THE EFFECTS OF BIO-MOS ON LAMB GROWTH AND IMMUNE FUNCTION

A Thesis

by

JEFFREY THOMAS THAYNE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Animal Science

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Co-Chairs of Committee,	W. Shawn Ramsey
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ABSTRACT

The Effects of Bio-Mos on Lamb Growth and Immune Function. (August 2007)

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Dr. J. Sawyer

The objective of this study was to evaluate the effects of inclusion of Bio-Mos in the growing ration for weaned lambs on growth rate, feed efficiency, and clinical measures of health of the lambs. Mannan oligosaccharides (MOS), when included as a supplement to the diet, have been shown to have a positive effect on immune response in several species and in turn, positively affect the growth of the animal. MOS are commercially available as BioMos®, which is a nutritional supplement manufactured by Alltech, Inc. out of Nicholasville, KY. Forty-seven weaned Suffolk × Hampshire (n=47) lambs were used in this trial. Of the group, twenty (n=20) were ewe lambs and twenty-seven (n=27) were wether lambs. The lambs were placed on their assigned diets and remained on the trial for a four week period (d+28). All responses evaluated in this study were influenced by time ($p < 0.05$) over the 28-d trial. A GENDER × WEEK interaction was observed for ADG and feed conversion ($p < 0.05$). Control lambs tended ($p = 0.10$) to have a higher intake over the 28-d period in comparison to Bio-Mos fed lambs. There were no statistically significant differences ($p < 0.05$) between control and Bio-Mos fed lambs for any of the growth parameters that were measured. There was a tendency ($p = 0.10$) for GENDER × WEEK to influence intake. Gender also tended to interacted with diet (GENDER × DIET, $p = 0.09$) to influence intake over the trial period.

A GENDER × WEEK interaction was observed ($p < 0.05$) for feed conversion. Diet influenced fecal pH ($p < 0.05$). This study indicates Bio-Mos had minimal influence on growth and health.

To my loving parents, grandparents, and my beautiful wife; none of this would be possible without their guidance and support.

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Thanks also to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a truly great experience. I especially want to thank Mr. Jake Franke, Mr. Matt Kennedy, and the Sheep and Goat Center crew for their assistance and support during this study. I appreciate the opportunities I was given to teach and interact with so many students during my time at Texas A&M University.

Finally, thanks to my wife, Aron, for her patience and love during the first year of our marriage, and I look forward to a prosperous and wonderful life together. Also, thanks to my parents and grandparents for instilling in me a strong work ethic and desire to be the best I can. I thank them for the many sacrifices made in their lives to help make my life more enjoyable. As I continue my journey, may the Lord always be with me.

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INTRODUCTION

Mannan oligosaccharides (MOS), when included as a supplement to the diet, have been shown to have a positive effect on immune response in several species and in turn, positively affect the growth of the animal. Mannan oligosaccharides are indigestible complex polysaccharide molecules derived from the cell wall of the yeast *Saccharomyces cerevisiae*, with approximately 45% of the cell wall consisting of mannose residues (Tizard et al., 1989). Mannan oligosaccharides are commercially available as BioMos®, a nutritional supplement manufactured by Alltech, Inc. (Nicholasville, KY). Mannan oligosaccharides have been reported to provide binding sites for enteric pathogenic bacteria, presumably reducing pathogen binding. Certain bacteria have a binding preference for certain carbohydrates and when these carbohydrates are included in the diet, specific intestinal bacteria will affix to the carbohydrate and cross the wall of the gut in the digestive process. The addition of MOS to the diet provides an alternate mannose binding site for bacteria, because MOS is not digestible, bacteria exit the digestive tract attached to the MOS. MOS have been shown to elicit a positive response on the immune system as well as serving as alternate attachment sites in the gut for gram-negative pathogenic organisms with mannose-specific type-1 fimbriae that adhere to intestinal epithelial cells to initiate disease (Ferket et al., 2002). Previous studies have demonstrated MOS reduces *in vitro* attachment of *Salmonella typhimurium* to cultured

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This thesis follows the style of Journal of Animal Science.

intestinal cells (Oyofo et al., 1989) and decreases fecal concentrations of *Clostridium perfringens* in poultry (Finuance et al., 1999). Different in vitro studies have demonstrated agglutination of *Escherichia coli, Salmonella typhimurium* and *S. enteritidis* in the presence of MOS (Spring et al., 2000). These compounds have also been reported to stimulate antibody production and influence gut morphological development in young animals. Supplemental MOS in poultry diets increased both plasma IgG and bile IgA (Savage et al., 1996). Mannan oligosaccharide supplementation increased serum IgM and tended to increase colostral IgG levels in sows (Newman and Newman, 2001). In dogs supplemented with MOS, total lymphocyte count was increased, and serum IgA concentrations tended to be greater (Swanson et al., 2002).

Non-prescription use of antibiotics in livestock feeds has been eliminated or severely limited in many countries because of consumer perception issues and concerns related to the development of antibiotic resistant human pathogenic bacteria. Therefore, alternatives to antibiotics are being investigated by those interested in the livestock industry. Most of the previous research involving MOS has investigated the positive performance benefits seen with the use of a MOS addition to production diets. Studies have demonstrated that the addition of MOS to the diet results in increased average daily gain of broilers (Hooge, 2003), increased gain-to-feed ratio of growing/finishing pigs (Davis et al., 2002), and heavier litter birth and weaning weights in swine (O'Quinn et al., 2001). The immune response elicited by MOS supplementation in swine, poultry, and cattle has recently begun to be investigated. Comparatively, little research has been

involved in lamb performance and immune response with the addition of MOS to the production diet.

These potential effects suggest that Bio-Mos may improve productivity of newly weaned growing lambs placed on an intensive growing program. Improved growth rate may result from improved health status or enhanced nutrient absorption due to gut development. However, fewer trials have directly evaluated performance of lambs in this production setting. The enhancement of performance and conversion rate combined with the reduced occurrence of diarrhea and other problems caused by these organisms in weaned lambs would result in healthier lambs and decreased financial loss due to veterinary expenses associated with lamb production. The objectives of this study are to evaluate the impacts of the mannan oligosaccharide Bio-Mos® on measures of lamb growth performance, efficiency, and health in an intensive growing program.

