EFFECTS OF CORN AND MOLASSES SUPPLEMENTS WITH AND WITHOUT FEED ADDITIVES ON PERFORMANCE, VOLUNTARY INTAKE, AND DIGESTIVE FUNCTION IN CATTLE FED BERMUDAGRASS HAY

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1996

This dissertation is dedicated to my wife Elena for the years of love, help, and encouragement and to my children Gonzalo, Nicolas and Maria Daniela.

ACKNOWLEDGMENTS

I wish to express sincere gratitude to the supervisory committee consisting of Drs. W.E. Kunkle, D.B. Bates, J.E. Moore, A.C. Hammond, and L.E. Sollenberger. Special gratitude is extended to Drs. Kunkle and G. Hembry for financial support during the last six months of my project. I am very thankful to the Instituto Nacional de Tecnologia Agropecuaria (INTA) for financial support during my first thirty months at UF. Special thanks to the efforts of Jerry Wasdin, Dan Price, the Pine Acres and Santa Fe crew, and Dane Bernis (Feed Mill). Special thanks is extended to Jeanette Filer and Angelita Mariano for their help in the lab and during the experiments. I am in debt to John Funk, Pamela Miles, and Nancy Wilkinson from Nutrition Lab and to Sandra Armantrout and Christa Jenssen from Extension. I am also in debt to E. Bowers from STARS-Brooksville, Drs. R.C. Hill and K. Scott for allowing me to use their GC, and Dr. C.H. Courtney and Qiyun Jeng for helping me with parasitology analysis. I am very thankful to Kevin Downs, Diane Campbell, and Francisco Olbrich for their help during the experiments. I would also like to extend special thanks to Diego Rochinotti for his friendship and help, and thanks to Pedro Garces-Yepez for sharing his experience with me.

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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December, 1996

Chairperson: W.E. Kunkle
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Ionophores and bambermycins have improved gain of growing cattle fed forage based diets when mixed in grain or mineral supplements. In limited research monensin has not improved gain of growing cattle when fed in molasses based liquid feeds offered at 2 kg/d or more and the efficacy of bambermycins in this supplement has not been evaluated.

Growing cattle fed bermudagrass hay were supplemented with 1.57 kg TDN from corn-urea (CU) or molasses-corn gluten meal (MCG), without and with monensin or bambermycins. Cattle fed supplements without antibiotics gained .62 kg/d. Monensin increased gain .035 kg/d in CU and decreased gain .029 kg/d in MCG. Bambermycins increased gain .106 kg/d in CU and .042 kg/d in MCG. Monensin decreased hay intake .14% of BW while bambermycins increased hay intake .14% of BW in

Year 1 and had no effect in Year 2. Monensin increased the difference between observed and predicted gains (an estimator of feed efficiency) .102 and .026 kg/d in CU and MCG, while bambermycins increased that difference .063 and .041 kg/d in CU and MCG, respectively.

Effects of CU or MCG with and without bambermycins on feed intake and digestive function were evaluated in two 4 x 4 Latin squares with ad libitum and restricted intake. Bambermycins increased total DM intake .08% of BW but did not affect digestibility. Bambermycins increased ruminal pH (6.63 vs 6.52), decreased butyrate molar proportions (9.8 vs 10.6), and did not affect acetate:propionate ratio (C_2:C_3) and microbial N efficiency. Ruminal pH, total VFA, VFA molar proportions, and C_2:C_3 exhibited a supplement by time postfeeding interaction ($P < .07$). Steers fed CU had higher ($P < .033$) apparent (3.59 vs 2.99 g N/100 g OM) and true (2.47 vs 2.19 g N/100 g OM) microbial N efficiency, and higher ruminal feed CP degradability (69.2 vs 58.9%) than those fed MCG.

Monensin improved gain in cattle fed corn but did not improve gain in cattle fed molasses supplement. Bambermycins improved gain in cattle fed corn and molasses supplements but this effect was greater in corn than in molasses. Increased gain due to bambermycins was not explained by changes in digestive function.

CHAPTER 1
INTRODUCTION

Warm-season grasses are the main feed resource for cow-calf and backgrounding production systems. Animal production based on warm season forages is usually lower than on temperate forages because intake and nutritive value of C_4 grasses is lower. Excess biomass production during the warm and humid season is conserved as hay, haylage or stockpiled forage to be used as the basal diet during the winter months. High animal performance is not possible with this feed resource alone because intake of digestible energy often is only enough to meet maintenance requirements or support low gains. Supplemental feeds to meet animal requirements for energy, protein, and minerals are recommended in Florida. Feed additives that enhance animal production and therefore improve the biological and economical response to supplemental feeding are desirable. Molasses is a locally available energy source competitively priced compared to traditional feeds. Researchers at University of Florida have evaluated high levels of molasses supplementation with the addition of dry ingredients containing natural protein sources (molasses slurries). An effective feed additive to improve gain in cattle fed

molasses slurries at levels of 30 to 40% of the total diet is not available. Limited research has suggested that ionophores are not effective when fed in molasses slurries but more evidence is necessary.

Objectives of this research are as follows:

1. Evaluate the efficacy of ionophore (monensin) and nonionophore (bambermycins) antibiotics to improve gain in growing cattle fed high forage diets (bermudagrass hay) supplemented with a corn- or molasses-based feeds.

2. Evaluate the effects of feeding bambermycins on voluntary hay intake and digestive function of cattle fed high forage diets supplemented with corn- or molasses-based feeds.

3. Compare the digestive function in cattle fed high forage-based diets supplemented with corn- or molasses-based feeds.

CHAPTER 2
LITERATURE REVIEW

Introduction

Animal performance (growth, reproduction) is often suboptimal when only warm-season forages are fed. Consequently, some type of protein and(or) energy supplementation is often needed. Molasses-based supplements are often fed to cattle consuming warm-season forage diets. Feed additives that enhance growth may improve biological and economical response to supplementation.

Competitive feedstuffs are defined as those that can also be used as human food, while complementary feedstuffs are not used directly for human consumption. Rumsey (1984) and Hammond (1991) discussed the noncompetitive nature of ruminant production using the protein conversion ratio (Table 2-1). Relative input/output for ruminant protein is less efficient than protein produced by nonruminant animals. However, the use of competitive feedstuffs inputs is lower in ruminant production systems. The advantage of ruminants is the use of complementary feeds. The challenge is, therefore, to increase the animal output using noncompetitive feeds.

Table 2-1. Conversions of total and competitive feed protein into animal protein

Production unit	Protein conversion ratio[a]	
	Total[b]	Competitive[c]
Ruminant		
Beef	7.11	2.30
Sheep	14.50	1.90
Dairy	4.10	.95
Average	8.57	2.05
Nonruminant		
Swine	5.92	5.50
Broilers	3.91	2.50
Layers	3.91	2.20
Average	4.58	3.40

[a] Rumsey (1984).
[b] Total input per unit produced.
[c] Competitive input per unit produced.

When considering intensification of ruminant production to improve its competitiveness, research focusing on the following items should be beneficial:

a) Improve the utilization of high fiber feeds to take advantage of the comparative advantage of ruminants. In developing countries the feed input in ruminant production is almost exclusively rangelands, improved pastures and crop residues.

b) Use supplementation strategies, when pasture quality and(or) quantity is decreased, as an effective way to increase digestible energy intake and(or) deliver protein and other essential nutrients needed to balance the diet. As part of these strategies, the use of feed additives could improve and potentiate the response to supplements, both biologically and economically. Supplementation programs vary

widely from the more traditional corn-soybean meal to a variety of by-product feeds.

This review will focus on the use of antibiotics as feed additives in ruminants. Molasses supplementation in cattle fed high roughage diets will be briefly discussed.

Antibiotic Feed Additives in Ruminants

Feed additives that enhance animal performance through increased growth rate and(or) feed conversion in clinically healthy and nutritionally normal animals are termed growth promoters. According to Armstrong (1986), growth promoters can be defined as substances, other than a dietary nutrient, that increase growth rate and(or) feed efficiency in healthy animals fed a balanced diet. In contrast, feed additives that act prophylactically as disease suppressants are not growth promoters. Sometimes the same compound may serve both roles. For example, ionophores are coccidiostats in poultry and growth promoters in cattle. In practice it is often difficult to differentiate which role is more prevalent in a given situation. Other names for these effects found in the literature include nutrition improvers, growth permittants, growth effectors, and rumen additives (Muir, 1985).

Hays (1991) presented an overview of the beneficial response to antibiotics used at subtherapeutic levels (Table 2-2). These data illustrate that the response in young calves and pigs is greater than that in older animals, which

is consistent with one of the mechanisms proposed (disease control). Improvement in gain and feed efficiency account for the major portion of economic benefits and have reduced food cost (beef, pork, chicken and poultry) to consumers by more than 3.5 billion dollars annually in the USA (CAST, 1981). It is estimated that 45 to 55% of the antibacterial agents produced in the USA are administered to animals. Such estimates include the ionophores (Hays, 1991).

Table 2-2. Beneficial responses to subtherapeutic levels of antibiotics by several species

Species[a]	Number of experiments	Percentage improvement	
		Gain	Feed:gain
Broiler chick	286	2.94	2.48
Turkey	126	7.03	3.83
Beef cattle	65	4.92	5.27
Layer hens	244	4.01	4.72
Pigs:			
Starter stage	378	16.09	6.90
Growth stage	276	10.68	4.47
Grower-finisher	279	3.97	2.08
Young calves	85	14.29	-

[a] From Hays (1991).

Mechanisms of Action

The mechanisms by which antibiotics improve animal production in healthy animals has not been fully clarified. Three modes of action has been postulated for both, monogastric and ruminant species (Hays, 1991):

Metabolic effect. A direct effect has been shown for antibiotics that are absorbed, for example, inclusion of

chlortetracycline in the diet altered water and nitrogen excretion in pigs. However, antibiotics that are not absorbed can have indirect effects through nutrients available for absorption. Data that support a metabolic effect also tend to support a disease control or nutritional effect as the metabolic processes may be influenced by systemic or gastrointestinal infections, or by absorption of microbial metabolites.

Nutrient sparing effect. An increased response to antibiotics in the presence of nutritional deficiencies can be of major economic significance. Antibiotics may partially bridge the gap between nutritionally optimal and economically practical diets. Nutrient sparing effects can occur by one or more of the following:

a. Bacteria with similar requirements for critical nutrients (vitamins and amino acids) are inhibited.
b. Improved absorption of those nutrients that are available in limited quantities (changes in gut wall thickness).
c. Interaction of protein levels (quantity) and source (quality) and antibiotics may occur. Beneficial effects of adding antibiotics have been enhanced in animals fed protein deficient diets (quantity) and when feeding vegetable protein diets, compared to milk protein diets (quality).

Interpretation is difficult because these effects can be confounded with intake change. Enhancement of growth and feed efficiency is frequently associated with an increase in feed intake.

Disease control effect. Mainly related with control of subclinical diseases (analogous to subclinical parasitosis

of the gastrointestinal tract). The major benefit from subtherapeutic use of antibiotics results from the suppression of harmful microorganisms.

In a summary of the effect of the gastrointestinal micro flora, Visek (1978) stated that they a) affect growth and development of the host, b) influence nutritional requirements, c) affect morphogenesis of the gastrointestinal tract, d) modify metabolic activity of endogenous and exogenous substances introduced into the gastrointestinal lumen and e) play an active role in preventing foreign microorganisms from becoming established. The most convincing evidence is the lack of improved growth under germ free-conditions. Additional evidence includes the following: a) inactivated antibiotics do not have any effect on growth or feed utilization, b) injected antibiotics promote growth to the extent that they are secreted into the gut after injection, c) antibacterial agents are generally more effective growth promoters in quarters where hygiene is poor than in new or clean environments (Visek, 1978).

It has been suggested that the overall effect of antibiotics in ruminants is likely to be a composite of the effect of the antibiotics on the micro flora and fauna within the reticulorumen, and that resulting from any subsequent effect of the antibiotic within the small intestine and probably in the cecum and colon (Armstrong, 1984). Ruminal effect will be covered when discussing

specific drugs. Direct and indirect effects at the intermediate metabolism level are difficult to separate from the above, but cannot be ruled out. For post-ruminal effects to occur, the antibiotic included in the feed must survive the ruminal environment and not be absorbed or excreted post-ruminally.

Events in the small intestine. It may be useful to review effects at the small intestine level, even though most information was generated with monogastric species. Most of the comments are extracted from Visek (1978), Coates (1980), and Parker and Armstrong (1987). In germ-free animals there are specific changes in the histology of small intestinal villi with a reduction in the rate of enterocyte migration up the villus. In addition, there are changes in enzyme activity and rates of nutrient absorption.

A finding that was observed early and reported by several laboratories is a reduction in weight of the small intestine in antibiotic-fed chickens, swine and rats. There is evidence, from studies in pigs, that inclusion of antibiotics in the diet resulted in changes in morphology of the small intestine. Elongated villi and higher villus:crypt ratio were reported which is indicative of a lower rate of enterocyte migration. It has been suggested that a reduction in the production of toxic by-products normally arising from microbial activity in the digestive tract could reduce enterocyte damage and therefore lower cell renewal rates.

Degradation of endogenous urea to ammonia has been proposed as one of the negative effects of the microbial flora. Ammonia concentration in the intestinal lumen is above the concentration required to kill cells, alter nucleic acid synthesis, and depress immune response. Depression of bacterial ammonia production in the small intestine may therefore be one mechanism by which antibiotics stimulate growth (Visek, 1978). Antimicrobial compounds reduce ammonia concentrations and the production of amines, particularly cadaverine (Parker and Armstrong, 1987).

In germ-free animals the intestine and associated lymphoid structures contain less tissue, and cells of the intestinal mucosa are replaced at a slower rate (Coates, 1980). Their intestines are thinner and nutrients pass through them more rapidly in vitro. Germ-free animals also have a lower basal metabolic rate (Visek, 1978).

Reduction of microbial activity has also been suggested as playing a role in bile acid metabolism, enzyme activity and efficiency of absorption. Data discussed by Armstrong (1986) showed that uptake of methionine and glucose was increased in germ-free compared with conventional chickens. However, this increase was significant when expressed per gram of intestinal tissue but was not significant when expressed per unit length of the intestine. Intestinal tissues of conventional animals fed diets supplemented with antibacterial agents develop

characteristics similar to those of germ-free animals (Visek, 1978; Coates, 1980).

Inclusion of avoparcin in rat diets resulted in increased aminopeptidase activity in the illeal mucosa. Microbes within the small intestine of poultry are able to deconjugate bile acids with impairment of lipid absorption but it is uncertain to what extent the process is of significance for the bird. Antimicrobial feed additives in pig diets resulted in increased sucrase activity throughout the length of the small intestine. It has also been suggested that bacterial protease activity may play a role in the turnover of brush-border proteins, in which case reduction of bacterial numbers might increase mucosal enzyme activity. In pigs, virginiamycin enhanced uptake (9%) of free amino acids from a temporarily isolated intestinal loop (Parker and Armstrong, 1987). In sheep, avoparcin increased the number or activity of glucose receptors in brush border membrane vesicles in vitro (Parker, 1990).

A population of approximately 10^6 bacteria/g of small intestine content has been reported. Most of the isolates were gram-positive and were able to utilize starch. Possible competition with the host for starch digestion and other ruminal bypass nutrients has been suggested (Nicoletti et al., 1984).

Also, improved animal performance may be due to reduced energy cost of gut metabolism (Visek, 1978; Parker and Armstrong, 1987; Parker, 1990).

Importance of Gut Metabolism

Gastrointestinal tract (GIT) is one of the most active of the organ masses. In a week-old pre-ruminant lamb the fractional synthesis rate of protein (FSR) was 69%/d which is three times the FSR in skeletal muscle of the same animal. In older animals, the GIT may contribute up to one-third of total protein synthesis in the animal and equal or exceed muscle synthesis by up to 250%. The passage from the pre-ruminant to ruminant increases protein synthesis not only in the reticulo-rumen but also in the intestines (Lobley, 1993). Contribution of different tissues to total protein synthesis is summarized in Table 2-3.

Protein FSR of more than 100%/d has been observed for jejunum and duodenum in 8-wk-old weaned lamb, which was equivalent to a mean half-life of 14 to 18 h. Epithelial cell renewal times did not explain the rapid turnover. Renewal times (estimated from cell migration rate) were 60 to 90 h in comparable lambs. Intracellular synthesis of secretory proteins may account for the difference. In his review, Lobley (1993) concluded that the larger GIT mass and the substantial contribution this tissue makes to both the whole-body synthesis and to the overall protein economy of

ruminants makes this a particular target for potential manipulation.

Table 2-3. Contribution of major tissues to whole body protein synthesis (% of total)

Animal (age)[a]	Tissue or organ				Rest of body
	Muscle	Skin	GIT tract	Liver	
Lamb (1 wk)	29	13	12 (4)	12	34
Lamb (8 month)	18	20	26 (6-8)	8	28
Cattle (1-8 yr)	20	14	35 (6-8)	4	27

[a] From Lobley (1993). Values in brackets are percentages of total body weight (wt/wt).

A manipulation of N partitioning towards muscle and away from the gastrointestinal tract should give two advantages to the animal. First, a significant drain to the N economy of the animal relates to secretions and desquamations occurring in the gastrointestinal tract. The desquamated epithelial cell protein, excreted mucosal proteins, and other digestive secretions are digested and the amino acids are absorbed, but this resorption is unlikely to approach 100%. Second, the amino acid composition of gastrointestinal protein and other tissues (muscle, wool) are different. The match in need versus supply is superior in muscle relative to other tissues. Gastrointestinal tract secretions have high demand for valine, threonine, serine and proline (MacRae and Lobley, 1991).

Data derived from fluxes across the portal-drained viscera (PDV, includes gut, pancreas, spleen and omentum)

and liver of multi-catheterized cattle provided measurements of energy metabolism of gut tissues. Oxygen uptake by the PDV gave an estimate of heat energy (HE) attributable to those tissues. The PDV accounted for 18 to 25% and the liver 17 to 25% of the whole body oxygen uptake, or energy lost as HE (Huntington, 1990). He concluded that PDV and liver are metabolically active at rates disproportionately greater than their contribution to body mass, together they account for half the HE. McBride and Kelly (1990) reviewed the contributions of various biochemical processes to overall energy in the GIT (Table 2-4). These data suggested that due to the large contribution of GIT and liver to whole-animal energy expenditure, their manipulation could alter the energetic efficiency of ruminant production.

Table 2-4. Metabolic energy expenditures pertaining to the ruminant gastrointestinal tract (GIT)

Item[a]	GIT energy expenditure, %	Whole-body energy expenditure, %
Na, K-ATPase	29 to 62	5.7 to 12.4
Protein synthesis	20 to 23	4.0 to 4.6
Protein degradation	4.3	.9
Total	53 to 90	10.6 to 17.9

[a] From McBride and Kelly (1990).

Nonionophore Antibiotics

Numerous antibiotics have been or are in use for growth promotion (Table 2-5). They represent a diverse group differing in chemistry, primary antibacterial spectrum, mode

of action of bacterial inhibition, molecular weight, and absorption from the GIT. Antibiotics that are not absorbed from the gut or poorly absorbed at the low dosage used are desirable as feed additives, because of the absence of residues in milk and meat and because there is no need for a withdrawal period before slaughter (Nagaraja, 1995).

Bacitracin, chlortetracycline, oxytetracycline, and tylosin have been approved for control of liver abscesses in the USA. Tylosin has proven to be more efficacious than other antibiotics for this purpose and it is used routinely with monensin as an additive in feedlot diets (Nagaraja, 1995).

Avoparcin, a glycopeptide antibiotic produced by S. candidus, interferes with bacterial cell wall biosynthesis. It is effective against gram-positive organisms and gram-negative species with a gram-positive structure (Armstrong, 1984). It is used as a feed additive in Europe and Australia, but it is not approved for use in the USA.

Bambermycins

Bambermycins (Gainpro™) is a fermentation product of a variety of Streptomyces spp., including S.bambergiensis, S. ghanaensis, S. ederensis and S. geysiriensis (Hoechst-Roussel, 1993). The first antibiotic complex of this group was moenomycin (flavomycin, bambermycins), reported in 1965 (Huber, 1979). They are classified as sugar lipid

Table 2-5. Characteristics of nonionophore antibiotics used in ruminants

Antibiotics[a]	Chemistry	Antibacterial spectrum	Bacterial inhibition	Molecular weight	Absorption from gut
Avoparcin	Glycopeptide	Narrow, Gram +	Cell wall synthesis	1500	No
Bacitracin	Polypeptide	Narrow, Gram +	Cell wall synthesis	1488	No
Chlortetracycline	Tetracyclines	Broad, Gram + and Gram -	Protein synthesis	479	Yes
Flavomycin or Bambermycins	Phosphorus containing glycolipid	Narrow, Gram +	Cell wall synthesis	1582	No
Neomycin	Aminoglucoside	Narrow, Gram +	Protein synthesis	909	No
Oxytetracycline	Tetracyclines	Broad, Gram + and Gram -	Protein synthesis	499	Yes
Spiramycin	Macrolide	Narrow, Gram +	Protein synthesis	842-898	Yes
Tylosin	Macrolide	Narrow, Gram +	Protein synthesis	915	Yes
Viginiamycin	Peptolide and macrocyclic lactone	Narrow, Gram +	Protein synthesis	525 and 823	Yes

[a] Adpated from Nagaraja (1995).

antibiotics (Berdy, 1980). These antibiotics are characterized by a high molecular weight from 1,600 to 2,100 daltons and a phosphorus concentration of about 2%. They consist of an oligosaccharide part, phosphoglyceric acid, a C_{25}-lipid alcohol, and an UV chromophore (Huber, 1979). These glycolipid antibiotics exhibit bacteriostatic activity at very low concentrations. At higher concentrations, they are bactericidal only against actively multiplying gram-positive bacteria (Huber, 1979). The mode of action of these antibiotics involves the inhibition of bacterial cell-wall biosynthesis by preventing formation of the cell wall component peptidoglycan (Huber, 1979; Berdy, 1980).

Ruminant Performance

Relatively few reports are available on the effect of bambermycins in ruminants. It has been in use as feed additive (Flavomycin™) for cattle and sheep for several years in Europe and Australia.

Bambermycins tested at 0 to 80 mg/d showed no improvement in ADG at dosages above 20 mg/d. Pooled analysis of the five studies presented in Table 2-6 for treatments 0, 5, 10 and 20 mg bambermycins demonstrated that bambermycins fed at 10 and 20 mg/d increased ($P < .05$) ADG of steers and heifers consuming pasture by .09 kg when compared with control cattle (Hoechst-Roussel, 1993). Grant et al. (1974) reported 5% average response to flavomycin in both gain and feed efficiency, when dosed at 0, 2.5, 5, 10, and 20 mg/d in

nine trials with cattle fed medium- to high-energy diets. Based on nine feedlot dose titration studies, a range of 10 to 20 mg bambermycins/d was approved to increase ADG and feed efficiency in feedlot cattle (Table 2-6, Hoechst-Roussel, 1993). Huber (1979) recommended 25 to 50 mg flavomycin for beef cattle. European studies used 40 to 50 mg flavomycin for beef cattle.

Two trials with growing and finishing feedlot cattle compared bambermycins with ionophores (Table 2-7). Bambermycins did not appear to depress intake and intake was higher than when monensin and lasalocid were added. Feed:gain was similar to lasalocid and ADG was similar to that achieved with monensin in one trial (Hoechst-Roussel, 1994). In the other trial, however, response to monensin was better than bambermycins for ADG and feed efficiency (Burris and Randolph, 1996). A pooled summary of four pasture trials (Table 2-7) showed that bambermycins and lasalocid had greater ADG than control, and bambermycins had greater ADG than monensin or lasalocid (Keith et al., 1995).

Flavomycin improved gain and feed efficiency when cattle were fed beet pulp but not when fed corn silage and had no effect on DM intake in either diet (Table 2-8, De Schrijver et al., 1990). Bambermycins increased gain and feed efficiency in heifers fed high forage growing diets (Dhuyvetter et al., 1996). Bambermycins combined with A. oryzae decreased fed intake (Table 2-8). Bambermycins was

also effective in improving gain in cattle on pasture offered a self fed supplement (Kunkle et al., unpublished results, Table 2-8).

Table 2-6. Gain (kg/d) in titration studies for cattle consuming pasture and feedlot diets, and gain and feed efficiency for feedlot cattle

	Bambermycins, mg/d						
Pasture	0	5	10	20	40	60	80
1. Buffalo grass	.762	-	1.033	.927	.927	.973	.893
2. Smooth brome grass	.690	-	.742	.793	.771	.812	.788
3. Fescue/ ladino clover	.777	-	.773	.842	.843	.863	.856
4. Bermuda/ bahiagrass	.465	.469	.505	.602	-	-	-
5. Wheat/ ryegrass	.876	.884	.903	.945	-	-	-
Pooled 1-3[a]	.78[d]	-	.86[e]	.89[e]	.87[e]	.91[e]	.87[e]
Pooled 4&5[b]	.67[d]	.67[d]	.70[d]	.77[e]	-	-	-
Feedlot:[c]							
ADG	1.14	1.17	1.18	1.18	1.18	-	-
Feed:gain	8.90	8.76	8.70	8.97	8.67	-	-

[a] Deetz et al. (1990). Yearling cattle received .45 or .9 kg control supplement or containing bambermycins. Quadratic effect ($P < .0005$), plateau was 18.5 mg of bambermycins.

[b] Deetz et al. (1992). Yearling cattle received .45 kg corn control or with bambermycins.

[c] Hoechst-Roussel (1993). Cattle dosed 5 mg bambermycins/d gained 1.15 kg (different from control, $P < .05$) and had 8.9 feed:gain (similar to control). Cattle dosed with 10 mg or more had higher ($P < .05$) gain and feed efficiency than control.

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

Table 2-7. Performance data for 112-day feeding experiments comparing bambermycins, monensin and lasalocid

Item	Control	Bamberm	Monen	Lasal	Ref
Feedlot:					
ADG, kg	-	1.16^{a}	1.10^{ab}	1.05^{b}	1
Intake, kg	-	8.14^{a}	7.70^{b}	7.75^{b}	
Feed:gain	-	7.00^{ab}	6.96^{a}	7.28^{b}	
ADG, kg	1.34	1.39	1.45	1.37	2
Intake, kg	9.04	9.05	8.85	8.96	
Feed:gain	6.77	6.52	6.14	6.57	
Pasture:					
Fescue	$.85^{b}$	$.94^{a}$	$.83^{b}$	$.84^{b}$	3
Crested wheat	$.61^{b}$	$.75^{a}$	$.69^{a}$	$.72^{a}$	
Bermudagrass	$.73^{a}$	$.73^{a}$	$.63^{b}$	$.76^{a}$	
Orchardgrass	$.51^{c}$	$.63^{ab}$	$.66^{a}$	$.56^{bc}$	
Pooled	$.67^{y}$	$.76^{x}$	$.70^{z}$	$.72^{yz}$	

^{abc} Means in a row with different superscript differ ($P < .05$).
^{xyz} Means in a row with different superscript differ ($P < .08$).

1 = Hoechst-Roussel (1994). First 56 days, ration composition was 52.6 % TDN and 57.1 % NDF (brome hay 44%, corn silage 52% and a protein-energy supplement); rest of the trial ration composition was 60.6 % TDN and 44.6 % NDF (alfalfa hay 17%, corn silage 63%, and a protein-energy supplement).

2 = Burris and Randolph (1996). Diet was corn silage (6.7% CP; 69% TDN) and 7% cracked corn ad libitum, along with .9 kg of a pelleted supplement (45% CP) which provided no additive (control), 20 mg bambermycins, 200 mg monensin or 300 mg lasalocid. Feed additives higher ADG than control ($P < .11$), monensin higher ($P < .01$) than bambermycins or lasalocid. Bambermycins higher ($P < .09$) feed intake than monensin or lasalocid. Monensin higher ($P < .02$) feed efficiency than bambermycins or lasalocid.

3 = Keith et al. (1995). All steers fed .9 kg supplement, non-medicated (control), with 20 mg bambermycins, and 150 mg monensin or lasalocid.

Table 2-8. Feed intake, gain, and feed efficiency in cattle fed bambermycins (flavomycin)

Reference and diets	Intake, kg DM	Gain, kg	Feed to gain
De Schrijver et al. (1990)[a]			
Basal-1 : corn silage + 1% BW concentrate	9.22	1.44	6.41
Basal-1 + 43 mg flavomycin	9.13	1.46	6.25
Basal-2: beet pulp 50%, concentrate 50%	10.15	1.31	7.69
Basal-2 + 53 mg flavomycin	10.55	1.51	6.99
Pooled analysis:[b]			
Basal-1 and 2	9.67	1.34	7.21
Flavomycin	9.80	1.43	6.84
Dhuyvetter et al. (1996)[c]			
Basal: corn silage 38%, oat hay 25%, barley grain 30.5%, protein supplement 5.6%	7.19	.98	7.37
Basal + 20 mg bambermycins	7.25	1.04	6.91
Basal + A. oryzae	7.17	1.03	6.92
Basal + bambermycins and A. oryzae	7.07	NR	NR
Kunkle et al. (unpublished)			
Bahiagrass pasture[d]			
Block supplement control	-	.45	-
Block supp. + flavomycin	-	.58	-
Bahiagrass pasture[e]			
Loose mineral control	-	.39	-
Loose mineral + flavomycin	-	.47	-

[a] White-blue bulls 350 kg initial BW. Trial duration was 12 wk for each basal diet.

[b] Animals were shifted diets over a 4-wk period. Probability values for intake, gain and feed:gain were: .67, .81, and .71 (basal-1); .23, .002, and .03 (basal-2); and .36, .09, and .13 (pooled analysis).

[c] Charolais crossbred heifers 260 initial BW. Bambermycins by A. oryzae interaction (P = .03) for DM intake. Animals fed bambermycins and A. oryzae combined had lower (P < .05) intake than all other treatments. Gain and feed:gain reported are main effects of bambermycins and A. oryzae. Both feed additives increased ADG (P < .02) and feed efficiency (P < .03). NR = not reported.

[d] Holstein steers and heifers of various breeds 250 kg initial BW. Supplement consumption was .29 kg/d. Gain higher (P < .05) with flavomycin.

[e] Holstein steers and heifers of various breeds 230 kg initial BW. Supplement consumption was .27 and .38 kg/d for control and flavomycin mineral supplement. Gain higher (P < .05) with flavomycin.

