useless product for the animal. Consequently, with greater propionate production, more dietary energy remains available for use by the animal. To determine the effects of lasalocid, salinomycin, and monensin on digestibility and nitrogen retention, a digestion trial was conducted. Volatile fatty acids concentrations in ruminal fluid were measured to determine and compare the effects of these three ionophores on digestion by steers.

Ionophores may increase the net energy for maintenance (NE_m) but not the net energy for growth (NE_g) according to Byers (1980). This may be associated with more efficient utilization of propionic acid by tissues. In addition, ionophores could influence tissue metabolism through effects on the sodium pump, one of the primary energy expenses of animal cells. This effect is difficult to quantify in the ruminant because of microbial actions and microbial adaptation in the rumen and

possible effects on absorption and coccidiosis. Thus, other methods must be used to test the hypothesis that ionophores alter the energy requirements of animal tissues. To examine the affect of ionophores on tissues, 192 broiler chicks were fed ionophores in two separate trials. Chicks were so young that coccidiosis should not confound the results and the amount of microbial action within their gastro-intestinal tract should be minimal. Weight gains and efficiency of feed use were monitored.

CHAPTER II

REVIEW OF LITERATURE

Ionophores

Description

By definition, ionophores are substances which have the ability to promote the transfer of ions from an aqueous medium into a hydrophilic phase (Dobler, 1981). Ionophores are complex organic chemicals which bind with cations to form lipid soluble complexes which can move across cell membranes. The three polyether antibiotics currently in use or in testing stages for feeding to cattle are: monensin, lasalocid and salinomycin. All three are naturally occurring carboxylic ionophores produced from different streptomycetes cultures.

Monensin, the most widely studied ionophore, is produced by a strain of Streptomycetes cinnamonensis. Monensin facilitates the movement of potassium across cell membranes, thus reversing the flow of sodium out of the mitochondria. This additive is marketed under the trade name, Rumensin, by Elanco Products Company, a Division of Eli Lilly and Company, Indianapolis, Indiana.

Lasalocid was discovered by researchers at Hoffman-La Roche (Berger et al., 1951). Produced by a strain of Streptomycetes lasaliensis, lasalocid is less selective for sodium and potassium ions than monensin, but has binds to some degree with calcium and barium ions. Lasalocid is currently approved for addition to feedlot diets and is marketed by Hoffman-La Roche Inc., Nutley, New Jersey, under the trade name Bovatec. Salinomycin is a carboxylic polyether antibiotic produced by a strain of Streptomycetes albus. Salinomycin was first described by Miyazaki et al. (1974). Presently, salinomycin is being field tested for feedlot cattle by A. H. Robbins Company, Richmond, Virginia.

Performance Effects

Monensin is fed widely to cattle to improve the efficiency of feed use. Feeding trials have demonstrated that monensin decreases feed intake but improves feed efficiency of cattle fed high concentrate diets. It also increases rate of gain and feed efficiency of cattle fed high roughage diets. In a review of monensin feeding trials, Utley (1976) summarized that feeding 100 to 200 mg. of monensin per head daily to young grazing cattle increased average daily gain by 27 percent to 32 percent. Utley (1976) also concluded high roughage diets supplemented with 33 ppm monensin reduced the amount of feed needed per unit of gain by 6 to 17 percent and produced daily gains equal to or more rapid than animals not fed monensin. With high energy finishing diets, feed intake decreased as monensin concentration increased up to 44 ppm, but there was little change in average daily gain. An improvement in efficiency of feed use was also shown in a six trial summary

from Oklahoma (Witt et al., 1980). However, feed efficiency of cattle fed high concentrates in the latter summary was increased by only 4.8 percent, somewhat less than the values suggested by Utley (1976). Raun et al. (1976) reported that daily gain of feedlot cattle was increased by 5.2 percent with addition of monensin at 11 ppm.

In a sixteen trial summary by Brandt (1982), cattle were fed lasalocid at 0, 11, 22, 33, 44, 49.5, 55, and 66 ppm. Each study employed a control (0 lasalocid) diet, but every level was not utilized at every trial. Average daily gain was increased by a mean of 5 percent at a level of 33 ppm and 3 percent at the 22 ppm level of feeding. Feed to gain ratios were improved by lasalocid feeding up to 45 ppm, with a mean of 6.3 percent. Average daily feed intake was decreased at all feeding levels, with the response being significant with all levels except 10 and 50 ppm lasalocid. The greatest decrease in feed intake was at a level of 60 ppm with which intake decreased a mean of 6.2 percent. A more recent trial by Owens and Gill (1982) showed an intake reduction of 4.1 percent and improvement of efficiency of gain of 5.9 percent with lasalocid additions.

Both monensin and lasalocid increase the efficiency of feed use by feedlot cattle and have been compared by researchers at several locations in the midwestern and southwestern states. A twenty trial summary of these finishing trials was prepared by Stuart (1982). Fifteen of the trials compared lasalocid with monensin with both fed at 33 ppm. Five of the trials compared these two ionophores fed on a mg/head/day basis, with levels ranging from

150 to 300 mg/head/day. The pooled analysis showed an increase in average daily gain due to either ionophore, with gain response to lasalocid (7.2 percent) being greater than response to added monensin (2.3 percent). Efficiency of feed use was improved 9.7 percent over controls with lasalocid feeding and 5.1 percent with monensin. Feed intake was decreased 3.3 percent with addition of lasalocid and 2.0 percent with monensin. These results show a significant increase in average daily gain of lasalocid (4.8 percent) in comparison to monensin, and a significant improvement in feed conversion of 4.9 percent. Feed intake tended to be reduced by lasalocid (1.4 percent). Results of feeding these two ionophores on a mg/head/day basis were similar to feeding on a ppm basis. Providing 200 to 300 mg/head/day of lasalocid tended to increase rate of gain more than monensin, although lasalocid fed animals consumed 1.2 percent more feed than did the monensin fed cattle.

Salinomycin is currently being field tested in feeding trials. In a Virginia trial (McClure et al., 1980), salinomycin improved feed efficiency by 21 percent at both a lower (16.5 ppm) and a higher level of feeding (33 ppm). Average daily gain was improved by salinomycin an average of .16 Kg over that of controls. Feed intakes tended to decline at levels of 33 and 50 ppm. This ionophore shows some promise but more work needs to be done, both in dose titration studies and in comparison studies with other ionophores.

Biochemical Aspects of Ionophores. Monensin alters rumen metabolism as measured in vitro. It decreases the acetate to

propionate ratio and lowers butyrate concentrations (Richardson, et al., 1976; Van Nevel and Demeyer, 1977; Chalupa, et al., 1980; Whetstone, 1980). These effects have been noted with both high concentrate and roughage diets. In vitro studies conducted using lasalocid also have shown increased propionate levels and decreased acetate levels (Bartley, 1979; Bartley and Nagaraja, 1982). Salinomycin had similar effects on the concentrations of VFAs (Fontenot, 1980), with increased proportions of propionate and decreased acetate at higher concentrations of salinomycin.

The ruminal response of animals fed ionophores appears to be similar to results found in vitro. Increased propionic and decreased acetic and butyric acid levels (Potter et al., 1976a; Raun, 1976; Richardson et al., 1976; Prange, 1978) have been reported with cattle fed high concentrate and high roughage diets with monensin feeding. Some studies have not obtained a decrease in acetic and/or butyric acids (Dinius et al., 1976; Lemenager et al., 1978), but in almost all trials, the acetate to propionate ratio has been decreased with added monensin. In vivo responses to lasalocid were reported by Brandt (1982). In nine different feeding studies, lasalocid consistently reduced the acetate to propionate ratio indicating that microbial fermentation in the rumen had been altered.

Although the exact mechanism by which feed efficiency is improved with ionophore feeding has not been determined, this shift in fermentation with an increased propionate concentration has been used as one explanation. Richardson et al. (1976) calculated the energy savings associated with a ten molar percent decrease in

acetic acid, an eight molar percent decrease in acetic acid, and a decrease in butyric acid concentration of two molar percent. By using theoretical energy conversions as described by Hungate (1966), these workers calculated that these changes in VFA production would increase the percentage of gross energy retained as VFA by 5.6 percent.

Raun et al. (1976) observed a three to six percent increase in energy savings due to an increase in propionate levels and concluded that this amount of savings could not explain all of the increased feed efficiency observed in feeding trials. Consequently, other energy conservation mechanisms must be working in conjunction with increased energy savings from the shift in microbial end products.

This reduced energy loss due to the formation of propionic acid in the rumen is a major advantage. When propionic acid is formed, two molecules of propionic are formed from one molecule of glucose and hydrogen ions are added, resulting in a net increase in energy. In contrast, formation of acetate and butyrate from glucose results in a net loss of hydrogen ions which may appear as methane. Energy conservation from glucose is 62.5 percent during the formation of two acetate molecules, 78 percent during the formation of butyric acid and 109 percent with the formation of two propionate molecules. Though on the surface this appears to contradict the first law of thermodynamics, the hydrogen used during propionate formation is obtained from the surplus formed during formation of acetate and butyrate, and a total fermentation balance needs to be calculated to fully explain the reactions.

An increase in propionate production is invariably associated with a decrease in methane production. Decreased methane loss was reported by Slyter (1978) with monensin addition to culture tubes. The decrease in methane production associated with increased propionic acid would be expected because propionic acid formation from glucose requires the addition of hydrogen equivalents which would otherwise be shunted to hydrogenation of carbon dioxide to form methane. Thornton and Owens (1981) observed energy loss as methane was decreased 16 percent at roughage levels between 15 and 45 percent of the diet and by 24 percent with a 66 percent roughage levels. They further observed that the depression in methane production from feeding monensin tended to decrease with time after feeding. In vivo methane production was decreased by two percent by monensin addition to a high concentrate diet for steers (Wedegartner and Johnson, 1980).