LITERATURE REVIEW

Lamb Growth

The importance of growth performance in the production of livestock cannot be underestimated. A key in the production of lambs is the added value gained by lambs offering more pay-weight. The ability to add this weight with a least cost and feed efficient formula is ultimately a key factor in profitability. Growth usually is defined as the production of new cells. But because growth is typically measured as an increase in mass, growth includes not only cell multiplication (hyperplasia) but also cell enlargement (hypertrophy) and incorporation of specific components from the environment (e.g., apatite deposition) (Owens et al., 1993). Following weaning, the practice of removing lambs from the milk diet provided by the ewe, lambs at this young state or age are typically fed in a drylot utilizing a concentrated grain diet. This separation can be stressful for both ewes and lambs. During the post-weaning period, the young lamb is undergoing many stressors and is susceptible to disease challenges and the presence of bacteria such as *E. coli*. A central feature of stress is the release of adrenocorticotropic hormone (ACTH) from the anterior pituitary, which regulates cortisol secretion by the adrenal glands. The pituitary-adrenal response is stimulated typically by emotional perturbations such as uncertainty or social dislocation (Dantzer and Morme`de, 1985). Social dislocation, such as weaning, elicits a stress response characterized by adaptive behaviors that may be quantified to assess the degree of stress. Excessive weaning stress may affect appetite, metabolism, and immune competence. Another feature of stress is

increased demand for ascorbic acid (Newberne and Conner, 1989). These health problems may, in turn, affect the growth of the lamb. In an attempt to halt lost performance due to disease, historically antibiotics have been added to the lamb's diet. The awareness of potential resistance and the interest in finding alternatives to antibiotic growth promoters, has led to the investigation of the efficacy of mannanoligosaccharides in this situation.

Growth usually is defined as production of new cells. But because growth typically is measured as an increase in mass, growth includes not only cell multiplication (hyperplasia) but also cell enlargement (hypertrophy) and incorporation of specific components from the environment. By definition, growth includes deposition of fat even though muscle mass is of primary interest in meat production (Owens et al., 1993). Growth and health of the animals are the primary focus of livestock producers. The ability to add tissue mass in the form of protein accretion in a fast and efficient manner is sought using many different additives and feedstuffs.

Energy intake can exceed genetic potential for lean tissue accretion rate. Rouse et al. (1970) reported the order of tissue maturation to be bone, lean, and fat. This also represents tissue priority for nutrients until the tissue is mature (Byers et al., 1988). Byers et al. (1988) also suggested that as ADG increases, protein deposition increases at decreasing rates, whereas fat deposition increases at increasing rates. This suggests reduced energy intake would lead to reductions in accretion rates of protein as well as fat, but at different levels.

In an attempt to add this tissue mass onto the animal, many different methods of promoting growth have been utilized within the industry. Animals can be fed in a pasture

setting or in drylot, fed *ad libitum* or restricted, and animals can be supplemented or not. The question of how to present and develop the diet for growing animals is one that has been investigated extensively in the animal science industry.

Huston et al. (1990) investigated the use of ionophore supplements to lambs and Angora kid goats on rangeland. These authors stated that weaned offspring of ruminant livestock species normally have fully functional reticuloruminal microbial populations to digest forage. However, range forages may not contain certain nutrients in sufficient concentrations to support adequate growth and development of young animals having high requirements. Overall, ionophores had minimal effects on the response criteria. Because feed intake and digestibility were not affected, any increase in gain or efficiency in lambs or kid goats on rangeland from consumption of ionophores was considered a result of their therapeutic value or of improved physiological efficiency.

Drylot

More recent research has shown daily accretion of carcass lean and fat was greater for lambs fed all-concentrate diets than for lambs grazed on cool-season grasses or alfalfa (Murphy et al., 1994). Feeding systems that promote rapid lamb growth, such as concentrates fed in drylot, usually result in greater efficiency (gain/feed; McClure et al., 1994). In a three-year study by these same authors, feed efficiency of lambs fed in drylot was 219, 237, and 206 g of gain/kg of feed in 1983, 1984, and 1985, respectively. This level of efficiency was similar to that reported by Notter et al. (1991) when lambs of a comparable age were fed similar diets. McClure et al. (1994) observed that growth and body condition scores of lambs were greatest for lambs fed in drylot (ADG = 257 g, BCS = 12.2), as compared to those grazed on alfalfa(ADG = 220 g, BCS = 10.3),

orchardgrass(ADG =127 g, BCS = 8.4), and perennial ryegrass(ADG = 129 g, BCS = 8.4), indicating that forage-fed lambs have lower daily gains and lighter carcasses than concentrate-fed lambs. Lower carcass weights result because quantity of carcass fat is reduced for lambs grazing alfalfa. Lambs finished on grass pastures have poorer performance and carcass composition with less muscle, fat, and bone than lambs finished on concentrate diets.

Ad libitum Feeding Regimen

Sheep grown for meat production are usually given ad libitum access to feed to maximize rate of gain and, presumably, feed efficiency because maintenance cost is diluted. The most common difficulty with *ad libitum* intake is that daily intake may fluctuate greatly; resulting in digestive disturbances and potentially decreased performance in lambs fed high-concentrate diets (Hart and Glimp, 1991). In studies summarized by Hicks et al. (1987), restricting intake of beef cattle by an average of 8.7% below *ad libitum* reduced daily gain 5.2% and improved feed efficiency 3.2%. Glimp et al. (1989) observed a 20% improvement in feed efficiency of lambs by restricting intake to 92.5% of *ad libitum*. Rate of gain was improved by the restriction and accounted for much of the improved feed efficiency. This improvement in rate of gain is not due to increased diet digestibility but some other mechanism, possibly a more stable gut environment. Further restriction to 85% of *ad libitum* reduced rate of gain by 7%, but feed efficiency was improved by 7% compared with animals with *ad libitum* intake. Old and Garrett (1987) observed a 20% improvement in feed efficiency by steers fed to gain 85% as fast as those fed for *ad libitum* intake. Anderson (1975) observed that bulls gained more efficiently when fed at 85% of *ad libitum* intake than when fed *ad libitum*.

However in a conflicting study, the investigators reported restricting daily dry matter intake by 15 and 30% leads to lower average daily gain. This reduction in ADG seems to be due to restrictions in fat accretion rates in lambs that are limit-fed (Murphy et al. 1994). These authors also found restricted feeding of concentrate diets provides adequate energy to achieve maximal lean tissue accretion but reduces daily fat accretion. Average daily gain decreased linearly with decreasing intake (Murphy et al., 1994). Andrews and Orskov (1970) also reported decreased ADG in lambs with decreasing intake level.