Other reports include those of Flachowsky and Richter (1991) in which flavomycin did not affect feed intake but increased ADG (10.5%) and reduced feed and energy required per unit gain (10.6%) in heifers. Alert et al. (1993) reported 3.5% higher gain and 3.2% better energy utilization in fattening Friesian bulls supplemented with 50 mg/d flavomycin. Carcass composition or organ weight were not affected by the additive. Feed intake was increased in the first 56 d of the trial. Poppe et al. (1993) reported no influence of flavomycin on feed intake of heifers. Scott and Kay (1984) reported no effect of 40 mg of flavomycins in gain or feed efficiency of cattle fed grass silage and rolled barley supplement while monensin and salinomycin improved feed efficiency. Kay et al. (1983) reported gain increases of .15, .07, and .05 kg in three trials in cattle fed grass silage and rolled barley supplement with avoparcin, monensin, salinomycin, and 40 mg of flavomycin. Galbraith et al. (1983) reported increased gain in cattle fed 40 mg of flavomycin on barley diets (1.66 vs 1.50 kg). In young calves flavomycin tended to ($P > .05$) increase gain by 5 to 8% and had no effect on feed intake (El-Jack et al., 1986; Fallon et al., 1986).

The limited information available show that bambermycins increased ADG by 1 to 29% and improved feed efficiency by 2 to 10%. Bambermycins did not affect or tended to increase feed intake when compared with control

diets, and tended to increase intake when compared with ionophores, especially monensin.

The effect of bambermycins on feed intake in sheep is not clear (Table 2-9). Aitchison et al. (1989b) and Murray et al. (1992) reported no effect of flavomycin on feed intake. Murray et al. (1992) reported slower rate of eating in sheep supplemented with flavomycin. The eating rate was dependent on the type of diet; it was decreased in animals fed hay-fishmeal and supplemented with flavomycins (Murray et al., 1990). In addition, sheep fed lupin seed twice a week with flavomycin and methionine ate less ($P < .05$) chaff on the day after feeding on the lupins and then ate more ($P < .05$) on the following day than sheep not fed any sulfur supplement (Murray et al., 1991).

Gain and wool production response to bambermycins appear related to diet (Table 2-9). Murray et al. (1992) suggested that the lack of wool production response to flavomycin in growing sheep may be related to partitioning of dietary protein towards tissue rather than wool growth. Maturity (age) and nutritional history of sheep may have an important effect on wool production. They also suggested that the best response to flavomycin will be obtained in adult sheep in areas where the feed supply is reasonably constant.

In summary, bambermycins increased gain of cattle fed a variety of diets, and it appears especially indicated in

Table 2-9. Effect of flavomycin and other feed additives in sheep

Reference and diets	Feed Intake, g/d	Daily gain, g/d	Daily wool growth, g/m^2
Aitchison et al., (1989a)			
Oaten chaff[a]			
Control	726		
Lasalocid		27	5.11
Avoparcin		27	4.40
Flavomycin		21	4.89
		43	5.52
Pellet[a]	591		
Control		-3	6.40
Lasalocid		-9	6.37
Avoparcin		-7	5.75
Flavomycin		9	6.82
Aitchison et al., (1989b)			
Run I (weeks 1 to 4)			
Wheaten chaff[b]			
Control	865	149	5.5
Flavomycin, 10 ppm	895	165	5.9
Flavomycin, 20 ppm	853	174	6.8
Tetronasin, 5 ppm	893	179	5.7
Tetronasin, 10 ppm	843	104	5.7
Pellet[b]			
Control	1503	352	11.5
Flavomycin, 10 ppm	1573	359	12.7
Flavomycin, 20 ppm	1500	344	14.1
Tetronasin, 5 ppm	1548	390	13.0
Tetronasin, 10 ppm	1519	367	11.8
Run II (weeks 5 to 9)			
Wheaten chaff[b]			
Control	926	38	6.2
Flavomycin, 10 ppm	920	25	5.8
Flavomycin, 20 ppm	962	30	5.8
Tetronasin, 5 ppm	965	7	7.0
Tetronasin, 10 ppm	912	25	5.5
Pellet[b]			
Control	1727	231	11.6
Flavomycin, 10 ppm	1875	289	11.8
Flavomycin, 20 ppm	1835	303	13.3
Tetronasin, 5 ppm	1800	278	14.0
Tetronasin, 10 ppm	1720	276	13.4

Table 2-9 --continued

Reference and diets	Feed Intake, g/d	Daily gain, g/d	Daily wool growth, g/m^2
Murray et al. (1990)			
Lucerne-lupins[c]	NR		
Control		138	13.4
Flavomycin, 10 ppm		144	13.0
Flavomycin, 20 ppm		162[d]	13.8
Flavomycin, 30 ppm		152	13.5
Hay-fishmeal[c]	NR		
Control		161	13.2
Flavomycin, 10 ppm		151	14.6
Flavomycin, 20 ppm		142[d]	15.5[d]
Flavomycin, 30 ppm		130[d]	15.4[d]

[a] Diets fed at maintenance to Merino wethers, 37 kg BW. Oaten chaff 6% CP; pellet diet (59% lucerne, 25% lupins, and 15% barley) had 20% CP. Lasalocid: 30, 50, and 70 ppm; avoparcin: 25, 50, and 75 ppm, flavomycin: 5, 15, and 30 ppm. Reported values are means of the three levels because no effect of level. Flavomycin higher ($P < .05$) gain than all others treatments. Flavomycin higher ($P < .01$) wool production than other additives and higher ($P < .1$) wool production than control. Pellet greater ($P < .001$) wool production than chaff diets.

[b] Weaner Merino wethers, 29 kg BW, given ad libitum access to diets. Chaff diet had 7.3% CP; pellet diet (59% lucerne, 25% lupins, and 15% barley) had 19% CP. Difference due to additive: both additives increased ($P < .001$) gain of sheep eating pellet in Run II, and both additives increased ($P < .01$) wool growth in sheep fed pellet in both Runs.

[c] Twenty-month old merino ewes fed at 3.5% of BW. Lucerne-lupin diet (58% lucerne, 25% lupin, 15% barley) had 18% CP; hay-fishmeal (24.5% lucerne, 51.5% wheat chaff, 10% lupin, 12% fishmeal) had 17.3% CP. Flavomycins linearly ($P < .001$) depressed gain in animals fed hay-fishmeal.

[d] Indicates value different from control ($P < .005$).

high roughage diets. Bambermycins appears to have little effect on feed intake when compared with control. Animals supplemented with bambermycins appear to have higher feed intake than the ones supplemented with ionophores, especially monensin. How bambermycins affects intake of warm-season grasses (pasture or hay) is unknown. Other feed additives, such as monensin, have been shown to have a variable effect on forage intake (Ellis et al., 1984).

Because bambermycins is targeted for use with high fiber diets it is a high research priority to evaluate its effect on intake in this type of diet. Bambermycins also improved efficiency of feed utilization. This information, however, has the same limitations indicated for intake.

Limited information suggests that bambermycins did not affect amount of feed intake in sheep. Reports only mentioned effect on rate of eating and it is not clear if this effect translated into effects on performance. Information from sheep research did little to clarify the effect of bambermycins on intake, gain and feed efficiency.

There are no available data on the effect of bambermycins with high roughage diets supplemented with molasses. Limited information suggests that ionophores may not be efficacious in those diets. Research is needed to test the efficacy of bambermycins for improving gain, and to evaluate its effects on feed intake and efficiency of feed utilization with cattle fed this type of diet.

Digestive Function

In vitro. Bambermycins included at 8 or 20 ppm in media had very little or no effect on several variables. Substrates included casein, amino acids, cellobiose-maltose, neutral detergent fiber, and starch. Variables measured included proportion of volatile fatty acids produced from different substrates, methane and ammonia production, efficiency of bacterial growth, and fiber and starch

digestion. The only effect of flavomycin was a higher proportion of acetic acid and lower proportion of butyric acid when neutral detergent fiber was the substrate. Flavomycin, one of 15 additives tested, had less effect on variables studied than most of the other additives (Van Nevel and Demeyer, 1990; Van Nevel and Demeyer, 1992).

Ruminal pH. Bambermycins inclusion in the diet increased ruminal pH at the end of week 4; however, by the end of week 9 there was no effect on pH (Murray et al., 1992). Using high (pellet) and low (chaff) quality diets at maintenance level, Aitchison et al. (1989a) found that inclusion of bambermycins increased ruminal pH (6.94 vs 6.57, average of both diets). When the same diets were given ad libitum, there was a trend toward a similar effect (Aitchison et al., 1989b). No effect of bambermycins on pH was found in diets supplemented with different sources of sulfur (Murray et al., 1991), or 10, 20 and 40 ppm bambermycins (Murray et al., 1990). Because samples were obtained with stomach tube in these trial, the sampling technique may have contributed to the variability observed.

Ruminal ammonia. Bambermycins increased ruminal ammonia concentrations in weaner lambs (147 vs 117 mg N/L) and adult sheep (180 vs 173 mg N/L) on a diet of alfalfa chaff (30%), chopped wheaten hay (52%), fishmeal (6%) and lupin grain (10%), containing 16.4% CP (Murray et al., 1992). Other work reported by the same researchers showed no effect of

bambermycins on ruminal ammonia with diets of different qualities and supplemented with several sources of sulfur (Murray et al., 1991). When alfalfa-lupin and hay-fishmeal diets were supplemented with 10, 30 and 40 ppm bambermycins, ruminal ammonia concentrations were depressed only in the hay-fishmeal diet (Murray et al. 1990). Bambermycins produced opposite effects on ruminal ammonia concentration depending upon the level of feed intake. Bambermycins added to high or low quality diets fed at maintenance level increased ruminal ammonia (349 vs 291 mg N/L) in the high quality diet only (Aitchison et al., 1989a). However, when those diets were fed ad libitum bambermycins reduced ruminal ammonia concentration (168 vs 216 mg N/L) in the high quality diet (Aitchison et al., 1989b). Bambermycins inclusion in concentrate fed to young calves had no effect on ruminal ammonia concentrations (El-Jack et al., 1986; Fallon et al., 1986). Rowe et al. (1982) also did not find an effect of flavomycin on ruminal ammonia in cattle.

Ruminal volatile fatty acids. Inclusion of bambermycins in the diet decreased the total VFA concentration (65.3 vs 78.5 mM/L) by the end of wk 4, but there was no effect of bambermycins by wk 9. Molar proportions of propionate were increased at both sampling times from 25 to 28 mol/100 mol (Murray et al., 1992). In another trial, bambermycins increased total VFA when the diet was supplemented with methionine, but it had no effect on total VFA or propionate

molar proportion when the diet was supplemented with other sulfur sources (Murray et al., 1991). In lucerne-lupin and hay-fishmeal based diets, addition of 10, 20 and 40 ppm bambermycins did not affect total VFA or acetate proportions. However, propionate proportion was increased, while butyrate was decreased in both diets. The level of 20 ppm of bambermycins was the most consistent in producing these effects (Murray et al., 1990).

Bambermycins did not affect total VFA or molar proportions of individual VFA when added to low or high quality diets fed at maintenance levels (Aitchison et al., 1989a). When these diets were fed ad libitum, 10 ppm bambermycins decreased total VFA in both diets. Addition of 20 ppm bambermycins increased propionate proportion in the high quality diet only (Aitchison et al., 1989b).

In fattening cattle, bambermycins did not affect total VFA or VFA molar proportions (Flachowsky and Richter, 1991; Alert et al., 1993). Also, in young calves, flavomycin inclusion in the dry feed had no effect on VFA proportions in ruminal fluid (El-Jack et al., 1986; Fallon et al., 1986). In contrast, Earley et al. (1996) reported that bambermycins lowered the acetate:propionate ratios in steers fed alfalfa-grass hay. Steers fed monensin, however, had lower acetate:propionate ratios than steers fed bambermycins. In a similar experiment, DelCurto et al. (1996) reported higher total VFA in steers fed a 90%

concentrate diet with bambermycins. In this trial, steers fed bambermycins had lower acetate:propionate ratios than the ones fed lasalocid.

Ruminal protozoa. Bambermycins in the diet did not affect the number of protozoa in a nine-week trial with sheep (Murray et al., 1992). Alert et al. (1993) reported similar findings in cattle.

In summary, bambermycins has not had consistent effects on ruminal pH, ammonia, total VFA concentrations or molar proportions of VFA. This may be related to experimental conditions and(or) bambermycins may not have a specific action on ruminal fermentation, in contrast to ionophores.

Ruminal digestion. Bambermycins did not affect cellulose degradation, total VFA or VFA proportions in the rumen in cattle (Rowe et al., 1982), even though they used a high dose (20 mg/100 kg body weight). This was interpreted as no effect of bambermycins on ruminal fermentation. In situ rate of digestion was not affected by addition of bambermycins or ionophores in steers on alfalfa-hay diets (Early et al., 1996). On the other hand, bambermycins decreased OM, CP and CF digestibility in the rumen (Poppe et al., 1993). Bacterial microbial protein production was also reduced. However, 30 g/d more amino acid, apparently of dietary origin, reached the gut in bulls supplemented with bambermycins.

Total tract digestion. Bambermycins did not affect total tract digestibility of DM, CP, fat, CF, ash and N-free extract in wethers offered a diet of 50% beet pulp and 50% concentrate at maintenance level (De Schrijver et al., 1991). Flachowsky and Richter (1991) also reported no effect of 5 or 10 mg of bambermycins/d on apparent OM digestibility in wethers. In an experiment with fattening Friesian bulls, 50 mg of bambermycins/d increased apparent DM, CF and N-free extract digestibility (Alert et al., 1993). Increased total tract OM digestibility was also reported by Poppe et al. (1993) in cattle. In young cattle, addition of flavomycin increased total tract CP digestibility (Fallon et al., 1986). Total tract digestibility tended to increase in steers supplemented with bambermycins or ionophores on alfalfa-hay diets (Earley et al., 1996). However, no effect of feed additive was observed in 90% concentrate diets (DelCurto et al., 1996).

There is no consistent effect of bambermycins on ruminal or total tract digestibility.

Post-ruminal Effects

Rowe et al. (1982) measured the post-ruminal antibacterial activity of bambermycins by inhibition bioassay using Bacillus subtilis. There appeared to be no loss of antibacterial activity of bambermycins in the sheep digestive tract. The presence of active antibiotic in the intestine prompted suggestions that bambermycins may act at

the post-ruminal level, similar to the mechanism of action proposed in monogastrics (MacRae, 1989; Rowe et al., 1991).

Bambermycins increased whole body protein accretion (Table 2-10) when given alone or in combination with clenbuterol. These findings support the notion that antibiotics active in the gastrointestinal tract reduce the mucosal cell turnover by reducing microbial invasion, thereby allowing a greater net partitioning of amino acids towards other body tissues (MacRae, 1989; MacRae and Lobley, 1991).

Post-ruminal effects have also been proposed for avoparcin. MacGregor and Armstrong (1984) used mature sheep fitted with ruminal cannulas and re-entrant cannulas at the proximal duodenum and the terminal ileum. Avoparcin and(or) saline solution were continuously infused into the proximal duodenum and subsequently into the rumen of four sheep. Results of their study and those of a previous one where avoparcin was incorporated in the diet (MacGregor and Armstrong, 1982) are presented in Table 2-11.

Table 2-10. Protein accretion (g/d) in sheep given clenbuterol (1.5 mg/d) and(or) bambermycins (20 mg/d)

Treatment[a]	Control	Clenbuterol[b]
Control	20.6	35.0
Bambermycins[c]	25.0	39.4

[a] From MacRae and Lobley (1991). Sheep (n = 12) were fed pelleted dried grass at twice maintenance level of energy intake.
[b] Effect of clenbuterol, $P < .001$.
[c] Effect of bambermycins, $P < .05$.

Table 2-11. Effect of avoparcin on the net uptake of amino acids from the small intestine (g amino acid N/g amino acid N entering the small intestine)

	Duodenal infusion		Ruminal infusion		Included in feed	
Amino acid[a]	Con	Avop	Con	Avop	Con	Avop
Total	.648	.697	.634	.692	.598[b]	.687[c]
Essential	.613	.679	.664	.734	.553	.682
Non-Essential	.628	.689	.673	.747	.580	.718

[a] MacGregor and Armstrong (1982).
[b, c] P <.05, trends for individual amino acids were in the same direction. Con = control; Avop = avoparcin.

Avoparcin increased net uptake of amino acids when included in the diet but not when ruminally or duodenally infused. Nevertheless, the authors felt that the trends were consistent with avoparcin enhancing net uptake of amino acids from the small intestine and that this effect was independent of any effects the antibiotic may have on digestion occurring in the rumen.

Further work in rats showed that increasing levels of avoparcin in the diet increased intestinal dipeptidase activity (units/g fresh weight of mucosa) and specific activity (units/mg protein). If the hydrolysis of dipeptides to amino acids by the action of dipeptidases was the rate limiting step in the transfer of amino-N from the intestinal lumen to the portal blood then an increase in dipeptidase activity stimulated by avoparcin could account for at least part of its growth-promoting effect (Parker et al., 1984).

Predominant bacteria in the small intestine are gram-positive which are sensitive to many antibiotic additives, whereas those in the large intestine are gram-negative. Therefore it is expected that the small intestine is the more likely site for antimicrobial effects (Parker, 1990).

Avoparcin was associated with increased N retention, probably due to lower turnover of gut mucosa (MacRae, 1989; (Parker, 1990). To test the hypothesis that avoparcin will affect gut tissue metabolism of ruminants, Parker (1990) conducted a trial in which weaned lambs were fed a pelleted diet containing either 0, 19 or 28 ppm avoparcin for 6 wk. At the end of the trial, five sheep from each group were anesthetized and injected with vincristine, which causes any cell entering into mitosis to be arrested at metaphase. Rate of cell division in the crypts of duodenal tissue after 90 min was significantly lower with avoparcin treatment, providing evidence for a nutrient-sparing effect in the small intestine. Thus, it appears that the effect of avoparcin in the small intestine of ruminants could be similar to those observed in monogastric species consuming diets supplemented with antibiotics.

Other effects. Bambermycins reduced the duration and prevalence of Salmonella shedding in calves and reduced the number of Salmonella resistant to other antibiotics (Dealy and Moeller, 1977a). Reduction of Escherichia coli resistant to other antibiotics has also been reported (Dealy and

Moeller, 1977b). Flavomycin exhibited a preferential inhibition of E. coli and S. typhimurium bearing plasmids (Huber, 1979).

Summary of Effects of Bambermycins

The limited information available suggests that bambermycins improves animal performance, but in some cases, this effect depends upon the nature of the basal diets. Effects on ruminal fermentation are not consistent. Some researchers have reported increased propionate, while most others reported no difference in VFA concentrations or molar proportions. Total tract digestibility has been increased in several reports, but not in others. The presence of active antibiotic in the small intestine suggests possible post-ruminal effects, and modes of action may be similar to those reported for avoparcin. Bambermycins improved gain in several experiments, but it was seldom associated with changes in ruminal fermentation that would suffice to explain this effect. Few ruminal effects support the hypothesis of post-ruminal effects. Research is needed to test this hypothesis in cattle. Techniques described by Jin et al. (1994) to evaluate intestinal growth, cell proliferation, and morphology may be useful for such purposes. However, this type of research is beyond the scope of this project. The effect of bambermycins on ruminal function and nutrient digestibility is not completely elucidated, and there is no information with high roughage

diets supplemented with molasses. Therefore this research will address the effect of bambermycins on digestive function in cattle fed these diets.

Ionophore Antibiotics

Ionophores have been defined as substances capable of interacting with metal ions, thereby serving as a carrier by which these ions can be transported across a bimolecular lipid membrane. Monensin can be described as a cation-proton antiporter while lasalocid does not display an obligatory cation-proton antiporter mechanism. Ionophores do not display the same affinity for all cations. Monensin mediates primarily Na^+-H^+ exchange, because the affinity of monensin for Na^+ is ten times higher than that for K^+. Lasalocid displays a higher affinity for K^+ (Bergen and Bates, 1984).

Accepted mechanisms by which ionophores negatively affect bacteria include nonphysiological ion leak caused by ionophores and consequently ATP depletion. This effect is greater in gram-positive bacteria. Gram-negative bacteria have a cellular envelope (outer membrane) that serves as a protective barrier, excluding ionophore complexes (Bergen and Bates, 1984; Russell and Strobel, 1989).

Bergen and Bates (1984) summarized the effects of monensin as follows: the ionophore acts on the flux of ions through membranes dissipating cation and proton gradients and interfering with the uptake of solutes and the primary

transport system in the cells. The organisms try to maintain primary transport by expending metabolic energy. Because gram-negative bacteria are able to produce ATP through electron transport, they can survive better, so there is a shift to these organisms in the rumen. It is this shift that is responsible for the final effect of an ionophore on ruminal metabolism.

Ionophores are generally bacteriostatic and not bactericidal (Nagaraja and Taylor, 1987). Bergen and Bates (1984) suggested that monensin would cause entry of protons into ruminal bacteria in exchange for Na^+. However, Russell (1987) using S. bovis as a model, showed that direction of Na^+ was opposite to this. Monensin produced a decrease in intracellular K^+ concentration and influx of protons, resulting in lower intracellular pH. Once intracellular pH was acidic, monensin produced an efflux of protons in exchange for Na^+. The inhibition of S. bovis was attributed to futile cycling of ions across the cell membrane resulting in loss of intracellular K^+, accumulation of intracellular Na^+ and depletion of ATP (Russell, 1987; Strobel et al., 1989). The postulated mechanism of inhibition may be affected by high mineral concentration, as will be discussed later.

A list of ionophores used or under investigation is given in Table 2-12, taken from Nagaraja (1995).

Table 2-12. Ionophores used or under investigation for use in ruminant diets

Ionophore[a]	Molecular weight	Cation Selectivity Sequence
Monensin	671	$Na^+>K^+$, $Li^+>Rb^+>Cs^+$
Lasalocid	591	Ba^{++}, $K^+>Rb^+>Na^+>Cs^+>Li^+$
Laidlomycin	721	ND[b]
Lysocellin	660	$Na^+>K^+$, Ca^{++}, Mg^{++}
Narasin	765	$Na^+>K^+$, Rb^+, Cs^+, Li^+
Salinomycin	751	Rb^+, $Na^+>K^+>>Cs^+$, Sr^+, Ca^{++}, Mg^{++}
Tetronasin	628	$Ca^{++}>Mg^{++}>Na^+$, $K^+>Rb^+$

[a] From Nagaraja (1995).
[b] ND = Not determined.

Effects on Performance

A review by Goodrich et al. (1984) summarized the results of 228 feedlot trials and 28 pasture studies (Table 2-13). In feedlot diets, the most significant effect of monensin is an improvement of feed efficiency, as a result of little effect on gain and a reduced feed intake. A more recent review (Owens et al. 1991) showed the same trend with feedlot cattle fed monensin.

Effects of other ionophores in concentrate diets are summarized in Table 2-14, adapted from Owens et al. (1991). The effect on feed intake is dependent on the ionophore used in feedlot diets. Monensin and laidlomycin appear to represent the extreme effects of ionophores on intake. Intake decreased with increasing levels of monensin. Lasalocid showed similar trends with less depression of intake, while laidlomycin increased feed intake (Owens et al., 1991).

Table 2-13. Summary of effect of monensin on intake and performance

Diet type	Variable	Control	Monensin	Change, %	Ref.[a]
Concentrate	ADG, kg	1.09	1.10	1.6	1
	Intake, kg	8.27	7.73	-6.4	
	Feed/gain	8.09	7.43	-7.5	
Concentrate	ADG, kg	1.26	1.27	.6	2
	Intake, kg	8.97	8.47	-5.6	
	Feed/gain	7.29	6.83	-7.5	
Pasture	ADG, kg	.609	.691	13.5	3
Pasture	ADG, kg	.786	.893	13.7	4
Pasture	ADG, kg	.540	.630	17	5
Pasture	ADG, kg	.560	.650	16.3	6
Pasture	ADG, kg	.590	.680	15.5	6
Harvested	ADG, kg	.612	.698	14.1	6
Forage	Intake, kg	7.39	7.18	-3.1	
	Feed/gain	12.4	10.5	-15.3	
Small Grain	ADG, kg	.540	.620	15	7
Pasture	ADG, kg	.540	.605	12	
	ADG, kg	1.04	1.12	7.8	
	ADG, kg	1.15	1.24	7.8	
Pasture	ADG, kg	.600	.640	6.7	8
	ADG, kg	.860	.880	2.3	
	ADG, kg	1.16	1.25	7.8	
	ADG, kg	.970	1.02	5.2	
	ADG, kg	.610	.690	13.1	

[a] References:
1 = Goodrich et al. (1984), summary of 228 trials.
2 = Owens et al. (1991), summary of 137 trials.
3 = Goodrich et al. (1984), summary of 24 trials.
4 = Wilkinson et al. (1980), 12 trials.
5 = Potter et al. (1976), 4 trials.
6 = Potter et al. (1986), 24, 11, and 12 trials respectively.
7 = Ellis et al. (1984), each mean is one trial.
8 = Parrot et al. (1990), 8, 8, 4, 4, and 4 trials respectively. Monensin delivered by ruminal bolus.

Table 2-14. Influence of ionophores on performance

Item[a]	Control	Monensin	Lasalocid	Laidlomycin	Salinomycin	Tetronasin	Lysocellin
Trials	156	137	33	44	37	13	6
ADG, kg	1.26	1.27[be]	1.31[bf]	1.35[be]	1.28[d]	1.29	1.31[d]
Feed, kg	8.97	8.47[b]	8.70[b]	9.07[c]	8.74[b]	8.47[c]	8.17[b]
Feed:gain	7.29	6.83[ce]	6.74[bf]	6.88[be]	6.90[bf]	7.30	7.29

[a] Owens et al. (1991). Adjusted performance measurement for each ionophores was calculated for ionophore dosage at the mean dosage level used based on linear or, when quadratic effect was detected (P < .1), linear and quadratic regression coefficients relative to the mean of cattle fed the control diet.
[b] Linear change (P < .01) with level of ionophores.
[c] Linear change (P < .05) with level of ionophores.
[d] Quadratic effect (P < .01) in addition to the above linear effect of ionophore level.
[e] Quadratic effect (P < .05) in addition to the above linear effect of ionophore level.
[f] Quadratic effect (P < .05) in addition to the above linear effect of ionophore level.

Effect of monensin on high roughage diets is also presented in Table 2-13. In general, the effect is translated into increased ADG and feed efficiency. The effect on feed intake appears variable. Under grazing conditions, ionophores usually improve ADG. Feed efficiency data are rarely available because inherent difficulty in measurement of feed intake in grazing animals. A more subtle effect such as no change in ADG with decreased pasture intake may occur. In this case, the benefit of feeding an ionophore will be realized only if stocking rate is increased. However, this effect is difficult to measure and may not have a real economic value (Rowe et al., 1991). Horton et al. (1992) reported an increased ADG in yearlings supplemented with ionophores (lasalocid or monensin) while grazing subtropical grass forages, but responses were inconsistent and appeared to be associated with forage quality and environmental conditions. This variable effect of ionophores (monensin) in grazing animals was related to the interaction of monensin with pasture digestibility and digestive function (Ellis et al. 1984). In grazing animals monensin generally reduces the turnover rate of undigested forage residues and thereby increases the digestibility of fiber. Intake of forages (45 to 65% OMD) was increased with monensin apparently as a result of increased undigested fill. Intake of poor quality forages (< 45% OMD) is decreased by monensin caused by a reduced turnover of

undigested dry matter combined with the animals' inability to accommodate further increases in fill of undigested dry matter. Intake of higher quality forages (> 65% OMD) appears to be decreased by monensin perhaps through a metabolic intake regulation, analogous to the lower intake observed with high concentrate diets. Thus the expected gain response to monensin decreases as the quality of forage consumed increases (Ellis et al., 1984). Rowe et al. (1991) suggested that in animals grazing low quality pastures, maintaining or losing weight, there is less chance of a positive response to ionophores. This opinion would agree with the depressed intake observed when ionophores are fed with low quality forage (Ellis et al., 1984).

Pond and Ellis (1979) reported three trials where the response to monensin was evaluated in cattle grazing bermudagrass pastures. Monensin increased intake (3.4%) in one trial, but it decreased intake in the other two trials (4.6 and 19.4%). Although intake was decreased, monensin increased ADG. This effect was explained by a reduction in rate of passage of digesta. The resulting increased residence time in the rumen increased digestibility of forage.

Gains were .460, .565, and .780 kg for cattle on bermudagrass pasture alone, pasture plus .9 kg corn, and pasture plus corn and 100 mg of monensin, respectively (Oliver, 1975). Monensin increased ADG by 38%. In a similar

experiment, cattle on bermudagrass pasture gained .42 and .52 kg for pasture plus .9 kg corn and pasture plus corn and 200 mg of monensin, respectively. Forage to gain ratios estimated for control and monensin were 19:1 and 15:1, respectively (Rouquette et al., 1980). In a different trial, ADG were .45, .47, and .68 for steers on pasture alone, pasture plus .9 kg corn, and pasture plus corn and 200 mg of monensin, respectively. Estimates of forage to gain ratios were 20.5:1, 19:1, and 13:1, respectively (Rouquette et al., 1980). Monensin increased gain by 24 to 45% in this trial.

Byers and Schelling (1984) used an isotope dilution technique to measure body composition. They reported that digestive tract fill in cattle grazing high-quality pastures was decreased by monensin or lasalocid. When cattle grazed more mature, low-quality forage, lasalocid reduced fill, while monensin had no effect on fill. Thus, fill may be different not only under the conditions as discussed by Ellis et al. (1984), but also with different ionophores.

Ionophores also can increase the response to supplements. This effect is particularly important because in high roughage diets ionophores are generally fed daily in .5 to 1 kg of a carrier supplement. Pasture plus supplement (no monensin) supported gains of cattle ranging from .24 to .96 kg/d (Potter et al., 1986). The addition of 200 mg monensin/d to the supplement increased gain by .09 kg/d (16.3%) across the 24 trials. In a different series of 11

trials, cattle on pasture alone gained .50 kg. Supplementation with .9 kg/d of energy supplement increased ADG by .09 kg, and the addition of monensin to supplement further increased ADG by .09 kg/d (Potter et al., 1986). In a series of 12 trials, monensin supplementation of harvested forage fed in confinement reduced feed intake by 3.1%, improved ADG by .09 kg (14.4%) and improved feed efficiency by 15.3%. Efficiencies of supplemental feed to extra gain (kg supplement:kg gain) were 10.1:1 and 5.0:1 for the supplemented only and the supplemented plus monensin groups, respectively (Potter et al., 1986).

Monensin can be administered through intraruminal devices, avoiding the need for a carrier supplement. Parrot et al. (1990) reported increased ADG in steers and heifers under different environmental conditions (Table 2-13). Response to monensin may be related to stocking rate and pasture quality (Cochran et al., 1990).