The effects of lasalocid on in vivo production of methane have not been established, although in vitro work (Bartley, 1979; Bartley and Nagaraja, 1982) suggests a similar effect to that of monensin. Van Nevel and Demeyer (1977) incubated substrates specific for methane bacteria and concluded that the decrease in methanogenesis was not due to action on specific methanogenic flora but due to an inhibition of hydrogen production from formate. Chen and Wolin (1979) also observed no inhibition of methane-producing bacteria in vitro with either monensin or lasalocid concentrations. These workers hypothesized that the addition of either of these ionophores to the rumen decreases the production of major fermentation products, acetate and butyrate, by inhibiting the

growth of species of bacteria fermenting carbohydrate and producing these end products and form both formate and hydrogen as by-products. Since both hydrogen and formate are used in production of methane in the rumen, inhibition of the growth of these bacterial strains would consequently reduce the production of methane in the rumen. This theory also supports the proposal of Van Nevel and Demeyer that the effects of monensin and probably lasalocid on rumen fermentation are due to selection of a microbial population which favors lowered acetate and butyrate and less methane than a population without manipulation by ionophores, and that ionophores do not directly inhibit methanogens. In support of this hypothesis, Short (1978) found no accumulation of formate in fermentations medicated with monensin. As mentioned above, the decrease in methane production or increase in energy retained as propionate can explain only about half of the increase in efficiency of animal production reported by most researchers. Therefore, the ionophores must have additional effects on animal metabolism.

Through altered end-products of fermentation, monensin may reduce the production of hydrogen ions in the rumen and may increase the pH of the rumen. The rumen microflora has optimal pH values for digesting certain feedstuffs, especially cellulose, and possibly for microbial cell production. In vitro results of Dinius et al. (1976) showed no effect of monensin on pH. This concept was supported by Poos et al. (1979) for lambs fed brewers grains. Yet slight increases in ruminal pH have been reported by Richardson et al. (1977) with monensin added to either a high roughage or a high

concentrate diet and by Thonney et al. (1981) with supplementation of lasalocid. No effect on pH was observed with the addition of salinomycin to high concentrate diets (Webb et al., 1980). This effect of ionophores on the pH of the rumen contents seems reasonable since propionate has a higher pK than acetate, fewer moles of propionate than acetate are produced per glucose fermented, and hydrogen ions as well as hydrogen protons are used in the production of propionic acid.

Diets with protein concentrations below those recommended by the NRC (1976) often have lower daily gains and feed efficiencies than adequate diets. Boling (1977) improved feed efficiency with supplementation of monensin to diets with a sub-adequate level of protein. Several researchers (Boling, 1977; Gates and Embry, 1977; Gill et al., 1977; Harvey, 1977; Hanson and Klopfenstein, 1979) also have observed this increase in efficiency with monensin addition to low protein diets and have suggested that monensin may have a "protein sparing effect". Lasalocid and salinomycin have not been tested by varying protein levels to test this theory, but the similarities of other actions of the ionophores suggests that they may also be more effective to improve efficiencies of energy use with diets of lower protein concentration.

Two sites of action could be involved with the "protein sparing" effect of ionophores. One possible action would be the sparing of glucogenic amino acids which are formed from propionate. Much of the glucose synthesized by ruminant animals comes from amino acids. Added propionate may provide this glucose directly, thereby sparing amino acids which would otherwise be deaminated in

body tissues for gluconeogenesis (Eskland et al., 1974; Van Maanen et al., 1978).

A second action is that ionophores may increase the bypass of fed protein which may improve the nitrogen economy by decreasing losses associated with the transfer of dietary protein to microbial protein. Owens et al. (1978) observed an increase in abomasal flow of non-ammonia nitrogen of 14 percent with monensin addition to an 85 percent concentrate diet, suggesting a possible reduction in ruminal protein degradation. Muntifering et al. (1980) reported that monensin decreased bacterial nitrogen by six percent but increased bypass of feed nitrogen by six percent. With the decrease in microbial protein, however, daily passage of amino acids and the efficiency of bacterial protein synthesis were not changed by monensin addition. In vivo results of Isichei and Bergen (1980), utilizing high concentrate and high roughage diets with monensin addition, also lend support to this theory, that feeding of ionophores will increase bypass of feed nitrogen but may decrease the amount or efficiency of microbial nitrogen passing out of the rumen and, consequently, may alter amino acid balance in the rumen.

Zinn et al. (1980) reported a no change in digestion of protein fractions in the rumen. Other research (Faulkner et al., 1982) using ensiled corn cobs also found no change in abomasal flow of non-ammonia nitrogen with monensin. In contrast, Poos et al. (1978) reported that bypass of intact plant protein to the lower gastrointestinal tract was increased when monensin was fed. The increased bypass was attributed to reduced proteolysis in the rumen

and was associated with a reduced ammonia concentration in the rumen. This phenomenon also was observed with sheep fed a purified protein-free diet (Van Nevel and Demeyer, 1979). Decreased ruminal ammonia concentrations with monensin feeding has been reported by several workers (Dinius et al., 1976; Hanson and Klopfenstein, 1979; Muntifering et al., 1980) with both high concentrate and high roughage diets. Potter et al. (1977) reported that monensin decreased ruminal ammonia concentrations on low protein diets. Chalupa et al. (1980) examined the effect of monensin on the utilization of an exogenous amino acid load and noted a 50 percent decrease in utilization of amino acids. He theorized that monensin suppressed deamination and perhaps decreased proteolysis as well.

Tolbert et al. (1977) and Richardson et al. (1975) reported decreased ruminal ammonia levels with monensin in vitro. Tolbert also reported a 9.6 percent increase in free amino acids with monensin supplementation. Supporting this concept, Whetstone et al. (1980) reported a decrease in microbial nitrogen and an inhibition of protein degradation in vitro which would result in increased dietary protein reaching the small intestine.

In a three trial summary of in vitro work with lasalocid, Bartley and Nagaraja (1982) found a depression in bacterial synthesis of protein. Even though the responses for lasalocid and monensin were similar in many cases, there was a tendency for less reduction of protein synthesis with lasalocid than with monensin inoculation.

Preliminary in vitro reports indicates that salinomycin (Webb et al., 1980) also decreases ammonia-nitrogen levels. The effects

of lasalocid and salinomycin in vivo are expected to be much like those of monensin although little work on passage or site of protein degradation has been reported with these newer ionophores.

In summary, ionophores seem to inhibit deamination and lower ruminal ammonia levels when measured in an in vitro system. Ionophores seem to inhibit proteolysis, reduce ruminal ammonia levels, and free amino acids in vivo though some research refutes this theory and shows little or no change in the total amount of non-ammonia nitrogen leaving the rumen. In most cases, bypass of dietary protein increases with the addition of ionophores to the diet. This may be associated with an increased efficiency of feed use if the dietary protein reaching the small intestine has a high biological value and digestibility. If bypassed protein has a low quality, or dietary protein is primarily non-protein nitrogen, little benefit from added bypass would be expected.

Digestibility Effects. Dinius et al. (1976) reported that in vivo digestibility of dry matter, crude protein, and hemicellulose from a forage diet fed ad libitum was not altered by supplemental monensin. Nitrogen digestibility was similar, but nitrogen retention tended to be slightly higher with monensin addition. Poos et al. (1979) reported a reduced digestibility of dry matter and nitrogen retention with monensin addition to a diet supplemented with either brewers dried grains or urea as the source of supplemental nitrogen. With the same two feedstuffs in a second lamb trial, Poos et al. (1979) again found that dry matter and acid detergent fiber digestibility were significantly reduced by the addition of monensin early in the trial. But by days 40 to 46,

digestibility differences had disappeared suggesting that animals may have adapted over time. Hanson and Klopfenstein (1979) reported a reduction of dry matter digestion and acid detergent fiber digestion with monensin feeding but also reported that differences decreased over time in the 40-day study with a diet of sorghum silage and corn cobs. Using sorghum as a substrate in an in vitro fermenter, Tolbert et al. (1977) reported that monensin increased dry matter digestibility.

Rust (1978) found that digestibility of dry matter, organic matter, starch, and nitrogen increased with added monensin. The increase in nitrogen digestibility seen with monensin was suggested to be due to increased starch digestion and decreased metabolic fecal nitrogen. Feed intakes were lower with added monensin which could increase digestibility slightly. With controlled and equalized feed intake of cattle, Tolbert and Lichtenwalner (1978) reported that monensin supplementation to a diet of a high concentrate diet increased the apparent digestibility of dry matter, crude protein, ether extract, and nitrogen free extract while crude fiber digestibility was decreased. In this case, the increased digestibility cannot be attributed to decreased intake.

Lemenager et al. (1978) reported that in vitro dry matter digestibility (IVDMD) of harvested range grass decreased when monensin was added to fermentation flasks. In vitro cellulose digestion was not significantly altered when monensin was added to the control supplement, however, cellulose digestion tended to be slightly lower with 50 and 100 mg/head/day additions than with the addition of 200 mg/head/day. Dinius et al. (1976) also observed no

change in cellulose digestion with incubation of cotton samples in vitro. Pond and Ellis (1978) reported an increase of organic matter digestibility of forage with supplementation of monensin on Coastal bermuda grass pasture. Monensin at 20 ppm in a 50 percent concentrate diet to lambs (Joyner et al., 1979) improved digestibility of dietary energy. Monensin thus increased the metabolizable energy of the diet. Linn et al. (1975) observed no significant effect of monensin on crude protein or dry matter digestibility of a corn silage diet though crude protein digestibility was slightly higher with monensin addition. Protein digestibility, as evidenced by digestion of casein, was increased with increasing monensin levels in an in vitro system utilized by Whetstone et al. (1980). Cellulose degradation was also markedly inhibited by monensin treatment. In a summary of six feeding trials, an anonymous publication by Elanco (1975) concluded that monensin increased nitrogen digestibility when fed at levels up to 300 mg/head/day but increased cellulose and dry matter digestibility only at a level of 100 mg/head/day.