Feed Additives

Antibiotics. Antibiotics have been used as feed additives in the swine industry for over 50 years as growth promotants and for therapeutic treatment of disease. The benefits of antibiotics in improving growth, reducing mortality and morbidity, and improving reproductive performance are well documented in numerous research studies (Hays, 1981; Cromwell, 2001). The discovery that antibiotics improved growth and feed efficiency led to widespread prophylactic antibiotic use (Visek, 1978), which continues in situations in which undiagnosed or subclinical systemic infections could limit growth and feed efficiency (Gustafson and Bowen, 1997). The use of antibiotics for prophylaxis is utilized within the industry, however these methods differ from products that are associated with changing ruminal fermentation profiles such as ionophores.

Use of antibiotics in animal production may contribute to antibiotic resistance of human pathogens such as salmonellae due to resistance of resistance to ceftriaxone and the fluoroquinolones (Fey et al., 2000). As a result interest in alternatives for antibiotics is strong. Some potential replacements include plasma proteins (Morrill et al., 1995;

Quigley and Drew, 2000), probiotic bacteria (Jenny et al., 1991) or yeast cultures (Seymour et al., 1995), and oligosaccharides (Kaufhold et al., 2000; Donovan et al., 2002; Quigley et al., 2002).

Ionophores. Monensin is an ionophore that was first used as a coccidiostat in poultry and was then applied to ruminants from the mid-1970s onward. It provides an economic benefit in terms of feed efficiency (an average 7.5% improvement; Goodrich et al., 1984), at least partly via its effect on ruminal fermentation (Wallace, 1994). Several other ionophores have been identified that provide similar benefits, including lasalocid, salinomycin, lysocellin, narasin, tetronasin, and the peptide antibiotic avoparcin. The toxicity of ionophores stems from their ability to translocate ions across biological membranes and consequently to disrupt transmembrane ion gradients (Bergen and Bates, 1984). Not all microorganisms are affected by ionophores: monensin and similar ionophores inhibit Gram-positive bacteria more than Gram-negative bacteria (Chen and Wolin, 1979). This selectivity is central to their manipulative effect, and depends on the permeability of the cell envelope (cell wall and outer membrane in Gram-negative bacteria, cell wall in Gram-positive bacteria) (Wallace, 1994). These authors also stated the effects that ionophores had on fermentation, such as changed fermentation stoichiometry and improved protein flow from the rumen, are in many ways consistent with their effects on the bacterial population.

In grazing studies, ionophores in supplemental feeds have had inconsistent effects on intake and weight change by cattle (Huston and Spiller, 1981). Monensin appeared to increase gain and (or) improve digestibility of forage as a result of an increased gastrointestinal fill and a decreased turnover rate of ruminal digesta (Ellis et al., 1981).

Huston et al. (1990) performed a study that involved 12 dietary treatments including a negative control (grazed forage only), positive control (grazing plus milo/cottonseed meal supplement), and a positive control with either monensin or lasalocid, with each at 33, 66, 99, 132, 165 mg/kg in the supplement. The authors found the effects of ionophore feeding on gastrointestinal retention time and turnover rate parameters were minimal and appeared without consequence. Hence, any improvement in growth rate and (or) efficiency from ionophore feeding must be the result of either treatment effects or improved physiological efficiency. In this study, weight gain was not different for sheep vs. goats, but was increased in both species by supplementation (sheep NC=44 g/d vs. goats NC=54 g/d; sheep PC=71 vs. goats PC=92g/d; sheep MON 33=106 g/d vs. goats MON 33=114 g/d; sheep MON 66=78 g/d vs. goats MON 66=108 g/d).

Yeast. Live microbial cultures and their extracts, particularly of *Aspergillus oryzae* and *Saccharomyces cerevisiae*, have been used as feed additives for many years. Their widespread use as manipulating agents for ruminal fermentation, so-called direct-fed microbials, is well documented (Wallace, 1994). On average, published data indicated microbial additives may benefit ruminant nutrition (in terms of live weight gain and milk production) by a similar magnitude to ionophores (7 or 8% improvement; Wallace and Newbold, 1993), in this case by increasing feed intake rather than feed efficiency (Williams and Newbold, 1990).

The efficiency of the rumen may be enhanced by microbial feed additives altering the products of fermentation. Live yeast cultures provide many substrates for bacteria growth, including B vitamins, amino acids, and other organic acids. The benefits of supplementing yeast products may be due to the utilization of metabolites or to the

interaction of the yeast and rumen microbes. Yeast supplements are expected to elicit the greatest response in times of stress. During times of stress, including growth stages, animals have higher nutrient requirements (Arambel, 1988). Phillips and von Tungelin (1985) fed yeast culture to post-stressed heifers and steers for four weeks. Cattle receiving the yeast supplement had greater DMI and an increase in ADG compared to cattle receiving control treatments. A study by Chaucjeyras-Durand and Fonty (2001) showed the inclusion of yeast in diets fed to gnotobiotically-reared lambs may have increased the rate at which cellulolytic bacterial species propagated in the rumen. The authors suggested this increase of growth rate was due to the ability of viable yeast cells to scavenge oxygen from the rumen. Cellulolytic species are extremely oxygen sensitive. Cellulolytic species deceased when the rumens of these lambs were exposed to oxygen during fitting of the cannula. The cellulolytic population remained stable in the rumens of the lambs fed a yeast supplement.

Yeast supplementation has been shown to alter ruminal VFA production and concentrations, including affecting acetate to propionate ratios and decreasing methane production. Enjalbert et al. (1999) showed an increase in the molar percentage of propionate and a decrease in the acetate to propionate ratio (A:P). Investigators have published conflicting reports in regard to changes in VFAs. Piva et al. (1993) showed no significant differences in VFA, but acetate and A:P tended to be higher in cows supplemented with yeast. In contrast, Harrison et al. (1988) found cows fed a yeast supplement had a higher molar propionate level and lower molar acetate, resulting in a decreased A:P. In the same study, yeast supplementation increased concentrations of

branched chain acids (isobutyrate, isovalerate, and valerate). These authors concluded that yeast serves to stabilize rumen fermentation.

Quigley et al. (1992) found yeast supplementation may also affect lactate production in the rumen. Jersey calves were fed experimental diets with the inclusion of either sodium bicarbonate or yeast. Calves fed yeast cells had decreased amounts of ruminal lactate at 4 h post-feeding. Plasma lactate declined with feeding, but tended to be lower when calves were fed yeast compared to bicarbonate.