Ionophore feeding has also been shown to benefit cow-calf production systems. Monensin feeding has been shown to increase ADG and reduce age at puberty in beef heifers (Sprott et al., 1988). This effect of monensin appears to be independent of growth rate (Lalman et al., 1993).

Ionophore Modes of Action

The mechanisms by which ionophores improve performance or feed efficiency have been attributed principally to alterations in ruminal fermentation. However, because

ionophores have activity in both prokaryotic and eukaryotic cells, part of the performance may be due to effects outside the rumen (Nagaraja, 1995). According to Bergen and Bates (1984) ionophore feeding affects ruminal fermentation in three major areas: a) Increased production of propionate and decreased production of methane, b) decreased protein degradation and deamination of amino acids, c) decreased lactic acid production and froth formation in the rumen.

A summary of known effects of bambermycins, avoparcin, monensin, and lasalocid is presented in Table 2-15.

Ruminal effects

Ruminal fermentation of carbohydrates, protein and glycerol result in anaerobic oxidation to acetate, carbon dioxide and ammonia. Methane, propionate, and butyrate are produced mainly as a result of electron and proton transfer reactions (hydrogen sinks). Methanogenesis keeps the partial pressure of hydrogen very low avoiding the formation of lactate or ethanol as major end products and allowing more acetate to be produced (Van Nevel and Demeyer, 1995).

Volatile fatty acids. The most consistent fermentation alteration when ionophores are fed is the increased molar proportion of propionic acid produced in the rumen (Table 2-16). Increased propionate production results in improved fermentation efficiency because of a greater recovery of metabolic hydrogen (Chalupa, 1984). Furthermore, Armstrong

Table 2-15. Effect of antibiotic feed additives on digestive function and disorders

Item[a]	Monen[b]	Lasal[c]	Avop[d]	Bamb[e]
Ruminal				
NH_3	-[f]	nc[g]	-	+[h]/[i]-/nc
Total VFA	nc/-	-	nc	nc/-
Acetic	-	-	-/nc	+/-/nc
Propionic	+	+	+	+/nc
Butyric		-	nc/-/+	-
A:P	-	-	-	-/nc
Methane	-	-	-	nc/-
Rumen fill	+	nc	nc/+	
Liquid turnover	-	nc/-	nc/-	
Solid turnover	-	-	-	
Rumen bacteria				
Yield	-	-	nc	-/nc
Gram positive	-	-	-	-
Lactate utilizers	nc	nc		
Rumen protozoa	-	-		nc
Rumen fungi	-			
Rumen digestibility				
DM	nc/-	-	+	-/nc
Fiber	nc	nc/+		nc/-
Protein	-	-	-	+/-
Starch	nc/-	-		
Total tract digestibility				
DM	nc/+	+	+	nc/+
Fiber	nc/+	+		nc/+
Starch	nc	nc		
Protein	+	+		nc
Other				
Bloat	-			
Coccidia	-	-		nc
Lactate	-	-	-	
3-Methylindol	-			

[a] Chalupa, (1984); Van Nevel and Demeyer, (1988, 1992); Bergen and Bates, (1984); Schelling, (1984); Faulkner et al., (1985); Spears, (1990); Owens et al., (1991), De Schrijver et al., (1990); Murray et al., (1990); Murray et al., (1992); Aitchison et al. (1989a, 1989b); Galbraith et al., (1983); Alert et al., (1983); Poppe et al., (1993); MacGregor and Armstrong, (1982); Chalupa et al., (1981); Froetschel et al., (1983); Nagaraja, (1995); Nagaraja et al., (1987); Early et al. (1996); DelCurto et al. (1996).

[b] Monen = monensin, [c] Lasal = lasalocid, [d] Avop = avoparcin, and [e] Bamb = bambermycins.

References: [f] - = decrease; [g] nc = no change; [h] + = increase; [i] / = or.

Table 2-16. Effect of monensin of ruminal volatile fatty acids in cattle

Diet[a]	Variable	Control	Monensin	% change
70:30[b]	Concentration, mM			
	Acetate	70	61[e]	-13
	Propionate	19	23[e]	+21
	Butyrate	10	8	-20
	Proportion, %			
	Acetate	71.0	66.8	-6
	Propionate	19.1	24.7[e]	+29
	Butyrate	9.9	8.5[e]	-14
	Production, M/d			
	Propionate	7.74	11.2[e]	+46
50:50[c]	Concentration, mM			
	Acetate	65.8	55.9	-15
	Propionate	41.1	41.9	+2
	Butyrate	13.5	9.1	-33
	Proportion, %			
	Acetate	53.5	51.3[e]	-4
	Propionate	33.4	38.4[e]	+15
	Butyrate	11.0	8.3	-25
	Production, M/d			
	Acetate	7.32	8.68	+19
	Propionate	4.82	7.30	+52
	Butyrate	2.12	1.76	-17
	Production, g/d			
70:30[d]	Propionate	441	659[e]	+49
20:80[d]	Propionate	510	899[e]	+76

Source: Nagaraja (1995).
[a] Roughage:concentrate.
[b] Prange et al. (1978).
[c] Rogers and Davis (1982).
[d] Van Maanen et al. (1978).
[e] Different from control, P <.05.

and Blaxter (1957) showed that the efficiency of utilization of acetate was low when infused into the rumen as the only energy source, but was increased by the addition of propionate. The heat increment of acetate is reduced by addition of glucose precursors to the diet (Tyrrell et al., 1979). Acetate clearance rate is increased by an incresed

ruminal propionate:acetate ratio (Cronje et al., 1991). Propionate can be used in gluconeogenesis or oxidation, while acetate can not be used for gluconeogenesis. The increased molar proportion of propionate in ruminal fluid may represent a conservative estimate of the amount available for subsequent metabolism. It has been shown in steers fed a high roughage diet with added monensin that propionate production rate was increased by 49% while the molar proportion of propionate in the ruminal liquor only increased by 15%; comparable figures for steers fed low roughage diets were 76% and 25% (Van Maanen et al., 1978).

Methane. Methane production can be as great as 12 L/h in beef cattle (Thorton and Owens, 1981). Methane production can represent as much as 12% loss of feed energy. Ionophores can decrease methane loses by 30% (Schelling, 1984). The effect of monensin on methane production in vivo is variable. Reduction of 16 to 31% in methane production has been reported according to research reviewed by Van Nevel and Demeyer (1995). About half of the decrease in methane production when monensin was fed was associated with the reduced feed intake. When cattle were fed hourly no effect of monensin on methane production was observed (O'Kelly and Spiers, 1992). However, depression of methane production may be transitory, with methane production returning to normal within two weeks (Rumpler et al., 1986). Monensin is not directly toxic to ruminal methanogens, but inhibits

organisms converting formate to carbon dioxide and hydrogen. Thus, monensin reduces the supply of substrate for methanogenesis (Van Nevel and Demeyer, 1995).

Ruminal nitrogen metabolism. Ruminal ammonia production often exceeds the needs of ammonia-utilizing species. Excess ammonia in the rumen is absorbed and converted to urea in the liver. Although some urea is recycled back to the rumen, much of it is lost in the urine (Russell and Strobel, 1989). Monensin decreases ammonia production in vitro (Van Nevel and Demeyer, 1977) and in vivo (Dinius et al., 1976; Hanson and Klopfenstein, 1979; Poos et al., 1979). Ionophores appear to affect ruminal degradation of peptides and deamination of amino acids to a greater extent than proteolysis. An apparent contradiction in the nitrogen sparing effect of ionophores was that the most active ammonia-producing bacteria (gram-negative) were resistant to ionophores. Three new gram-positive species with high activity of ammonia production have been isolated. These new isolates were sensitive to ionophores and had a 20-fold greater ammonia production than previously identified ruminal bacteria species (Russell, 1991; Russell et al., 1991). Decreased peptide degradation and amino acid deamination caused by ionophores is attributed to inhibition of these ammonia-producing bacteria (Yang and Russell, 1993b). Monensin decreased by 10-fold the number of highly active amino acid-fermenting ruminal bacteria in vivo. These

bacteria utilize peptides and amino acids, but not carbohydrates for growth. As a result, there was less amino acid deamination and less ammonia production. In this study monensin did not increase soluble protein, peptides or amino acids in ruminal fluid. Monensin, however, increased the concentration of bacterial protein in ruminal fluid, which would provide additional protein for the animal. They suggested that monensin-resistant bacteria utilized the peptides and amino acids from dietary protein (soybean meal) that were spared from deamination and converted these to microbial protein. Some ruminal bacteria, such as Prevotella ruminicola showed increased growth efficiency when peptides and amino acids were their source of N (Russell, 1984). In another experiment Yang and Russell (1993a) added protein hydrolysates directly to the rumen. Peptide and amino acid concentrations in ruminal fluid decreased at a logarithmic rate after addition. When cows were fed 350 mg monensin/d the rate of peptide and amino acid disappearance and ammonia concentration were decreased. Monensin increased the ruminal outflow of peptides and amino acids from infused hydrolysates. The effect was dependent on the source: greater ruminal outflow for gelatin than soybean hydrolysates. These reports suggest that monensin increased passage of amino-N out of the rumen, although by a different mechanism (increased bacterial-N and dietary amino-N flow, respectively). It is noteworthy that the experimental model,

cows fed at frequent intervals to achieve steady state conditions, was the same in both experiments.

Monensin decreased ruminal urease activity by 66% (Starnes et al., 1984). This effect would have a beneficial effect on urea utilization in ruminants, because the rate of urea hydrolysis is faster than the rate of ammonia assimilation by ruminal bacteria (Starnes et al., 1984).

The net effect of ionophores on the nitrogen economy of the animal will depend upon specific dietary situations. Increased flow of amino acids to the small intestine could improve production when diets are: a) marginal in crude protein, b) the crude protein is high quality true protein, c) the rate of proteolysis is rapid and d) the rate of carbohydrate fermentation is slow (Russell, 1991). Thus, it is conceivable that the effect of ionophores on metabolizable protein for the host animal will depend upon the net result of all these processes.

Other effects. Other effects of ionophores on rumen function include reduction of turnover rate of solids and liquids, modification in ruminal fill and retention time, and depression of ruminal motility (Lemenager et al., 1978a; Ellis et al., 1984; Deswysen et al., 1987). These changes may explain changes in feed intake, especially in high roughage diets.

Total tract digestibility

Spears (1990) suggested that the higher energy digestion could be explained by increased fiber digestion (Table 2-17). This higher fiber digestibility may result from longer solid retention time in the rumen, thus allowing greater time for microbial digestion of fiber.

Total tract digestibility of starch was not affected by ionophores. However, lasalocid and monensin reduced ruminal digestibility of starch and increased the quantity of starch digested in the intestine. This shift in site of digestion should have resulted in more energy absorbed from starch as glucose rather than as VFA and improved energy utilization (Muntifering et al., 1981; Spears, 1990).

Higher apparent nitrogen digestibility could be explained by: a) a higher ratio of dietary to microbial protein entering the small intestine because feed protein is usually more digestible than microbial protein, b) fecal endogenous nitrogen losses may be reduced, by decreased microbial protein synthesis in the large intestine and cecum or by decreased sloughing of intestinal cells (Spears, 1990).

Ionophores improve absorption of several minerals. In his review, Spears (1990) concluded that ionophore supplementation increased apparent absorption of Mg, P, Zn and Se, whereas absorption of Ca, K and Na were affected inconsistently by ionophore feeding.

Table 2-17. Apparent digestibility of energy and nitrogen in cattle fed ionophores

Nutrient/ Ionophore[a]	Digestibility, %		Percent change	Number of trials
	Control	Ionophore		
Energy				
Monensin	70.3	72.4	-.9 to 9.2	17
Lasalocid	75.7	77.7[b]	1.9 to 2.2	8
Nitrogen				
Monensin	62.2	65.7[b]	.3 to 8.0	15
Lasalocid	70.8	76.4[b]	.2 to 7.2	3

[a] Adapted from Spears (1990).
[b] Means for control and treated animals differ ($P<.05$) when analyzed by analysis of variance using experiment as replicate.

Chalupa (1984) summarized the increased retention of energy and protein produced by addition of monensin in the diet (Table 2-18). In those experiments the increase in energy retention was related to an increase in the amount of metabolizable energy by decreasing fecal and methane energy losses.

Metabolism of the host animal

Inhibition of methane production in monensin-treated animals is responsible for about one-third of the improvement in energy utilization (Van Nevel and Demeyer, 1988). There are several studies where significant increases in propionate molar proportions were measured without any improvement in feed conversion efficiency, and there are also studies in which the increase in propionate was too small to explain the magnitude of the improvement observed (Rowe et al., 1991).

Table 2-18. Energy and nitrogen partitioning in animals supplemented with monensin

Item[a]	Trial		
	Sheep[b]	Sheep[c]	Steer[d]
Energy, % of control			
Feces	98	93	90
Digested	101	103	104
Urine	92	84	99
Methane	74	69	74
Metabolized	105	108	107
Heat	102	105	104
Retained	111	115	119
Nitrogen, % of control			
Feces	97	98	88
Digested	102	101	107
Urine	92	87	99
Retained	127	138	120

[a] Data summarized by Chalupa, 1984.
[b] Monensin at 10 ppm in 50% grain diet.
[c] Monensin at 20 ppm in 50% grain diet.
[d] Monensin at 3 mg/kg BW^{75}, 80% grain diet.

In cattle and sheep, about half the dose of monensin is absorbed, metabolized, excreted in the bile, and eliminated in feces (Donoho, 1984). This suggests that monensin may have systemic effects. Plasma concentration of minerals (Mg, Na, K) has been altered with ionophores (Spears, 1990; Owens et al., 1991). Depression of heat increment and amino acid sparing effects have also been cited (Bergen and Bates, 1984).

A second "protein sparing effect" can occur in the host. Increased propionate production in the rumen and its subsequent absorption may reduce catabolism of amino acids for gluconeogenesis (Van Nevel and Demeyer, 1988). These

investigators also reported effects of monensin beyond the rumen, including changes in blood concentrations of several metabolites, hormones, and minerals.

Evidence of an effect of monensin on metabolism in ruminants independent of alterations in ruminal microbial metabolism have been provided (Armstrong and Spears, 1988). Intravenous administration of monensin depressed plasma concentrations of K, P, and Mg, and increased glucose and free fatty acids concentrations. Changes in plasma mineral concentrations were suggested as indices of the cellular effect of monensin.

Other indications that effects of monensin on animal performance may not be totally explained by changes in ruminal fermentation are provided by measurement of net nutrient flux (Harmon and Avery, 1987; Harmon et al., 1993). These investigators suggested that changes in the products of ruminal fermentation may not be translated into the products appearing in the portal circulation. Urea recycling was reduced in both concentrate- and forage-fed cattle. Changes in VFA net absorption from feeding monensin in forage fed animals were not consistent with its role in increasing ruminal propionate production, because total net energy flux did not change. They questioned the role of monensin in improving feed efficiency solely through increased ruminal propionate production.

Animal health

Altered ruminal fermentation associated with ionophore feeding reduces the incidence of acidosis, bloat, and acute bovine pulmonary edema and emphysema (Nagaraja, 1995). Probably the more important effect is the reduction in lactate production, resulting in reduced incidence of lactic acidosis in high concentrate diets. Reduction of lactic acid production resulted from a direct antibiotic effect on the gram-positive bacteria which are the more important lactate producers (*S. bovis*, *Lactobacillus spp.*). Lactate utilizers are not sensitive to ionophores, providing an additional way of lowering lactic acid concentration (Bergen and Bates, 1984; Nagaraja, 1995).

Ionophores in the diet had positive effects on blood glucose levels, reduced blood 3-hydroxybutyrate concentrations in late pregnancy and eliminated signs of pregnancy toxemia in ewes (Parker and Armstrong, 1987).

Subclinical coccidiosis in lambs has been reduced when an ionophore was added to the diet. The problem appears to be particularly severe in lambs between 3 and 10 wk of age after which natural immunity builds up. In intensive lamb production, the use of ionophores could give a distinctive advantage over other feed additives that have no effect on coccidia (Armstrong, 1986).

Growth promotion has also been observed in young calves. Monensin fed to young calves (7 to 10 d of age)

resulted in 10 to 47% higher gains during the suckling period (30 d) and of 6 to 17% higher gains during the next 90 d. Feed intake was increased during suckling period and decreased thereafter. These effects were independent of coccidia control because no coccidia were found (Ilan et al., 1981). In a separate trial they found increased dry matter digestibility when monensin was administered either in the milk replacer or directly into the rumen.

Interaction with Minerals

It has been shown that elevated dietary concentrations of Na and K may decrease the response of cattle to lasalocid and monensin (Rumpler et al., 1986; Russell, 1987; Russell and Strobel, 1989; Schwingel et al., 1989). High dietary K appears to inhibit the antibacterial effect of lasalocid more than that of monensin. Research at the University of Florida evaluating monensin and lasalocid in molasses slurries consumed at 2 to 3 kg/d has not shown improvement in gains of grazing cattle (Kunkle and Bates, personal communication). It was suspected that the high concentration of minerals in molasses, especially K (3 to 4%) and the high consumption of the molasses contributed to the lack of efficacy of ionophores in these studies.

The interaction with minerals has not been completely clarified. Greene et al. (1986) has suggested that monensin appears more effective in decreasing the acetate:propionate ratio in lambs when fed with high dietary K. High dietary Na

may also decrease the effectiveness of ionophore supplementation of cattle (Bergen and Bates, 1984; Rogers and Davis, 1982). High dietary Na reversed the depression of microbial synthesis (urinary allantoin) induced by monensin in sheep (Dewhurst et al., 1992). Increasing K concentration in the growth medium of pure cultures of ruminal bacteria increased the resistance of these organisms to ionophore. High extracellular K increased the minimum inhibitory concentration of lasalocid in several species. The effect of K on minimum inhibitory concentrations of monensin was similar to, but not as great as, the effect on lasalocid (Dawson and Boling, 1987). Funk et al. (1986) noted an interaction of lasalocid and K (1 and 2.5% K in the diet) for plasma urea N, acetate:propionate ratio, and NDF digestion in lambs. These interactions, however, were not reflected in lamb gains or feed intake.

Research conducted at the University of Florida has shown that changes in the concentration of K and Na resulted in altered in vitro VFA production (Schwingel et al., 1989). Important findings were: a) high K concentration increased acetate:propionate ratio when lasalocid was fed, b) high Na concentration reduced VFA production when either lasalocid or monensin were fed. This research suggested potential problems associated with high dietary K and lasalocid, and high dietary Na and either lasalocid or monensin. The nature of the interaction appears complex, as Bates and Schwingel

(unpublished results) have shown different effects of lasalocid and monensin on S. bovis and R. albus. Monensin was less toxic to S. bovis than lasalocid, but more toxic to R. albus. Increasing Na in the growth medium allowed S. bovis to proliferate in the presence of ionophores, especially monensin. High Na concentration, however, increased toxicity of ionophores to R. albus. Increasing K permitted R. albus to survive in the presence of lasalocid, whereas no appreciable effect was observed with monensin.

Because high dietary K potentially decreases the efficacy of lasalocid more than that of monensin, it has been hypothesized that monensin will be more effective in supplementation programs utilizing molasses slurries. However, there are reports of improved ADG in cattle on wheat pasture supplemented with monensin (Horn et al., 1981; Davenport et al., 1989) and lasalocid (Andersen and Horn, 1987). Potassium concentration in wheat pasture is usually high, between 2 to 4% of DM (Grunes et al., 1984). Response to monensin feeding in cattle grazing wheat pasture may also be related with reduction of bloat (Horn et al., 1981). It was suggested that monensin may be useful in neutralizing K-related depression of Mg absorption in ruminants consuming diets high in K (Greene et al, 1986). Hypomagnesemic tetany is a metabolic disorder common in cattle grazing small-grain pastures (Grunes et al., 1984).

Garret et al. (1989) reported improved gain in feedlot cattle consuming a diet containing 30% sugar beet molasses and with monensin added. Feed efficiency was improved by monensin in cattle consuming 30 and 60% molasses in the diet. Increasing levels of molasses in the control diets depressed animal performance. Apparently monensin was effective in overcoming bloat in supplemented cattle.

Frequency of Feeding

Molasses supplements are usually delivered 2 to 3 d/wk in most production situations. It is therefore relevant to address the issue of frequency of feeding on the efficacy of ionophores. Efficacy of monensin administration on alternate days compared to daily feeding was evaluated in five trials involving 342 cattle in 32 pastures (Muller et al., 1986). Pooled ADG were .544, .621, and .626 kg for control supplement fed daily, monensin supplement fed daily, and monensin supplement fed on alternate days, respectively. This response was similar to other trials where control and monensin supplements were fed daily (Potter et al., 1976). These results demonstrate that monensin can be effectively administered to pasture cattle in dry supplements that are fed on alternate days. Research conducted at Ona (Horton et al., 1992) with lasalocid fed daily or three times a week in dry supplement showed higher ADG in cattle fed three times a week (.64 vs .56 kg). Monensin was administrated in a dry supplement (average .7 kg/d) fed every other day to stocker

cattle on wheat pasture (Andrae et al., 1994). Improvement in gain response to supplements containing monensin were similar to previous trials conducted under similar pasture conditions, but with daily feeding of supplement monensin.

Soybean meal or corn gluten meal, with or without monensin, was fed on a daily or alternate day schedule to cattle consuming ground corn stalk basal diets (Collin and Pritchard, 1992). Interactions of feeding interval by monensin, and protein source by monensin were observed for ADG and feed intake. Monensin fed at 48-h intervals reduced feed intake in steers. Monensin added to diets supplemented with corn gluten meal reduced ADG by .21 kg but monensin increased ADG in diets supplemented with soybean meal. Monensin fed on alternate days in a high ruminal escape protein supplement was not recommended based on this study. It is noteworthy that protein sources with low ruminal degradability are recommended for molasses slurries (Stateler et al., 1995; Kunkle et al., 1994; Pate et al., 1995). Therefore, it is relevant to test the effect of monensin included in molasses supplements formulated with protein sources of low ruminal degradability.

Based on the literature reviewed, it appears that frequency of feeding is unlikely to be involved in observed lack of response of ionophore fed in molasses supplements. Inherent differences in the energy substrate in the supplement carrier do exist (starch vs sugar) in addition to

the mineral composition. Interactions of energy substrate and ionophore can not be ruled out.

Summary of Effects of Ionophores

Monensin is perhaps the most researched antibiotic feed additive for ruminants. Yet, the mechanism by which it improves animal performance has not been completely elucidated. Effects of monensin on feed intake and gain in cattle fed high roughage diets appears variable. Research has shown that interactions of ionophores with different dietary mineral concentrations are complex.

Limited information suggests that monensin is not efficacious to improve gain when fed in molasses supplements. High molasses mineral concentration, especially K, has been suggested as the probable cause of this lack of efficacy. However, monensin has increased gain in diets high in K, such as small grain pastures. More research is needed to clarify this issue. Energy substrate (sugars), protein level and degradability may also play a role and future research may need to consider these factors.

The present research was undertaken to evaluate the efficacy of monensin to improve gain in cattle fed a high roughage diet and supplemented with different sources of energy (molasses or corn).

Considerations in Feeding Molasses.

Animal responses to feeding molasses have been extensively reviewed. Effects of molasses on rumen function, feed intake, digestibility, animal performance, and metabolic disorders were summarized from trials that covered many different dietary situations (Pate, 1983). More recently, the value of liquid supplements for animals on low quality forage has been addressed (Bowman et al., 1994). Kunkle et al. (1994) and Kunkle et al. (1996) summarized research conducted at the University of Florida comparing sources of N (urea and natural protein of different degradability in molasses slurries). Moore et al. (1995) gathered a data base from different dietary situations and analyzed feed intake and animal performance response to liquid supplements. Factors that affect liquid supplement consumption by grazing ruminants were also reviewed (Bowman and Sowell, 1995b). Effects of low levels of molasses on rumen function of high producing animals, especially dairy cows, have also been summarized (Emanuele, 1996).

Because recent reviews have summarized many aspects of molasses-based supplements these topics will not be discussed. Rather, the effect of molasses on rumen function will be emphasized and highlights on intake and animal performance will be summarized.

Digestive Function

Ruminal microorganisms. Most of the ruminal bacteria that degrade complex carbohydrates are also capable of fermenting some of the simple sugars. In addition, Treponema bryantii, T. saccharophilum, Lactobacillus vitulinus and L. ruminus have been identified as sugar fermenters in the rumen (Stewart and Bryant, 1988). The utilization of soluble sugars is thought to be the major role of the large bacteria Quins's Oval, which has been found to proliferate in the rumen when sugar-rich diets are fed (Stewart and Bryant, 1988). When molasses is fed in high amounts, methanol can be produced from the breakdown of pectin by pectinesterase (Russell, 1984). Eubacterium limosum, which is capable of using ethanol, was found in rumen of sheep fed a molasses-based diet. Secondary fermentations in the rumen of cattle and sheep on high-molasses diets have been reported (Rowe et al., 1979b). The bacteria Methanosarcina bakerii is capable of transforming acetate to methane and carbon dioxide. They suggested that this finding may explain the low acetate concentration found in ruminal fluid when high molasses diets are fed. This bacteria is found in mud and sludge, and because it has a slow growth rate, its survival would be possible only under low dilution rate, a condition in the rumen which is known to occur in high-molasses diets (Rowe et al., 1979a). Pate (1983) concluded that a somewhat different microbial population would be expected in the

rumen of cattle fed molasses diets in view of fermentation patterns (see below) and the substrate requirements of different microorganisms. He also suggested that more research is needed to identify the microbial population in molasses-fed cattle.

Protozoal densities in molasses- and sugar cane-based diets are similar (1 to 5 x 10^5/mL ruminal fluid) but their species population differs. Protozoal biomass is larger with sugar cane diets because large holotrichs predominate. With molasses based diets the smaller entodinia predominate. It appears that at feeding, protozoa are distributed through the rumen more uniformly. After feeding, the large isotrichs quickly store carbohydrate and through increased density they settle in the ruminal fluid and congregate. This results in selective retention of protozoa in the rumen. In slaughtered cattle on sugar cane diets, large isotrichs were not found in omasal fluid. On molasses diets, approximately 20% of the small entodinia left the rumen (Preston and Leng, 1980). Because considerable engulfment and breakdown of bacteria by protozoa took place in the rumen, a reduction in bacterial protein available to the animal occurred. Estimations suggest that the hourly turnover rate due to protozoal predation is higher than that of ruminal fluid turnover in most cases (Ushida et al., 1991). In a summary of 11 experiments (Ushida et al., 1991), defaunation under different dietary conditions resulted in increased flow of

microbial CP and efficiency of bacterial CP synthesis (3.17 vs 4.78 g N/100 g OM digested). Defaunation consistently resulted in higher animal performance in animals on high energy (molasses or sugars) and low protein (urea) diets (Bird and Leng, 1978; Bird et al., 1979; Bird et al., 1984). Defaunation appeared to have greater effects on wool production than on growth, reflecting perhaps a specific sulfur amino acid requirement for wool production.

Increased protozoal numbers with inclusion of sugar in the diet was not always shown. Chamberlain et al. (1985) reported an increased protozoal population in starch-supplemented rather than in sucrose-supplemented diets. Khalili and Huhtanen (1991a) could not find differences in protozoal populations between a grass silage basal diet and basal diet plus 1 kg (16% of DM) of sucrose, infused either continuously or two times a day. Bird (1989), cited by Leng (1990), suggested that response to defaunation may not be related to protozoal population densities, a low density being as detrimental as a relatively high density. Defaunation improved animal performance on molasses-urea diets but the mechanism was not clear. Improved microbial protein supply to the host, changed protein:energy ratios in absorbed products of digestion, and improved efficiency of feed utilization have been offered as explanations (Leng, 1990). On the other hand, defaunation did not result in improved animal performance on higher quality diets high in

true protein. In a review, Veira (1986) stated that the major nutritional effect of protozoa is to change the ratio of protein to energy in the nutrients absorbed, with faunated animals having lower protein and higher energy availabilities compared with defaunated ruminants.

Ryle and Orskov (1987) suggested that the positive response to defaunation in molasses-fed animals may be related with the particular population of protozoa. Because holotrics are more sensitive to pH fluctuations, entodinia predominate and they are more active predators. They suggested that increasing dietary fiber (long hay) may create favorable conditions for holotrics. They also noted that holotrics were associated with high propionate concentrations, while entodinia where associated with higher butyrate concentrations.

Defaunation under Florida conditions, where the basal diet (medium to low quality hay or stockpiled pasture) is supplemented with molasses slurries (often containing true protein) may not be beneficial. If urea is used as the major source of N, then the protozoal population may become relevant.

Ruminal volatile fatty acids. Feeding molasses to cattle increases the molar proportion of butyric acid in the rumen. This increase appeared to be at the expense of propionic acid when molasses is substituted for grain, or at the expense of acetic acid when molasses is fed as a

supplement in forage-based diets (Pate 1983). Feeding of molasses did not appear to have a consistent effect on the total VFA concentration or ruminal pH.

Beever (1993) summarized three dietary scenarios (Table 2-19). These suggest that an acetate-inducing fermentation is more efficient with respect to both VFA production and ATP yield than high propionate or butyrate fermentation. However, the yield of methane is higher in acetate fermentation. With the high-cereal diet, more energy is recovered in the end products of fermentation (VFA and VFA plus ATP). Net ATP production is important because it will be used for microbial growth and maintenance. Russell and Wallace (1988) suggested, from the pathways of VFA production, that the net ATP production is 4, 4, and 3 mol/mol of hexose fermented for acetate, propionate and butyrate, respectively. Only 2 mol of ATP will be produced if propionate is synthesized by the acrylate pathway.

Because VFA absorption rates may change with pH or VFA concentrations, VFA molar proportions in ruminal fluid may not reflect the actual VFA proportions in which they are produced (Dijkstra, 1994).

Protozoal contribution to VFA production in the rumen varied between 16 and 37%. End products of protozoal fermentation are mainly acetic and butyric acids, while only trace amounts of propionic acids are produced. Thus, starch and sugars fermented by bacteria would yield more propionic

acid and less acetic and butyric acids than would fermentation of the same substrate by protozoa (Dijkstra, 1994). This investigator stressed that VFA produced is not only related to type of substrate, but also the characteristics of the diets. Stoichiometric yield parameters for VFA production from soluble carbohydrate, derived from a large data set, were 1.38, .41, and .10 for acetate, propionate and butyrate in high roughage diets. For a high concentrate diet, the estimated yields were .90, .42, and .30, for acetate, propionate and butyrate, respectively.