Monensin improved the digestibility of dietary energy, neutral detergent fiber, and nitrogen with steers fed a high concentrate cracked corn diet (Wedegartner et al., 1980). Daily energy retention of cattle fed monensin, adjusted for intake, was virtually identical to that of animals fed the control diet. With monensin addition at 33 ppm of a 90 percent concentrate diet, Muntifering et al. (1980a) observed no effect on apparent digestibility of dry matter, gross energy, or starch, though digestibility of crude protein tended to increase with monensin

supplementation. In metabolism trials with 76 percent sorghum diets, monensin improved apparent digestibility of crude protein but not dry matter or gross energy (Muntifering et al., 1980a), and nitrogen retention expressed either as a percentage of nitrogen intake or as a percentage of nitrogen absorbed tended to improve with added monensin. In a separate experiment, Muntifering et al. (1980b) reported that added monensin had no effect on apparent digestion of organic matter, starch, and crude protein on a high concentrate, corn-based diet.

Averaged across three fiber levels (Thornton and Owens, 1981), dry matter digestibility and the digestibility of carbohydrate fractions were not altered. Nitrogen retention also was not altered by monensin addition but digestibility of all three components tended to increase with monensin feeding.

Salinomycin increased the digestibility of crude protein and crude fiber with steers limit-fed a high concentrate diet (Webb et al., 1980). Effects of lasalocid on digestibility have not been reported.

In summary, these trials suggest that digestibility of crude protein and dry matter are often increased with the addition of ionophores, but cellulose and fiber digestibility may be depressed with added monensin.

Tissue Effects. Besides action in the intestinal tract, ionophores may have effects on tissue metabolism, either directly or indirectly through altered fermentation end-products. Propionic acid may be used more efficiently than acetic and butyric acid at the tissue level for growth and maintenance. Increased propionate

levels in blood plasma were observed by Thonney et al. (1981) and Van Maanen et al. (1977) indicating that the source of energy available for tissues was altered by monensin feeding. Increased plasma glucose concentrations also were observed by Thonney et al. (1981) for cattle consuming lasalocid. Hungate (1966) observed a lower heat increment for propionate than that observed for acetate. Since the use of ionophores increases propionate levels in the rumen and decreases acetate in most cases, the animal may also have a lower heat increment than observed without ionophore addition, and this could also contribute to increased efficiency of feed use. Although no increase in heat production was observed with monensin feeding by Thornton and Owens (1981), heat production was increased with monensin feeding in a study by Wedegartner and Johnson (1980) even though retained energy was increased by addition of monensin; both studies were conducted using respiration calorimetry.

Lofgreen (1976) reported increases in both net energy for maintenance (NE_m) and net energy for gain (NE_g) with addition of monensin to diets. Byers (1980) suggested that linear regressions show that monensin decreases the maintenance requirement and/or increases the efficiency of use of energy from the diet for maintenance but not for growth.

Interactions

Ionophores by Feed Source. Utley et al. (1977) observed no corn type by monensin interaction when monensin was added to either dry rolled corn or propionic acid-treated high moisture corn. Monensin additions decreased average daily gain and feed intake but increased feed efficiency of both corn types. In

contrast, Rust (1978) found that digestibility of whole shelled corn was increased by monensin addition much more than digestibility of high moisture corn grain.

Ionophore by Protein Level. Gill et al. (1977) reported a monensin by protein interaction with protein levels of 9.5, 10.3, 11.2 and 12.3 percent in corn based feedlot diets. Monensin depressed feed intake and rate of gain to a greater extent at higher protein levels, but the advantage in feed efficiency was greatest with lower dietary protein levels. At low protein levels, monensin tended to improve both rate of gain and feed efficiency but had little effect on feed intake. Potter et al. (1977) using two protein levels with concentrate or alfalfa diets observed no interaction of monensin with protein level or source on intake of dry matter, average daily gain, or feed efficiency. Rust (1978) reported a protein by monensin interaction for nitrogen retained per unit of organic matter digested with monensin decreasing retention at a low protein level (9 percent) while monensin increased nitrogen retention at a higher level of protein. No interactions indicative of a "protein sparing effect" were noted.

Physical Effects of Ionophores

Rumen Turnover Rate. Lemenager et al. (1978) reported that monensin feeding decreased feed intake, decreased turnover of rumen solid and liquid and decreased rate of digestion in the rumen. Steers fed forage had a 30.8 percent slower rumen liquid turnover rate and a 43.6 percent slower solid turnover rate while consuming monensin. With steers limit-fed a high concentrate diet and intake of feed was constant, monensin still decreased turnover

rate. This suggests that the decrease in ruminal turnover rate with monensin occurs independent of the depression in intake, and therefore may be a cause for, and not the result of, decreased intake.

Digestive Enzymes. If digestive enzymes produced by the lower gastrointestinal tract were increased, the digestibility of certain feedstuffs could be enhanced. Van Hellen et al. (1977) reported an increased level of pancreatic amylase enzyme activity with monensin feeding. Earlier, Van Hellen et al. (1976) reported a decrease in amylase activity in steers fed monensin, with no difference between grain intake levels. It seems that data are inconclusive concerning the effect of ionophores on the activity of digestive enzymes.

Microbial Population. Numbers of protozoa, total bacteria, and cellulolytic bacteria were not altered when up to 33 ppm monensin was fed to steers in a forage diet (Dinius et al., 1976). However, Richardson et al. (1978) reported protozoal numbers may be decreased with monensin feeding. Bartley and Nagaraga (1982) observed decreased protozoal numbers in vitro with both monensin and lasalocid but observed no difference in total protozoal counts in vivo. Several individual protozoal strains appeared to be inhibited, but total numbers were not affected. These same workers observed that strains of bacteria sensitive to lasalocid and monensin were of four major types: 1) those that produce lactate as major end products, 2) those that produce butyrate as a major end product, 3) those that produce formate, and 4) those that produce hydrogen. These results are supported by the

work of Dennis et al. (1981). It seems that while total numbers of bacteria and/or protozoa are unchanged, there may be drastic effects on individual strains of bacteria and protozoa in the rumen.

NPN Addition. Lowered average daily gains have been observed with the replacement of protein by urea in diets supplemented with monensin (Gill, 1977b; Klopfenstein, 1977). These researchers also observed lowered feed efficiencies associated with urea addition to a monensin diet. In contrast, Davis and Earhart (1975) observed an superior feed efficiency with monensin added with NPN. Martin et al. (1977) reported that addition of monensin increased intake and average daily gain but had no effect on feed efficiency with a shelled corn diet containing .5 percent urea. Adams (1982) evaluated lasalocid in a diet containing either cottonseed meal or urea as the nitrogen source and observed no effect on average daily gain, a tendency to reduce feed intake, and a tendency to improve feed conversion. This effect was noted with both the urea and the cottonseed meal diet. Though monensin may show more benefit with diets supplemented with intact protein, lasalocid appears to work well with urea supplemented diets. More research is needed before drawing conclusions about protein source and ionophore benefits.

Carcass Characteristics. Brown et al. (1974) reported that the addition of monensin to concentrate diets increased the carcass cutability but did not alter quality grade. Potter et al. (1976b) summarized the effects of monensin feeding on carcass characteristics. No effect of monensin was observed on the carcass

measurements or the proportions of fat, lean or bone in the edible portion of the carcass. Monensin had no effect on moisture, fat or protein of the rib eye muscle. Decreased fat over the twelfth rib was observed by Davis and Earhart (1975) with corn based diets and by Linn et al. (1975) with high roughage diets.

Brandt (1982) summarized the results of eleven finishing experiments and found no significant differences in carcass parameters among cattle supplemented with lasalocid at various levels. Stuart (1982) observed a decrease in the incidence of liver abscesses in both high roughage and high concentrate finishing diets with addition of lasalocid. Davis et al. (1978) observed a decrease in federal quality grade with lasalocid feeding. Conversely, Owens and Gill (1982) observed an increase in percent of steers grading choice due to an increase in marbling score with lasalocid added to the diet.

Antimicrobial Action. Ionophores have moderate in vitro activity against gram positive organisms (Richardson et al., 1975; Dobler, 1982). Monensin and lasalocid are effective in preventing coccidiosis in poultry when fed at higher levels. Salinomycin has proven to be effective against some species of Eimeria at lower levels (25-75 ppm) than monensin and lasalocid. McDougald et al. (1981) observed no significant differences in anticoccidial action in broiler chicks with salinomycin supplemented at 66 ppm, monensin 100 and 121 ppm, and lasalocid at 75 and 125 ppm. Note that these are all higher than the 33 ppm used in feedlot diets. Salinomycin has shown some promise in improving growth rates in swine (Leeson

et al., 1981; Blair and Shires, 1981). This may be due to antimicrobial activity of the ionophore.

Monensin is effective in preventing severe clinical coccidiosis in ruminants as well (Fitzgerald and Mansfield, 1973; Bergstrom and Maki, 1976) and lasalocid has shown to have similar effects (Horton, 1982).

CHAPTER III

SALINOMYCIN LEVELS FOR FEEDLOT STEERS

M. C. Ferrell, F. N. Owens and D. R. Gill

SUMMARY

A new feed additive, salinomycin, was fed to 140 finishing steers (initial weight of 357 kg) for 110 days. Salinomycin was fed at 0, 5.5, 11, 22 and 33 ppm of an 89 percent whole shelled corn, 5 percent cottonseed hull diet. Averaged across salinomycin levels, gain was increased by 9.4 percent, efficiency of feed use was increased by 7.8 percent, and feed intake was increased 1 percent by salinomycin. At the optimum drug level in this trial (11 ppm) gain and feed efficiency were increased by 12.9 and 9.5 percent, respectively. Feces tended to be drier and contain more starch when the drug was fed. Carcass measurements were not changed by salinomycin feeding.