Effects of yeast supplementation on health status. Seymour et al. (1995) suggested that yeast has a beneficial effect on the overall gut health of dairy calves. These authors reported yeast had a positive effect on fecal scores as well as feed to gain ratio. Data were recorded on a scale of 1 to 4, with 1 being normal and 4 being fecal scours. During the transition from milk replacer to dry feed, calves fed yeast had a lower DMI, but showed a better feed to gain ratio, indicating the yeast may have helped the calves adapt to dry feed. In period 3, after transition to dry feed, calves fed yeast showed a lower percentage of fecal scours and a lower incidence of abnormal body temperatures. The authors speculated that Cr supplied by the yeast may have improved the immune response; however, Cr was not assayed.

Mannan oligosaccharides. Carbohydrates are the most abundant biological molecules, and fill numerous roles in living things, including the storage and transport of energy and structural components. Additionally, carbohydrates and their derivatives play major roles in the functioning of the immune system, fertilization, pathogenesis, blood clotting, and development. Carbohydrates are important structural components of the majority of cell-surface and secreted proteins of animal cells (Osborn and Khan, 2000).

Carbohydrates are also a major source of metabolizable energy in the diet. Oligosaccharides are made from isomerization of disaccharides, enzymatic hydrolysis of polysaccharides, or by direct extraction from the cell wall of yeasts. The type of carbon backbone to which they adhere typically classifies these structures. Mannose is a monosaccharide that forms the building block of MOS. The small intestine does not contain the digestive enzymes required to break down mannan oligosaccharide bonds, and therefore they arrive at the large intestine intact after ingestion and passage through the small intestine (Strickling et al., 2000). Mannose-based oligosaccharides occur naturally in cells walls of the yeast *Saccharomyces cerevisiae* and are relatively easy to obtain by centrifugation from a lysed yeast culture (Spring et al., 2000). The commercially available product Bio-Mos® (Alltech, Inc., Nicholasville, KY) is a source of MOS from *Saccharomyces cerevisiae* cell walls. This product was introduced in 1993 as a feed additive for broiler chickens (Hooge, 2003). Bio-Mos® has shown promise in suppressing enteric pathogens, modulating the immune response, improving the integrity of the intestinal mucosa, and promoting improved growth and feed conversion in studies with chickens and turkeys (Olsen, 1996; Spring, 1999a, 1999b; Iji et al., 2001; Sonmez and Eren, 1999; Spring et al., 2000; Savage and Zakrzewska, 1997; Valancony et al., 2001).

Much of the negative perception concerning oligosaccharides, or more specifically, soy oligosaccharides, stems from assumed depression in nutrient digestibilities and the increase in gas production resulting from fermentation of these substrates (Hata et al., 1991). Intestinal gases (H_2, CO_2, and CH_4) originate from colonic fermentation of the nondigestible oligosaccharides, raffinose, and stachyose (Delzenne

and Roberfroid, 1994). Yet oligosaccharide fermentation also yields products that are beneficial to the host, namely the short-chain fatty acids acetate, propionate, and butyrate (Buddington, 2001).

In a study by Smiricky-Tjardes et al. (2003) investigating the fermentation characteristics of oligosaccharides in swine fecal microflora, mannan oligosaccharides were studied for gas production, pH, and short chain fatty acid production. Mannan oligosaccharide fermentation resulted in the lowest quantity of gas production, the lowest rate of gas production, and the longest time to attain maximal rate of gas production. This is coupled with high pH and low SCFA production. Unlike most of the oligosaccharides tested in the experiment, mannan oligosaccharide is a crude extract from yeast and contains 6% N, 41% total dietary fiber, 8% fat, and 44% total monosaccharides on a dry matter basis. Therefore, ingredients that do not ferment as rapidly, such as N and fat, could potentially inhibit fermentation. Additionally, the fiber component of mannanoligosaccharides could slow its fermentability. In this same study, fermentation of mannanoligosaccharides resulted in less production of SCFA when compared to all other substrates (fructooligosaccharides, raffinose, stachyose, soy solubles, granular and liquid forms of transgalactooligosaccharides, glucooligosaccharides, mannanoligosaccharides, and xylooligosaccharides) except for raffinose. Also, rate of SCFA production was lowest for mannanoligosaccharides, indicating a lower fermentative capacity. In agreement with this data, Vickers et al. (2001) reported substantially lower acetate (0.89 vs. 2.3 mmol/g of OM sample), propionate (0.3 vs. 0.9 mmol/g of OM sample), and butyrate (0.2 vs. 0.3 mmol/g of OM) values when mannanoligosaccharide was fermented for 12 h when compared to short-chain

fructooligosaccharides. This may explain why mannan oligosaccharides still have some binding effect in the lower gut, and the portions that are fermented may increase the nutrient supply or alter fermentation profiles which would result in positive performance effects.

Mannan oligosaccharides have improved performance in nursery pigs (Dvorak and Jacques, 1998) and weight gain and grain intake in dairy calves (Dvorak and Jacques, 1997). In addition, investigation continues into the potential relationship between oligosaccharides and human intestinal function (Jenkins et al., 1999) and their role in modulation of human gastrointestinal microflora (Gibson, 1999).

Mannans on the cell surface are the primary antigenic components of whole yeast cells and cell walls (Ballou, 1970). Because many gram-negative bacteria attach to the intestinal epithelium using mannose-specific fimbriae (Ofek et al., 1977), MOS provides competitive binding sites for these intestinal pathogens. Multiple strains of *Escherichia coli* and *Salmonella* agglutinated MOS in vitro (Spring et al., 2000). The MOS is not enzymatically digested in the small intestine; therefore, bacteria bound to MOS likely exit the intestine without attaching to the epithelium (Spring et al., 2000). Mannan oligosaccharides may also enhance health by stimulating antibody production (Savage et al., 1996) or by affecting intestinal morphology and function (Iji et al., 2001). Inhibition of the bacteria responsible for toxin production could prevent or decrease the severity of diarrhea (Giannella, 1983).

Growth Performance

The use of antibiotics in food animal diets is a known and common practice throughout the industry. Antibiotics have been shown to improve growth, feed

efficiency, and overall herd health when used in poultry, swine, and cattle production diets. Due to increasing regulatory restrictions based on consumer concerns, producers have begun the search for substances to replace the use of antibiotic growth promotants in production diets. Mannan oligosaccharide supplementation has been and continues to be investigated as an alternative to antibiotic supplementation to improve performance traits.