Table 2-19. Fermentation of 1 mol of contrasting carbohydrate sources

Item[a]	High forage	High cereal	High molasses
VFA produced, mol	1.90	1.80	1.67
Acetate	1.34	.90	.94
Propionate	.45	.70	.40
Butyrate	.11	.20	.33
Methane produced, mol	.61	.38	.54
ATP produced, mol	4.62	4.38	4.54
Energy from original substrate:			
VFA energy, %	73	80	75
VFA + ATP energy, %	85	92	87
VFA, mol/100 mol			
Acetate	70.5	50.0	56.2
Propionate	23.7	38.9	24.0
Butyrate	5.8	11.1	19.8

[a] Based on estimations of Beever (1993).

Table 2-20. Effects of molasses level on volatile fatty acid concentrations, ammonia and pH

Item	No molasses	Low molasses	Medium molasses	High molasses
Molasses level[a],				
kg DM	0	1.5	3.0	4.5
% of total DM	0	13.9	26.0	35.2
Total VFA, mM	103.2	102.4	89.4	100.6
Molar proportion				
Acetate	72.6	67.7	64.8	57.3
Propionate	16.0	18.4	17.4	20.5
Butyrate	10.6	12.8	16.4	20.5
Ammonia, mM	9.45	7.71	6.29	5.75
pH	6.62	6.57	6.57	6.24
Molasses level[b],				
kg DM	0	1.0	2.0	3.0
% of total DM	0	12.9	24.5	36.5
Total VFA, mM	101.3	117.8	117.7	109.6
Molar proportion				
Acetate	70.0	69.2	67.7	63.8
Propionate	16.2	16.9	18.3	21.7
Butyrate	11.4	12.0	12.5	12.8
Ammonia, mM	7.65	7.50	7.14	9.71
pH	6.43	6.31	6.32	6.34

[a] Khalili (1993). Basal diet: grass hay ad libitum and 2 kg of cottonseed cake. Linear contrast ($P < .05$) for individual VFA, ammonia and pH.

[b] Osuji and Khalili (1994). Basal diet: grass hay ad libitum and 4 kg DM of wheat bran. In the other diets wheat bran was replaced with molasses. Linear contrast ($P < .05$) for individual VFA.

The increase in butyrate concentration in ruminal fluid appeared to be related to the level of molasses in the diet. In fattening systems using 77% molasses in the diet, molar percents were 31, 19 and 41 for acetic, propionic and butyric acids respectively (Marty and Preston, 1970). Two experiments where molasses was added to a basal diet (or substituted for other ingredient) are summarized in Table 2-20. Increasing molasses from none to 4.5 kg doubled the proportion of butyrate in the first experiment. In the

second, however, increasing molasses from none to 3 kg had small effects on butyrate molar percent. It is noteworthy that 2 to 3 kg molasses (representing 30 to 40% of diet DM) have beeb supplemented in Florida.

Data summarized by Pate (1983) showed that sugars, not the ash, in molasses are responsible for the increase in butyrate. Inclusion of molasses or sugars in the diet almost always increased the proportion of butyrate in ruminal fluid. The magnitude of the increase, however, was variable and not always related to level of inclusion of molasses or sugars in the diet.

Nitrogen utilization. Much of the N in molasses is non-protein. Stateler (1993) estimated from an in vitro semi-continuous fermentation trial that between 75 and 85% of total N was available for bacterial growth. Urea is usually added to molasses to increase the CP content. Because molasses is low in P, phosphoric acid is usually added. When urea and phosphoric acid are combined, a urea-phosphate salt is formed. Urea-phosphate given to sheep resulted in lower ruminal pH and blood ammonia than when urea alone was given (Perez et al., 1967). Addition of 3% phosphoric acid to a 10% urea liquid supplement prevented ammonia toxicity, apparently due to decreased ruminal pH caused by the phosphoric acid addition, reducing absorption of free ammonia (Davidovich et al., 1977). Increasing urea levels in molasses depressed molasses intake. Urea and monensin,

independently or combined, have been used to regulate intake of molasses. Intake was regulated effectively with 30 g urea per kg of molasses or with 120 mg of monensin per kg of molasses (Gulbransen and Elliot, 1990).

The addition of sugar-based or starch-based supplements to a basal diet almost always resulted in a decrease in ammonia concentration in ruminal fluid. The lowered ruminal ammonia levels in energy-supplemented animals is associated with an increased rate of fermentation. Intake of energy supplements are often associated with an increased influx of urea into the rumen, but ruminal ammonia levels are decreased because of increased uptake of ammonia by microbes (Obara et al., 1991). In sheep fed a lucerne hay basal diet, infusion of 200 g sucrose (17% of the DM intake) improved N balance, reduced ruminal ammonia and plasma urea N concentrations, increased transfer of urea to the gut and rumen and increased ammonia capture into microbial N. In a similar experiment (sucrose infusion, 20% of DM intake) using sheep fed fresh lucerne, the results were similar (Obara et al., 1991).

The use of molasses has been proposed in diets with a high concentration of non-protein N such as silage. Increased ruminal microbial protein synthesis has been reported when silage was supplemented with sugar (Khalili and Huhtanen, 1991a) or molasses (Huhtanen, 1988). Supplementing silage with a source of readily available

energy has been found to reduce ruminal ammonia concentration and increase the flow of microbial protein to the small intestine (Rooke et al., 1987; Huhtanen, 1988). These studies were conducted with restricted feeding. When Petit and Veira (1994) fed ad libitum timothy silage mixed with 7.5 or 15% molasses, they found that molasses decreased ruminal ammonia concentrations. Nitrogen retention or plasma urea concentration, however, were not affected by molasses addition to silage diet (Petit et al., 1994). They suggested that sugar supplementation in animals fed ad libitum would decrease ruminal ammonia N concentration as a result of decreased degradability of silage CP, whereas sugar supplementation in feed-restricted animals would reduce ruminal ammonia N concentration as a result of increased microbial CP synthesis in the rumen. Supplementation of silage diets reviewed by Emanuele (1996) suggested that molasses and sugar can be used to replace corn or barley without detrimental effects at low levels of inclusion in the diet. He concluded that molasses fed with protein sources that supply amino acids and peptides to ruminal bacteria supports a higher level of performance than molasses alone or molasses and urea combinations.

According to data summarized by Pate (1983), urea-nitrogen was less efficiently utilized in forage diets supplemented with molasses than those supplemented with starch or corn. Bates et al. (1988) found that N retention

was lower with molasses-urea than with aeschynomene hay or alfalfa meal supplementation of a basal diet low in CP and digestibility. The inefficient use of supplemental non-protein N occurred because much of the N absorbed from the gastrointestinal tract was excreted in the urine. They suggested that efficient N recycling in ruminants may limit the effectiveness of supplements which contribute primarily to the ruminally available N pool.

Pate (1983) suggested that the feeding of moderate to high levels of molasses reduced the apparent digestibility of CP by 5 to 15%. Practical implications would be an increase in CP requirement above the levels recommended at that time, with the old CP system (NRC, 1976). The fact that young bulls gaining 1 to 1.1 kg/d needed 30 to 60% more CP (as fish meal supplement) than recommended by NRC (1976) may indeed reflect high ruminal N losses as ammonia and(or) low microbial yield.

The finding that 15 to 25% of N from molasses may be unavailable (Stateler, 1993) may provide a partial explanation to lower CP digestibility. Molasses may also depress protein digestibility of the basal diet. It was shown that sucrose or molasses supplementation depressed ruminal degradability of silage CP (Huhtanen, 1988; Petit and Veira, 1994).

Efficiency of microbial synthesis was low on molasses-based diets, and efficiency was increased with the addition

of a starch source (Rowe et al., 1980). They suggested that addition of starch provided a more uniform supply of fermentable energy for the ruminal bacteria. Barley-urea increased duodenal N flow more than molasses-urea when sheep were given cereal straw, suggesting better efficiency of ammonia capture in microbial protein when starch was the energy source (Oldham et el., 1977). Obara et al. (1991) infused sucrose (20% of the DM intake) in the rumen of sheep fed fresh alfalfa. Nitrogen balance was improved and ruminal ammonia concentration was reduced by sucrose infusion. An unexpected result was that there was no increase in ammonia incorporation into microbial N. Calculation from data presented shows that microbial efficiency was 4.03 and 2.75 g N/100 g OM digested, with basal and basal plus sucrose infusion, respectively. No difference was observed in the protozoal population.

In his review, Pate (1983) found evidence that sugars, and particularly sucrose, were less effective than starch in promoting microbial synthesis from urea. Nitrogen retention was also lower for molasses-urea than for corn-urea diets. He inferred that if biological value of all microbial protein is similar, then the higher urinary-N losses observed in animals fed molasses-urea indicate that urea-N was less efficiently synthesized into microbial protein.

Pulse of glucose added to glucose-limited cultures of S. ruminantium and B. ruminicola caused an immediate

doubling of heat (energy spilling) production and little increase in cell protein (Russell, 1986). Van Kessel and Russell (1996) reported that when ammonia was the growth limiting nutrient of predominant ruminal bacteria, the impact of energy spilling was very great, and additional ammonia caused a large increase in yield. However, when energy-excess batch cultures were provided with amino N, the growth rate increased and less energy was spilled (Van Kessel and Russell, 1996). Ruminal conditions created by feeding molasses and non-protein N with low quality forage may be similar to those described for energy-excess cultures. This may explain, at least partially, the low efficiency of N utilization.

Digestive associative effects. Pate (1983) concluded that molasses increased the digestibility of the total diet, but depressed forage DM and fiber digestibility, particularly low quality forages. The degree of depression was dependent upon the level of molasses in the diet and the crude protein balance. With properly balanced forage-based diets, molasses increased DM digestibility and did not appear to severely depress the digestibility of fiber.

Brown et al. (1987) found no effect on OM digestibility and depression of NDF digestibility when limpograss hay was supplemented with 25% DM molasses. The same effect was seen when the basal diet was rice straw. Kalmbacher et al. (1995) found that molasses-based supplements increased the apparent

OM digestibility of total diet (creeping bluestem basal diet), but decreased NDF digestibility. Similar results were obtained by Brown (1993) using ammoniated stargrass as the basal diet.

Mould et al. (1983) reported that reduction of fiber digestion by molasses supplementation appeared related to the presence of highly fermentable carbohydrate (carbohydrate effect) rather than to low ruminal pH. Ruminal infusion of sugars depressed fiber digestion although pH was not affected (Huhtanen, 1988; Rooke et al., 1987). Increasing levels of molasses supplements (1.5 to 4.5 kg molasses) caused a linear increase in DM and OM apparent digestibility and a decrease in NDF digestibility with increasing level of molasses (Khalili, 1993). Addition of bicarbonate with the higher level of molasses (37% of the diet) did not affect DM, OM or NDF ruminal digestibility. He suggested that the depressed fiber digestibility may have been associated with a preference by ruminal microbes for soluble carbohydrates, as previously observed in vitro (Russell, 1984).

Intake and Performance

Feed intake. Moore et al. (1995) analyzed the effect of liquid supplements on forage intake based on 151 comparisons of voluntary forage intake when fed alone and with supplement. When the forage was balanced (DOM:CP < 7) supplements almost always decreased forage intake. When the

forage was very unbalanced (DOM:CP > 12) all types and levels of supplements increased forage intake. When forage DOM:CP was between 7 and 12, forage intake was both increased and decreased by supplements.

When intake of forage fed alone was >1.75% of BW, supplements decreased forage intake; when forage intake was <1.75% BW, supplements increased forage intake. The level of supplement was also important: forage intakes were depressed by liquid supplements when supplement intake was >.8% BW. Supplement CP concentration also affected forage intake. Forage intake was increased when liquid supplement CP was >25% of OM.

Animal performance. Moore et al. (1995) analyzed the effect of liquid supplements on animal performance based on 148 comparisons of non-supplemented control (grazed or fed forage) and supplemented with molasses. They concluded that daily gains were generally, but not always, increased by feeding liquid supplements. When a source of N was added, gains were greater than when molasses alone was fed. When supplement CP concentrations were above 15% of OM, gains were almost always increased. When supplemental CP intake was greater than .1% of BW, gains were always increased.

Forage quality was also important. When forage intake was low and DOM:CP was unbalanced, liquid supplements increased both intake and gain, but gain was still low or even negative. When forage intake was high and the DOM:CP

was balanced, liquid supplements decreased forage intake generally, but increased gains if the supplement contained meal or combination of meal and non-protein N. Pate (1983) concluded that a source of N should be provided in molasses when supplemented to low quality forage diets. He also recognized that natural protein was superior to non-protein N sources.

Kunkle et al. (1994) reviewed experiments where molasses slurries were fed as supplements on basal diets of subtropical pastures or hays. They found that supplemental ruminal undegraded protein (feather, blood and/or corn gluten meal) increased gains in growing cattle from .08 to .30 kg/day and averaged .15 kg/day. They recommended that a source of protein of low ruminal degradability be included after the requirements for ruminal degraded protein are met.

Pate et al. (1995), and Stateler et al. (1995) obtained a good response of ADG in growing cattle when the molasses slurries contained part of the total CP as ruminally undegradable protein.

Summary of Feeding Molasses

When high levels of molasses are fed, ruminal fermentation is characterized by high butyrate molar proportion, increased population of entodinia protozoa, and lower ammonia concentration. Secondary fermentation (sludge-type fermentation) and low ruminal motility has been reported with high molasses diets. Molasses supplementation

at about 30% of the diet, as recommended in Florida, is not expected to produce dramatic changes in ruminal fermentation.

In silage diets, a low level of molasses supplementation appeared to improve N utilization. However, provision of ruminal degradable protein appears necessary.

Addition of non-protein N was better than molasses alone when the basal diet was low in CP. Research with molasses slurries showed that natural protein sources improved performance over non-protein N. Provision of additional protein sources with low ruminal degradability in molasses slurries increased gain in growing cattle fed forage diets.

Several reports suggested that cattle used N (especially non-protein N) less efficiently with molasses than with grain. Research conducted with silage diets suggested that ruminal feed N degradability may be depressed by molasses supplementation. Furthermore, between 15 to 25% of N in molasses may be unavailable.

There is no direct measurement of provision of non ammonia N (an estimator of metabolizable protein supply) in cattle fed high roughage diets supplemented with molasses. More information is needed to understand the supply and utilization of nutrients, especially protein, when molasses is fed.

The present research will evaluate the effects of moderate levels of molasses and corn supplementation on characteristics of ruminal fermentation, efficiency of microbial growth, and nutrient supply in cattle fed bermudagrass hay.

CHAPTER III
EFFECT OF BAMBERMYCINS AND MONENSIN IN CORN OR MOLASSES SUPPLEMENTS ON PERFORMANCE OF GROWING CATTLE

Introduction

Florida has approximately 1 million beef cows and some of the weaned calves are stockered after weaning. Molasses is usually the lowest cost energy source available for supplementing grazing beef cattle in Central and South Florida. Liquid feeds require less labor to feed than grain-based supplements which reduces supplementation costs.

Researchers at University of Florida developed molasses slurries by adding 10 to 25% dry ingredients such as cottonseed meal, feather meal, blood meal and(or) wheat midds. Molasses slurries are consumed at higher levels than traditional liquid supplements. These higher levels of intake are usually needed to reach the desired performance in growing calves grazing perennial forages in Florida during the fall and winter. Molasses slurries are often limit-fed 3 d/wk in tubs or troughs. Molasses slurries formulated with natural protein that is undegraded in the rumen have been shown to improve the performance of growing cattle (Pate et al., 1995; Stateler et al., 1995).

Ionophores such as monensin (Rumensin™) and lasalocid (Bovatec™) have been effective in improving gains of grazing cattle. Limited research at the University of Florida evaluating monensin and lasalocid in molasses slurries has not shown improvements in gains of grazing cattle (Kunkle et al., 1990; Pate, 1995). However, more evidence is needed to corroborate this finding.

Bambermycins (Gainpro™) is a feed additive that has improved gains of grazing cattle (Deetz et al., 1990). Its efficacy in molasses-based supplements is not known, at least under Florida conditions.

A feed additive that improves gains when delivered in molasses supplements fed at high levels is needed to improve the cost effectiveness of supplementation. The objective of this experiment is to evaluate the efficacy of monensin and bambermycins in corn and molasses slurry supplements.

Materials and Methods

Performance trials were conducted at the University of Florida Pine Acres Research Unit located in northern Marion County from December 1, 1994 to March 23, 1995 (Year 1, 112 d), and at the Santa Fe Research Unit located in northern Alachua County from December 20, 1995 to April 3, 1996 (Year 2, 106 d).

Year 1. Seventy-six Angus and Brahman x Angus steers and 92 heifers of varying percentages of each breed, weighing from 190 to 320 kg (average 244 kg for all cattle) and 7- to 12-months-old at the beginning of the trial were used. Cattle were balanced by sex and breed type in each pen. Each pen (experimental unit) had three heifers and three steers, except for eight pens which had four heifers and two steers. Seven treatments were completely randomized across the 28, .9-ha paddocks, dormant bahiagrass (Paspalum notatum) frosted before the trial. All animals were dewormed and deloused at the beginning of the trial (Ivomec™ pour on).

Full weights were taken on d 0, 28, 56, 84 and 112. Shrunk weights were measured on d 1 and 113 after an overnight feed and water withdrawal. Body condition score (BCS) was evaluated by a single evaluator on d 1 and 113 using a 1 to 9 scoring system (Herd and Sprott, 1986). Initial hip height was calculated as the average of measurements made on d 0 and 1, and final hip height was the average of measurements made on d 112 and 113. Blood samples from all animals were collected via jugular venipuncture on d 28, 56, 84 and 112 for plasma urea N (PUN) analysis. Blood was collected with polypropylene syringes containing 1.6 mg potassium EDTA/mL of blood as an anticoagulant (Monovette, Sarstedt Inc., Newton, NC). Ruminal fluid was obtained from two animals per pen on d 28, 56, 84 and 112 using a stomach

tube. The tube was fitted with a ruminal strainer at the end and introduced via the mouth through a Frick speculum. Ruminal fluid was aspirated with an electric vacuum pump. Ruminal fluid samples were filtered trough four layers of cheesecloth and acidified with 5 mL of 20% sulfuric acid/100 mL of ruminal fluid. Samples were obtained between 3 to 5 h after feeding corn supplements. Sampling was conducted the day after new molasses supplements were offered (it was not possible to control sampling time after feeding in this case). Rectal grab samples of feces were collected from all animals on d 28, 56, 84 and 112 for coccidia oocyte and nematoda egg counts. All samples were stored on ice until being translated to Gainesville for processing and storage. Blood samples were centrifuged at 1,500 g the morning after sampling. Ruminal fluid was frozen upon arrival. Fecal samples were refrigerated until analysis were conducted within one week.

Year 2. The breed types of steers and heifers were similar to those used in Year 1. Initial weight ranged from 245 to 275 kg (average 260 kg for all cattle). Animal allocation to pen and treatment was similar, except that sex was confounded with pen, so that in any given pen only one sex was present. Different animal allocation was decided based on animal availability and the need to gather data useful for modeling work (e.g., intake and performance data by sex).

Animal management and sampling were conducted as described for Year 1, with the following differences: Full weights were taken on d 0, 28, 56, 84 and 106; shrunk weights were measured on d 1 and 107; BCS was evaluated on d 1 and 107; initial hip height was measured on d 0 and 1, and final hip height was taken on d 106 and 107. Blood samples for PUN were obtained from 3 animals per pen on d 28, 56, and 84. Rumen fluid was obtained from 2 animals per pen on d 28 and 84. Fecal samples were collected from 2 animals per pen on d 28, 56, 84 and 106.

Diets. Diets consisted of bermudagrass (Cynodon dactylon) hay (large round bales harvested during the previous summer) fed alone or with corn or molasses supplements. Treatments were:

1. Hay + corn meal (CC)
2. Hay + corn meal + monensin (200 mg/day)(CM)
3. Hay + corn meal + bambermycins(20 mg/day) (CB)
4. Hay + molasses slurry (MC)
5. Hay + molasses slurry + monensin (200 mg/day) (MM)
6. Hay + molasses slurry + bambermycins(20 mg/day) (MB)
7. Hay alone (HAY)

Details of supplement formulation (projected intake and ingredients) are described in Table 3-1.

The source of bypass protein in both molasses slurry and corn-urea was corn protein. Ruminal degradable protein was balanced using urea. Eighty-five percent of CP in molasses was assumed to be available in the rumen (Stateler, 1993); the rest was considered unavailable. Amount of

supplement delivered as fed was calculated to provide the same quantity of TDN from the supplements.

Table 3-1. Supplement formulation and estimated composition

Item	Supplement[a]	
	Corn	Molasses
Ingredient, % as fed:		
Corn meal	93.8	0
Cane molasses[b]	0	89.6
Corn gluten meal	0	10.0
Urea	2.8	.4
Limestone	1.0	0
Dicalcium phosphate	1.8	0
Dynamate	.6	0
Estimated composition[c]		
TDN, % DM	84.4	73.4
CP, % DM	18.4	16.7
DIP, % CP	74	74
UIP, % CP	26	26
Ca, % DM	.86	.90
P, % DM	.66	.67

[a] Rumensin™ and Gainpro™ added in the corresponding treatments to deliver 200 and 20 mg/an/d of monensin and bambermycins, respectively.
[b] Blackstrap molasses not less than 40% inverted sugars, fortified with phosphoric acid and 25,000 U.S.P. units vit A, 33,000 U.S.P. units vit D, and 22 Int. units vit E per kg, and .0005% Cu, .00001% Co, .02% Fe, .001% Mn, .0025% Zn, and .00007% I. Sulfur concentration no less than 1%, as fed basis (U.S. Sugar Corporation, FL).
[c] Calculated from tables (NRC, 1984) and Stateler (1993). Assumes 85% of molasses N available for microbial growth.

Feed additives were diluted in a carrier and mixed with the total supplement (corn-urea) or with the dry ingredients (corn gluten meal-urea) for the molasses supplement.

A mineral supplement containing 17.2 to 20.6% salt, 17.2 to 20.6% Ca, 9% P, 1% Fe, .2% Mn, .01% I, .01% Co, .2% Mg, .12% F, 1,500 ppm Cu, 20 ppm Se, and 4,000 ppm Zn was offered free choice in mineral feeders in all pens.

Feeding procedures. Hay bales were weighed, core-sampled with a forage sampler 2.5 cm in diameter, and offered free choice in round-bale feeders. Corn supplements were offered daily while molasses supplements were offered on Monday, Wednesday and Friday of each week. Molasses and dry ingredients were weighed and mixed mechanically in open trough feeders in each pen on each feeding day. Uneaten molasses supplements were weighed and recorded the next delivery day, but uneaten supplement was found only during the first 3 wk of the trial. Following the consumption of every third bale (Year 1), hay orts were collected, weighed, and sampled for dry matter determination. A visual estimation of hay waste not collected was recorded each time orts were collected. Weights of hay offered, orts, and waste estimates were used to estimate hay intake. During the last 3 to 4 d of the experiment a fresh bale was delivered to each pen which had less than a third bale of hay left in the feeder, attempting to avoid bias due to fill in the final weights. In Year 2, hay orts were collected after feeding every 5 to 6 bales because hay refusal was small, resulting in lower weigh back expressed as percent of offered hay.

Laboratory analysis. Hay and dry supplement ingredients DM was determined at 105° C for 18 h in a forced air oven and OM at 550° C for 6 h in a muffle furnace. Nitrogen concentration in hay, corn mix, corn gluten mix, and base molasses samples were determined by the method of Gallaher

et al. (1975) (aluminum-block digestion), and colorimetric analysis (Technicon AutoAnalyzer, Technicon Instruments Corp., Tarrytown, NY; Technicon, 1978). Neutral detergent fiber was determined in hay, corn, and corn gluten meal following the procedures of Goering and Van Soest (1970), modified by Moore and Foster (1986), with the addition of alpha amylase to concentrate samples only. Hay in vitro OM (IVOMD) digestibility was determined by the procedure of Moore and Mott (1974). Molasses DM was determined by freeze drying. Molasses samples were diluted (weight/volume) in 20 parts of distillate water and pH measured with a portable pH meter (Corning M90, Corning, Inc. NY). Whole ort samples (about 50 to 100 g) were analyzed only for DM at 65° C for 48 h in paper bags.

Mineral concentration of supplement was determined following the procedure of Fick et al. (1979). Calcium, Mg, Na, and K were determined by flame atomic absorption spectrophotometry using a Perkin-Elmer AAS 5000 (Perkin-Elmer, Norvalk, Connecticut). Phosphorus was analyzed by a colorimetric procedure (Harris and Popat, 1954). Plasma urea N was analyzed as described by Hammond et al. (1994), using an automated colorimetric procedure (Technicon AutoAnalyzer II Industrial Method no. 339-01, Technicon Instruments Corp., Tarrytown, NY) based on the diacetyl monoxime method of Marsh et al. (1965). Samples of ruminal fluid were thawed, centrifuged, and supernatant filtered through .45 μm

microcel filters (Gelman Sciences, Ann Arbor, MI). Volatile fatty acids were analyzed by gas chromatography (Perkin Elmer AutoSystem XL, Norwalk, CT) using a packed column (Supelco, 1990b). Fecal nematoda eggs and coccidia oocyte counts were determined using the Wisconsin flotation technique (Benbrook and Sloss, 1948). For Year 2, coccidia oocyte were not counted but given a score from 0 (no coccidia present) to 4 (more than 40 cysts per field).

Statistical analysis. Statistical analysis was conducted using the GLM procedure of SAS PC (SAS, 1987), as a completely randomized design using the pen as the experimental unit. The model included the following effects: year, treatment, and year x treatment. Repeated measurements (PUN, VFA, parasites) were also analyzed by year using the repeated statement in the GLM procedure. Probability level for time and time by treatment interaction were obtained from F using adjusted degrees of freedom (G-G test, Littel, 1989). When no time by treatment interaction was detected, data were pooled and analyzed with treatment as the only effect in the model. In addition, six single degree of freedom preplanned contrasts were evaluated. Coefficients for all contrasts are presented in Table 3-2. These partition the five degrees of freedom in the 3 x 2 factorial arrangement of the six supplement treatments (supplements, additives and the interaction of each additive by supplement), the remaining degree of freedom was used to

compare hay alone vs all supplements. All probabilities levels for treatment contrasts are presented in tables grouped for related variables.

Table 3-2. Coefficients for preplanned comparisons for treatment effects

	Treatments						
Contrasts	CC	CM	CB	MC	MM	MB	HAY
C1-Corn vs molasses	1	1	1	-1	-1	-1	0
C2-Monensin vs ctrl	1	-1	0	1	-1	0	0
C3-Bamberm vs ctrl	1	0	-1	1	0	-1	0
C4-Monensin x supp	1	-1	0	-1	1	0	0
C5-Bamberm x supp	1	0	-1	-1	0	1	0
C6-All supp vs hay	1	1	1	1	1	1	-6

Results and Discussion

Composition of supplements used each year is presented in Table 3-3. Average supplement CP concentrations analyzed were 16.6 and 16.3% of DM for corn- and molasses-based supplements, respectively. Calculated TDN concentrations were 84.4 and 73.4% of DM for corn- and molasses-based supplements, respectively (Table 3-2). The CP concentration of the molasses in this trial was higher than tabular values (NRC 1996), but consistent with values reported by Chapman et al. (1965) for molasses produced from cane grown on organic soils in Florida (7 to 10% CP). Phosphorus concentration in blackstrap molasses is typically .1% of DM.

Phosphoric acid was added to increase the P concentration of the molasses base. Analyzed concentrations of monensin and bambermycins in supplements are presented in Appendix Tables A-1 to A-3. Apparently, there was difficulty with the bambermycins analysis. All mix formulations were recalculated and found to be accurate. The original premix was still 100% efficacious 4 months after the experiment was finished.

Table 3-3. Composition of supplements by analysis

	Corn mix		Corn gluten meal mix[a]		Molasses base[a]	
Item	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
DM	86.1	86.1	89.9	91.5	77.5	77.5
As % DM:						
OM	95.2	94.6	98.3	98.3	83.4	83.7
CP	16.3	16.9	67.0	75.2	9.3	8.5
NDF	9.3	9.3	5.2	5.2	-	-
Ca	.65	.76	.03	.04	.71	.74
P	.67	.71	.44	.46	.88	.74
Mg	.25	.29	.07	.09	.49	.49
K	.45	.51	.13	.16	4.28	4.26
Na	.01	.01	.03	.02	.11	.08
pH	-	-	-	-	4.51	4.71

[a] Calculated CP in offered molasses slurries (10.4% corn gluten mix, 89.6% base molasses) were 16.1 and 16.5% of DM for Year 1 and Year 2, respectively.

Composition of bermudagrass hay is given in Table 3-4. As expected, there were no differences ($P > .3$) for any component due to treatment. All bales were kept in a barn and delivered as needed, therefore a random assignment was presumed and composition data were pooled across treatments.

Table 3-4. Composition of bermudagrass hay

Variable	Mean	Std Dev	Minimum	Maximum
Year 1 (n = 265)				
Dry matter, %	90.5	.32	89.6	91.6
Percent in DM				
Organic matter	93.8	.62	91.8	95.1
Crude protein	9.62	1.74	5.96	15.96
NDF	81.9	1.88	76.2	87.3
IVOMD, %	42.7	2.98	34.1	49.7
Year 2 (n = 218)				
Dry matter, %	88.8	1.10	82.6	90.4
Percent in DM				
Organic matter	94.8	.58	92.1	96.3
Crude protein	9.90	1.56	6.37	14.50
NDF	79.4	2.16	73.9	87.7
IVOMD, %	46.6	2.59	39.6	53.4

The model level 1 (NRC, 1996) was used to estimate the TDN concentration of the hay from observed gains of animals fed hay alone. Predicted and observed gains were similar when 54% TDN was used in both Year 1 and Year 2. Therefore, a value of 54% TDN (DM basis) for the hay offered was used for estimation of efficiency of feed utilization.

Animal Performance

There was no interaction of year by treatments for measures of animal performance, therefore means are discussed by year (Table 3-5) and by treatments (Table 3-6). Probability values (F test) for differences due to year, year by treatment interactions, and contrasts are presented in Table 3-7. Results for each year are summarized in Appendix Tables A-6 and A-9.