INTRODUCTION

Feed additives of a class called ionophores have proven to increase efficiency of feed use by feedlot cattle. Monensin, lasalocid and salinomycin are three ionophores. Monensin and lasalocid are approved for feeding to feedlot cattle and are widely

fed today. Salinomycin has been evaluated previously in one study in Virginia (McClure et al., 1980). In that trial, gain and efficiency increases of 21 percent for beef steers fed a 20 percent roughage diet were reported. In this trial, salinomycin was fed at five levels to finishing steers to examine its effect on rate and efficiency of gain.

EXPERIMENTAL PROCEDURE

One hundred forty steers of mixed breeding which had grazed together on wheat pasture for several months near Purcell, Oklahoma, were sorted, vaccinated for bovine rhinotracheitis, leptospirapomona, bovine virus diarrhea, parainfluenza 3, blackleg and malignant edema and transported to Stillwater, Oklahoma May 29, 1981. On arrival, steers were held on pasture for three weeks and were blocked by weight into four weight groups with 35 steers per weight group. Steers within each weight group were randomly allocated to one of five pens with 7 steers for each of the 20 pens. Salinomycin was fed at five levels: 0, 5.5, 11, 22 and 33 ppm of feed. These are equivalent to 0, 5, 10, 20 and 30 g per ton of diet. Cottonseed hulls and corn comprised 94 percent of the diet, the other 6 percent a pelleted supplement. The percentage hulls in the diet sequentially decreased from 40 to 30 to 20 to 12.5 and 5 percent at 3-day intervals at the start of the trial until the final diet (Table I) was being fed. Steers were weighed following withdrawal of feed and water at the start of the trial and on day 110. Other weights were taken full. Steers had access to feed from self-feeders throughout the trial. The final weight was taken on day 124, following a 14-day drug withdrawa. Three

steers were removed from the experiment due to sudden death and chronic health problems. Feed intakes were adjusted for removal of steers by deducting an amount of feed equivalent to that calculated to be consumed according to the net energy equations using calculated the net energy of the diet. One day 106, fecal grab samples were obtained for analysis from two steers in each pen. Starch was analyzed as total alpha-linked glucose polymers by the enzymatic procedure of Macrae and Armstrong (1968). Fecal pH was measured with a combination electrode. Salinomycin was withdrawn from the pelleted supplement on day 110. On day 124, steers were trucked to Booker,TX, for slaughter and carcass evaluation. Statistical analysis of data was a randomized block design, with removal of block effects and means compared by Duncan's multiple range test (Barr and Goodnight, 1980).

RESULTS AND DISCUSSION

Daily gain and feed intake were increased with salinomycin added to the diet (Table II). Steers fed salinomycin at 10 ppm had heavier weights at 110 and 124 days than the control steers. Although no significant effect on daily gain was observed from day 0 to day 56 or from day 0 to the end of the trial, daily gain were increased by a mean of 6.3 percent the first 56 days and 11.9 percent the second 56 days with salinomycin addition to the diet. Gain increased with salinomycin by a mean of 9 percent and 6.5 percent over the entire feeding period, for days 0 to 110 and 0 to 124, respectively. Efficiency of feed use was increased with salinomycin supplementation more for the second 56 days than the initial period (9.9 vs. 5.7 percent). Feed efficiency was improved

7.7 percent for days 0 to 110 and improved 3.7 percent from 0 to drug withdrawa (day 124). Efficiency of feed and energy use was maximized when intake was maximum with 10 g per ton salinomycin. With this diet, gain and feed efficiency were improved by 12.9 and 9.5 percent. Higher salinomycin levels gave slightly less response.

Feces of steers fed the 10 ppm salinomycin diet were drier and contained more starch than feces of steers fed the control diet (Table III). These values are percent starch in feces and may not reflect starch digestion. Fecal pH was not altered by salinomycin supplementation. Carcass weight, dressing percent, fat thickness, cutability, and percent carcasses grading choice, all obtained 15 days after withdrawal of the drug, were not altered with salinomycin addition to the diet (Table IV). The incidence of liver abscesses was increased. Increased incidence of liver abscesses has been reported occasionally when monensin has been supplemented as well though the incidence may not be increased with lasalocid feeding (Stuart, 1982). Though performance and efficiency responses were less than observed in this trial than in the trial with salinomycin reported from Virginia (McClure et al., 1980), comparison with other ionophores (Table V) suggests that this compound has promise as a feed additive for feedlot steers. Responses to drugs differ with diet composition, environment and feeding conditions. Thus, responses from experiment stations will differ.

TABLE I

FEED AND PELLET COMPOSITIONS,
DRY MATTER BASIS[a]

Ingredient	IFN[b]	Percent
Corn, whole shelled	4-02-931	89.00
Cottonseed hulls	1-01-559	5.00
Pelleted supplement[c]		6.00
Soybean meal	5-04-600	57.00
Limestone	6-02-632	16.00
Urea		7.75
KCl	6-03-756	6.25
Salt		4.75
Alfalfa meal	1-00-023	4.50
Dicalcium phosphate	6-01-080	3.50
Trace minerals		0.25
Vitamin A-30[d]		0.18

[a]Average analysis: 90.2% dry matter, 11.8% protein, ME = 3.10 on dry matter basis.

[b]International Feed Number

[c]0, 91.5, 184, 367 or 551 ppm active drug added to pelleted supplement

[d]30,000 IU per gram

TABLE II

PERFORMANCE DATA

Item	Salinomycin, ppm 0	5.5	11	22	33	SE
Weight, kg						
Initial[a]	354	357	361	357	360	3.9
28 days[b]	414	411	419	418	418	5.4
56 days[b]	454	462	472	463	463	5.4
84 days[a]	492[b]	503[ab]	512[a]	503[ab]	502[ab]	6.6
110 days[b]	509[b]	526[ab]	536[a]	524[ab]	526[ab]	6.5
124 days[c]	534[b]	551[ab]	558[a]	548[ab]	548[ab]	6.4
125 days	530	547	551	546	540	6.3
Daily gains, kg						
0-56 days	1.40[b]	1.47[ab]	1.56[a]	1.48[ab]	1.44[ab]	.07
57-110 days	1.42[b]	1.61[a]	1.61[a]	1.56[ab]	1.58[a]	.05
0-110 days	1.41[b]	1.53[ab]	1.59[a]	1.52[ab]	1.51[ab]	.04
0-125 days	1.42	1.53	1.54	1.53	1.45	.03
Fed/Intake, kg/Day, DM						
0-56 days	9.3	9.5	9.6	9.5	8.8	.25
57-110 days	9.1	9.2	9.2	8.9	9.3	.18
0-110 days	9.2	9.3	9.4	9.2	9.1	.20
0-124 days	9.0	9.2	9.2	9.2	9.2	.23
Feed/Gain, dry matter						
0-56 days	6.68[a]	6.49[ab]	6.17[b]	6.39[ab]	6.14[ab]	.22
57-110 days	6.42[a]	5.76[b]	5.71[b]	5.71[b]	5.97[ab]	.17
0-110 days	6.53[a]	6.09[b]	5.91[b]	6.05[b]	6.05[b]	.14
0-125 days	6.34	6.02	5.99	6.03	6.37	.13
Metabolizable energy[d] mcal/kg	3.13[b]	3.26[ab]	3.34[a]	3.28[a]	3.31[a]	1.3

[a]Shrunk Weights.
[b]Full weight X .95
[c]Carcass weight/.62
[d]Calculated from gain and feed, DM intake

TABLE III

FECES COMPOSITION

Item	Salinomycin, ppm					
	0	5.5	11	22	33	SE
Dry matter, %	23.9^{b}	24.9^{b}	30.7^{a}	23.2^{b}	28.4^{a}	1.0
Starch, % of DM	17.0^{c}	24.5^{ab}	27.2^{a}	17.9^{bc}	21.9^{abc}	2.3
pH	5.95	5.95	5.94	5.95	5.92	0.22

^{abc}Means in a row with different superscripts differ significantly ($P < .05$).

TABLE IV

CARCASS CHARACTERISTICS

Item	Salinomycin, ppm					
	0	5.5	11	22	33	SE
Carcass weight, kg	329	339	342	339	335	3.9
Dressing percent	64.2	64.1	63.8	64.3	63.7	.37
Liver conditions						
Abscesses						
Incidence, %	29	43	36	43	41	8.3
Severity	1.9	1.9	1.8	1.6	1.5	0.3
Flukes, %	3.6	-0-	7.1	-0-	5.0	3.3
Rib eye area						
sq. cm.	83.2	86.4	84.5	83.2	83.9	2.13
sq. cm./100 kg car.	25.3	25.5	24.7	24.5	25.0	.03
Fat thickness, mm.	14	15	14	15	15	.84
KHP, %	2.69	2.75	2.84	2.79	2.63	.09
Marbling score[a]	13.7	13.5	13.6	14.5	13.7	.41
Federal grade[b]	12.8	12.8	12.9	13.1	12.9	.11
Cutability	49.8	49.7	49.5	49.3	49.3	.43
Percent choice	61	71	64	68	64	9.1

[a]Slight plus = 12; Small minus = 13.

[b]High good = 12; Low choice = 13.

CHAPTER IV

SALINOMYCIN LEVELS FOR FEEDLOT STEERS AND HEIFERS

M. C. Ferrell, F. N. Owens and D. R. Gill

SUMMARY

Salinomycin, an ionophore, was fed to seventy finishing steers (initial weight of 285 kg) and seventy finishing heifers (initial weight of 225 kg) for 139 and 145 days, respectively. Salinomycin was fed at 0, 5.5, 11, 16.5 and 22 ppm of a ground corn based diet. Averaged across salinomycin levels, gain was increased 2.6 percent and efficiency of feed use by 7.8 percent. Feed intake was increased slightly with the lower levels of salinomycin. At the optimum drug level in the trial, 16.5 ppm of feed, gain and feed efficiency were increased by 8.9 and 10.9 percent, respectively. Carcass measurements were not changed by salinomycin feeding. This drug shows excellent promise for improving efficiency and rate of gain of both feedlot steers and heifers.