Cattle. The effects of MOS supplementation in cattle diets has received less attention relative to production-enhancements effects of poultry and swine supplemented diets. Heinrichs et al. (2003) investigated the effects of MOS or antibiotics in dairy calf milk replacer diets, and found the addition of 4 g MOS/day was as effective as antibiotic use to maintain normal fecal fluidity and consistency and to decrease scours severity. Addition of MOS or antibiotics increased the probability of normal scores for fecal fluidity, scours severity, and fecal consistency as compared to controls over the course of the study. Feed consumption increased when MOS was included in the diet, but this did not result in a difference in growth measures (Heinrichs et al., 2003). In this study, calves were fed to an age of six weeks. The gut morphology of neonatal calves (as during the time period of this trial) allows feed to bypass the rumen, therefore this study may not be indicative of a true ruminant trial.

Broilers. Waldroup et al. (2003) conducted a study to evaluate the effects of combinations of antibiotics, mannan oligosaccharides, and organic forms of copper in the diet of broilers. These authors found that overall, Bio-Mos® had no significant effect on feed conversion but interacted with some of the other factors. At 21 d there was an interaction between the antibiotic program and the inclusion of Bio-Mos®; adding Bio-Mos® in the absence of antibiotics tended to improve feed conversion while adding Bio-

Mos® in the presence of antibiotics tended to decrease feed conversion. Lack of response to antibiotics in later stages of growth suggests that the birds were performing well with minimal stress, and perhaps is the reason for the lack of response to Bio-Mos® or to the copper sources. It is also possible that the levels of Bio-Mos® used in this study were not sufficient to elicit a positive response.

Turkeys. Fritts and Waldroup (2003) investigated the use of Bio-Mos® as a potential replacement for growth promoting antibiotics in the diet of growing turkeys. Body weight, mortality, breast meat yield, and intestinal breaking strength were not significantly influenced by dietary treatments. Feed conversion from 0 to 20 wk of age was significantly improved by Bio-Mos®. This study is in agreement with the findings of Olsen (1996), and Savage and Zakrzewska (1997).

Swine. Though results have been somewhat inconsistent, some research suggests MOS may improve growth performance in young pigs (Davis et al., 1999; Pettigrew, 2000). White et al. (2002) investigated the use of brewers dried yeast as a source of mannan oligosaccharides in the diets for young pigs. Results indicated growth performance was not enhanced by supplementing the basal diet with brewers dried yeast. Pigs fed the two yeast-containing diets consumed less feed, which resulted in reduced growth rates over the 28-d test period. Feed:gain ratios tended to be inferior in the yeast-fed pigs during the initial phase of the experiment.

Immunity

Swine. White et al. (2002) reported serum protein levels, a general indication of immune status, were not different among the dietary treatment groups at the end of a 28-d study. Pigs fed yeast tended to have higher levels of IgG and IgA levels at study

termination, but the differences were significant only at $p < 0.15$. Fecal pH and VFA concentrations were determined by the authors because they are indicative of fermentation patterns. However, only minor changes in fecal pH and VFA concentrations occurred in the feces of pigs fed the different diets.

Cattle. Franklin et al. (2005) concluded supplementation of MOS to dry cows resulted in enhanced response by the cows to immunization against rotavirus and a tendency for enhanced concentrations of rotavirus antibodies in the serum of calves. Supplementation of cows with MOS during the dry period may enhance transfer to the offspring of passive immunity against specific organisms, which may result in decreased use of therapeutic antibiotics in calves. In the case of viral pathogens, where antibiotics are not as effective even though commonly administered to calves with diarrhea, the supplementation of MOS to dry cows to enhance transfer of passive immunity to calves may lead to decreased morbidity and medical treatments for calves.

RATIONALE

The ability of Bio-Mos® to enhance the productivity of different livestock species in several stages of production makes it an attractive option as a supplement to the diet throughout the livestock industry. Sheep producers are interested in the health and performance of weaned lambs, and the ability of Bio-Mos® to stimulate antibody production, influence absorption and binding of enteric pathogens, serve as a gut buffering agent, and alter fermentation profiles could prove to be a viable option. Improved growth rate of the lambs could be a function of enhanced health status or gut function or gut health. The capacity of Bio-Mos® to improve the health status, efficiency, and growth rate of weaned lambs needs to be investigated further.

HYPOTHESIS

The addition of Bio-Mos® to a weaned lamb diet should increase daily gain and enhance feed efficiency due to an improvement in the health status and immune function of the lambs during this period of high stress, and potentially through alterations in ruminal function that stabilize or enhance intake patterns and reduce digestive disturbances.

OBJECTIVES

The objective of the study was to evaluate the effect of inclusion of Bio-Mos® in the growing ration for weaned lambs on growth rate, feed efficiency, and clinical measures of health.

MATERIALS AND METHODS

Animals

Forty-seven weaned Suffolk × Hampshire (n=47) lambs were used in this trial. Lambs were obtained from the Texas A&M University Sheep and Goat Center, and experimental procedures were approved by the Texas A&M University Institutional Animal Care and Use Committee, Animal Use Protocol number 2007-25. Within gender, lambs were stratified by body weight and randomly assigned within strata to one of two dietary treatments. The lambs ranged from 69 to 92 days of age at the start of the trial. Of the group, twenty (n=20) were ewe lambs and twenty-seven (n=27) were wether lambs. The lambs were placed on their assigned diets and remained on the trial for a four week period (d=28).

Housing and Management

During the course of the trial, the lambs were housed at the Texas A & M University Sheep and Goat Center 8.05 km west of College Station, Texas. The lambs were housed in soil-surfaced pens equipped with automatic waters and bunk-style feeders, such that each lamb had a minimum of 38.1 cm of linear trough space and 6.97 square meters of pen space. A routine vaccination and anthelmintic schedule for all animals on trial was followed by farm management. Lambs in this study were not in stalls, but were in pens where they were free to move around. This enabled us to achieve levels of intake comparable to those observed in production studies.

Diets

Dietary treatments consisted of a commercially available growing ration 1) with (EXP) or 2) without (CON) the mannan oligosaccharide Bio-Mos® (Bio-Mos®, Alltech, Nicholasville, KY). Ingredients and nutrient composition are shown in Table 1. The level of Bio-Mos® inclusion was consistent with manufacturer-recommended levels and was added at 0.50%. Feed was delivered twice daily at 0800 hours (AM feeding) and 1600 hours (PM feeding). Feed was provided to appetite daily, feed refusals were collected and recorded daily. Loose trace mineral and fresh water were available at all times.