Animals used in Year 2 were heavier (P = .0001) and had lower BCS (P = .0007) at the beginning; they gained more (P = .0001), consumed more hay (P = .0001), had lower height change (P = .0001) and higher BCS change (P = .013) than animals used in Year 1. Initial shrink (kg BW loss after feed and water withdrawal/100 kg BW, data not shown) was higher (P = .0001) in Year 1 (7.4%) than in Year 2 (2.6%). Final shrink was also higher (P = .0002) for animals in Year 1 (8.7%) than those in Year 2 (7.4%). Differences in size, hay intake and shrink may explain the higher shrunk ADG for animals in Year 2. The winter was warmer in Year 1, resulting in some pasture regrowth providing additional feed, which may explain the lower hay intake recorded. In contrast, in Year 2 the animals were completely dependent on the hay supply. The lower temperatures in Year 2 may have increased the maintenance energy requirement. The effects of higher maintenance requirements and lower initial fill for Year 2 would tend to cancel each other when estimating efficiency of gain.

Animals fed corn gained .047 kg more (P = .005) than those fed molasses, due to greater effect of feed additives in corn than in molasses supplements. Cattle fed CC and MC had similar gains (.621 and .616 kg) and hay intake (1.54 and 1.64% BW), indicating that the TDN from corn and molasses was utilized with similar efficiency when no antibiotics were added. The feeding value of molasses has

Table 3-5. Effect of year on animal performance

Variable	Year 1	Year 2	SE	Probability value: Year	Probability value: Year by treatment
Initial BW, kg	244	263	1.5	.0001	.7136
Initial BCS	5.48	5.27	.04	.0007	.6145
Initial height, cm	119	118	.4	.0593	.6694
ADG, kg	.507	.668	.0103	.0001	.4466
Height change, cm	6.79	5.17	.218	.0001	.4427
BCS change	.16	.33	.046	.0125	.3934
Hay intake,					
kg DM/d	4.03	5.30	.097	.0001	.5560
DM, % BW	1.49	1.79	.031	.0001	.5346
Change [a], % BW	-.58	-.51	.031	.0001	.5346
Supplement intake,					
kg DM/d	1.97	2.00	.004	.0001	.0004
DM as % BW	.72	.67	.004	.0001	.8133
% of total DM	33.9	28.2	.504	.0001	.5746
kg TDN[b]/d	1.55	1.57	.003	.0001	.0004
% of total TDN	42.8	36.4	.57	.0001	.3475
Total TDN[b], kg/d[b]	3.50	4.21	.056	.0001	.3392
Total TDN[b], % BW	1.29	1.41	.017	.0001	.5699

[a] Hay intake change = hay intake when fed alone minus hay intake when fed with supplements.

[b] Total TDN intakes for hay were calculated assuming 54% TDN (back calculation of TDN from gain on hay alone treatment using NRC, 1996). For supplement, tables values were used (NRC, 1984).

Table 3-6. Effects of treatment on animal performance

Item	Corn			Molasses			HAY	SE
	Control	Monensin	Bamb[a]	Control	Monensin	Bamb[a]		
Initial BW, kg	252	256	251	257	252	251	256	2.9
Initial BCS	5.37	5.41	5.33	5.36	5.30	5.41	5.44	.113
Initial height, cm	118	119	118	118	118	117	119	.6
Shrunk ADG, kg	.621	.656	.727	.616	.589	.658	.245	.031
Height change, cm	6.18	6.56	6.50	5.90	6.39	6.20	4.40	.648
BCS change	.28	.40	.47	.30	.26	.38	-.37	.102
Hay intake,								
kg DM/d	4.43	4.09	4.75	4.79	4.30	4.64	5.68	.287
DM, % BW	1.54	1.40	1.63	1.64	1.50	1.61	2.10	.094
Change[b], % BW	-.56	-.70	-.47	-.46	-.60	-.49	-	.094
Supplement intake,								
kg DM/d	1.86	1.86	1.86	2.12	2.09	2.12	0	.007
DM, % BW	.65	.64	.64	.73	.74	.74	0	.007
% of total DM	30.1	31.6	28.5	31.4	33.4	31.6	0	.87
kg TDN[c]/d	1.57	1.57	1.57	1.56	1.54	1.56	0	.005
% of total TDN[b]	40.1	41.9	38.3	38.2	40.5	38.6	0	.98
Total TDN[c], kg/d	3.96	3.78	4.12	4.14	3.86	4.06	3.07	.11
Total TDN[c], % BW	1.39	1.29	1.42	1.42	1.36	1.41	1.13	.032

[a] Bamb = bambermycins.

[b] Hay intake change = hay intake when fed alone minus hay intake when fed with supplements.

[c] Total TDN intakes for hay calculated assuming 54% TDN (back calculation of TDN from gain on hay alone treatment using NRC, 1996). For supplement, table values (NRC, 1984) were used.

Table 3-7. Probability values for contrasts, animal performance

	Contrasts[a]					
Variable	C1	C2	C3	C4	C5	C6
Initial BW, kg	.8747	.9814	.2744	.1109	.4541	.3191
Initial BCS	.8426	.9273	.9383	.4855	.5623	.3637
Initial height	.3706	.9196	.2879	.9889	.6047	.3866
ADG, kg	.0049	.8508	.0004	.1148	.1010	.0001
Height change, cm	.6436	.4858	.4507	.6171	.9853	.0001
BCS change	.3442	.6672	.1221	.3591	.5203	.0001
Intake,						
Hay, kg	.3658	.0341	.6145	.6725	.2281	.0001
Hay, % BW	.2257	.0236	.6431	.9198	.3459	.0001
Hay change, % BW	.2257	.0236	.6431	.9198	.3459	-
Supplement,						
Kg DM/d	.0001	.0590	.9265	.0590	.9265	-
DM as % BW	.0001	.6086	.8589	.1023	.1690	-
% of total DM	.0057	.0473	.4629	.7447	.2938	-
Kg TDN/d	.0001	.0590	.9265	.0590	.9265	-
% of total TDN	.2257	.0482	.4700	.7887	.2809	-
Total TDN, kg/d	.4703	.0309	.6786	.6309	.2371	.0001
Total TDN, % BW	.2532	.0161	.6728	.7297	.4632	.0001

[a] Contrasts:
C1 = corn vs molasses
C2 = monensin vs control
C3 = bambermycins vs control
C4 = monensin by supplement type
C5 = bambermycins by supplement type
C6 = all supplements vs hay alone.

produced mixed results in previous research. Earlier work suggested that molasses is utilized with decreasing efficiency as its level in the diet increases (Lofgreen and Otagaki, 1960). Brown and Weigel (1993) presented data suggesting a lower feeding value of molasses when compared with corn and soybean hulls. However, Preston et al. (1969) reported that the efficiencies of metabolizable energy

utilization were 15 to 20% and 26 to 32% for diets with 33 and 72% molasses, respectively. Lofgreen (1965) estimated that the NEg of molasses was .78 and .70 Mcal/kg when fed at 5 to 15 and 20% of the diet, respectively, a difference smaller than previously determined (Logfreen and Otagaki, 1960). Similarly, data presented by Pitzer et al. (1986) suggested that the TDN in molasses and corn was used with similar efficiency (.21 kg of added gain/kg supplemental TDN). In the present experiment, each kg of TDN, either from corn or from molasses slurry, increased gain by .24 kg.

Associative effects on intake were similar in animals fed CC and MC (-.56 and -.46% BW lower hay DM intake when compared with animals consuming hay alone). Digestibility may also exhibit associative effects (deviation from additivity). An empirical model was developed from a dry supplement data set to predict, among other effects, the expected change in ME concentration of the total diet when supplements are fed with forages (Brant, 1993; Moore and Kunkle, 1995, 1996). Hay and supplement intake, and hay and supplement OM, CP, and TDN concentration are inputs for this model component. A small negative associative effect on digestibility was predicted (-.08 Mcal ME/kg) for both, corn- and molasses-supplemented diets. This probably resulted from the moderate level of supplementation (.64 to .73% BW) and a balanced total diet (TDN:CP < 7) when supplements were fed.

Gains observed with CC (.62 kg) were similar to gains reported with bermudagrass plus corn-soybean meal fed at 25% of total TDN intake (Garces-Yepez, 1995), while ADG and intake of the hay alone also was similar (.30 vs .25 kg and 1.99 vs 2.10% BW, respectively). Higgins et al., (1991) also reported a similar gain in one of the bermudagrass hays evaluated (.29 and .67 kg/d with hay alone and hay plus .75% BW of corn-soybean meal supplement). Intake of hay alone in the current experiment was similar to intake measured by Stateler et al. (1995) using a similar technique (1.92 to 1.96% BW). Gains reported by Stateler et al. (1995) with molasses slurries including soybean meal or blood meal-hydrolyzed feather meal were lower (.46 kg) and higher (.71 kg), respectively, than gain observed with MC (.62 kg). Animals supplemented with blood-feather meal consumed .14 kg of ruminal UIP from the supplement while in this experiment estimated UIP intake was .09 kg. Quantity rather than quality of UIP was probably more important in explaining the lower gain observed in this experiment because the NRC (1996) model did not predict limiting amino acids at this rate of gain. Moreover, energy and not protein was limiting gain. However, escape protein may provide substrate for gluconeogenesis and improve the efficiency of energy utilization (Preston and Leng, 1980).

Inclusion of monensin tended to produce different ADG changes when fed in corn or molasses (monensin by supplement

type interaction, $P = .11$). Monensin increased ADG .035 kg in corn supplement and depressed ADG .029 kg in molasses supplement. Animals fed CM had .067 kg higher ADG than those fed MM.

Effects of monensin have been variable in high roughage diets. Reports involving several trials of grazing cattle or cattle fed forage diets suggest a 14 to 17% increase in ADG when monensin was added to dry supplements fed at .5 to 1 kg/d (Potter et al. 1976; Wilkinson et al. 1980; Potter et al., 1986). Horton et al.(1992) concluded that improvement in ADG to feeding ionophores (lasalocid and monensin) was inconsistent in cattle grazing subtropical grasses, and the variable responses appeared to be associated with forage quality and environmental conditions. Ellis et al. (1984) suggested that the expected gain improvement to monensin decreases as the quality of forage consumed increases, and as the realized gain approaches the genetic potential for gain by the animal. Under the conditions of this experiment, neither of these factors would apply because the gain on hay alone was moderate, indicating low forage quality, and the highest gains were below the animal genetic potential for gain. Improvement in gain when monensin was fed in corn was 21.9% in Year 1 but gain was not improved in Year 2. Reasons for this variability are not evident and can not be explained.

The failure of ionophores to improve gain when fed in molasses supplements was consistent with previous research. Pate (1995) reported that gains were not improved when lasalocid was added to molasses supplements. Kunkle et al. (1990) reported that 200 mg/d of monensin added to molasses-soybean meal slurry (2.7 kg/d) in heifers on bahiagrass pasture did not improve gains (ADG responses to monensin were +.02 to -.07 kg). In contrast, Garrett et al. (1989) reported improved gain in feedlot cattle when monensin was added to high concentrate diets with 30% of sugar beet molasses, probably because monensin reduced ruminal disorders.

This experiment and previous research suggests that no change or small depression in ADG should be expected when monensin is added to molasses slurries consumed at about 30% of the total DM in warm season grass diets.

Cattle fed bambermycins in corn or molasses had .074 kg higher (P = .0004) ADG than those fed control supplements. Because of a tendency for bambermycins by supplement type interaction (P = .101) it is risky to generalize. Animals fed CB had .106 kg higher ADG than those fed CC, while animals fed MB had .042 kg higher ADG than those fed MC. Animals fed CB had .064 kg higher ADG than those fed MB.

Bambermycins included in dry supplements increased ADG by 15% in pasture fed cattle (Deetz et al., 1990; Deetz et al., 1992). In cattle fed bahiagrass pasture (W.E. Kunkle,

unpublished data), bambermycins increased ADG by 22% (.39 vs .47 kg) and 29% (.45 vs .58 kg). Gain increased 28.2% (34.4 in Year 1 and 22.5% in Year 2) with corn supplements, which is similar to values obtained by W.E. Kunkle (unpublished data) and somewhat higher than other reports.

Research on the efficacy of bambermycins in molasses-based supplements could not be found. Gain increased 11.3% when bambermycins was fed in molasses supplements (16.7% in Year 1 and 6.3% in Year 2). Because of this variable response, the efficacy of bambermycins in molasses supplements to improve gains is inconclusive and more research is needed.

A comparison of responses estimated as the difference between ADG when an additive was included in a supplement minus the ADG obtained with that supplement without additive, was analyzed as a 2 (supplement type) x 2 (feed additive) factorial, with year included in the model. No interactions were found (supplement x additive, $P = .95$; year x supplement, $P = .39$; year x additive, $P = .74$, and year x supp. x add., $P = .48$). Antibiotics added to the supplements improved gain more ($P = .04$) in Year 1 (.062 kg) than in Year 2 (.016 kg), improvements were higher ($P = .007$) in corn (.071 kg) than in molasses (.007 kg), and higher ($P = .003$) with bambermycins (.074 kg) than with monensin (.004 kg). The order of responses was CB (.106 kg) > MB (.042 kg) and CM (.035 kg) > MM (-.028 kg).

All supplements increased (P = .0001) BCS and height change when compared with hay alone. Similar results were reported by Stateler et al. (1995). However, in their experiment cattle in all treatments lost BCS, suggesting that energy retention in BW gain was higher in this experiment. Bambermycins tended (P = .12) to increase BCS and had no effect (P = .45) on height change. Monensin did not affect BCS (P = .67) or height change (P = .49).

Corn supplements were completely consumed. Molasses supplements were not consumed completely during the first 3 wk after the start of the trial but were consumed completly thereafter. Monensin included at 120 mg/kg of molasses acted as an effective intake regulator (Gulbransen and Elliot, 1990), which may explain the trend for lower molasses intake when monensin was added at 74 mg/kg in this experiment.

All supplements decreased (P = .0001) hay intake from .47% BW (CB) to .70% BW (CM) when compared with hay alone. A similar response was reported by Garces-Yepez (1995) and Higgins et al. (1991) when bermudagrass was supplemented with corn-soybean meal. Stateler et al. (1995) reported .21 to .41% of BW depression of bermudagrass hay intake when about 2 kg of molasses slurries were consumed. Depression of forage intake should be expected when the hay is balanced (TDN:CP < 7, Table 3-4), according to the general conclusion of Moore and Kunkle (1995).

Monensin decreased (P = .024) and bambermycins did not affect (P = .35) hay intake when included in supplements. However, when analyzed by year, monensin tended (P = .099) to decrease and bambermycins tended (P = .073) to increase hay intake in Year 1. In Year 2, monensin tended to decrease (P = .099) and bambermycins did not affect (P = .40) hay intake.

Ellis et al. (1984) suggested that the effect of monensin on forage intake depends upon forage quality. It was hypothesized that monensin decreased intake of low quality forage by monensin's effect on reducing passage rate of undigested forage residue out of the rumen combined with the animal's inability to accommodate further increases in fill of undigested dry matter. Monensin increased intake of medium to high quality forages as a result of increased undigested matter fill, and it would decrease intake of high quality forage by a mechanism similar to depression of intake in high concentrate diets (metabolic control of intake). Whether or not this reasoning is applicable to hay based diets supplemented with concentrate at about 30% of total DM is not known.

In attempting to explain the drop in hay intake, it is relevant to consider the effects of monensin on rumination and ruminal motility. Two-hundred mg of monensin fed daily to 625-kg steers resulted in a 16% decreasing of forage intake of dry winter range (Lemenager et al., 1978b). At the

same time ruminal liquid and solid turnover rates were 31 and 44% slower. In a companion trial, monensin (0, 50, 100, and 200 mg/d) reduced linearly ruminal fluid turnover rate in cattle limited-fed a high concentrate diet. These findings were interpreted as monensin depressing ruminal turnover rate independent of depression in intake. Lemenager et al. (1978a) also reported a 13.6% and 19.6% reduction in forage intake in cows grazing low quality range when 50 and 200 mg of monensin were fed, respectively. Grazing time was also reduced by 14.6% when cows were fed 200 mg of monensin. Coombe et al. (1979) reported a reduction in cereal straw intake from 2 to 1.5% BW and from 2.6 to 2.1% BW, depending on the straw treatment, when monensin was fed. Deswysen et al. (1987) reported that 100 mg of monensin given to 290-kg cattle fed corn silage indirectly affected rumination through a lowered ruminal motility. Monensin reduced the daily numbers of normal boli and total boli and increased the mean duration of one rumination bolus cycle. Monensin increased the duration of the main morning meal and decreased total daily ruminal contractions, and tended to depress silage intake. They also found differences among animals and several interactions of monensin by period and monensin by animal, suggesting that the effects of monensin on intake, intake behavior, and ruminal motility were variable. Monensin reduced the strength of contraction of intestinal waves (Job, 1971). Based on this observation,

Deswysen et al. (1987) suggested that strength of ruminal contraction may have been reduced, in addition to reduction in number of contractions.

Mastication during ingestion and rumination appears to be the primary mechanism for comminution. Chewing during rumination is more important for the continued comminution of large particles (Ulyatt, et al., 1986). All these findings may explain the slower rate of ruminal turnover, increased or no effect on ruminal fill, and variable effects on intake found in other experiments with high forage diets (Lemenager et al., 1978a, 1978b; Pond and Ellis, 1979; Pond et al., 1980; Ellis et al., 1984). The suggested dose of monensin for grazing cattle is 100 mg/d (Delaney and Ellis, 1983). Faulkner et al. (1985) found that 100 mg of monensin was better than 0 or 200 mg in a growing trial with 236-kg cattle fed ensiled cornstalks. Monensin linearly decreased intake and quadratically affected ADG. The effects of monensin on rumination and ruminal motility (Deswysen et al. (1987), and depression of feed intake have been found at the 100 mg/d feeding level. The linear effect of increasing monensin levels on ruminal liquid passage rate (Lemenager et al. 1978b) and on intake (Faulkner et al., 1985) suggest that these effects may have been magnified in the current experiment where cattle of similar BW were given twice this dose. High doses were used in an attempt to overcome the presumed inhibitory effect of molasses.

Variable effects of bambermycins on feed intake have been reported in cattle. Some research reported an increased feed intake (Alert et al., 1993), and other research reported no effect (Flachowsky and Richter, 1991; Poppe et al., 1993; Burris and Randolph 1996). Many of the published trials were grazing trials and intake of forage was not available.

Efficiency of feed utilization was estimated by several variables. Metabolic BW (MBW) was included as a covariate in an attempt to account for maintenance. Gains were predicted by pen with the actual hay and supplement intake, mean BW and sex, using the Level 1 of the NRC (1996) model. For Year 1, predicted gains were obtained for heifers and steers, and averaged. Differences between observed and predicted ADG was analyzed as an another estimator of efficiency. Pen observed and predicted ADG are plotted in Figure 3-1. Points plotted above the line $y = x$ indicate that observed gains were higher than predicted. If the treatments did not affect the efficiency of feed utilization, all points are expected to fall in that line with some variation due to errors of measurements of feed intake and BW gain.

Feed to gain and TDN to gain ratios were lower for Year 2, which is consistent with higher gains (Table 3-8). Feed to gain, TDN to gain, and TDN to added gain ratios were lower (P = .0001, .0007, and .037, respectively) in animals fed corn than in those fed molasses supplements, indicating

the better response to feed additives with corn supplements (Tables 3-9 and 3-10).

Animals fed monensin had 10% (CM) to 3% (MM) higher efficiency of total gain ($P < .03$) and similar efficiency of added gain than the ones fed control supplements. Monensin increased ($P = .004$) by .102 kg (CM) to .041 kg (MM) the difference between observed and predicted ADG. There were trends for interactions for TDN to total gain adjusted for MBW ($P = .062$) and for difference of observed and predicted ADG ($P = .13$), indicating that the increased efficiency was higher in corn than in molasses.

Animals fed bambermycins had 13% (CB) to 8% (MB) higher efficiency of total ($P < .003$) and 23% (CB) to 8% (MB) higher efficiency of added gain ($P < .007$). Bambermycins increased ($P = .013$) by .063 kg (CB) to .041 kg (MB) the difference between observed and predicted ADG. However, the increased efficiency obtained with bambermycins appeared mostly in Year 2 (Figure 3-2). In Year 1, the increased ADG was explained by increased hay intake. In Year 2, however, there was no effect of bambermycins on hay intake and the increased ADG was explained by increased efficiency of feed utilization.

Bambermycins increased feed efficiency in several experiments (Grant et al., 1974; Flachowsky and Richter, 1991; De Schrijver et al., 1991; Alert et al., 1993;

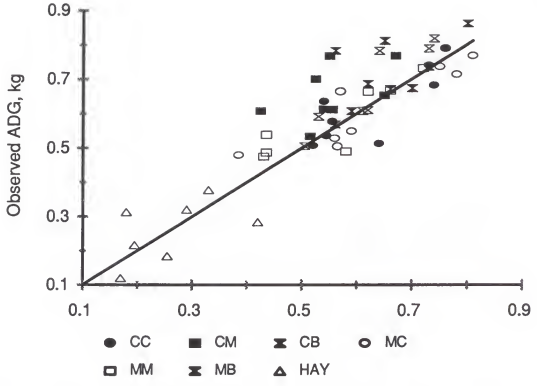

Figure 3-1. Observed vs predicted gains, by pens Year 1 and Year 2. Line indicates y=x.

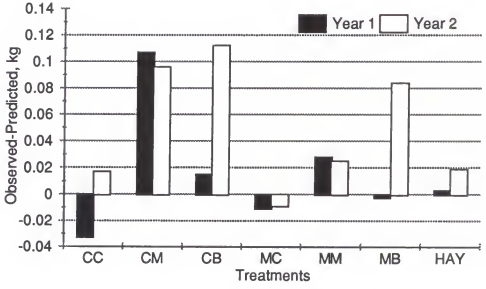

Figure 3-2. Difference between observed and predicted gains, by treatment and year.

Table 3-8. Effect of year on efficiency of feed utilization (hay alone not included)

Item	Year 1	Year 2	SE	Probability value: Year	Probability value: Year by treatment
AVGBW[a], kg	275	301	1.6	.0001	.5894
ADG, kg					
Observed	.564	.725	.012	.0001	.3761
Predicted[b]	.547	.670	.016	.0001	.3260
Feed/gain	10.5	9.9	.18	.0301	.6027
TDN/gain[c]	6.51	6.02	.104	.0022	.5892
TDN/gain[d]	6.76	5.77	.160	.0017	.4636
Added gain[e], kg	.398	.400	.015	.8820	.3761
TDN/added gain[f]	3.99	4.05	.127	.7529	.5310
TDN/added gain[g]	3.82	4.22	.210	.2908	.6266
TDNA/added gain[h]	2.31	2.32	.134	.9900	.4806
Difference[i], kg	.018	.054	.014	.0620	.4311

[a] Initial + final body weight / 2.
[b] Predicted with Level 1 model, NRC (1996), see text.
[c] Total TDN / total gain.
[d] Total TDN / total gain, lsmeans with MBW as covariate.
[e] Gain with supplement - gain with hay alone.
[f] Supplemental TDN / added gain.
[g] Supplemental TDN / added gain, lsmeans with MBW as covariate.
[h] Increment of TDN = (change in hay TDN + supplement TDN)/added gain.
[i] Difference = observed ADG - predicted ADG.

Table 3-9. Effect of treatment on efficiency of feed utilization (hay alone not included)

	Treatments						
Item	CC	CM	CB	MC	MM	MB	SE
AVGBW[a], kg	285	292	290	290	284	287	2.8
ADG, kg							
Observed	.621	.656	.727	.616	.589	.658	.020
Predicted[b]	.629	.554	.664	.626	.563	.617	.030
Feed/gain	10.20	9.14	9.13	11.30	10.90	10.40	.30
TDN/gain[c]	6.45	5.81	5.71	6.77	6.59	6.26	.18
TDN/gain[d]	6.51	5.73	5.67	6.73	6.67	6.28	.23
Added gain[e], kg	.376	.411	.482	.371	.344	.413	.020
TDN/add gain[f]	4.24	3.96	3.28	4.23	4.50	3.91	.22
TDN/add gain[g]	4.20	4.00	3.31	4.26	4.44	3.90	.23
TDNA/added gain[h]	2.38	1.76	2.21	2.85	2.29	2.40	.23
Diff[i], kg	-.008	.102	.063	-.010	.026	.041	.020

[a] Initial + final body weight / 2.
[b] Predicted with Level 1 model, NRC (1996), see text.
[c] Total TDN / total gain.
[d] Total TDN / total gain, lsmeans with MBW as covariate.
[e] Gain with supplement - gain with hay alone.
[f] Supplemental TDN / added gain.
[g] Supplemental TDN / added gain, lsmeans with MBW as covariate.
[h] Increment of TDN = (change in hay TDN + supplement TDN) / added gain.
[i] Difference = observed ADG - predicted ADG.

Dhuyvetter et al., 1996). The increase in feed efficiency, however, was lower than the efficiency achieved with monensin in cattle fed corn silage diets (Burris and Randolph, 1996).

Monensin consistently decreased hay intake by .14% BW in both corn and molasses, and increased by 10% and 3% total efficiency in corn and molasses, respectively. Monensin may be more useful when hay is in short supply or expensive.

Table 3-10. Probability values for preplanned comparisons for efficiency of feed utilization

	Contrasts[a]					Effect[b]	
Effect	C1	C2	C3	C4	C5	Treat	Covar
AVGBW[c], kg	.3440	.9492	.7454	.0326	.1789	.3222	-
ADG, kg							
Observed	.0069	.8567	.0007	.1284	.1139	.0005	-
Predicted[d]	.5547	.0174	.6478	.8409	.4303	.0636	-
Feed/gain	.0001	.0211	.0027	.2609	.7157	.0001	-
TDN/gain[e]	.0007	.0264	.0013	.2134	.5376	.0006	-
TDN/gain[f]	.0002	.0205	.0007	.0615	.2894	.0002	.0540
Added gain[g]	.0069	.8567	.0007	.1284	.1139	.0005	-
TDN/add gain[h]	.0372	.9689	.0062	.2251	.1560	.0090	-
TDN/add gain[i]	.0568	.9764	.0073	.4340	.2456	.0196	.3013
TDNΔ/add gain[j]	.0445	.0152	.1888	.8942	.5553	.0664	-
Diff[k], kg	.0908	.0036	.0131	.1261	.6659	.0136	-

[a] Contrasts: C1 = corn vs molasses; C2 = monensin vs control; C3 = bambermycins vs control; C4 = monensin by supplement type; C5 = bambermcycins vs supplement type.
[b] Treat = treatment; covar = covariate (MWB).
[c] Initial + final body weight / 2.
[d] Predicted with Level 1 model, NRC (1996), see text.
[e] Total TDN / total gain.
[f] Total TDN / total gain, lsmeans with MBW as covariate.
[g] Gain with supplement - gain with hay alone.
[h] Supplemental TDN / added gain.
[i] Supplemental TDN / added gain, lsmeans with MBW as covariate.
[j] Increment of TDN = (change in hay TDN + supplement TDN) / added gain.
[k] Difference = observed ADG - predicted ADG.

Increased ADG in cattle fed bambermycins apparently resulted from increased hay intake and feed efficiency in Year 1 and through increased feed efficiency and no change in feed intake in Year 2. Bambermycins should be used when maximum use of hay is desired.

Volatile Fatty Acids

Volatile fatty acid data are presented averaged over sampling times (Table 3-11 and 3-12, P-values in Table 3-13). Because a few interactions of treatments by sampling date were observed, data are also presented by year and sampling date (Appendix Tables A-7 and A-10, P-values in Appendix Tables A-8 and A-11).

Total VFA concentrations were higher in Year 1 (P = .0001) than in Year 2. This variable should be taken with caution because the sampling technique may introduce considerable error due to salivary contamination. It is possible that differences between years reflect different sampling conditions. Cattle were sampled in temporary facilities in Year 2, and therefore greater opportunity for salivary contamination may have occurred. Total VFA concentrations were higher (P = .0001) in animals fed corn than in those fed molasses supplements, possibly reflecting more substrate for fermentation at the time of sampling. Corn supplements were delivered 3 to 5 h before sampling while molasses were delivered the day before sampling.

There was a trend (P = .118) for monensin by supplement type interaction. Monensin tended to increase by 3% total VFA in corn and to decrease by 7% total VFA in molasses supplements. Bambermycins depressed (P = .011) by 13 and 3% total VFA in corn and molasses supplements, respectively.

Table 3-11. Effect of year on ruminal volatile fatty acids and plasma urea nitrogen

Variable	Year 1	Year 2	SE	Probability value	
				Year	Year by treatment
Total VFA, mM	70.1	57.6	1.14	.0001	.1323
VFA, mol/100 mol					
Acetate	69.9	68.2	.33	.0012	.1988
Propionate	18.4	20.1	.26	.0001	.1010
Butyric	9.8	10.6	.20	.0106	.3232
BCVFA[a]	1.18	.73	.127	.0163	.0632
Acetate:Propionate	3.98	3.56	.06	.0001	.0914
Plasma urea N, mg/dL	11.6	9.49	.26	.0001	.8181

[a] Branched-chain VFA (iso-butyric + iso-valeric).

Table 3-12. Effect of treatment on volatile fatty acids and plasma urea nitrogen

Item	Corn			Molasses			HAY	SE
	Control	Monensin	Bamb[a]	Control	Monensin	Bamb[a]		
Total VFA, mM	72.4	74.8	63.1	60.9	56.5	58.8	60.3	2.13
VFA, mol/100 mol								
Acetate	70.2	66.5	70.6	69.0	66.4	67.6	73.2	.63
Propionate	17.3	24.1	16.6	18.7	21.9	19.2	16.9	.49
Butyrate	10.7	7.9	10.5	11.2	10.7	12.0	8.3	.37
BCVFA[b]	1.15	1.13	1.77	.38	.51	.64	1.08	.24
Acetate:Propionate	4.14	2.88	4.33	3.81	3.17	3.64	4.41	.11
Plasma urea N, mg/dL	12.1	12.0	11.9	9.3	10.8	9.5	8.0	.49
Coccidia[c]								
Year 1	626	6	1057	881	6	805	827	149
Year 2	.78	.25	1.03	.78	.23	.72	.78	.09

[a] Bamb = bambermycins.

[b] Branched-chain VFA (iso-butyric + iso-valeric).

[c] Presented by year because different counting techniques, Year 1 are cysts/5 g of fresh feces, Year 2 are scores (0 = none present to 4 = heavy infestation).