INTRODUCTION

Feed additives of a class called ionophores have proven to increase efficiency of feed use by feedlot cattle. Monensin,

lasalocid and salinomycin are three ionophores. Monensin and lasalocid are widely fed today. Salinomycin has been evaluated previously in one study at Oklahoma State (Ferrell, et al.,1983). In that trial, gain and efficiency increases of 10 to 13 percent for beef steers fed a five percent roughage diet were reported. The optimal level in that trial was 11 ppm and 33 ppm appeared to be above the optimal level for steers. Further, all previous trials had been conducted with feedlot steers, so effectiveness with heifers had not been appraised. Consequently, lower levels were tested in this trial with both steers and heifers to again determine the effect of five levels of salinomycin on rate and efficiency of gain of finishing beef cattle.

EXPERIMENTAL PROCEDURE

Seventy steers of mixed breeding which had commonly grazed pasture in Purcell, Oklahoma, were sorted by size and transported to Stillwater, Oklahoma, on November 12, 1981. Seventy heifers were purchased at Oklahoma City Stockyards and transported to Sillwater on November 13, 1981. On arrival, animals were vaccinated for bovine rhinotracheitis, leptospirapomona, bovine virus diarrhea, parainfluenza 3, blackleg and malignant edema, and ear tagged. Cattle were held on pasture until December 4, 1981, and were then blocked into two groups based on sex and two weight groups within sex. Cattle within a block were then randomly allocated to one of five pens and the five levels of salinomycin (0, 5.5, 11, 16.5, and 22 ppm of feed) were randomly assigned to pens with each group.

Cottonseed hulls, alfalfa pellets, and corn comprised 92.3 percent of the diet with the percentage hulls and alfalfa pellets in the diet sequentially decreasing from 40 to 26 to 17 and 12 percent at three day intervals at the start of the trial until the final diet (Table V) was being fed.

Cattle were weighed following withdrawal of feed and water at the start of the trial and on day 140 for steers and 146 for heifers. Other weights were taken full. When body weights were taken without a period of fasting, the net weight was calculated by deducting five percent of the weight to account for fill. Hair coat length was visually appraised and rectal temperature measured on day 112 of the trial.

On day 112 of the trial, after steers had been weighed, the steer with the greatest and the steer with the least rate of gain for the trial in each of ten pens received 20 g of chromic oxide in two gelatin boluses. Fecal samples were obtained after 30, 54, 78, and 102 hours after boluses were administered. Chromium content of feces was determined as described by Hill and Anderson (1977). Chromium removal from the rumen was presumed to parallel removal of solids from the rumen and was used to calculate rate of exit of material. Rate of output, dilution or turnover rate, was calculated from fecal concentrations of chromium at the various times for each steer by regressing the natural logarithm of the chromium concentration of fecal dry matter against time.

At slaughter, three heifers, two from pen 11 (16.5 ppm salinomycin) and one from pen 12 (control), were found to be pregnant and another heifer aborted during the trial. Data include

information for these animals, because of problems associated with attempting to remove these effects. One heifer in pen 20 (salinomycin at 11 ppm) died from acidosis during the trial. Feed intake was adjusted for removal of the heifer by deducting an amount of feed equivalent to that calculated to be consumed according to the net energy equations using calculated the net energy of the diet. Salinomycin was withdrawn from the diet on day 139 for steers and 145 for heifers. The endpoint of the trial was determined by predicting by visual appraisal when the cattle had reached an average of 80 percent choice quality grade. On day 154 for heifers and day 160 for steers, cattle were trucked to Oklahoma City, Oklahoma, and Booker, Texas, respectively, for slaughter and carcass evaluation. Statistical analysis of data was a randomized block design, with removal of block effects. Means were compared by Duncan's multiple range test (Barr and Goodnight, 1980).

RESULTS AND DISCUSSION

Daily gain and feed intake tended to increase with salinomycin added to the diet for steers (Table VI). Daily gains were increased by 10 percent the first 56 days and by 12 percent during the final 56 days of the trial with addition of salinomycin to the diet. Efficiency of feed use followed the same pattern, increasing with salinomycin by 5.8 and 9.5 percent for 0 to 56 day and 57 to 140 day periods, respectively. Daily gains were increased more during the 0 to 140 day period, during which the drug was fed, than during the total trial including the 20 day withdrawal period (10.4 vs. 4.7 percent). Feed to gain ratios for the entire feeding period were increased by salinomycin by 8.2

percent and 3.7 percent for 0 to 140 days and 0 to 160 days, respectively. These comparisons suggest that rate and efficiency of gain were improved slightly more during the second than the first portion of the feeding trial. Performance data of the heifers indicates the same types of trends (Table VII) though period effects differed. Daily gain and feed intake tended to increase with salinomycin addition to the diet. Daily gains were increased by 5.4 percent over the first 56 days, and 3 percent for the final 56 days of the trial. Daily gains were improved by 3.9 percent from days 0 to 146 with added salinomycin, but no improvement was seen for days 0 to 154. Efficiency of feed use was increased by salinomycin feeding a mean of 7.1 and 1.5 percent for the initial and final portion of the trial, respectively. Results for the entire feeding period show a 5.4 percent improvement in efficiency of feed use with salinomycin over days 0 to 146 and a one percent improvement for days 0 to 154. Efficiency of feed and energy use was maximized with 16.5 ppm salinomycin with both steers and heifers. With this diet, gain and feed efficiency were improved with salinomycin an average of 8.4 and 10.8 percent. This compares with 12.9 and 9.5 percent maximum improvements in the previous trial (Ferrell, et al., 1983) with steers fed salinomycin at 11 ppm. The 20 ppm salinomycin level gave slightly less response.

Carcass characteristics were obtained 21 and nine days after withdrawal of the drug from the diet for steers and heifers, respectively (Tables VIII and IX). The incidence of liver abscesses tended to increase with this drug with both steers and

heifers as in a previous trial (Ferrell, et al., 1983). Rib eye area declined slightly for steers fed 11 and 16.5 ppm levels of salinomycin for steers only. No such effect was apparent with heifers in this trial or steers in the previous trial. The percentage kidney, heart and pelvic fat of steers generally increased with added drug as occurred in an earlier trial though some spurious values are noted for certain drug levels with both steers and heifers. Cutability also tended to decline with added salinomycin, possibly due to heavier carcass weights. Marbling scores and percent choice carcasses tended to be higher with heavier carcasses in this and the earlier trial. Hair coat length, which may relate to performance, seemed slightly less and rectal temperature slightly lower with drug feeding.

Results indicate that efficiency of feed use of feedlot steers and heifers can be improved with added salinomycin. Optimal drug level from this trial for feed efficiency of both steers and heifers was 16.5 ppm ton though lower levels (5.5 and 11 ppm) produced more rapid gain. Responses to salinomycin feeding generally paralleled results of the earlier trial and at the optimal level of the diet considerably exceeded gain and efficiency responses observed from other ionophores (Ferrell, et al.,1983). Rate and efficiency of gain except for heifers in the second trial appeared increased slightly more during the first than the second half of the feeding trials.

Chemical composition of feces was not significantly changed with added salinomycin through fecal ash appeared to increase slightly (Table X). Dilution rate or outflow of ruminal solids

tended to be slower with supplemental salinomycin. This would parallel the effect of monensin on ruminal passage. Longer retention of solids in the rumen may help increase digestibility but, may also decrease rumen bypass.

The steers gaining weight most rapidly had feces higher in dry matter and starch content than steers gaining less rapidly (Table XI). Dry matter and starch content have been shown to change together (Table XII), the correlation calculated was 5.3. Higher gains probably reflect higher levels of feed intake. Limiting feed intake usually decreases the concentration of starch in fecal matter (Teeter et al., 1981). Surprisingly, rate of passage of chromium, and presumably solids, from the rumen averaged the same for rapidly and slowly gaining steers. If faster gaining steers are eating more feed but rate of passage from the rumen is not changed, this means that faster gaining steers must have larger rumens than slower growing steers. Selection for feed intake may increase ruminal volume and reduce digestibility but result in faster gains.

A summary of ionophore trials at Oklahoma State University (Table XIII) using steers indicate an increase in daily gain using lasalocid and salinomycin (0.6 and 9.7 percent increase, respectively) but, no increase in gain with monensin supplementation to diets. All ionophores gave a favorable response in feed efficiency. The summary indicates that for feed savings, feeding an ionophore to feedlot cattle is consistently beneficial.

TABLE V

DIET COMPOSITION, DRY MATTER BASIS[a]

Ingredient	IFN[b]	Ration sequence, %			
		1	2	3	4
Alfalfa, dehy-pellets	1-00-023	39.63	16.35	7.36	7.31
Cottonseed hulls	1-01-559	10.00	10.00	10.00	5.00
Corn, rolled	4-02-931	54.51	64.69	75.22	80.81
Soybean meal	5-04-600	4.92	7.58	5.33	4.71
Salt		0.35	0.35	0.35	0.35
Dicalcium phosphate	6-01-080	0.46	0.38	0.43	0.40
Potassium chloride	6-03-756	----	----	0.06	0.15
Urea		----	----	0.30	0.30
Calcium carbonate	6-01-069	0.12	0.64	0.94	0.96
Premix		0.01	0.01	0.01	0.01

[a]Average analysis ration 4: 90.2% dry matter, 12.20% protein, ME = 3.10 on a dry matter basis. Premix contained trace mineral, vitamin A (to supply 30,000 IU per day) and Salinomycin (0, 5.5, 11, 16.5, 22 ppm).

[b]International Feed Number.