Table 1. Nutrient composition of control and Bio-Mos® growing ration on a DM basis.

Item	**Control**	**Bio-Mos**
Ingredients(%)		
Corn	38.57	38.37
Dehy. Alfalfa 17%	30.27	30.07
Soybean Hulls	12.26	12.16
Cottonseed Meal	5.68	5.68
Rice Bran	5.27	5.27
Liquid Binder	2.50	2.50
Feather Meal	1.50	1.50
DDG (Solulac)	1.25	1.25
Dried lignin	1.00	1.00
Ammonium Chloride	0.60	0.60
Bio-Mos	0.00	0.50
Salt Mixing	0.50	0.50
Urea 287	0.25	0.25
Blood meal	0.25	0.25
Deccox	0.06	0.06
Beef Vit	0.03	0.03
Sheep Fort	0.03	0.03
Nutrient Content		
Crude Protein %	17.75	17.75
Crude Fat %	4.44	4.44
Crude Fiber %	15.41	15.41

Body Measurements

Lambs were weighed at the start of the trial (d 0), and on d 7, 14, 21, and 28. Lambs were weighed individually on an electronic digital walk-on scale prior to the AM feeding. Temperatures were taken per rectum using a digital thermometer at the same times as weights.

Fecal Samples

Fecal grab samples were obtained per rectum at the same intervals as weighing. Fecal samples were collected in plastic bags, and transported to the laboratory for evaluation immediately following the conclusion of the weight collections.

Fecal scores were assigned for each sample using a 5-point scale. The fecal scores were assigned based on the following criteria (1=firm, dry, well-formed pellet; 2=loose to firm, moist, well-formed individual pellet; 3=soft, moist pat with some indication of individual pellet formation, 4=soft, wet pat with no pellet formation; 5=diarrhea).

Following the rating of each sample for fecal score, pH was determined for each sample. An electronic pH meter was used to determine values. One gram of fecal material was placed in a 10 ml glass beaker and mixed using a plastic stirring rod with four ml of distilled water. The distilled water/fecal material solution were mixed into a slurry of uniform consistency. An electronic meter fitted with a glass electrode was used to measure slurry pH.

Data Analysis

This experiment was analyzed as a completely randomized design with a factorial treatment arrangement. Treatment factors are gender (ewes versus wethers) and diet

(Control versus Bio-Mos®). Repeated measures were taken on the experimental units so that time becomes another factor.

Each response variable was modeled using the effects of gender, diet, and the interaction of gender and diet, as repeated measures in time using the MIXED procedure of SAS (Version 9.1.3, SAS Institute, Cary, NC). The subject of repeated measures (i.e., the experimental unit) was pen within the diet X gender combination. The best fitting covariance structure according to Aikey's Information Criterion was auto regressive with a lag of one. The other type of structures that were tested were compound symmetry and unstructured. Effects with probabilities less than $p = 0.05$ were considered significant.

RESULTS AND DISCUSSION

All responses evaluated in this study were influenced by time ($p < 0.05$) over the 28-d trial (Table 2). Lambs gained faster in week 2 than other weeks, and this increased rate of gain resulted in increases in feed efficiency. Intake increased over time. Fecal pH appeared to cycle, increasing from week 1 to 2, decreasing from week 2 to 3, and then increasing again from week 3 to 4. Fecal consistency was firmer in week 3 compared to other weeks, but the magnitude of this change was small and does not appear to be related to feed intake or fecal pH. Temperature was numerically higher during week 1 and week 2 of the study and was lower for week 3 to 4. This response in temperature may be due to lambs undergoing a higher degree of stress over the first half of the study. Over the second half of the study the lambs may have become more adapted to the environment. As well, lambs were vaccinated prior to entering the study which may have caused an increase in temperature initially. Alternatively, over the first weeks of the study the investigators were not as efficient in the handling of the lambs which may have increased the time to measure each individual lamb. In turn, in the first two weeks the lambs may have been more stressed during handling, increasing temperature, and it may have been later in the morning by the completion of the measurements, increasing environmental temperature.

Table 2. Effect of time on weaned lambs fed Bio-Mos® diet or control diet.

	Treatment				
Item	Week 1	Week 2	Week 3	Week 4	SE
ADG (g)	241.72[a]	481.62[b]	272.93[a]	232.24[a]	29.292
Gain:Feed	0.1932[a]	0.3510[b]	0.1665[a]	0.1307[a]	0.0186
Intake(lamb/wk) (kg)	8.706[a]	9.647[b]	11.574[c]	12.246[d]	0.1368
pH	6.1313[a]	6.3500[ab]	6.0963[a]	6.4250[b]	0.0841
Fecal Score	3.2838[ab]	3.3288[a]	2.9563[b]	3.3625[a]	0.1572
Temperature(C)	39.706[ab]	39.889[a]	39.539[b]	39.561[b]	0.0723

[a,b,c,d]Means within a row with different subscripts differ; P < 0.05.

ADG

Diet, gender, and their interaction had minimal influence on ADG ($p > 0.58$).

Growth responses to diet by week are shown in Table 3.

Table 3. Growth performance of weaned lambs.

Item	Control	Bio-Mos®	SE
Avg. initial wt (kg)	24.56	23.65	
Avg final wt (kg)	33.22	32.21	
Week 1 (d 0 to 7)			
Daily gain/hd (g)	241.31	242.13	41.43
Intake(lamb/wk) (kg)	8.657	8.755	0.194
Gain:Feed	0.1862	0.1747	0.0263
Week 2 (d 7 to 14)			
Daily gain/hd (g)	463.93	499.31	41.43
Intake(lamb/wk) (kg)	10.091[a]	9.202[b]	0.194
Gain:Feed	0.3182	0.3759	0.0263
Week 3 (d 14 to 21)			
Daily gain/hd (g)	301.64	244.26	41.43
Intake(lamb/wk)(kg)	11.693	11.454	0.194
Gain:Feed	0.1533	0.1238	0.0263
Week 4 (d 21 to 28)			
Daily gain/hd (g)	228.38	236.09	41.43
Intake(lamb/wk) (kg)	12.527	11.965	0.194
Gain:Feed	0.0823	0.0815	0.0263
Entire Experiment (d 0 to 28)			
Daily gain/hd (g)	308.81	305.45	15.663
Intake(lamb/wk) (kg)	10.742	10.344	0.132
Gain:Feed	0.1471	0.1393	0.009

[a,b]Means within a row with different subscripts differ; $p < 0.05$.