Table 3-13. Probability values for contrasts, volatile fatty acids and plasma urea nitrogen

	Contrasts[a]					
Variable	C1	C2	C3	C4	C5	C6
Total VFA, mM	.0001	.6383	.0106	.1182	.0979	.0773
VFA, M/100 M						
Acetate	.0083	.0001	.3794	.3953	.1498	.0001
Propionate	.1574	.0001	.8387	.0006	.2183	.0001
Butyrate	.0001	.0001	.4535	.0031	.1817	.0001
BCVFA[b]	.0001	.8234	.0723	.7723	.4565	.5658
Acetic:propionic	.0078	.0001	.9018	.0054	.0980	.0001
Plasma urea-N	.0001	.1721	.9690	.1043	.6920	.0001

[a] Contrasts:
C1 = corn vs molasses
C2 = monensin vs control
C3 = bambermycins vs control
C4 = monensin by supplement type
C5 = bambermycins by supplement type
C6 = all supplements vs hay alone.

[b] Branched-chain VFA.

Animals fed hay alone tended (P = .08) to have lower VFA concentrations than those fed supplements.

Individual VFA molar proportions and ratios should be independent of salivary contamination. Cattle fed corn had a 2% higher (P = .008) acetate molar proportion than those fed molasses supplements. Monensin decreased (P = .0001) by 5%, while bambermycins did not affect (P = .38) acetate molar proportion in both corn and molasses supplements. All supplements decreased (P = .0001) acetate molar proportion when compared with hay alone.

There was a monensin by supplement type interaction (P = .0006) for propionate molar proportion. Monensin increased by 39% propionate molar proportion in corn and by

17% in molasses supplements. Bambermycins did not affect (P = .84) propionate molar proportion. All supplements increased (P = .0001) propionate molar proportion when compared with hay alone.

Animals fed molasses had a 16% higher (P = .0001) butyrate molar proportion than those fed corn supplements. Butyrate molar proportion increased in animals fed molasses or sugars (Marty and Preston, 1970; Pate, 1983; Beever, 1993). There was a monensin by supplement type interaction (P = .003) for butyrate proportions. Monensin decreased by 16% butyrate in corn and it did not affect butyrate in molasses supplements. Bambermycins did not affect (P = .45) butyrate molar proportions in any type of supplement. Animals fed supplements (with the exception of CM) had higher (P = .0001) butyrate than those fed hay alone.

Animals fed corn had a higher (P < .0001) molar proportion of branched-chain VFA (BCVFA) than those fed molasses supplements (1.35 vs .51 mol/100 mol). Monensin did not affect (P > .8) BCVFA molar proportion and bambermycins tended (P = .07) to increase by 61% molar proportion of BCVFA in both corn and molasses supplements. Branched-chain VFA are considered growth factors for cellulolytic bacteria and they arise from deamination of branched chain amino acids (Russell, 1984).

Animals fed molasses had a 6% lower (P = .008) acetate:propionate ratio (C_2:C_3) than those fed corn

supplements. Moloney et al. (1994) reported lower C_2:C_3 ratios in steers fed a silage diet and supplemented with molasses than in those supplemented with barley (4.28 vs 3.57). There was a monensin by supplement type interaction (P = .005) for C_2:C_3. Monensin depressed C_2:C_3 by 44% in animals fed corn and by 21% in animals fed molasses. Bambermycins did not affect (P = .90) C_2:C_3 in either supplement type but tended (P = .098) to exhibit an interaction by supplement type. Animals fed supplements had lower (P = .0001) C_2:C_3 than those fed hay alone. Acetate to propionate ratio decreased when changing from high forage to high concentrate diet (Owens and Goetsch, 1988; Van Nevel and Demeyer, 1988; Beever, 1993). Supplementation of forage diets with highly fermentable carbohydrates (sugars, starch) decreased C_2:C_3 (Owens and Goetsch, 1988; Beever, 1993).

The effect of monensin on VFA molar proportions is consistent with the widely known effect of monensin on ruminal fermentation: a reduction in acetate and butyrate, and an increase in propionate molar proportion (Bergen and Bates, 1984; Van Nevel and Demeyer, 1988). The lack of effect of monensin on performance in cattle fed molasses supplements does not appear to be related to the effect on VFA shift. Dawson and Boling (1987) reported an increased resistance of ruminal bacteria to monensin with increasing K concentration in vitro. Greene et al. (1986) and Chirase et al. (1987) reported that monensin was more effective in

decreasing $C_2:C_3$ ratio in lambs fed high dietary K. Research conducted at the University of Florida has shown that changes in concentration of K and Na resulted in altered in vitro VFA production (Schwingel et al., 1989). With monensin fermentation $C_2:C_3$ ratios were higher at 48 mM K than at 168 mM K. The decrease of $C_2:C_3$ ratio with increasing K concentration was interpreted to be the consequence of a change in the microbial ecology. Total VFA production was severely depressed by monensin, especially at the high Na levels (Schwingel, 1988). The nature of the interaction appears complex, as Bates and Schwingel (unpublished data) have shown different effects of lasalocid and monensin on the growth of S. bovis and R. albus with different K and Na concentrations. Schwingel (1988) pointed out that the effects may be even more complicated in the rumen, where Na and K concentrations affect the concentration of each other. Total VFA production appeared to be negatively affected by the combination of monensin and high dietary K, because monensin tended to reduce total VFA concentration in animals fed molasses supplements. The combined effects of less feed (hay) intake, less VFA, and probably less bacterial protein available to the animal may explain the failure of monensin to increase ADG when fed with molasses. Coombe et al. (1979) reported that monensin markedly reduced intake and gain with all diets (pelleted and alkali-treated barley or wheat

straw), and this effect occurred even though monensin had the usual effects on rumen fermentation.

A negative association has been reported for corn gluten meal and monensin when fed on alternate days. Steers fed monensin at 48-h intervals had a reduced feed intake. Monensin supplementation of diets that contained corn gluten meal reduced ADG by .21 kg while increasing ADG with diets that contained soybean meal by .13 kg. Monensin feeding in an alternate day supplementation with high ruminal escape protein was not recommended as a result of this study (Collin and Pritchard, 1992). It is unlikely that a similar effect occurred in this trial because even though molasses was delivered three times a week, molasses was consumed for more than 1 d, especially with monensin included in molasses. Furthermore, monensin has also failed to increase gain when soybean meal was the protein source in molasses slurry (Kunkle et al., 1990).

Bambermycins appeared to have little effect, if any, on VFA proportions. Van Nevel and Demeyer (1992) reported that in vitro bambermycins was one of the feed additives with little effect on fermentation of different substrates. In that experiment, bambermycins did not depress fiber degradation. Similarly, Rowe et al. (1982) reported no effect on fiber digestion in situ. Several researchers have found no effects of bambermycins on ruminal fermentation (Galbraith et al., 1983; El-Jack et al., 1986; Fallon et

al., 1986; Flachowsky and Richter, 1991; Alert et al., 1993). Other research has reported changes in VFA concentrations (DelCurto et al., 1996; Earley et al., 1996).

Plasma Urea Nitrogen

Plasma urea N data are presented averaged over sampling times (Table 3-12, P-values in Table 3-13). Because an interaction of treatments by sampling date have been observed for Year 1, data are also presented by year and sampling date (Appendix Tables A-7 and A-10).

Plasma urea N was 2.1 mg/dL lower in Year 2, perhaps reflecting the total dependency on hay versus some pasture regrowth throughout the experimental period in Year 1 (Table 3-11). In addition, higher gains may have required higher metabolizable protein. Higher hay (energy) intake may have captured more ammonia in the rumen. Major dietary factors shown to affect PUN concentration in cattle include protein level, ruminal protein degradability, energy level, protein to energy ratio, and level of intake (Hammond, 1992; Hammond et al., 1993). Animals fed corn had higher (P = .0001) PUN concentrations than those fed molasses supplements. Whether this is a true difference or an artifact caused by the short time elapsed between feeding corn supplements and ruminal sampling is not known. Hammond and Chase (1996) showed that in beef cows supplemented with cottonseed meal twice a week, PUN ranged from a high of 14 mg/dL in the afternoon after supplementation to a low of 7 mg/dL 2 d after

supplementation. Diets were formulated to provide the same quantities of rumen degradable protein. The rate of degradability of the main DIP source, urea in corn and non-protein N in molasses supplements, may be different. Different degradation rates of the N and energy source may also result in excess ammonia being absorbed and transformed into urea in the liver. Molasses-based supplements may have captured more N in the rumen, and therefore PUN would be lower. However, Stateler et al. (1995) reported higher PUN concentration in cattle fed similar levels of molasses slurries but with higher CP concentration. It is unlikely that DIP was limiting in either supplement type because the PUN concentration were 9 mg/dL or higher. Hammond et al. (1993) suggested that PUN concentrations between 9 and 12 mg/dL were a transition range below which ADG response to protein supplementation was greater than above this range. Model level 2 of NRC (1996) predicted a negative bacterial N balance (-13% of requirements) in animals fed molasses and 8% surplus in animals fed corn supplements. Predicted metabolizable protein was not limiting for gain in molasses or corn supplements.

There was a tendency (P = .10) for monensin by supplement type interaction on PUN and bambermycins did not affect (P = .97) PUN concentrations. Animals fed supplements had higher (P = .0001) PUN concentrations than those fed hay alone. The average PUN concentration for hay alone in Year 1

was 9.41 (7.86 mg/dL was the lowest in February), while the average for Year 2 was 6.77 mg/dL (lowest 6.07 in March) suggesting that at some point, and especially in Year 2, animal performance of cattle fed hay alone may have been limited by DIP. However, the TDN:CP ratio of the hay fed was less than 7, suggesting sufficient protein relative to energy (Moore and Kunkle, 1995). Garces-Yepez (1995) reported mean ruminal ammonia and PUN concentrations of 2.6 and 3.9 mg/dL respectively in steers fed bermudagrass hay containing 5.7% CP, which may be considered more indicative of N deficiency.

Parasites

Nematoda egg counts were low in both Year 1 and Year 2 and were not affected by treatments (data not shown). Deworming at the beginning of the trial in addition to low grazing activity during the winter probably created little opportunity for infestation. Counts tended to be lower in Year 2 (means from 0 to 2 eggs/5 g of feces) than in Year 1 (means from 8 to 29 eggs/5 g of feces) probably reflecting 'cleaner' pastures in the facilities used in Year 2. The pens used in Year 2 were finished just before the trial started and that area of pasture did not have high animal density during the previous warm season.

Monensin consistently suppressed ($P < .0004$) coccidia counts in both corn and molasses supplements in Year 1 and Year 2 (Table 3-12). This suggests that monensin was

effective at the intestinal level in molasses supplements, and it can be used for prophylaxis for coccidia in either supplement. This effect of monensin and other ionophores has been documented (Bergstronm and Maki, 1974; Stromberg et al., 1982; Watkins et al., 1986). It is unlikely that coccidia control accounted for the effect of monensin on animal performance in this experiment, because: a) the counts were low, b) the animals were yearling and likely less susceptible than calves, and c) suppression of coccidia in molasses did not result in higher animal performance. Bambermycins had no effect ($P > .2$) on coccidia counts, which is in agreement with literature from the manufacturer (Hoechst-Roussel, 1993).

CHAPTER IV
EFFECTS OF BAMBERMYCINS FED IN CORN OR MOLASSES SUPPLEMENTS ON INTAKE, DIGESTIBILITY, AND DIGESTION KINETICS IN HEIFERS

Introduction

Feed intake is an important determinant of animal production and changes in intake may be associated with changes in digestibility, and both intake and digestibility may be related to digesta kinetics. Some feed additives, such as monensin affect intake, digestibility and digesta kinetics (Ellis et al., 1984). Results from the performance experiment (Chapter III) suggested that bambermycins may affect intake and efficiency of feed utilization. The present research was conducted to verify these effects. The objectives were to: 1) determine the effects of bambermycins included in corn or molasses on diet intake, digestibility and digesta kinetics, and 2) compare the effects of different energy sources (starch and soluble carbohydrates) on these variables.

Materials and Methods

The experiment was conducted at the University of Florida Nutrition Laboratory in Gainesville, from November 1, 1995 to February 8, 1996.

Experimental design. A balanced 4 x 4 Latin square design with a factorial arrangement of treatments was used. Treatments were:

Supplement type	Bambermycins level	Code
Corn-urea	0 mg	CC
Corn-urea	20 mg	CB
Molasses slurry	0 mg	MC
Molasses slurry	20 mg	MB

Each experimental period consisted of 25 d, with 17 d for adaptation to the experimental diet, and 8 days for sample collection. Initial assignment of animals to treatments, and pens was at random.

Pre-trial. Before the experiment was initiated, a 21-d (14-d adaptation to diet and 7-d collection) pre-experimental period was conducted with the purpose of characterization of the hay to be used in the experiment. Feed intake, digestibility and digesta kinetics were measured in four animals (239 kg BW) fed bermudagrass (Cynodon dactylon) hay alone using the same methodology described below. Data from the pre-trial period were not included in the Latin square analysis and means are reported separately.

Animals. Six crossbred Angus x Brahman heifers were weaned in early September 1995 at the Santa Fe Teaching Unit, vaccinated, dewormed, and transported to the Nutrition Laboratory facilities, where they were grazed on bahiagrass (Paspalum notatum) pasture and fed bermudagrass hay for 1 wk. Four heifers were selected by temperament (docility), dewormed, and housed in individual pens with concrete floor. They were given ad libitum access to bermudagrass hay and fed 2 kg of molasses slurry for 2 wk. They were given ad libitum access to water and a mineral mixture containing 17.2 to 20.6% salt, 17.2 to 20.6% Ca, 9% P, 1% Fe, .2% Mn, .01% I, .01% Co, .2% Mg, .12% F, 1,500 ppm Cu, 20 ppm Se, and 4,000 ppm Zn. After 2 wk, heifers were offered only bermudagrass hay. Once the voluntary hay intake was about 2% of BW, the pre-trial period was started (October 11). After the end of pre-trial period, one heifer was replaced due to injury. The estimated shrunk BW (defined as the average BW before the morning feeding on d 1 and d 25 x .95) were 238 kg for period 1 and 287 kg for period 4 of the Latin square. The average weight of each heifer in each period was used to express variables as percentage of BW.

Diets. Bermudagrass hay harvested during the early summer of 1995 from the Pine Acres Research Unit was stored in a barn for use in this experiment, in the performance trial (Year 2, described in Chapter III), and in a ruminal metabolism experiment (Chapter V). The hay was chopped as

needed to approximately 6 cm and fed ad libitum twice a day (0730 and 1930), as the base diet. The amount of hay offered was determined by adjusting the quantity fed daily to provide a minimum of .8 kg of orts each day.

Supplements were formulated as described for the performance trial (Chapter III), designed to provide equivalent amounts of TDN, DIP and UIP. Supplements were fed daily in separate feeders at 0715. All feeds were offered after cleaning the pens. Amount of corn supplement fed was adjusted at the beginning of each period and fed at .8% % BW (as fed basis). Molasses slurry was delivered to provide the same amount of TDN as the corn supplements. Because molasses slurry consumption was not complete, the dry component (corn gluten meal-urea, with or without bambermycins) was delivered separately before the morning feed was offered to assure that the feed additive and protein source were consumed at the designed doses. Consumption of this dry ingredient was completed in about 10 min in all cases. Molasses was top-dressed with 5% corn meal (no additives) and offered within 30 min after dry ingredient consumption. Top dressing with corn appeared to stimulate consumption of molasses. Water and the mineral mix described above was made available at all times.

Feed sampling procedures. Procedures for determining voluntary intake and digestibility in sheep, described by Moore (1981), were followed with pertinent adaptations.

Because the amount of hay offered changed, 5% of the total offering was sampled each day to avoid bias. Grab samples of hay were obtained, placed in air-tight plastic bags and sealed. Daily samples from a given heifer in each collection period was placed in the same bag. The total weight of the hay sampled was recorded prior to grinding.

During the 8-d experimental period, orts were collected prior to the morning feeding. Feeders were swept and orts collected, and transferred to woven plastic bags. Weight of orts was recorded prior to grinding. Waste was collected by sweeping the floor around feeders and handled as described above.

The week following the collection period, composited hay samples were ground in a hammer mill, then ground in a Wiley mill to pass 4-mm and 1-mm screens and stored in plastic bags (Whirl-Pak, Nasco, Fort Atkinson, WI) until analyzed. Orts and waste from each heifer were air dried before grinding, and stored as described for samples of hay. Analysis of DM for intake calculation was performed the same day that the hay, orts or waste were ground.

Samples of corn mix and corn gluten meal-urea were taken daily during the last 8-d collection period, composited as sampled and stored in separate bags for each animal and period. One molasses sample per period was collected directly from the storage tank and stored frozen until analyzed.

Preparation of ytterbium-marked fiber. Bermudagrass hay was ground in a hammer mill and then ground in a Wiley mill to pass a 4-mm screen, and washed in cloth bags in an automatic washer with water heated to 80° to 90° C. The material was washed through two normal cycles with commercial detergent (Tide™) to remove loose material and most of the cell contents (Udén et al.,1980). Two additional washing cycles were used to remove the detergent.

After drying at 60° C, fiber particles were immersed for 24 h in aqueous solution of ytterbium nitrate ($YbNO_3.5H_2O$) containing 2% of the dry fiber weight as Yb. Acetic acid was used to keep the pH of the solution below 7 (Ellis et al., 1982; Luginbuhl et al., 1994). After soaking, excess fluid was decanted through a 0.5-mm screen to recover fiber particles. Six successive washes were accomplished by resuspending the material in deionized water (one per hour) and repeating the screening procedure. Marked fiber was dried in a forced air oven at 55° C for 72 h, analyzed for Yb concentration, and stored in air-tight bags until used.

Dosing procedure. On d 15 of the pre-trial period and on d 19 of each Latin square period prior to the morning feeding, 60 to 90 g of Yb-labeled fiber (11 mg Yb/g fiber) was mixed with 400 g of corn meal (pure) and placed in the clean feeder. Doses were estimated using an equation presented by Ellis et al. (1982). Any uneaten material was recovered for Yb analysis. Effective doses (average 790 mg

Yb/animal) were estimated from the amount delivered minus the amount recovered. The corn plus Yb-labeled fiber mix was made available to animals for a maximum of 30 min. Most of the time, animals consumed the marker in a 15-min period. Immediately after dosing, hay and supplement were fed as usual, except that the amount of supplement was adjusted to account for the corn meal eaten with the fiber. This dosing procedure minimized animal handling to reduce possible effects of stress on voluntary intake.

Fecal sampling. Feces for use in standards and blanks were collected the day before dosing. Samples for Yb analysis were collected every 4 h after dosing up to 56 h, at 8-h intervals from 56 to 72 h, and at 12-h intervals from 72 to 132 h. Fecal grab samples were taken from the rectum only if animals did not defecate within ±15 min of designated sampling time. The act of entering into pens often caused the animals to stand up, move around, and defecate. Typically, minimum disturbance of animals resulted and minimum effect on voluntary intake was presumed.

Fecal samples were dried in a forced-air oven at 55° C for 72 h and ground in a Wiley mill to pass a 1-mm screen. During the longer sampling intervals, 1- to 2-h modifications were made to allow samples to represent every other hour of the day (from 0400 to 2400, 11 samples) for nutrient analysis. After grinding, a 5-g subsample from

these 11 samples were composited for DM, OM, NDF, and N analysis.

Ytterbium analysis. Each individual sample of ground feces (1 to 2 g) was ashed in 50-mL beaker at 500° C for 8 h. Ash was recovered in .1 M DTPA solution, extracted for 12 h and filtered. The final extract was analyzed by atomic absorption spectrophotometry (Perkin Elmer 5000) with nitrous oxide flame. Standard and blank solutions were prepared from pre-dosing fecal samples treated as described above (Ellis et al., 1982). Similar procedures were followed for analysis of Yb in Yb-marked fiber, except that .2 g of sample was used and standards and blanks were prepared with unlabeled hay.

Digesta kinetics. Excretion curves for Yb in feces were fitted to gamma age-dependent, age-independent two-compartment models with increasing orders of gamma age dependency (G1G1 to G4G1), using the nonlinear procedure of SAS (1987; PROC NLIN, iterative Marquardt method) described by Pond et al. (1988). The SAS program published by Moore et al. (1992) was used. The age-dependent and age-independent compartments also are described as the fast and slow compartments, respectively, and passage from the slow compartment represents passage from the rumen (Moore et al., 1992).

The model was selected using criteria that best fit the data for all animals in all treatments, considering the

lowest residual errors and the most observations hidden in graphs of predicted vs actual data points (Moore et al., 1992). The best fitting model selected to evaluate digesta kinetic estimates was G2G1 for all period by animal combinations.

The following variables were directly estimated by the G2G1 model or they were calculated from model parameters according to formulas presented by Moore et al., (1992) and Luginbuhl et al., (1994).

1. Passage rate parameter (L) of the marker from the age-dependent compartment (Lambda in the model). The passage rate from this compartment is the product of L x .59635. The number is a constant related to age dependency (constant = .59635 when age dependency = 2).
2. Passage rate (PR) parameters of marker from the age-independent compartment (k in the model). The PR from this compartment is equal to k, an estimate of passage out of the rumen.
3. Time delay (TD) in h, time elapsed between dosing and first appearance of marker in feces (calculated directly by the model).
4. Total tract mean retention time (TMRT) = 2/L + 1/k + TD. The mean retention time of the fast compartment (FMRT) = 2/L, and the mean retention time for the slow compartment (SMRT) = 1/k, or ruminal mean retention time.
5. Fecal DM output (FO) = (DOSE/C_o) x k x 24 h, where DOSE is the amount of Yb dosed and C_o represents the initial Yb concentration if instantaneously mixed in the age-independent compartment; C_o is estimated by the model.
6. Fill of undigested DM in the whole gastrointestinal tract = DOSE/C_o + (DOSE x k)/(L x .59635 x C_o). The first term of the sum represents the fill of the slow compartment and the second term represents the fill of the fast compartment.

In addition, ruminal PR was calculated according to Grovum and Williams (1973). In this model (designated LN here), ruminal PR is the absolute value of the slope of the

linear, down sloping portion of the natural log transformed excretion curve. Ruminal mean retention time (RMRT) was calculated as 1/PR.

Chemical analysis. The hay, orts, waste, and dry supplement, molasses and composited fecal samples were analyzed for DM, OM, NDF, and CP as described in Chapter III. Hay and supplements were also analyzed for minerals (Chapter III).

Intake of OM, NDF and CP were estimated based on their concentration in DM of hay, supplements, orts, and waste. Intake of TDN was calculated assuming no associative effects adding the TDN intake from hay (estimated from IVOMD, Moore and Kunkle, personal communication) and TDN intake from supplements (table values, NRC, 1984).

Digestibility (D) of each fraction (DM, OM, NDF, and CP) was estimated using their respective dietary and fecal concentrations: $D = (I - F)/I \times 100$; where I = intake of each fraction; F = fecal output of each fraction; and fecal output of each fraction = FO x fecal fraction concentration (% in DM)/100.

Statistical analysis. Intake of DM was averaged over 7 d in the pre-trial period and 8 d (d 18 to 25) of each period in the Latin square. Data were analyzed as a 4 x 4 Latin square design using the GLM procedure of SAS (1987). Sums of squares were separated into effects of heifer, period, supplement type, feed additive and the interaction

of supplement type by feed additive. When an interaction of supplement type by feed additive was present, treatment means were separated using the LSD with alpha = .05 (SAS, 1987).

Results and Discussion

Composition of feeds averaged over the four periods is presented in Table 4-1. Molasses had lower DM (72.0 vs 77.5%) and lower phosphorus concentrations (.34 vs .88 to .74%), and had higher pH (5.14 vs 4.51 to 4.71) than molasses used in the performance experiment (Chapter III). This suggests that less phosphoric acid was added to the molasses used in this experiment.

Bambermycins concentrations in supplements are presented in Appendix Table A-4. Apparently there was analytical difficulty with bambermycins. Because the drug was active in the original pre-mix 5 months after the end of the experiment and mix formulation was correct, the formulated concentration was presumed.

Bermudagrass hay varied among periods, average IVOMD and CP for periods 1 through 4 were: 47 and 9.7; 44 and 10.3; 48 and 9.2 and 44 and 8.8% respectively, which are lower than TDN and CP of the hay used in pre-trial period.

Table 4-1. Composition of feeds fed during feed intake studies

Item	Corn Mix	Molasses[a]	Corn Gluten Mix	Bermuda Hay[b]
DM, %	86.5	72.0	89.0	87.9
IVOMD	-	-	-	45.7
As % DM,				
OM	95.0	82.0	98.4	94.5
CP	15.6	9.8	78.7	9.5
TDN[c]	84.4	72	89	-
NDF	9.3	-	5.2	75.7
ADF	-	-	-	40.5
Lignin	-	-	-	4.90
Ca	.66	.61	.03	.33
P	.66	.34	.44	.20
Mg	.26	.53	.06	.40
K	.43	3.76	.15	1.19
Na	.01	.12	.03	.02
pH	-	5.14	-	-
TDN:CP ratio	5.41	7.35	1.13	5.37

[a] Blackstrap molasses not less than 40% inverted sugars, fortified with phosphoric acid and 25,000 U.S.P. units vit A, 33,000 U.S.P. units vit D, and 22 Int. units vit E per kg, and .0005% Cu, .00001% Co, .02% Fe, .001% Mn, .0025% Zn, and .00007% I. Sulfur content no less than 1%, as fed basis.

[b] Hay composition for pre-trial period was: 87.5% DM, 49.1% IVOMD, 94.5% OM, 10.6% CP, 53.0% TDN, 73.3% NDF, 37.1% ADF, 4.77% lignin, and 5.0 TDN:CP ratio.

[c] Calculated from table values for supplements(NRC, 1984)

Pre-trial

Intake, digestibility, and digesta kinetic data for the pre-trial are summaryzed in Table 4-2. Absolute digestibility obtained with FO estimated through marker techniques may be not comparable to digestibility estimated with FO measured by total fecal collection. Underestimation of FO would increase apparent digestibility.

Table 4-2. Intake, digestibility and digestion kinetics for heifers fed hay alone (pre-trial)

Item	Mean	Std Dev	Min	Max
Intake, kg				
DM	5.25	.59	4.61	6.02
OM	5.06	.54	4.37	5.69
NDF	3.89	.43	3.35	4.40
CP	.58	.05	.52	.64
Intake DM, % BW	2.21	.30	1.93	2.60
Apparent digestibility, %				
DM	65.4	3.41	61.3	68.9
OM	66.8	2.93	62.7	69.5
NDF	68.4	2.62	65.0	71.1
CP	62.8	3.31	58.0	65.4
Digestible OM intake, kg	3.38	.40	2.98	3.42
Digestible OM intake, % BW	1.41	.24	1.32	1.70
Passage rate[a], %/h				
Age-dependant	20.8	6.41	13.49	26.56
Age-independent	3.26	.43	2.78	3.83
Ruminal passage rate[b], %/h	4.03	.42	3.66	4.63
Mean retention time[a], h				
Fast compartment	6.2	2.1	4.5	8.8
Slow compartment	31.0	4.0	26.1	35.9
Time delay	12.5	2.2	10.4	14.8
Total	49.7	3.0	45.3	51.5
Ruminal mean retention time[b], h	25.0	2.4	21.6	27.3
Fecal output[a], % BW	.76	.07	.66	.82
Fill undigested DM[a], % BW				
Fast compartment	.15	.06	.11	.23
Slow compartment	.89	.15	.79	1.10
Total	1.04	.13	.92	1.22

[a] Estimated with nonlinear model (G2G1).
[b] Estimated from linear model (Grovum and Williams, 1973).

Moore et al. (1992) suggested that when the digestibility is of interest, other markers with known concentrations such as chromic oxide should be used because of errors in estimating the amount of marker dosed. However, they found that all nonlinear models provided estimates of

FO within 5% of FO measured by total fecal collection in sheep. Good agreement between FO estimated with pulse dosed and continuously infused marker has been reported also (Luginbuhl et al., 1994). Even if an overestimation of digestibility occurred, there is no apparent reason to think that a bias existed that would favor one treatment over the other in the Latin square experiment. Estimation of hay intake, digestibility and digesta kinetics obtained in this period will be referred to when discussing the effects of supplements in the next section. Concentration of PUN (10.4 ± 1.3 mg/dL) was consistent with the TDN:CP ratio of the hay, and indicates that N was probably not limiting ruminal fermentation (Hammond et al., 1993).

Latin Square - Intake and Digestibility

Supplement and additive main effects on intake and digestibility are presented in Table 4-3 and treatment means are shown in Table 4-4. Supplement and additive interactions were not observed ($P > .2$) for any variables.

Total diet CP concentration (% DM) was 11.1% CP and 12.4% for corn- and molasses-supplemented diets, respectively. Intake of the molasses-based supplement was less than planned due to incomplete consumption. Lower ($P = .098$) molasses intake than corn (% BW) may result in a confounding of supplement type with supplement level on all variables measured.

Table 4-3. Effect of supplement and additive on intake and digestibility in heifers

	Supplement		Additive			P value for Effect		
Variable	Corn	Molasses	None	Bamb	SE	S[a]	A[a]	SxA[a]
Total intake, kg								
DM	6.59	7.09	6.81	6.87	.86	.0062	.5994	.2704
OM	6.24	6.58	6.37	6.44	.71	.0157	.5109	.1979
NDF	3.85	4.30	4.03	4.11	.51	.0008	.3104	.1832
CP	.74	.83	.78	.79	.12	.0019	.4580	.4142
Suppl. intake, % total								
DM	26.5	19.6	23.3	22.8	1.75	.0316	.8317	.8069
OM	26.6	18.2	22.7	22.1	1.60	.0100	.8062	.7759
NDF	4.2	.5	2.4	2.3	.09	.0001	.3509	.3288
CP	36.6	35.3	36.2	35.7	1.24	.4853	.7578	.5429
DM intake, % BW								
Total	2.54	2.69	2.57	2.65	.03	.0066	.0728	.2592
Hay	1.87	2.15	1.97	2.05	.03	.0011	.1416	.3678
Supplement	.67	.54	.61	.61	.05	.0980	.9974	.9997
Fecal output, kg DM	2.33	2.31	2.31	2.33	.07	.9070	.8752	.7915
App. digestibility, %								
DM	64.7	67.3	65.9	66.1	1.22	.1773	.9136	.8380
OM	66.0	67.7	66.7	66.9	1.10	.3189	.8584	.7858
NDF	60.0	64.6	62.2	62.3	1.12	.0266	.9457	.7949
CP	60.8	64.7	61.4	64.1	1.34	.0844	.1988	.5354
Digestible OM int., kg	4.12	4.45	4.25	4.31	.11	.0734	.6930	.4526
Digestible OM int., % BW	1.58	1.87	1.61	1.66	.04	.0984	.3517	.5163

[a] S = Supplement main effect, corn or molasses; A = Feed Additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive. Bamb = bambermycins.