TABLE VI

PERFORMANCE DATA, STEERS

Item	Salinomycin, ppm 0	5.5	11	16.5	22	SE
Weight, kg						
Initial, shrunk	284	286	286	285	284	2.1
31 days, full	346	356	346	352	350	5.0
56 days, full	381	390	384	393	390	8.0
84 days, full	418	438	428	430	422	9.0
112 days, full	461	468	469	467	457	8.0
140 days, shrunk	465	491	488	488	473	8.3
160 days, carcass/.62	501	528	517	508	498	8.0
Daily gains, kg						
0-56 days	1.38	1.51	1.42	1.58	1.56	.10
57-140 days	1.22	1.43	1.47	1.36	1.21	.06
0-140 days	1.29	1.46	1.45	1.45	1.34	.05
0-160 days	1.36	1.51	1.45	1.40	1.34	.04
Feed intake, kg/day, DM						
0-56 days	8.78	9.47	8.90	8.70	8.94	.32
57-140 days	9.06	9.43	9.10	8.98	8.74	.22
0-140 days	8.95	9.43	9.02	8.86	8.82	.20
0-160 days	8.90	9.39	9.02	8.86	8.70	.21
Feed/gain, Dry Matter						
0-56 days	6.34	6.35	6.27	5.53	5.75	.26
57-140 days	7.38[a]	6.61[ab]	6.19[b]	6.62[ab]	7.29[a]	.23
0-140 days	6.93[a]	6.50[ab]	6.22[b]	6.15[b]	6.56[ab]	.13
0-160 days	6.56[a]	6.23[c]	6.22[c]	6.31[bc]	6.50[ab]	.05
Metabolizable energy[d]						
mcal/kg	2.87	2.98	3.04	3.08	2.96	.02

[abc] Means with different superscripts differ ($P < .05$).

[d] Calculated from gain and feed dry matter intake

TABLE VII

PERFORMANCE DATA, HEIFERS

Item	Salinomycin, ppm 0	5.5	11	16.5	22	SE
Weight, kg						
Initial, shrunk	225	222	224	226	227	1.59
31 days, full	269	262	263	271	272	3.40
56 days, full	293	292	292	300	303	5.13
84 days, full	326	321	328	329	341	6.44
112 days, full	358	347	355	362	359	4.49
140 days, full	371	369	372	369	377	7.39
146 days, shrunk	374	371	381	382	381	5.35
154 days, carcass/.62	384	372	387	383	390	4.85
Daily gains, kg						
0-56 days	.97	.99	.95	1.06	1.09	.09
57-146 days	1.10	1.09	1.12	1.00	1.06	.03
0-146 days	1.02	1.03	1.08	1.07	1.06	.04
0-154 days	1.03	.98	1.06	1.02	1.06	.04
Feed intake, kg/day, DM						
0-56 days	6.41	6.04	6.57	6.41	6.78	.27
57-146 days	6.94	7.02	7.14	6.29	6.65	.33
0-146 days	6.70	6.58	6.86	6.29	6.66	.18
0-154 days	6.70	6.53	6.82	6.33	6.70	.20
Feed/gain, Dry Matter						
0-56 days	6.81	6.05	6.88	6.08	6.30	.64
57-146 days	6.33	6.39	6.37	6.33	5.84	.19
0-146 days	6.59[a]	6.39[ab]	6.35[ab]	5.90[b]	6.28[ab]	.15
0-154 days	6.46	6.66	6.43	6.21	6.29	.16
Metabolizable energy[c] mcal/kg	3.10[b]	3.13[b]	3.13[b]	3.33[a]	3.20[ab]	.04

[ab]Means in a row with different superscripts differ ($P < .05$)

[c]Calculated from gain and feed dry matter intake.

TABLE VIII

CARCASS MEASUREMENTS, STEERS

Item	Salinomycin, ppm					
	0	5.5	11	16.5	22	SE
Carcass Weight, kg	311	327	321	315	309	4.8
Dressing percent	63.6[a]	63.0[ab]	62.0[ab]	61.3[b]	62.1[ab]	.92
Liver abscess incidence, %	21.4	28.6	28.6	29.8	28.6	12.4
Ribeye area,						
sq. cm.	82.6[a]	81.3[ab]	78.1[b]	76.8[b]	80.6[ab]	1.08
sq. cm./100 kg car.	26.6[a]	24.9[ab]	24.3[b]	24.4[ab]	26.1[ab]	.57
Fat thickness, mm.	11	16	12	12	10	15
KHP, %	2.46[b]	2.89[a]	2.79[a]	2.15[c]	2.71[a]	.05
Marbling score[d]	11.7	12.8	12.1	12.2	12.1	.79
Federal grade[e]	12.5	12.8	12.4	12.6	12.4	.22
Cutability, %	50.8	48.9	49.6	50.1	50.7	.56
Percent choice	42.9	71.4	42.9	42.9	28.6	19.1
Hair coat[f]	3.2[a]	2.2[b]	2.3[b]	2.9[ab]	2.9[ab]	.20
Temperature, ^{o}C[g]	39.4	39.2	39.0	39.3	39.2	.17

[abc]Means in a row with different superscripts differ ($P < .05$).

[d]Slight plus = 12; Small minus = 13.

[e]High good = 12; Low choice = 13.

[f]Short = 0; long = 5 on day 112.

[g]Rectal temperature on day 112, ^{o}C.

TABLE IX

CARCASS MEASUREMENTS, HEIFERS

Item	Salinomycin, ppm					
	0	5.5	11	16.5	22	SE
Carcass Weight, kg	238	231	240	238	242	3.0
Dressing percent	62.6[a]	60.9[b]	61.6[ab]	61.7[ab]	62.0[ab]	.31
Liver abscess incidence, %	7.1	---	15.5	28.6	21.4	23.2
Ribeye area,						
sq. cm.	70.3	67.7	71.0	69.0	68.4	.90
sq. cm./100 kg car.	29.5	29.3	29.6	29.0	28.3	.57
Fat thickness, mm.	13	12	13	13	13	1.27
KHP, %	2.89[ab]	2.36[c]	2.64[bc]	2.68[abc]	3.04[a]	.09
Marbling score[d]	13.1	11.9	12.0	12.2	12.2	.33
Federal grade[e]	12.6	12.4	12.5	12.6	12.6	.04
Cutability, %	50.2	50.7	50.4	50.3	49.9	.38
Percent choice	42.9	35.7	46.4	57.1	57.1	8.1
Hair coat[f]	5.6	5.1	5.0	5.2	5.1	.59
Temperature, °C[g]	39.1	39.1	39.2	39.1	38.9	.20

[abc]Means in a row with different superscripts differ ($P < .05$)

[d]Slight plus = 12; Small minus = 13.

[e]High good = 12; Low choice = 13.

[f]Short = 0; long = 5 on day 112

[g]Rectal temperature on day 112, °C

TABLE X

COMPOSITION OF FECES FOR STEERS FED SALINOMYCIN

Item	Salinomycin, ppm					SE
	0	5.5	11	16.5	22	
Feces dry matter, %	27.6	24.2	27.2	24.8	26.7	.47
Fecal starch, % of DM	13.2	12.3	9.9	16.6	12.5	1.35
Fecal ash, % of DM	7.1	9.3	9.4	7.9	11.1	.59
Chromium dilution rate, % per hour	4.4	3.8	4.3	3.2	3.9	.35

TABLE XI

FECES COMPOSITION OF SLOWLY AND RAPIDLY GAINING STEERS

Growth rate	Feces Composition			Cr Dilution Rate % per hour
	Dry Matter %	Starch % of DM	Ash % of DM	
Rapid	27.2[a]	16.6[a]	8.4	3.9
Slow	25.0[b]	9.2[b]	9.5	3.8

[ab]Means in a column with different superscripts differ ($P < .01$).

TABLE XII

CORRELATIONS

Fecal Comp.	Fecal Composition		Chromium Dilution rate
	Starch	Ash	
Dry matter	.53[a]	-.46[a]	.09
Starch	1.00	-.70[b]	-.23
Ash	1.00	1.00	.06

[a]Significant at $P < .05$.

[b]Significant at $P < .001$.

TABLE XIII

IONOPHORE COMPARISONS FROM FEEDLOT TRIALS AT OKLAHOMA STATE - STEERS

Ionophore	Cattle Fed	Trials	Daily Gain kg Con.	Daily Gain kg Drug	% Response	Feed Effy. kg Con.	Feed Effy. kg Drug	% Response
Monensin	800	7	1.51	1.51	0.0	5.82	5.53	5.0
Lasalocid	84	1	1.53	1.54	0.6	5.75	5.31	7.7
Salinomycin	210	2	1.35	1.48	9.7	6.74	6.19	8.2

CHAPTER V

IONOPHORES AND DIGESTIBILITY OF FEEDLOT DIETS

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SUMMARY

Monensin, lasalocid or salinomycin at 33 ppm were added to a 95 percent concentrate whole shelled corn diet and these three diets plus a diet without addition of an ionophore were fed to 12 steers (290 kg) in a digestion trial. Adding ionophores increased digestibilities of dry matter, organic matter and nitrogen ($P < .05$). Starch digestibility tended to increase with ionophores, but nitrogen retention was unaffected. Though effects were largely similar, results suggest that these compounds may have slight biological differences. Increased ($P < .05$) organic matter digestion with added ionophores should increase biological efficiency by about 3.2 percent. Relative ruminal proportions of propionate increased ($P < .05$) while butyrate decreased with ionophore feeding ($P < .05$). The acetate proportion was not changed though the ratio of propionate to acetate and the ratio of

non-glucogenic to glucogenic VFA were increased with ionophore addition to the diet. Due to this change, the efficiency of energy retention in VFA was significantly enhanced ($P < .05$) and methane loss per mole of glucose fermented was reduced with ionophore addition.

INTRODUCTION

Ionophores are a class of feed additives which increase the efficiency of the feed use by feedlot cattle. Monensin is the most widely known ionophore. Salinomycin and lasalocid have been shown to have similar effects of efficiency but often depress intake less than monensin.