A GENDER × WEEK interaction was observed for ADG and feed conversion ($p < 0.05$; Table 4). The interaction of time and gender appear mainly at week 3 and 4 (Table 4),

Table 4. Effect of GENDER × WEEK on weaned lamb growth performance.

	Treatment								
	Ewe				Wether				
	Week				Week				
Item	1	2	3	4	1	2	3	4	SE
ADG (g)	202.76[a]	491.24[b]	171.00[a]	347.32[c]	280.68[a]	471.96[b]	374.89[bc]	117.16[a]	0.091
Gain:Feed	0.1573[a]	0.3571[b]	0.0979[a]	0.1786[a]	0.2111[a]	0.3331[b]	0.2281[a] ,	0.053[c] ,	0.026

[a,b,c]Means within a row with different subscripts differ; $p < 0.05$.

where rank changes occurred.

McClure et al. (2000) found cumulative ADG was greater for wethers than for ewes, similar to that reported in this study. This lack of growth increase due to addition of Bio-Mos® contradicts Rozeboom et al. (2005) who reported that in a 42-d study Bio-Mos® increased growth rate over the course of a study involving pigs. Our finding that Bio-Mos® did not affect growth rate are in agreement with the investigation of weanling pigs with Bio-Mos® added to the ration by LeMieux et al. (2003).

There are at least two possibilities why growth rate was not influenced by MOS supplementation, as suggested by Rozeboom et al. (2005). First, it might be that the product decreased pathogenic challenges in the intestine, but growth rate was not a good indicator of the degree of the challenge. Second, the response to the product observed in

other studies might have been due to other factors than protection against enteric pathogenic challenges.

It was expected that the lambs fed Bio-Mos® would have increased growth rate due to enhanced gastrointestinal health. Improving the overall intestinal health by binding potential pathogens and by enhancing the animal's ability to defend against potential antigens by increasing the level of antibody titres, immunoglobins, and macrophage activity indicates a greater capacity to cope with potential diseases and will ultimately lead to better health and better growth performance (Rozeboom et al., 2005).

Intake

Control lambs tended ($p = 0.10$) to have a higher intake over the 28-d period in comparison to Bio-Mos® fed lambs (Table 3). There were no statistically significant differences ($p < 0.05$) between control and Bio-Mos® fed lambs for any of the growth parameters that were measured. There was a tendency ($p= 0.10$) for GENDER × WEEK to influence intake (Table 4). Gender also tended to interacted with diet (GENDER × DIET, $p = 0.09$) to influence intake over the trial period. Wether intake was similar for both diets (10.48 kg for controls vs. 10.52 kg for Bio-Mos®, SE=0.186), whereas ewe intake tended ($p = 0.09$) to be higher for control diet (10.98.± 0.186 kg) relative to the Bio-Mos® diet (10.18.±0 .186 kg). A DIET × WEEK interaction significantly ($p < 0.05$) influenced intake over the course of the experiment (Table 3).

Throughout the duration of the experiment, all the lambs performed well, all the pens progressed well from an intake standpoint and all pens gained weight. In our study, growth was actually depressed when Bio-Mos® was included, apparently due to reduced feed intake. This data is in agreement with a previous study performed by White et al.

(2002) in which growth performance was not enhanced by supplementing the basal diet with either brewers dried yeast alone or with the combination of yeast and citric acid. Pigs fed the two yeast-containing diets consumed less feed ($p < 0.05$), which resulted in reduced growth rates ($p < 0.05$) over the 28-d test period.

Feed Conversion

A GENDER × WEEK interaction was observed ($p < 0.05$) for feed conversion (Table 4). Treatment had little impact on feed conversion ($p = 0.80$), Bio-Mos® fed lambs had a numerically lower gain:feed ratio compared to control fed lambs (Table 3). The data shows that the ewes exhibited poor feed conversion during week 3 while the remained relatively constant in their ability to convert feed. However, during week 4 ewes returned to a steady level, whereas wethers were poor converters.

As expected, in the weeks where the lambs had a higher average daily gain they were more feed efficient and the inverse is true as well. Overall, diet had little influence on the feed conversion of the lambs involved in the study. This corresponds to the White et al. (2002) study in which feed:gain ratios tended to be inferior in the yeast-fed pigs during the initial phase of the experiment. Rozeboom et al. (2005) showed variable feed efficiency responses; the MOS improved feed efficiency in a trial involving pigs from one location, but had no impact on efficiency in pigs from two other farms.

Davis et al. (2004) performed a study similar to the present trial but using swine. These authors found that pigs fed diets including mannans had greater ADG and G:F than pigs fed the basal diet from d 0 to 14 post-weaning. Although ADG, ADFI, and G:F were unaltered as a result of dietary treatment from d 14 to 21 post weaning, the improvement in ADG and G:F was maintained in the overall experiment. This was

reflected by the greater BW of pigs fed mannans on d 14 and 21 of the experiment compared with pigs fed the basal diet.

In the present study it was expected that the Bio-Mos® fed lambs would have enhanced gain, efficiency, and intake relative to the control diet; however, minimal effects of MOS were observed. Previous trials have been variable in other species. In some mannan oligosaccharides show little effect on growth responses, in others a large effect has been observed. The addition of phosphorylated mannans to weanling pig diets has been reported to increase gain and feed intake (Kim et al., 2000; Davis et al., 2002). In contrast, other work has reported no benefit when adding mannans to weanling pig diets when compared with a positive-control diet with antibiotics or a negative control diet devoid of antibiotics (Ko et al., 1998). Studies involving dairy calves reported no differences in feed intake and growth with the inclusion of Bio-Mos® as a part of the calf diet (Donovan et al., 2002; Heinrichs et al., 2003). These inconsistent responses to mannan supplementation may be because of varying environmental conditions and health status within herds. The improvement in growth performance from mannan addition may be greater when it is supplemented to slower-growing pigs, where slow growth is speculated to be indicative of herd health challenges (Pettigrew, 2000).