Table 4-4. Effect of treatments on intake and digestibility in heifers fed ad libitum

Variable	Treatment[a]				SE	P value for Effect		
	CC	CB	MC	MB		S[b]	A[b]	SxA[b]
Total intake, g/d								
DM	6.48	6.70	7.13	7.05	.12	.0062	.5994	.2704
OM	6.13	6.35	6.61	6.54	.10	.0157	.5109	.1979
NDF	3.75	3.94	4.31	4.29	.72	.0008	.3104	.1832
CP	.73	.76	.83	.83	.17	.0019	.4580	.4142
Suppl. intake, % total								
DM	27.1	25.9	19.6	19.6	2.47	.0316	.8317	.8069
OM	27.2	25.9	18.1	18.2	2.26	.0100	.8062	.7759
NDF	4.4	4.1	.5	.5	.13	.0001	.3509	.3288
CP	37.4	35.7	35.0	35.6	1.76	.4853	.7578	.5429
DM intake, % BW								
Total	2.47	2.60	2.67	2.70	.04	.0066	.0728	.2592
Hay	1.80	1.93	2.13	2.16	.05	.0011	.1416	.3678
Supplement	.67	.67	.54	.54	.07	.0980	.9974	.9997
Fecal output, kg DM	2.30	2.35	2.32	2.31	.10	.9070	.8752	.7915
App. digestibility, %								
DM	64.4	64.9	67.4	67.2	1.72	.1773	.9136	.8380
OM	65.6	66.3	67.7	67.6	1.56	.3189	.8584	.7858
NDF	59.7	60.2	64.6	64.4	1.59	.0266	.9457	.7949
CP	58.8	62.8	64.0	65.4	1.90	.0844	.1988	.5354
Digestible OM int., kg	4.03	4.21	4.48	4.42	.15	.0734	.6930	.4526
Digestible OM int., % BW	1.53	1.63	1.68	1.70	.05	.0984	.3517	.5163

[a] Treatments: CC = corn control; CB = corn bambermycins; MC = molasses control; MB = molasses bambermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed Additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive

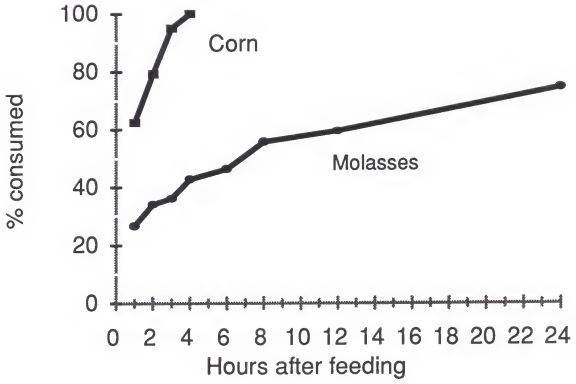

Figure 4-1. Pattern of corn and molasses supplement consumption in heifers given ad libitum access to bermudagrass hay.

Supplement intake with and without bambermycins was similar (P = .9) and therefore the effect of feed additive should not be confounded with level of supplement intake.

Pattern of supplement consumption was different (Figure 4-1). About 60% of corn and 30% of molasses was consumed by 1 h after feeding. By 3 h after feeding, consumption of corn was almost complete while that for molasses was only 45%, resulting in consumption of molasses more distributed throughout the day. Animals tended to consume most of the corn in one meal. This pattern of consumption is similar to the pattern observed in production situations. Supplement consumption is affected by many factors. There appears to be an optimum level of feeding competition that reduces intake variation (Bowman and Sowell, 1995a). In four studies that measured liquid supplement intake (review by Bowman and Sowell, 1995b), between 1 and 20% of experimental animals refused to consume any molasses-urea supplement. Supplement consumption varied from .002 to 2.54 kg/d and 30% of the beef cows in the experiment consumed only trace amounts of the supplement (Bowman and Sowell, 1995a).

Heifers fed molasses had higher (P = .007) total DM intake (% BW) than those fed corn, resulting from higher (P = .001) hay intake. Bambermycins increased (P = .07) total DM intake (% BW) and tended (P = .14) to increase hay DM intake (% BW) when compared to control supplements. This trend is consistent with results from Year 1 of the

performance trial (Chapter III). In other studies, bambermycins did not affect feed intake when compared with control diets (De Schrijver et al., 1990; Flachowsky and Richter, 1991; Poppe et al., 1993; Burris and Randolph 1996; DelCurto et al., 1996; Earley et al., 1996). However, bambermycins increased intake of hay-corn silage and corn silage diets when compared with ionophores (Hoechst-Roussel, 1994; Burris and Randolph 1996). Alert et al. (1993) reported that bambermycins increased intake in fattening bulls but the composition of diet was not available.

Compared to the pre-trial period, hay intake changes (HIC) were -.34 and -.06% of BW for corn and molasses supplements respectively, while substitution rates (SR) were .51 and .11, for corn and molasses supplements, respectively. These values are close to those reported by Garces-Yepez (1995) for corn supplemented at .83% BW (-.4 and .48 for HIC and SR, respectively). Goetsch et al. (1991) concluded after analyzing several experiments that each kg of corn DM would decrease bermudagrass intake by .46 kg.

The molasses supplement consumed had minimal effects on FIC and SR. When intake of molasses supplements was expressed on an OM basis, the supplementation level (.45% BW) was similar to the low corn treatment (.36% BW) reported by Garces-Yepez (1995). Observed HIC (-.06) and SR (.11) for molasses were similar to reported HIC (-.04) and SR (.11) values for corn supplemented at comparables rate. Similar

effects have been observed with small amounts of grain in many experiments (Horn and McCollum, 1987; Moore and Kunkle, 1995). Moore et al. (1995) suggested, after analyzing a large data base, that there were no obvious inherent differences between liquid and dry supplements in their effects on forage intake.

Calculated HIC of -.24 and -.16, and SR of .39 and .26 for control and bambermycins supplements are consistent with the trend of increased hay intake when animals received supplements with bambermycins. The apparent effect (no statistics) of bambermycins on HIC in corn (-.41 vs -.28) and in molasses (-.08 and -.05) supplements was similar in relative terms. The biological significance of the effect of bambermycins on hay intake may be greater when the basal diet is supplemented with a moderate level of concentrate rather than with low levels of concentrate. It also may suggest that with a moderate level of supplement, the effect may emerge and increase the total DM intake. Thus, the low amount of molasses intake in this experiment may have precluded statistical detection of an effect of bambermycins on hay intake. Support for this suggestion is given by the observation that bambermycins increased hay DM intake by .13 and .03% BW in corn and molasses, respectively (Table 4-4). Further research, with several levels of supplementation as well as type of supplements will be needed to test this hypothesis. In such research, pattern of consumption may

need to be controlled to resolve any confounding with type and level of supplement. This last aspect is of academic interest with little practical value.

Digestibility of NDF was higher (P = .027) when heifers were fed molasses compared to corn, perhaps a result of a lower associative effect on fiber digestion due to lower molasses intake. Predicted associative effects (change in ME) using the Forsup10 model (Moore and Kunkle, 1995) were -.09 and -.02 Mcal ME/kg OM for corn- and molasses-supplemented diets, respectively. This effect may be associated with longer (P = .049, Table 4-5) SMRT in molasses supplements, which would increase the extent of ruminal NDF digestion.

Several mechanisms have been proposed to explain the depression of fiber digestion when a source of highly fermentable carbohydrate is added to forage-based diets. For example, lower pH with negative effects on cellulolytic bacteria, retardation of microbial attachment and increase of the lag time, competition of microbial population for essential nutrients, and use of alternative energy sources by cellulolytic bacteria have been suggested (Horn and McCollum, 1987; Orskov and Ryle, 1990). The animal may or may not be able to compensate for ruminal escape of potentially digestible fiber by shifting the site of digestion to the lower gut (Owens and Goetsch, 1986; Galyean and Owens, 1991).

Estimates of NDF digestibility with both corn and molasses supplements were lower (no statistics) than when hay was fed alone in the pre-trial period. Several workers reported depressed NDF digestibility when energy supplements were fed. On bermudagrass hay diets, NDF digestibility (% of DM) for hay alone and hay plus levels of corn supplements comparable to those used in this experiment were: 56.7 vs 53.5, and 52.9 vs 47.2 (Galloway et al., 1993a); 56.4 vs 53.9 (Galloway et al., 1993b); 64.3 vs 57.1 (Hardin et al., 1989); 57.6 and 45.8 (Brake et al., 1989). Based on results from several experiments, Goetsch et al. (1991) suggested that each kg corn DM would depress NDF digestibility by 3.3 percentage units.

Similar reports are available on the effect of molasses on NDF digestibility. For example, molasses included at 25% of the diet depressed NDF digestibility (% DM) in limpograss (Hemarthria altissima)- (57 vs 51), and in rice straw- (56 vs 46%) based diets (Brown et al., 1987). A similar response has been observed with ammoniated stargrass (Cynodon nlemfluensis)(Brown, 1993), and native grass (Kalmbacher et al., 1995). Khalili (1993) reported NDF digestibilities of 68.4 and 64.8% DM when grass hay was fed alone or supplemented with molasses at .58% BW. These digestibilities are numerically identical to NDF digestibility depression when the pre-trial period is compared to the supplementation periods.

Bambermycins did not affect ($P > .8$) DM, OM or NDF digestibility. Reports found in the literature are contradictory. Bambermycins did not affect in vitro NDF digestion (Van Nevel and Demeyer, 1992), or in situ cellulose digestion (Rowe et al., 1982), or total tract digestibility of DM, CP, fat, CF, ash and N-free extract in wethers (De Schrijver et al., 1991), or apparent OM digestibility in wethers (Flachowsky and Richter, 1991). In contrast, 50 mg of bambermycins/d increased apparent DM, CF and N-free extract digestibility (Alert et al., 1993) and increased total tract OM digestibility in cattle (Poppe et al., 1993). Total tract digestibility tended to increase in steers supplemented with bambermycins or ionophores on alfalfa (Medicago sativa) and grass hay diets (Earley et al., 1996). However, no effect of bambermycins was observed in 90% concentrate diets (DelCurto et al., 1996).

Heifers fed molasses had 4 percentage units higher ($P = .08$) apparent CP digestibility than those fed corn. Lower depression of fiber digestion by molasses would result in less escape of potentially digestible OM from the rumen, with the consequence that less substrate would be available for fermentation in the lower gut. With the corn supplement, more fiber and starch may have escaped rumen fermentation with a shift in site of digestion to the intestines. The passage of potentially digestible carbohydrate to the cecum and colon can increase fecal N losses through increased

fermentation and resulting unabsorbed microbial matter (Orskov et al., 1972). Microbial matter accounts for most organic metabolic matter in feces (Van Soest, 1994), and metabolic fecal N is mostly microbial matter (Mason, 1984) in ruminants.

Bambermycins tended to (P = .2) increase by 2.7 percentage units the apparent CP digestibility, in agreement with a report of increased apparent CP digestibility in young cattle (79 vs 74%) on ad libitum concentrate diets (Fallon et al., 1986). This effect would be consistent with the lower microbial activity in lower gut and lower intestinal cell sloughing. It has been reported that bambermycins survives the ruminal environment (Rowe et al., 1982). A similar antibiotic, avoparcin, has been shown to reduce intestinal cell turnover (Parker, 1990). Bambermycins increased N balance (MacRae and Lobley, 1991), and a reduction of gut cell turnover has been suggested as the mechanism of action.

Intake of digestible OM tended (P = .098) to be .29% BW higher with molasses resulting from a trend for (P = .18) 2.6 percentage units higher DM digestibility and .15% BW higher (P = .007) total DM intake. Earley et al. (1996) reported no effect of bambermycins or ionophores on digestible DM intake of alfalfa/grass hay diets, even though DM digestibility tended to increase by feeding feed additives.

In short, bambermycins tended to increase DM intake from hay and had no effect on total tract digestibility. Even though there were no interactions ($P > .2$), these effects were apparent when bambermycins was fed with corn but not with molasses supplement.

Latin Square - Digesta Kinetics

Data for the pre-trial period are presented in Table 4-2, while data for the Latin square experiment are presented in Table 4-5 (main effect means) and Table 4-6 (treatment means).

Biological interpretation of the age-dependant, age-independent, two-compartment model has been described by Ellis et al. (1994). All estimations should be taken as the average over the sample collection period. According to Ellis et al. (1994), the age-dependant flow-paths appear to correspond to the large rumination pool as conceived by Hungate (1966). Residence time in such a rumination pool appears to be of similar magnitude to that resolved for FMRT. This flow-path also appears descriptive of the flow process involving interactions between rumination and fermentation-based buoyancy. The age-independent flow process appears to be described by mass action competition for escape. The residence time of this compartment appears to be resolved by SMRT of the model. There is not agreement, however, on the adequacy of a particular model to describe

Table 4-5. Effects of supplement type and bambermycins on digesta kinetics in heifers fed hay ad libitum

	Supplement		Additive			P value for Effect		
Variable	Corn	Molasses	None	Bamb	SE	S[a]	A[a]	SxA[a]
Particles passage rate[b], %/h								
Age-dependent	8.98	11.46	9.89	10.56	1.15	.1788	.6933	.4430
Age-independent	5.68	4.25	5.07	4.85	.45	.0650	.7476	.5021
PR from LN model[c], %/h	4.93	4.50	4.88	4.55	.07	.0057	.0181	.0752
Mean retention time[b], h								
Fast compartment	14.5	11.0	13.2	12.3	1.42	.1321	.6500	.5099
Slow compartment	19.2	24.1	21.6	21.7	1.42	.0493	.9715	.6011
Time delay	9.9	11.1	10.1	10.8	.54	.1556	.3906	.2699
Total	43.5	46.2	45.0	44.8	.65	.0276	.8555	.5213
Rumen MRT from LN model[d], h	20.7	22.4	20.8	22.3	.20	.0026	.0064	.0912
Undigested DM[b] fill, % BW								
Fast compartment	.45	.34	.41	.38	.04	.1142	.6732	.4916
Slow compartment	.71	.87	.78	.80	.07	.1696	.8222	.6394
Total	1.16	1.21	1.19	1.19	.04	.4398	.9717	.9074
Fecal output[b], % BW	.90	.88	.87	.90	.03	.5734	.5347	.7950

[a] S = Supplement main effect, corn or molasses; A = Feed Additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive. Bamber = bambermycins.

[b] Estimated from non-linear model (G2G1).

[c] Ruminal particle passage rate estimated from linear model (Grovum and Williams, 1973).

[d] Ruminal mean retention time estimated from linear model (Grovum and Williams, 1973).

Table 4-6. Effect of supplement type and bambermycins digesta kinetics in heifers fed ad-libitum (treatment means)

Variable	Treatment[a]					P value for Effect		
	CC	CB	MC	MB	SE	S[b]	A[b]	SxA[b]
Particles passage rate[c], %/h								
Age-dependent	7.98	9.99	11.79	11.13	1.62	.1788	.6933	.4430
Age-independent	6.01	5.34	4.13	4.37	.63	.0650	.7476	.5021
PR from LN model[d], %/h	5.21	4.65	4.55	4.44	.10	.0057	.0181	.0752
Mean retention time[c], h								
Fast compartment	15.7	13.3	10.8	11.2	2.00	.1321	.6500	.5099
Slow compartment	18.6	19.8	24.7	23.6	2.00	.0493	.9715	.6011
Time delay	9.0	10.7	11.2	11.0	.76	.1556	.3906	.2699
Total	43.3	43.8	46.6	45.8	.93	.0276	.8555	.5213
Rumen MRT from LN model[e], h	19.6	21.7	22.0	22.8	.35	.0026	.0064	.0912
Undigested DM[c] fill, % BW								
Fast compartment	.48	.42	.33	.35	.06	.1142	.6732	.4916
Slow compartment	.68	.75	.88	.86	.10	.1696	.8222	.6394
Total	1.16	1.17	1.22	1.21	.06	.4398	.9717	.9074
Fecal output[c], % BW	.88	.92	.87	.88	.04	.5734	.5347	.7950

[a] Treatments: CC = corn control; CB = corn bambermycins; MC = molasses control; MB = molasses babermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed Additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive

[c] Estimated from non-linear model (G2G1).

[d] Ruminal particle passage rate estimated from linear model (Grovum and Williams, 1973).

[e] Ruminal mean retention time estimated from linear model (Grovum and Williams, 1973).

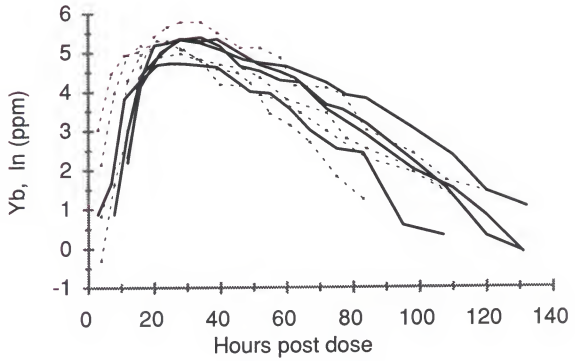

Figure 4-2. Natural log transformed fecal ytterbium concentrations in heifers given ad libitum access to bermudagrass hay and fed corn at .67% BW. Each line represents one animal. Control: ___ ; Bambermycins: - - -.

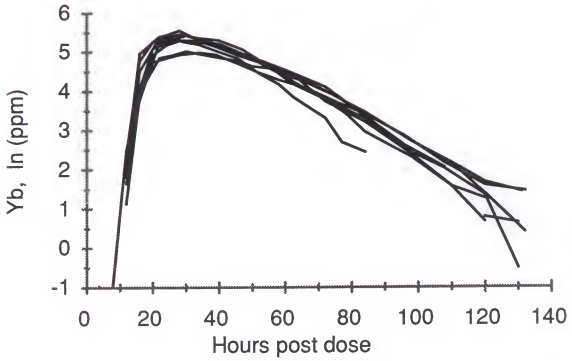

Figure 4-3. Natural log transformed fecal ytterbium concentrations in heifers given ad libitum access to bermudagrass hay and fed molasses at .54% BW. Each line represents one animal fed control or bambermycins supplement.

biological processes during digestion and passage (Faichney, 1986; Mertens, 1993; Van Soest, 1994).

The slow age-independent compartment appears confined to preduodenal sites (rumen) while the fast age-dependent compartment seems to reside both in preduodenal (about 60%) and postduodenal segments of the gastrointestinal tract (Pond et al., 1988; Huhtanen and Kukkonen, 1995). However, this partition may depend upon the type of particle and(or) level of intake, as Poore et al. (1991) found that with marked corn in the lactating dairy cow most of the slow and fast compartment occurred in the rumen. The fast compartment also was the compartment that varied the most depending on the model used to fit the data, suggesting that partitioning of total retention time into small compartments may be difficult (Lalles et al., 1991).

Even though the G2G1 model was selected, this model was not the best for all animals. If the best model for each animal were selected, all G1G1 to G4G1 models would had been selected for a particular animal by period combination. Plots of log transformed Yb fecal concentration vs time after dose are presented in Figures 4-2 and 4-3. Data from corn supplemented heifers appear more variable than that from molasses supplemented heifers. Part of this higher variation was likely due to effects of bambermycins on digestion kinetics in corn but not in molasses.

Marked fiber passed 34% faster (P = .065) out of the rumen in heifers fed corn than those fed molasses supplements (non-linear model). When the PR was estimated by the LN model, there was an interaction of supplement type by bambermycins (P = .075). Passage rate in CC was higher (P < .05) than all other treatments.

Use of rare earth as markers has been criticized because of possible marker migration (Faichney, 1986; Combs et al., 1992). Moore et al. (1986) found that 6 to 23% of Dy or Yb dissociated from marked feeds that were incubated in vitro for 24 h, but only .3 to 1.4% of the rate earth markers migrated to unmarked feed, which suggested that dissociated rare earth would pass with the small particles and liquid fraction of the digesta. One possibility is that marker may have partially dissociated from the Yb-marked fiber to enter the more rapidly flowing liquid portion of the digesta. Moore et al. (1992) reported that in sheep given fescue hay or commercial pelleted diets, fluid PR were 8.7 and 8.9%/h, respectively, which were higher than the particulate PR (4.26 and 6.06%/h for Yb-marked hay and pellets). We did not measure fluid PR in this experiment. Predicted fluid PR using the equation reported by Owens and Goetsch (1986) were 8.97 and 9.52%/h for corn and molasses, respectively, which is almost double the PR observed for Yb-marked hay. Another consideration is the marker concentration to avoid saturation of binding capacity of

feedstuffs (Teeter et al., 1984). Marker concentration in our fiber (1.1% Yb) was similar to 1.7 and 2% reported by Moore et al. (1992), but higher than the Yb-marked fiber (masticated stem, .46%) reported by Luginbuhl et al., (1994).

A third consideration is the dosing procedure. In experiments conducted by Moore et al. (1992) the marked fiber was dosed in gelatine capsules or placed in closed paper bags in the dorsal cranial sac of the rumen (Luginbuhl et al., 1994). We fed the marker already mixed with corn meal, which would subject the marked fiber to ingestive chewing, salivation and more mixing before arriving at the reticulorumen. The marker mixed with heavy corn particles may have been deposited in close proximity of the reticulo-omasal orifice. In this position, it is possible that part of the marked material directly exited the rumen. This possibility would be greater when marked material is dosed at the beginning of the meal. Pond et al. (1989) reported PR of 5.96 and 3.32%/h for Yb-marked NDF from bermudagrass hay when the fiber was dosed at the beginning and at the end of a meal, respectively.

Taken all those considerations together, it appears that the Yb-marked fiber may not have dissociated in significant proportion, and the PR observed is consistent with marker administered at the beginning of the meal. The increase in PR observed in corn supplements (5.7%/h) was

higher (no statistics) than PR from pre-trial period (3.26%/h), which is consistent with numerical increments observed when a basal hay or pasture diet was supplemented with a small level of grain (Pordomingo et al, 1991; Fredrickson et al., 1993).

In pre-trial period (hay alone) the PR estimated by the LN model was 4.03%/h. Reported PR estimated using the LN model for bermudagrass hay and hay plus corn at comparable levels were (%/h): 3.89 vs 4.26 (Galloway et al., 1993a), 4.18 vs 4.80 (Galloway et al., 1993b), 3.51 vs 3.80 (Hardin et al., 1989). These PR are similar to our estimates for hay alone and hay plus corn using the LN model. With this model heifers fed corn had higher (P = .006) ruminal PR, and consequently lower (P = .003) RMRT than those fed molasses. The interaction (P < .09) observed for PR and RMRT was due to lower effect of bambermycins in molasses than in corn supplements (Table 4-6).

The discussion on PR of hay particles when hay is fed alone would also apply to PR of hay particles when hay was supplemented with molasses. This suggestion is based on a low associative effect (higher NDF digestibility with molasses), high rate of sugar fermentation, and intake of a small amount of molasses distributed throughout the day. Very little OM from the molasses supplement would exit the rumen, except for a small amount (about 130 g, assuming 40% degraded in the rumen) of undegraded corn gluten meal.

There was a tendency (P = .13) for higher FMRT in corn supplements, which would be consistent with more rumination with molasses supplements. If a total ruminal location is accepted for this compartment, then it appears that mixing, rumination and fermentation processes were more efficient in releasing small particles to the age-independent pool in molasses-supplemented diet. Higher hay intake with molasses would be consistent with more rumination. Lower associative effects on ruminal digestion may also explain lower retention time in this compartment. Another possibility is the existence of other mixing, age-dependent site acting postruminally in corn supplemented diets. Passage of undigested fiber (reduced NDF digestibility with corn) and possibly undigested corn matter may form a mixing pool in the abomasum, cecum or colon. Pond et al. (1988) suggested that about 40% of the fast compartment may be at the postduodenal site. Excretion curves of marker were more variable with corn supplements (Figures 4-2 and 4-3), suggesting perhaps more interactions between hay and corn particles.

Ruminal retention time was higher (P = .049) in heifers fed molasses, resulting also in higher (P = .028) TMRT. Partitioning of TMRT was also different with corn and molasses supplements. Marked hay particles in corn supplemented diets tended to have longer FMRT, slower SMRT and faster TD. In molasses, particles tended to have shorter

FMRT and faster SMRT. Total MRT (43 to 46 h) was consistent with TMRT reported by Pond et al. (1989) for marked fiber dosed at the beginning of the meal (48 h). The TD, however, was considerably longer (22 h) than the TD in our experiment (10 to 11 h). Luginbuhl et al. (1994) reported longer TMRT, 57 to 80 h, depending on the digesta fraction marked, for steers fed at 99% of ad libitum. Estimation of ruminal MRT (SMRT) were similar for non-linear and LN models.

Total fill was not affected (P = .45) by supplement type. The partitioning of undigested DM fill into fast and slow compartments is related to FMRT and SMRT. There was a trend (P = .11) for .11 % BW lower fill in the fast compartment and numerical (P = .16) .16% BW higher fill in the slow compartment with molasses, probably reflecting the higher hay intake. A large pool of small particle size which would qualify for exiting the rumen exists in forage-fed animals. The rate of comminution does not appear to be the rate-limiting step for exiting the rumen (Kennedy and Doyle, 1993). The tendency for higher fill in the fast compartment with corn supplement may reflect the already discussed less efficient flow of hay particles from the age-dependent to the age-independent compartment in the rumen (ruminal raft to small particle pool), and the possible existence of postruminal mixing pool.

Bambermycins did not affect (P > .39) digesta kinetics estimated by the non-linear model. There was an interaction

(P = .09) for ruminal PR and ruminal MRT estimated by LN model. The ruminal PR was lower (P < .05) in CB than in CC and similar in MC and MB. Numerical differences in the same direction were observed with the non-linear model. The resulting ruminal MRT with the LN model was 11% higher (P < .05) for CB than for CC, while MB was only 3.4% (numerical) higher than MC. The statistically significant differences detected by the LN model may not be biologically significant because they are numerically small and were not translated into effects on digestion (Tables 4-3 and 4-4). Early et al. (1996) reported that indigestible ADF fill and passage were not affected by bambermycins. Other reports on the effect of bambermycins on digesta kinetics could not be found.

Inspection of Table 4-6 suggests that differences produced by bambermycins appears greater in corn than in molasses and the same trend was observed for intake. Because molasses intake was lower than corn, it is not possible to know if the trends observed were related to supplement type, supplementation level or both.

Other feed additives are active in digesta kinetics. Monensin depressed the PR by 14 to 21 % (Ellis et al., 1984) probably through effects on rumination and ruminal motility (Deswysen et al., 1987). Monensin also increased fill and retention time, and these changes were associated with decreased forage intake and increased digestibility (Ellis

et al., 1984). These effects were also dependent on forage quality.

Voluntary hay intake and gain were similar in animals receiving CC or MC treatment in the performance experiment (Chapter III). The higher hay intake observed in this experiment can be explained by lower molasses intake. Heifers fed molasses had higher NDF digestibilities and a longer mean retention time, which suggests less associative effect compared to heifers fed corn supplements. Higher hay intake was not associated with higher ruminal passage rate of undigested hay DM.

Bambermycins increased hay intake in Year 1 (.14% of BW) and had no effect in Year 2 (Chapter III). Bambermycins increased gain in both Year 1 and 2, but apparently through different mechanisms. The effect of bambermycins on gain tended to be higher in corn than in molasses supplements. Bambermycins produced small increases (.08% of BW) of total DM intake and tended to increase hay DM intake in heifers given ad libitum access to hay in this experiment. However bambermycins did not affect total tract digestibility. These minor effects of bambermycins on digesta kinetics may not have biological significance and they do not explain the trend for higher intake or the increased gain.

CHAPTER V
EFFECTS OF BAMBERMYCINS FED IN CORN OR MOLASSES SUPPLEMENTS ON RUMEN FUNCTION

Introduction

Antibiotic feed additives may increase animal performance through several mechanisms. Monensin changes the pattern of ruminal fermentation favoring propionate production, decreases deamination, ruminal motility, and feed intake (Bergen and Bates, 1984). The mechanism of action of bambermycins has received less research attention and contradictory information exists on its effects on digestive function (Chapter II). Bambermycins increased gain in the performance experiment (Chapter III). This effects appeared associated to increased hay intake in Year 1 and to increased efficiency of feed utilization in Year 2.

This experiment was designed to evaluate the effects of bambermycins on ruminal function when used with molasses and corn supplements, and to document characteristics of digestion of diets fed in the previous experiments.

Materials and Methods

This study was conducted at the University of Florida Nutrition Laboratory in Gainesville, from September 27 to December 19, 1995.

Experimental design. A balanced 4 x 4 Latin square design with a factorial arrangement of treatments was used.

Treatments were:

Supplement type	Bambermycins level	Code
Corn-urea	0 mg	CC
Corn-urea	30 mg	CB
Molasses slurry	0 mg	MC
Molasses slurry	30 mg	MB

Each experimental period consisted of 21 d, with 13 d for adaptation to the experimental diet, and 8 d for sample collection. Initial assignment of animals to treatments and pens was at random.

Animals. Four mature crossbred steers, weighing 630 kg (average shrunk BW) with ruminal and proximal duodenal T-cannulae were used. Surgical fitting of cannulae was performed 20 mo before conduct of this experiment. Steers were dewormed and deloused before the beginning of the experiment and allotted to individual pens, with ad libitum access to water and mineral mix containing 17.2 to 20.6% salt, 17.2 to 20.6% Ca, 9% P, 1% Fe, .2% Mn, .01% I, .01% Co, .2% Mg, .12% F, 1,500 ppm Cu, 20 ppm Se, and 4,000 ppm Zn.

Diets and feeding procedures. Diet formulation was described in Chapter IV. Feed intake and dietary proportions of bermudagrass (Cynodon dactylon) hay and concentrates are presented in Table 5-1. Feed allocated was restricted to maintenance level and quantities of hay and supplement delivered were designed to match hay to supplement proportions of diets fed in the performance experiment (Chapter III). The molasses slurry supplement was delivered to provide the same amount of TDN as the corn supplement. The 5% lower calculated TDN intake from molasses is based on actual intakes and was due to lower molasses consumption (20%) by one animal and to lower DM concentration of molasses than expected. Except for the noted refusal, all animals ate all the hay and supplement offered. Hay was delivered at 0800 (60% of allowance) and at 2000. Supplements were delivered after complete consumption of the first allotment of hay (at 0830).

Feed sampling and analysis. Procedures described in Chapter IV were followed, except that no orts or waste collection was necessary. Hay sample sizes were 200 and 150 g for the morning and evening feedings, respectively.

Digesta Kinetics

Ruminal fluid and fiber particle kinetics were estimated with cobalt-EDTA and Yb-marked fiber as external markers.