Energy, protein and starch digestibility have been increased slightly with the addition of monensin to a whole shelled corn diets in two previous trials (Thornton, et al., 1978; Rust et al., 1979). Effects of these drugs on fecal measurements are outlined from other feeding studies in this report, but due to animal and feed intake differences, measurements from steers in feedlot pens may be unreliable. This experiment was conducted to compare the effects of three different ionophores - monensin, lasalocid and salinomycin - on digestibility of a high concentrate diet and on ruminal fermentation characteristics with feedlot steers.

EXPERIMENTAL PROCEDURE

A diet containing whole shelled corn and cottonseed hulls (Table XIV) was limit fed to twelve crossbred steers in three simultaneous four by four latin squares. Animals were randomly allotted to squares. Initial weights were recorded to adjust intake. The average initial weight of the steers was 290 kg and

the feed intake was limited to 2 percent of body weight or a maximum of five kg dry matter per head daily. Steers were rotated among diets so that each steer received each drug for 14 days. Pelleted supplements containing lasalocid, salinomycin and monensin were added to the diet at feeding time to achieve dietary levels of 33 ppm of dry matter. Periods were 14 days in length, with total urine and fecal collection during the final five days. Urine was collected as often as necessary, and fecal collection was done every other day. Animals were housed in metabolism stalls throughout the trial. Hydrochloric acid (250 ml of 6 N acid/day) was added to urine collection containers to reduce pH in the collection vessel below three to reduce ammonia loss. Urine pH was measured with pH paper at time of collection and further reduced with 6 N HCl if necessary. One percent of the urine was retained and frozen for later analysis. Wet feces were weighed an a ten percent aliquot was retained. Aliquots for each steer within a period were composited, mixed, subsampled, and dried for laboratory analysis. Rumen samples were collected via stomach tube on day 15 of each period, approximately three hours after the first feeding. The pH of the rumen sample was measured with a combination electrode. Metaphosphoric acid (.25 percent) was added at a ratio of one ml per 50 ml rumen fluid and the sample was stored frozen for gas-liquid chromatography analysis as described by Sharp et al. (1982). Digestibilities of dry matter, starch, protein and organic matter were calculated. Starch was determined as total alpha-linked glucose polymers by the enzymatic procedure of Macrae and Armstrong (1968). Total nitrogen was determined on urine,

dried feces, and dried feed samples by the macro-Kjeldahl procedure (AOAC, 1975). Fecal pH was determined by combination electrode when aliquots were composited after thawing.

Statistical analysis followed the General Linear Models procedure of the SAS system of Barr and Goodnight (1981) with removal of animal effects and subdivision of treatment effects into orthogonal contrasts. These contrasts were: no ionophore vs. mean of all ionophores; monensin vs. mean of lasalocid plus salinomycin; and lasalocid vs. salinomycin treatment.

RESULTS AND DISCUSSION

Addition of ionophores to this diet had no significant effect on ruminal pH but increased ($P < .05$) fecal pH (Table XV). Nitrogen percentage in fecal dry matter was higher with monensin than lasalocid or salinomycin supplementation. Fecal ash was also higher when steers were fed the monensin supplement that when steers were fed the other two drugs. Fecal dry matter was greater with lasalocid than with salinomycin. Fecal starch tended to be slightly higher with control and lasalocid supplements. The amount of whole kernels of corn observed in the feces was slightly lower with supplemental salinomycin than with other drugs. Total fluid output was increased by 16 percent with added drugs suggesting that these compounds may increase water intake.

Digestibility of both organic matter and dry matter were increased by the addition of ionophores (Table XVI) with greater effects from added monensin than either lasalocid or salinomycin. On the average, organic matter digestion increased by 3.2 percent with addition of an ionophore. Starch also tended to increase with

drug additions, but the difference was not significant. Ash digestion tended to be greater with monensin and lasalocid supplementation.

Ionophores decreased fecal nitrogen output but had little effect on loss of nitrogen in the urine (Table XVII). The apparent digestibility of nitrogen was enhanced by added drugs, but nitrogen retention was not significantly altered. Although these three compounds are chemically similar, some of their effects differ slightly. Since all three increased digestibility of most nutrients, they should all increase biological efficiency of feedlot steers.

Addition of ionophores to the diet (Table XVIII) had no significant effect on the total molar concentration of VFA in the rumen. Some differences in molar proportions were detected, however. Molar proportion of acetate was not significantly altered ($P > .05$) but tended to decrease with ionophore feeding. Propionate proportion was increased a mean of 3.5% with ionophore addition to the diet. This caused a significant decrease ($P < .05$) in the acetate to propionate ratio and an increase in the non-glucogenic VFA ratio. Butyrate proportion was decreased by ionophore addition. Proportion of isovalerate was greater with lasalocid (3.7 um/ml) than for salinomycin (2.4 um/ml) but the proportions of isobutyrate, valerate, and caproate were not changed with ionophore addition.

The energetic efficiency of ruminal fermentation was calculated from the fermentation balance equations of Wolin (1960) and Ørskov (1968). The equations are valid only if ruminal

concentrations reflect ruminal production rates of VFA, which may not be necessarily true (Sharp et al., 1983), and the total hexose fermented in the rumen is equal for all test diets. This assumption also can be questioned from the work of Muntifering et al. (1980a) and Zinn et al. (1980). Calculated yield of ATP produced per glucose fermented and energetic efficiency of VFA formation were increased with ionophore addition. Methane loss per mole of glucose fermented was significantly decreased with ionophores, suggesting that methane production should decrease with ionophore supplementation of the diet. The change in VFA ratios and decreased methane loss with monensin addition in this study is equal to approximately 1.9 percent of the energy fermented in the rumen. If 65 percent of the organic matter digested in the total tract is fermented to VFA in the rumen, added ionophores in this study could increase efficiency of use of digested energy by about 1.2 percent. Added to the increased digestibility of 3.2 percent, an energetic advantage of 4.4 percent with ionophores could be explained.

TABLE XIV

DIET COMPOSITION,
DRY MATTER BASIS

Ingredient	IFN[a]	%
Whole shelled corn	4-02-931	88.58
Cottonseed hulls	1-01-559	5.16
Pelleted supplement		
Soybean meal	5-04-600	3.39
Alfalfa meal	1-00-023	.279
Dicalcium phosphate	6-01-080	.234
Calcium carbonate	6-01-069	1.069
Potassium chloride	6-03-756	.418
Salt		.318
Urea		.512
Trace mineral mix		.017
Vitamin A-30[b]		.01
Drug[c]		+

[a]International Feed Number

[b]30,000 IU per gram

[c]Premix added in amounts to yield dietary levels of 33 ppm of monensin, salinomycin or lasalocid.

TABLE XV

RUMINAL, FECAL AND URINARY MEASUREMENTS

Item	Drug			
	None	Monensin	Salinomycin	Lasalocid
Ruminal pH	6.23	6.16	6.29	6.23
Fecal pH[a]	5.67	6.15	5.91	6.03
Fecal dry matter, %[c]	29.30	29.90	28.30	31.10
Fecal starch, % DM	15.7	13.50	13.60	15.20
Fecal N, % DM[b]	2.90	3.11	2.99	2.89
Fecal ash, % wet matter[b]	2.25	2.47	2.20	2.36
Whole kernels in feces[d]	1.25	1.33	1.00	1.58
Urine, liter/day	5.92	7.06	8.88	6.99
Total fluid output, liter/day[e]	8.22	8.82	10.95	8.90

[a]Drugs altered measurement ($P < .05$).

[b]Response to monensin differ from other drugs ($P < .05$).

[c]Response to lasalocid differs from response to salinomycin ($P < .05$).

[d]Kernels not detected = 0; few particles = 1; large amounts = 3.

[e]Fecal plus urinary water output.

TABLE XVI

DIGESTIBILITY

Item	Added Drug			
	None	Monensin	Salinomycin	Lasalocid
Dry matter[ab], %	81.4	84.8	82.5	83.0
Organic matter[ab], %	81.0	85.0	82.6	83.1
Starch, %	95.4	96.7	96.3	96.0
Ash, %	62.0	66.3	61.6	65.4

[a]Drugs altered measurement ($P < .05$).

[b]Response to monensin differs from other drugs.

TABLE XVII

NITROGEN METABOLISM

Item	Drug			
	None	Monensin	Salinomycin	Lasalocid
Nitrogen intake, g	87.42	85.09	82.74	89.63
Fecal nitrogen output[a], g	27.40	23.14	24.59	25.24
Urinary nitrogen output, g	24.53	26.35	22.00	23.45
Digestibility, %[a]	68.6	72.6	70.00	71.70
Retention, g/day	35.5	35.6	36.1	40.9

[a]Drugs altered measurement ($P < .05$).

TABLE XVIII

VOLATILE FATTY ACID PRODUCTION

Volatile Fatty Acid	Control	Ionophores			SE
		Monensin	Lasalocid	Salinomycin	
Total, molar %	130	116	113	109	.89
Acetate, molar %	61.2	58.1	60.4	59.7	1.08
Propionate, molar %[a]	26.5	30.7	28.4	30.8	1.10
Isobutyrate, molar %[a]	.3	0	0	0	.158
Butyrate, molar %[a]	8.6	7.4	6.9	5.5	.74
Isovalerate, molar %[c]	2.1	2.6	3.7	2.4	.46
Valerate, molar %	1.2	1.2	.6	1.6	.43
Caproate, molar %	.1	0	0	0	-
C_2/C_3[a]	2.30	1.89	2.13	1.93	1.08
Nonglucogenic[ad] ration	3.07	2.62	2.65	2.35	.07
Efficiency indices[e]					
ATP/glucose[af]	4.88	4.93	4.94	4.99	.022
VFA/glucose[ag]	.767	.784	.774	.782	
CH_4/glucose[ah]	.171	.154	.164	.156	.004

[a]Control differs from ionophores ($P < .05$).