The mechanism for improved feed efficiency observed by lambs whose intake is restricted is not attributable to changes in diet digestibility or ruminal characteristics (Hart and Glimp, 1991). Possibly, a reduction in the size of the liver and (or) the small intestine reduces the maintenance requirement of the animal (Baldwin et al., 1980). Also, the efficiency at which energy is metabolized may be affected by the differences in feeding patterns (lambs on restricted intake regimens tend to consume the majority of

their feed within 4 h of feeding, whereas animals given *ad libitum* access to feed consume feed throughout the day). Ferrell (1988) and Koong et al. (1985) have shown animals fed at high levels have higher liver and small intestine weights than animals with lower levels of intake. Animals on the high intake regimen also had higher maintenance energy requirements.

Health Parameters

All health parameters were within normal limits throughout this study indicating that these lambs were under low stress, which may have influenced the effect of the additive. The weaned lambs in the present study maintained good health status both prior to and after the experiment, indicating that this group of lambs either already had high immune function or experienced minimum disease challenge, which might limit the potential growth response to MOS. The health parameters throughout the study are shown in Table 5.

Table 5. Health parameters of weaned lambs.

Item	Control	Bio-Mos®	SE
Week 1 (d 0 to 7)			
Temperature (C)			
Ewes	39.77	39.74	0.0723
Wethers	39.70	39.61	0.0723
Fecal pH	6.2700	5.9925	0.1191
Fecal Score	3.2600	3.3075	0.2223
Week 2 (d 7 to 14)			
Temperature			
Ewes	39.88	39.69	0.0723
Wethers	39.92	40.08	0.0723
Fecal pH	6.5900	6.1100	0.1191
Fecal Score	3.3075	3.3500	0.2223
Week 3 (d 14 to 21)			
Temperature			
Ewes	39.59	39.54	0.0723
Wethers	39.40	39.63	0.0723
Fecal pH	6.2500	5.9425	0.1191
Fecal Score	2.9000	3.0125	0.2223
Week 4 (d 21 to 28)			
Temperature			
Ewes	39.44	39.62	0.0723
Wethers	39.74	39.44	0.0723
Fecal pH	6.5350	6.3150	0.1191
Fecal Score	3.3675	3.3575	0.2223
Entire Experiment (d 0 to 28)			
Temperature	39.68	39.67	0.0699
Fecal pH	6.4113[a]	6.0900[b]	0.0648
Fecal Score	3.2088	3.2569	0.1626

[a,b]Means within a row with different subscripts differ; $p < 0.05$.

Temperature

Rectal temperatures of the lambs being studied varied only with week ($p < 0.05$). Other variables did not affect temperature ($p > 0.20$). Rectal temperature was evaluated as an indicator of clinical health status of the lambs. The time effect could possibly be due to differences in the weather and external temperature over the course of the trial period. However, each pen was equipped with large circulating fans to combat this issue, and all temperatures were taken by 1100 hours on each collection day.

Fecal Score

Time was the only factor that statistically affected ($p < 0.05$) fecal score over the trial period. According to the scale used in this study, a lower fecal score would indicate improved gut health. Very few lambs on any treatment had severity scores of 5. Fecal scores were lower (less fluidity) during week 3 of the study. At this point it is speculated that the lambs may have been more accustomed to their respective diets, and as their gastrointestinal tracts continue to mature they are better able to digest the high concentrate diets. This may explain the decrease in fecal fluidity. However, with a large increase in intake over the last two weeks of the studies, the increase in fecal scores over the last week of the study may have been a response to increasing feed intake.

Heinrichs et al. (2003) showed an antibiotic and MOS treatments had a higher overall probability of normal feces throughout a study with dairy calves. A large majority of calves showed some degree of increased fecal fluidity during the first 2 wk of age, this may be a similar situation to placing weaned lambs directly on a high concentrate diet. In the present study the addition of Bio-Mos® to the diet had no effect on fecal score, and is reflected in the time effect observed.

Fecal pH

Diet influenced fecal pH ($p < 0.05$). The Bio-Mos® fed lambs had a more acidic fecal pH compared to controls. Fecal pH also varied with week of the trial ($p < 0.05$). Fecal pH was analyzed as an indication of gastrointestinal tract fermentation patterns.

In the White et al. (2002) study, the authors found fecal pH showed only minor changes occurring in the feces of pigs fed the four diets. However, in that study the yeast diet had a more basic pH as compared to control diet, which contradicts data in the

present study. Hart and Glimp (1991) reported ruminal pH values that could be used as a comparison to those in the present study, in that case ruminal pH was lower for the higher concentrate diets following the increase in total concentration of VFA. Ruminal pH was 5.45 for pelleted concentrate versus 5.62 for whole shelled corn diets. It is possible that the pH value for Bio-Mos fed lambs in the present study is more acidic due to an increase in VFA production in the gastrointestinal tract of the lambs. However, this conflicted with a Smiricky-Tjardes (2003) study which found that when comparing many oligosaccharides present in feed ingredients tested at the 12 h fermentation time, manna oligosaccharide fermentation produced the least amounts of acetate and propionate when compared to all other substrates. In this cited trial however, there is no comparison to a non-oligosaccharide. In our study, because the control lambs tended to have a higher intake, it is less likely that the pH shift was because of increased VFA production.

The inclusion of yeast into the diet has been shown to reduce lactate production in ruminants (Quigley et al., 1992), potentially reducing the effects of lactic acidosis in ruminants consuming high concentrate diets. However, the lack of observation of symptoms of acidosis in either treatment group and the more acidic fecal pH observed in lambs fed MOS suggest that there was no reduction in acid production due to feeding MOS.

CONCLUSIONS

This study indicates that the addition of Bio-Mos® to the diet of weaned lambs had minimal influence on the growth and performance of the lambs. Bio-Mos® addition to the diet had little impact on the health parameters of the lambs utilized in the study. However, fecal pH was influenced by the Bio-Mos® diet, making those fecal samples have a more acidic pH. This may be due to an increase in VFA production. The animals used in this study had normal health parameters, which may imply that these lambs were under low stress and may have influenced the affects of the Bio-Mos® addition. Lambs in this study were never subjected to a challenging environment, as lambs were never transported or exposed to new pathogens. It is possible that if lambs had been relocated to a new environment the influence of Bio-Mos® would have been greater. Another possibility is that Bio-Mos® has no influence on growing lambs when supplemented in the diet. It is determined that more investigation is necessary to determine if different levels of Bio-Mos® would impact the lamb performance. It may be necessary to stress challenge the lambs over the course of the study to induce more enhancement from the additive.

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