[b]Monensin differs from mean of other ionophores ($P < .05$).

[c]Lasalocid differs from salinomycin ($P < .05$).

[d]$(C_2 + .5C_4)/C_3$

[e]Calculations based on fermentation balance equations of Wolin (1960) and Ørskov (1968).

[f]Assuming 2 ATP generated per acetate, 3 ATP per propionate and butyrate, and 1 ATP per methane molecule

[g]Calories in VFA/calories in glucose fermented.

[h]Calories in methane/calories in glucose fermented.

CHAPTER VI

IONOPHORES FOR GROWING BROILER CHICKS

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SUMMARY

To determine the influence of ionophores on maintenance energy requirements, broiler chicks were fed monensin, lasalocid and salinomycin in two experiments. In trial one, chicks (three weeks of age) were fed diets containing .3 or 2 percent NaCl with monensin, lasalocid and salinomycin added at 0 or 33 ppm of feed for eight days. In trial two, chicks (eight days of age) were fed ionophores at 0 or 33 ppm or monensin at levels of 16.5, 66 and 132 ppm. No differences were observed in either trial for weight gain or efficiency of feed use with ionophore addition to the feed. Results do not support the theory that ionophores reduce the energy requirements of tissues.

INTRODUCTION

Ionophores are commonly used as coccidiostats in diets for poultry. Monensin and lasalocid are approved at levels of 99-121 ppm and 75-124 ppm of the diet, respectively, to prevent coccidiosis in poultry (Anonymous, 1979). For cattle, monensin,

lasalocid and salinomycin are fed at 5.5 to 33 ppm to increase energetic efficiency through reduced loss of methane and increased energy digestibility as reviewed by Owens (1980). Monensin has been suggested to also have an effect at the tissue level, as it increased the energetic efficiency of maintenance by 5.7 percent without increasing the efficiency of energy use for growth according to Byers (1980). He suggested that monensin may reduce the energy requirements for maintenance. It can be reasoned that monensin could alter the sodium flux in tissues, and pumping sodium is one of the major energy costs of muscular tissue. Salt was added to the test diet in experiment one to see if sodium flux is altered. However, feeding monensin at levels of 121 ppm or 165 ppm have tended to reduce efficiency of energy of energy use in growing chicks (Parsons and Baker, 1982). These experiments were designed to test the effect of three ionophores - monensin, lasalocid and salinomycin - at the lower levels fed to ruminants on rate and efficiency of growth of chicks at an age before coccidiosis should be encountered.

EXPERIMENTAL PROCEDURE

In experiment one, one hundred-ninety-two commercial broiler chicks were subdivided into 24 pens of eight chicks each at three weeks of age. Chicks were fed a diet (Table XIX) without ionophores or with 33 ppm as monensin, lasalocid or salinomycin plus NaCl at either .3 or two percent of the diet. Chicks were weighed following 12 hours without feed and water initially (21 days of age) and after eight days on test diets.

In experiment two, one hundred-ninety-two chicks of the same breeding but eight days of age were subdivided into 24 pens of eight chicks each. Chicks were fed the same diet used in experiment one (Table XIX) with salt at the .3 percent level. Chicks were fed a diet without ionophores or with 33 ppm monensin, lasalocid, or salinomycin. In addition, monensin was fed at levels of 16.5, 66 and 132 ppm of diet. Chicks were weighed following a five hour shrink initially (eight days of age) and after seven days on test diets. Feed and water were available ad libitum during both trials and feed intake was monitored.

RESULTS AND DISCUSSION

Daily gain and gain to feed ratios were not significantly altered by ionophore addition in the first experiment (Table XX) though daily dry matter intake was slightly increased with ionophore addition. Added NaCl had no significant effect on feed intake, rate of gain, or gain to feed ratio (Table XXI) and did not interact with ionophores. In experiment two, daily gain, daily intake and gain to feed ratio were not changed by added ionophores or by various levels of monensin (Tables XXII and XXIII).

Results indicate that these ionophores at the levels fed did not decrease energy requirements for growth and maintenance of growing chicks suggesting that ionophores may not reduce the energy requirement for maintenance. Since sodium and potassium metabolism of chicks differs from that of mammals (Robbins, 1982), extrapolation of results to mammals may be misleading. Nevertheless, results do not support the theory that ionophores decrease the energy requirement for maintenance.

TABLE XIX

DIET COMPOSITION[a]

Ingredient	IFN[b]	Percent
Corn	4-02-931	47.69
Soybean meal (44%)	5-04-600	34.20
Corn oil		5.00
Meat and bone meal	6-00-397	4.75
Alfalfa meal (17%)	1-00-023	2.85
Live yeast culture (14%)	7-05-527	2.85
dl methionine		.095
Calcium carbonate	6-01-069	.855
Phosphorus supplement (Ca 20, P 18)		.950
Trace mineral		.095
Salt		.285
Vitamin mix (turkey breeder)		.380

[a]Ionophores or salt (1.7%) added to form test diets.

[b]International Feed Number.

TABLE XX

IONOPHORE EFFECT ON GAIN,
TRIAL 1

Item	Drug			
	0	Monensin	Lasalocid	Salinomycin
Intial weight, g	288	296	301	301
Daily gain, g	24.0	24.8	24.1	24.5
Daily DM intake, g	55.0	57.9	58.0	57.5
Gain/feed	.42	.43	.41	.43

TABLE XXI

INCREASED SALT EFFECT ON GAIN,
TRIAL 1

Item	NaCl level	
	.3	1.7
Initial weight, g	297	295
Daily gain, g	24.6	24.1
Daily DM intake, g	57.2	57.0
Gain/feed	.43	.42

TABLE XXII

IONOPHORE EFFECT UPON GAIN
TRIAL 2

Item	Drug			
	0	Monensin	Lasalocid	Salinomycin
Initial weight, g	120	123	121	120
Daily gain, g	25.1	24.2	24.8	24.5
Daily DM intake, g	35.3	35.8	36.0	35.3
Gain/feed	.70	.67	.68	.68

TABLE XXIII

INCREASED MONENSIN EFFECT ON GAIN
TRIAL 2

Item	Monensin level, ppm				
	0	16.6	33	66	132
Initial weight, g	120	123	123	123	123
Daily gain, g	25.1	24.8	24.2	25.2	24.2
Daily DM intake, g	35.3	35.5	35.8	35.5	34.3
Gain/feed	.70	.69	.67	.70	.69

CHAPTER VII

SUMMARY AND CONCLUSIONS

In the two feeding trials, salinomycin supplementation increased the rate of gain of feedlot cattle (9.4 percent in one trial and 2.6 percent in the other). These values are the average improvement for all salinomycin levels. Such an increase in weight gain has not been observed with the addition of monensin, or lasalocid, suggesting that ionophores may have different mechanisms of action within the animal. Feed efficiency was improved 7.8 percent with salinomycin feeding in both feeding trials. This effect is similar to results with monensin or lasalocid supplementation. Although heifers also responded to salinomycin feeding with an increased rate and efficiency of gain, performance and responses tended to be much lower than that with the steers. Feed intake of the heifers was decreased slightly with ionophore addition.

The optimal drug levels were 11 ppm and 16.5 ppm in the two trials though levels slightly above or below these levels were effective. With the addition of salinomycin at 11 ppm in trial one, gain and feed efficiency were improved 12.9 and 9.5 percent,

respectively. In trial two, 16.5 ppm improved gain 8.4 percent and feed efficiency 10.8 percent. These levels are considerably below the levels suggested to be optimal for lasalocid or monensin. Feeding trials directly comparing these three ionophores at various levels are needed.

The efficiency of metabolizable energy in the diet was increased by 4.6 percent with salinomycin addition, suggesting that salinomycin may increase the digestibility of certain feed components. The feces of steers fed 11 ppm salinomycin in experiment one tended to be drier and contain more starch than steers fed the control diet. Data from trial two tends to support this theory, showing a positive correlation ($r = .53$) between fecal starch and fecal dry matter. Fecal starch and ash in feces were negatively correlated ($r = -.7$) suggesting that starch was diluting ash in fecal material.

Changes in carcass characteristics with salinomycin feeding were minor. In both trials, the incidence of liver abscesses tended to increase with added salinomycin and rib eye area declined slightly with higher salinomycin levels in one of the trials.

Digestibilities of dry matter and organic matter were increased with feeding of any of the three ionophores. The increase in organic matter digestion with ionophores could explain in increase in biological efficiency of about 3.2 percent. The digestibility of nitrogen was increased with ionophore addition, but nitrogen retention was not changed. Since all three ionophores increased digestibility of nutrients, they all should increase the biological efficiency of feedlot steers.

The ruminal proportion of propionate was increased with addition of any of the three ionophores to the diet while butyrate proportion decreased. The acetate proportion tended to decrease, so the acetate to propionate ratio and the non-glucogenic to glucogenic VFA ratio decreased with ionophore feeding. Calculated yield of ATP/glucose tended to increase slightly with added ionophores. This would not explain the decreased energetic efficiency of microbial protein synthesis in the rumen suggested by several workers to occur with monensin supplementation. Loss of energy in the form of methane was reduced and energy retention in VFA tended to increase with added ionophores. VFA changes suggest that salinomycin and lasalocid should decrease methanogenesis much like monensin. To more closely monitor these parameters, trials with respiration-calorimetry chambers and rumen fistulated steers would be useful.

The effect of ionophore addition on energy requirements at the tissue level was examined in two chick trials. Energetic efficiency was not increased with ionophores at the levels tested. Results do not support the theory that energy requirements at the tissue level are reduced when ionophores are fed. But, since the energy and ionophore metabolism of chicks may differ from those of ruminants, results may not be directly applied. More research on tissue effects of ionophores using other non-ruminants or tissue cultures may help to clarify additional modes of action in the ruminant animal.

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