Table 5-1. Steer feed intake for each supplement

Item	Corn	Molasses
Intake,		
DM, kg	8.00	8.00
OM, kg	7.54	7.26
Intake, % of total DM		
Hay	65.6	64.7
Supplement	34.4	35.3
Intake, % of total TDN[a]		
Hay	54.0	56.5
Supplement	46.0	43.5

[a] Calculated from IVOMD for hay (J.E. Moore and W.E. Kunkle, personal communication) and from table values for supplements (NRC, 1984).

Ruminal fluid kinetics. Cobalt-EDTA was prepared in two batches according to the technique described by Udén et al.(1980). Recovered Co-EDTA complex was dried at 90° C in a forced air oven and stored until used. On d 14, 60 mL Co-EDTA solution containing 2 g Co was placed under the ruminal mat (cranial, middle and caudal locations within the rumen) immediately before hay feeding (0800), using a 100 mL syringe fitted with polypropylene tubing. Ruminal fluid samples (approximately 500 mL in each collection) were collected using a core sampler described by Firkins et al. (1986) from the anterior, middle, and posterior regions of the rumen at 2, 4, 6, 8, 12, 18, 24, and 36 h after dosing.

Ruminal content samples were strained through four layers of cheesecloth into a plastic collection bucket. Ruminal fluid was acidified (5 mL of 20% H_2SO_4 per 100 mL of

fluid; Streeter et al., 1990), transferred to bottles, and frozen at -20 °C until analysis.

Prior to analysis, ruminal fluid samples were thawed, centrifuged (10,000 x g, 15 min), and filtered (Whatman no. 541). Cobalt concentration of the filtrate was determined by atomic absorption spectrophotometry (Model 5000 series X03, Perkin-Elmer, Norwalk, CT). Liquid turnover was estimated by regressing the natural log of ruminal cobalt concentration vs time (Grovum and Williams, 1973). Ruminal fluid passage rate (FPR, %/h) was the absolute value of the slope, and ruminal fluid volume (L) was estimated by dividing the amount of cobalt dosed by the antilog of the intercept (zero time). The product of ruminal volume x FPR x 24 h was the ruminal fluid outflow (L/d). Mean retention time (MRT) expressed in hours was the inverse of FPR.

Ruminal particle kinetics. Procedures described in Chapter IV for Yb-marked fiber preparation, marker analysis and model fitting for the Yb marker excretion curve were followed, with the following exceptions. Marked fiber was administered on d 14 immediately before Co-EDTA dosage. Average dose was 173 g of marked fiber (1.9 g Yb/an), the total dose was split and enclosed in two paper bags, introduced through the ruminal cannula and mixed with the ruminal raft at the anterior and posterior regions of the rumen. Approximately 250 mL of duodenal digesta were collected through the duodenal cannula, discarding the

initial plug, in plastic bags (Whirl-Pak, Nasco, Fort Atkinson, WI) at 4, 8, 12, 16, 20, 24, 32, 40, 48, 60, 72 and 84 h after dosing. After collection, bags were closed and stored frozen (-20 °C). Before analysis, frozen samples were transfer to flat containers and the whole sample was lyophilized. Marker concentration curves were fitted to age-dependent, age-independent, two-compartment model (G1G1 to G4G1). Because the ascending part of the excretion curves was slow, the G4G1 model best fit the data and this model was used for all animals in all periods.

Characteristics of Ruminal Fluid

Ruminal pH. Ruminal fluid pH was measured with a portable pH meter (Corning M90, Corning, Inc. NY) in the same samples obtained for Co analysis immediately after filtration in collection buckets.

Ruminal volatile fatty acids, lactic acid, and ammonia. Samples obtained for Co analysis (2 to 24 h after dosing) were frozen at -20 °C. Samples were thawed, centrifuged, and supernate filtered through .45 μm microcel filters (Gelman Sciences, Ann Arbor, MI). Volatile fatty acids were analyzed by gas chromatography (Perkin Elmer AutoSystem XL, Norwalk, CT) using a capillary column (Supelco, 1990a), lactic acid was analyzed by gas chromatography (Perkin Elmer Sigma 3B, Norwalk, CT) using a packed column (Supelco, 1990b). Ammonia concentration in ruminal fluid, prepared as described for

VFA, was determined by automated colorimetric technique (Technicon, 1978).

Ruminal sodium and potassium. In the same samples (2 to 24 h after dosing) prepared for VFA analysis, Na and K were determined by atomic absorption spectrophotometry (Model 5000 series X03, Perkin-Elmer, Norwalk, CT) following procedures outlined by Fick et al. (1979).

Ruminal and Total Tract Digestion

Digestion was estimated by in situ degradation and using Cr as an external marker to estimate duodenal and fecal DM output.

In situ. The nylon bag technique was used to determine lag time, rate and extent of disappearance of DM and CP from corn gluten meal (CGM) in the rumen. Nylon bags of 10 x 21 cm (Ankon Co., NY) with an average pore size of 30 x 70 μm were used. The open side of bags was closed using a rubber stopper (no. 8) which was secured with two rubber bands (no. 18). Five grams of CGM (as fed basis) was weighed directly into one nylon bag. Bags were placed inside a polyester bag (38 cm x 45 cm) that was attached to the ruminal cannulae through a plastic string. Starting on d 16 at 2400, bags were placed in the rumen in reverse order of the following incubation times: 0, 1, 2, 4, 6, 12, 18, 24, 36, 48 and 60 h. All bags were removed at the same time (d 19 at 1200), and rinsed several times with tap water in a 20-L container until the water appeared clear. Bags were then washed

individually under tap water and dried overnight in a forced air oven at 55° C, air equilibrated and weighed. Concentrate remaining inside the bag was analyzed for DM and N. Percent of DM and N remaining at each incubation time was fitted to the model described by Mertens and Loften (1980).

In vivo digestion. Gelatin capsules containing 10 g of Cr_2O_3 were dosed at 0800 and 2000 during d 13 to 21. Duodenal (300 mL) and fecal grab samples (200 g) were collected at 6-h intervals during days 20 and 21. Therefore, 8 individual samples for each site representing 0300, 0600, 0900, 1200, 1500, 1800, 2100 and 2400 were collected.

Duodenal samples were collected as described for Yb and stored frozen at -20 °C until analyzed. At the end of all four periods, duodenal samples were thawed, transfer to 600-mL beakers, thoroughly mixed, and 200 mL from each beaker were composited by animal and period. A 300-mL aliquot of the composited duodenal samples for each animal-period was freeze dried, ground in a lab mill to pass 1-mm screen, and stored in Whirl-Pak bags until analyzed. Duodenal digesta and feces were analyzed for DM, OM, N and NDF using the same techniques described in Chapter III. Chromium concentration of duodenal digesta and feces was measured as described by Williams et al.(1962) using atomic absorption spectrophotometry.

Fecal samples were placed in a plastic pan and dried in a forced air oven at 55° C. The whole sample for each

animal-period was ground through a 1-mm screen using a Wiley mill, and a subsample of 30 g was saved for analysis of Cr, DM, OM, N and NDF. Duodenal and fecal DM output were calculated by the marker ratio technique (Schneider and Flatt, 1975). Digestibility of each component was calculated using their respective dietary, duodenal, and fecal concentrations.

Nitrogen Flow and Microbial Efficiency

Procedures suggested by Broderick and Merchen (1992) were followed. Purine content was used as an internal bacterial marker.

Bacterial rich material. Ruminal contents were sampled as described by Cecava et al. (1990), and Ludden and Cecava (1995). Ruminal contents (approximately 1,000 mL) were collected twice a day from each steer at 3 and 9, and 6 and 12 h after the morning feeding on d 20 and 21, respectively. Samples were collected from anterior, middle and posterior sites within the reticulo-rumen using a core sampler described by Firkins et al. (1986). At each collection, 500 mL of contents and an equal volume of .9% saline were homogenized in a Waring blender set at high speed for 1 min to dislodge particulate-associate bacteria. Blended contents were strained through four layers of cheesecloth, 1% (wt/vol) formaldehyde was added, and 250 mL of filtrate was stored at 4° C. After collection was completed (d 21), samples (homogenized fluid + small particles) were

composited by animal, centrifuged at 500 x g for 20 min at 5° C, pellet discarded, and supernate centrifuged at 500 x g for 10 min. Clarified supernate was centrifuged 27,000 x g for 20 min, washed with saline solution, and final microbial-rich pellet collected, and stored at -20 °C until freeze dried. Dry material was ground in a Wiley mill to pass 1-mm screen.

Analysis. In addition to analysis described above, a portion of the wet duodenal digesta (100 mL) was centrifuged (25,000 x g for 20 min at 5° C) and the supernatant analyzed for ammonia N, as described for rumen fluid. Purine content of the bacterial-rich fraction and duodenal digesta were analyzed according to Zinn and Owens (1982, 1986), as modified by Ushida et al. (1985) using RNA Type IV from torula yeast (Sigma Chemical Co., St Louis, MO) as a standard. The bacteria-rich fraction and dry duodenal digesta were analyzed for N, using the same technique described in Chapter III.

Calculations. Duodenal flow of DM (g/d) was equal to amount of Cr dosed (g) divided by the Cr (g/g DM) concentration in duodenal digesta. Organic matter, NDF, and N flow were calculated by multiplying DM flow by the concentration of each component in duodenal DM. Microbial N (MBN) flow at the duodenum (g/d) was estimated for each steer and period combination by dividing purine:N ratio of duodenal digesta by the purine:N ratio of the bacterial-rich

fraction and multiplying this quotient by the total duodenal N flow for each individual observation.

The remaining N was assumed to contain undegraded N of feed origin, ammonia N, and endogenous N. Duodenal ammonia N flow was estimated by dividing the ammonia concentration in duodenal fluid by duodenal DM and multiplying this quotient by the duodenal DM flow. Duodenal non-ammonia N flow (NAN, g/d) was estimated as the difference between total duodenal N and ammonia N flow. The non-ammonia, non-microbial N flow (NANMN, g/d) represents the feed N plus endogenous N flow and was estimated as the difference between the NAN and MBN flow. Feed N flow was the difference between NANMN and endogenous N flow. A value of 4 g N/kg of DM flow to duodenum was assumed for endogenous N (Taminga et al., 1979).

Microbial efficiency was expressed as g of microbial N per 100 g of OM apparently and truly digested in the rumen. True OM digested in the rumen was estimated by the difference between the OM apparently digested and the OM of microbial origin. Bacterial CP was also expressed as g CP/100 g of OM digested in the total tract.

Statistical analysis. Data were analyzed as a 4 x 4 Latin square design using the GLM procedure of SAS (1987). Sums of squares were separated into effects of steer, period, supplement type, feed additive and the interaction of supplement type by feed additive. Ruminal data sampled

over time were analyzed as a split-plot over time with the Greenhouse-Geiser correction of degrees of freedom for all F-tests involving time effects, using the REPEATED statement of the SAS program (Littel, 1989). If no interaction between treatment and time was present, then means averaged over time are reported. When an interaction of supplement type by feed additive was present, treatment means were separated using the LSD with alpha = .05 (SAS, 1987).

Results and Discussion

Composition of feeds averaged over the four periods is presented in Table 5-2. Molasses used was the same used in the experiment described in Chapter IV. Molasses had lower DM (72 vs 77.5%) and phosphorus concentrations (.34 vs .88 to .74%), and had higher pH (5.14 vs 4.51 to 4.71) than molasses used in the performance experiment described in Chapter III. Bermudagrass hay composition was similar among periods, except for a lower IVOMD in period 4. Average IVOMD and CP for periods 1 through 4 were: 50 and 10.8; 48 and 10.9; 49 and 9.2 and 44 and 10.3%, respectively.

Patterns of supplement consumption were similar for both molasses and corn supplements. By 2 h after offering, 70 to 80% of supplements were consumed. Restricted level of feeding may be responsible for this pattern of consumption because the molasses supplement was consumed at a slower rate than the corn supplement when animals were given ad

libitum access to hay (Chapter IV). In this experiment both supplements were consumed at the desired levels and had similar patterns of consumption. Results from this experiment, therefore, may not be completely applicable to typical production situations where a different pattern of molasses consumption would be expected.

Table 5-2. Composition of supplements and hay fed in metabolism trial

Item	Corn Mix	Molasses[a]	Corn Gluten	Bermuda Hay
DM, %	86.5	72.0	89.0	88.8
IVOMD	-	-	-	47.7
Concentration in DM, %				
OM	95.0	82.0	98.4	94.3
CP	15.6	9.8	78.7	10.3
TDN[b]	84.4	72.0	89.0	52.1
NDF	9.3	-	5.2	76.4
ADF	-	-	-	39.0
Lignin	-	-	-	4.59
Ca	.66	.61	.03	.33
P	.66	.34	.44	.20
Mg	.26	.53	.06	.40
K	.43	3.76	.15	1.19
Na	.01	.12	.03	.02
pH	-	5.14	-	-
TDN:CP ratio	5.41	7.35	1.13	5.06

[a] Blackstrap molasses not less than 40% invert sugars, fortified with phosphoric acid and 25,000 U.S.P. units vit A, 33,000 U.S.P. units vit D, and 22 Int. units vit E per kg, and .0005% Cu, .00001% Co, .02% Fe, .001% Mn, .0025% Zn, and .00007% I. Sulfur content no less than 1%, as fed basis.

[b] Calculated from table values for supplements(NRC, 1984), and from IVOMD for hay (J.E. Moore and W.E. Kunkle, personal communication).

Digesta Kinetics

Fluid and hay particle digesta kinetics are presented in Table 5-3 (main effect means) and Table 5-4 (treatment means).

Fluid kinetics. Supplement type and bambermycins did not affect ($P > .2$) FPR, fluid MRT, and fluid outflow. Observed FPR were consistent with predicted FPR (6.4%/h) from equation presented by Owens and Goetsch (1986). Steers fed bermudagrass hay and corn supplement (1.35% BW total DM intake) had FPR of 6.4%/h (Galloway et al., 1993b). A similar value (6.7%/h) was reported by Galloway et al. (1993a) in steers fed at a higher level (2.17% BW DM total intake). Molasses fed at 1% BW or higher reduced FPR (Rowe et al., 1979a).

Steers fed molasses had 8.8% higher ruminal fluid volume expressed in L ($P = .049$) or as percent of BW ($P = .054$) than those fed corn supplements, which is consistent with ruminal volume reported in animals on high molasses diets. Ruminal fluid volume increased from 32 L when .75% BW forage was fed with molasses to 75 L when the forage was removed from the diet (Rowe et al., 1979a). In cattle, ruminal fluid volume averaged 15 to 21% BW (Owens and Goetsch, 1988). Predicted ruminal volume (14.5% BW) from their equation based on feed intake is close to estimated volumes (overall mean 13% BW). They also reported that ruminal fluid volume and FPR are negatively related, tending

to produce consistent estimates of ruminal fluid outflow. This probably reflects the physiological control of outflow or may be due to errors in marker use that bias volume and FPR estimates in opposite directions (Owens and Goetsch, 1986).

Animals were observed drinking water (not measured) during and after molasses consumption, which may explain part of the higher volume. Possibly the high osmolarity of molasses induced water consumption to keep ruminal fluid tonicity within the physiological range (Carter and Grovum, 1990). Under production situations, the high tonicity and high rate of fermentation of molasses may explain frequent consumption of small meals.

Bambermycins did not affect (P = .17) ruminal fluid volume as percent of BW. Earley et al. (1996) reported lower liquid fill and higher FPR in steers fed alfalfa-grass hay diets supplemented with bambermycins compared to steers supplemented with monensin and lasalocid.

Particle kinetics. Steers fed corn tended (P = .14) to have increased (8.82 vs 6.20 %/h) hay PR from the fast compartment than those fed molasses, which may imply higher mixing, ruminal motility and rumination. Higher fluid volume and lower numerical FPR and hay particle PR would suggest lower ruminal motility with molasses. The opposite trend was observed with ad libitum intake (Chapter IV). The difference, however, may be explained by higher hay intake

Table 5-3. Main effects of supplement type and bambermycins on ruminal digesta kinetics

Variable	Supplement		Additive		SE	*P* value for Effect		
	Corn	Molasses	None	Bamb[a]		S[b]	A[b]	SxA[b]
Fluid:								
Passage rate, %/h	7.28	6.94	6.90	7.32	.22	.3149	.2288	.6420
Mean retention time, h	13.8	14.5	14.6	13.8	.44	.2846	.2623	.6013
Outflow, L/d	140.3	145.3	142.6	143.0	6.37	.5955	.9627	.4770
Volume, L	80.6	87.6	86.2	81.9	2.01	.0494	.1819	.4882
Volume, % BW	12.5	13.6	13.4	12.7	.32	.0545	.1734	.4684
Particles PR[c], %/h								
Age-dependant	8.82	6.20	8.02	7.00	1.09	.1385	.5310	.5510
Age-independant	3.45	2.76	2.90	3.30	.66	.4977	.6867	.2163
Ruminal PR from LN[d], %/h	2.36	2.05	2.34	2.06	.16	.2165	.2596	.4376
Mean retention time, h								
Fast compartment	22.4	27.4	23.6	26.1	3.04	.2919	.5822	.4131
Slow compartment	36.6	40.3	38.0	38.9	5.16	.6329	.9108	.1319
Time delay	3.0	1.6	2.9	1.7	1.30	.4833	.5397	.7926
Total	61.9	69.2	64.5	66.7	3.15	.1539	.6448	.1074
Ruminal MRT from LN[e], h	44.5	55.0	47.7	51.9	4.14	.1239	.5009	.5466
DM output, % BW	.80	.81	.83	.78	.06	.9542	.5354	.3999
Fill of undigested DM, % BW								
Fast compartment	.47	.57	.51	.53	.09	.4702	.8817	.3582
Slow compartment	1.14	1.24	1.21	1.17	.09	.4807	.7370	.0954
Total	1.61	1.80	1.72	1.69	.04	.0190	.7194	.1132

[a] Bamb = bambermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

[c] Particle passage rate from non-linear model.

[d] Passage rate from linear model (Grovum and Williams, 1973).

[e] Ruminal mean retention time from linear model (Grovum and Williams, 1973).

Table 5-4. Effect of supplement type and bambermycins on ruminal digesta kinetics (treatment means)

Variable	Treatment[a]					*P* value for Effect		
	CC	CB	MC	MB	SE	S[b]	A[b]	SxA[b]
Fluid:								
Passage rate, %/h	7.15	7.42	6.65	7.23	.31	.3149	.2288	.6420
Mean retention time, h	14.0	13.6	15.1	14.0	.62	.2846	.2623	.6013
Outflow, L/d	143.5	137.1	141.7	149.0	9.00	.5955	.9627	.4770
Volume, L	83.8	77.4	88.7	86.5	2.84	.0494	.1819	.4882
Volume, % BW	13.0	12.0	13.8	13.4	.45	.0545	.1734	.4684
Particles PR[c], %/h								
Age-dependant	9.82	7.83	6.22	6.17	1.54	.1385	.5310	.5510
Age-independant	2.60	4.28	3.21	2.32	.90	.4977	.6867	.2163
Ruminal PR from LN[d], %/h	2.41	2.31	2.28	1.81	.23	.2165	.2596	.4376
Mean retention time, h								
Fast compartment	19.3	25.5	28.0	26.7	4.30	.2919	.5822	.4131
Slow compartment	42.5	30.7	33.5	47.0	7.29	.6329	.9108	.1319
Time delay	3.3	2.6	2.4	.7	1.83	.4833	.5397	.7926
Total	65.1	58.8	63.9	74.5	4.46	.1539	.6448	.1074
Ruminal MRT from LN[e], h	41.3	44.8	51.1	59.0	5.86	.1239	.5009	.5466
DM output, % BW	.79	.81	.87	.74	.08	.9542	.5354	.3999
Fill of undigested DM, % BW								
Fast compartment	.39	.54	.63	.51	.13	.4702	.8817	.3582
Slow compartment	1.29	1.00	1.13	1.34	.13	.4807	.7370	.0954
Total	1.68	1.54	1.76	1.85	.06	.0190	.7194	.1132

[a] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = Molasses bambermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed Additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

[c] Particle passage rate from non-linear model.

[d] Passage rate from linear model (Grovum and Williams, 1973).

[e] Ruminal mean retention time from linear model (Grovum and Williams, 1973).

by animals fed molasses in that experiment. Estimates of PR from the slow compartment (rumen) by LN and G4G1 models have high standard errors. Possible explanations are that sampling from duodenum may be subjected to error because of unrepresentative sampling (Faichney, 1975), the level of intake was low enough to depress PR, or the time of sampling after dose may have been too short (84 h). Using the same steers and marker, but giving steers ad libitum access to hay, Garces-Yepez (1995) sampled for only 72 h after dosing and detected differences among treatments. He reported PR of Yb-labeled particles of 8.5%/h from the fast and 3.3%/h from the slow compartments for steers fed hay plus corn (35% of diet), which are similar to the PR estimates for corn supplemented diets in this trial.

There was a trend for supplement type by feed additive interaction (P = .13) for slow compartment particle MRT and total MRT (P = .11). Steers supplemented with molasses tended (P = .12) to have longer (55.0 vs 44.5 h) ruminal particle MRT compared to steers supplemented with corn estimated with the LN model, which may be biologically significant. However the ruminal NDF digestibility (Table 5-14) was similar with corn and molasses diets.

Ruminal DM output was not affected (P > .5) by supplement or feed additive and numerical values are similar to values reported by Garces-Yepez (1995).

An interaction of supplement type by feed additive was detected for fill of the slow compartment (P = .095). Fill of the slow compartment was consistent with the ruminal fluid volume, with an estimated 8 to 10% of undigested hay DM in rumen content. Total hay DM fill was higher (P = .019) in steers fed molasses than the ones fed corn. The increased fill of hay DM and fluid volume, and the tendency for longer MRT with molasses supplementation may be the result of less ruminal motility. A more sluggish vago-vagal reflex by lower afferent stimulus from a diet producing lower tactile stimulation of mechanoreceptors has been suggested (Rukebusch, 1988). High osmolarity of ruminal fluid may also depress ruminal motility (Grovum, 1986 ; Carter and Grovum, 1990). One or both mechanisms may have operated in animals fed molasses. In the experiment with heifers (Chapter IV), total fill was not affected and the model partitioned total fill differently. Heifers fed corn tended to have higher fill in the fast compartment and lower fill in the slow compartment than heifers fed molasses. However, differences found in that experiment may be explained by higher hay (ad libitum) and lower molasses (20% of the diet) intake.

Combined data from this experiment and the one described in Chapter IV do not suggest a biologically significant effect of bambermycins on digesta kinetics. Data also suggest minimal differences between energy sources. The possible confounding of level of supplement intake and

supplement type (Chapter IV) and the restricted level of feeding imposed in this experiment limit extrapolation to production situations.

Characteristics of Ruminal Fluid

Treatment means averaged over time are presented in Table 5-5. Because there were supplement type by time of sampling interaction for several variables, means are also presented by time in Tables 5-6 and 5-7. Time postfeeding in the following discussion refers to time after the morning feeding. Animals were fed a second meal of hay alone 12 h after the morning feeding.

Ruminal pH. Ruminal pH exhibited a supplement by time interaction ($P = .0001$), therefore treatment means are presented by time in Table 5-6. At 4 and 6 h after feeding, steers fed molasses had lower ($P < .02$) pH than those fed corn. Immediately before the morning feeding (24 h), at 2 and 12 h postfeeding, pH was lower ($P < .08$) in steers fed corn. Lowest pH values were at 6 and 12 h postfeeding molasses and corn, respectively. Soluble sugars are fermented at a faster rate than starch, which explains the faster depression of ruminal pH after feeding molasses. Galloway et al. (1993a) reported pH from 5.95 to 6.27 in the ruminal fluid of steers fed bermudagrass hay and ground corn (30% of the diet, 2.17% BW total intake), with lowest pH recorded 8 to 14 h postfeeding. They reported total corn

Table 5-5. Effect of supplement type and bambermycins on characteristics of ruminal fermentation (treatment means averaged over time)

	Treatment[a]					*P* value for Effect			
Variable	CC	CB	MC	MB	SE	S[b]	A[b]	SxA[b]	T[c]
Ruminal pH[d]	6.54	6.63	6.49	6.63	.04	.5529	.0464	.5284	.0009
NH_3-N, mg/100 mL	12.67	11.46	11.42	10.03	.89	.1818	.1931	.9218	.0001
Total VFA[e], mM	100.2	97.2	98.3	94.2	4.07	.5617	.4141	.9050	.1277
VFA, mol/100 mol									
Acetate[f]	72.61	73.26	70.61	71.94	.88	.1078	.3009	.7127	.1991
Propionate[g]	14.37	15.26	16.48	15.80	.63	.0808	.8761	.2600	.1007
Butyrate[h]	10.72	9.20	10.56	10.32	.49	.3648	.1192	.2350	.0086
Isobutyrate	.66	.62	.58	.42	.09	.1803	.3477	.5478	.0571
Valerate	.67	.67	.91	.75	.03	.0034	.0497	.0740	.5222
Isovalerate	.97	.99	.86	.76	.09	.1050	.7119	.5261	.0039
Branched chain	1.62	1.61	1.43	1.19	.17	.1183	.4808	.5117	.0144
Acetic:Propionic[i]	5.11	4.86	4.48	4.66	.21	.0972	.8806	.3416	.1036

[a] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = Molasses bambermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

[c] Time of sampling after feeding main effect, probability value for time and its interactions are for F with adjusted degrees of freedom (Greenhouse-Geisser).

[d] S x T interaction, P = .0001.

[e] S x T interaction, P = .0688.

[f] S x T interaction, P = .0258.

[g] S x T interaction, P = .0031.

[h] S x T interaction, P = .0119.

[i] S x T interaction, P = .0035

Table 5-6. Effect of supplement type and bambermycins on ruminal pH, total VFA, and acetate to propionate ratio (treatment means by time)

Variable	Treatment[a]				SE	*P* value for Effect		
	CC	CB	MC	MB		S[b]	A[b]	SxA[b]
Ruminal pH								
2 h	6.64	6.76	6.77	6.83	.04	.0469	.0603	.4706
4 h	6.84	6.88	6.38	6.44	.08	.0019	.5481	.9434
6 h	6.63	6.68	6.34	6.50	.07	.0200	.2082	.5122
8 h	6.50	6.57	6.39	6.55	.07	.3861	.1295	.5261
12 h	6.33	6.44	6.45	6.60	.07	.0756	.0884	.7735
16 h	6.47	6.51	6.55	6.76	.10	.1352	.2475	.3830
24 h	6.42	6.54	6.54	6.71	.05	.0443	.0368	.6609
Total VFA, mM								
2 h	107	95	98	103	8.2	.9492	.6677	.3449
4 h	93	87	107	108	9.8	.1212	.8057	.7828
6 h	98	96	91	99	6.8	.7380	.6246	.4604
8 h	102	99	102	92	4.9	.5535	.2106	.5544
12 h	95	95	96	79	7.4	.3411	.2859	.3050
16 h	110	110	99	96	2.4	.0022	.4902	.5358
24 h	97	99	95	83	6.3	.2020	.4668	.2969
Acetate:propionate								
2 h	5.50	5.44	4.49	4.06	.34	.0122	.4974	.5950
4 h	5.44	5.42	3.60	3.90	.14	.0001	.3609	.2941
6 h	4.97	4.92	4.22	4.24	.29	.0502	.9719	.9094
8 h	4.70	4.43	4.23	4.58	.37	.6782	.9236	.4269
12 h	4.81	4.35	4.82	5.39	.27	.0988	.8470	.1029
16 h	4.99	4.50	5.13	5.21	.45	.3793	.6616	.5505
24 h	5.35	4.95	4.86	5.26	.39	.8285	.9962	.3434

[a] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = Molasses bambermycins.
[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

Table 5-7. Effect of supplement type and bambermycins on ruminal acetate, propionate, and butyrate molar proportions (treatment means by time)

	Treatment[a]					P value for Effect		
Variable	CC	CB	MC	MB	SE	S[b]	A[b]	SxA[b]
Acetate, mol/100 mol								
2 h	73.7	74.4	71.5	69.5	1.19	.0253	.6128	.3082
4 h	73.5	74.6	66.9	69.1	.92	.0005	.1216	.5768
6 h	72.6	74.1	70.5	70.5	.80	.0120	.3857	.3633
8 h	71.6	72.5	69.2	71.4	1.62	.3283	.3860	.6884
12 h	71.4	72.0	71.8	74.4	1.06	.2255	.1860	.3809
16 h	72.1	71.9	72.9	73.7	1.33	.3540	.8398	.6994
24 h	73.3	73.3	71.5	75.0	2.19	.9644	.4455	.4614
Propionate, mol/100 mol								
2 h	13.6	13.8	16.1	17.7	.85	.0094	.3512	.4246
4 h	13.6	13.9	19.2	18.0	.69	.0004	.5230	.3083
6 h	14.7	15.2	16.9	16.7	.90	.0822	.9065	.7109
8 h	15.4	16.5	17.4	15.6	1.24	.6701	.8132	.3031
12 h	15.0	16.6	15.2	13.8	.68	.1083	.8435	.0690
16 h	14.6	16.0	14.9	14.5	.96	.5717	.6364	.3784
24 h	13.7	15.0	15.7	14.3	1.09	.5948	.9361	.2756
Butyrate, mol/100 mol								
2 h	9.9	9.0	10.7	10.5	.70	.1527	.4767	.6003
4 h	10.6	9.2	11.2	11.1	.76	.1449	.3617	.4582
6 h	10.5	9.0	11.1	11.5	.69	.0649	.4522	.2188
8 h	10.9	9.2	11.1	11.3	.63	.1207	.2952	.1938
12 h	11.5	9.5	10.3	10.3	.33	.5619	.0206	.0245
16 h	11.4	9.6	10.3	9.6	.45	.2845	.0301	.2558
24 h	10.3	8.9	9.1	7.9	.54	.0968	.0470	.8692

[a] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = Molasses bambermycins.
[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

consumption in less than 20 min. Similarly, Royes (1996) reported fast corn consumption followed by low ruminal pH. Inclusion of urea in the corn supplement may explain the lower rate of consumption. Feeding urea generally increased ruminal pH (Owens and Zinn, 1988). Both rate of consumption and inclusion of urea (2.8% as fed) in corn supplements may explain higher ruminal pH in this experiment.

The magnitude and timing of the postprandial drop in ruminal pH in steers fed molasses agrees with other reports (Khalili, 1993; Khalili et al., 1993; Osuji and Khalili, 1994). They observed a somewhat faster increase in pH after the lowest value, probably due to higher forage intake. Animals given ad libitum access to hay may have increased salivary secretion, dilution rate and buffering capacity in the rumen.

There were no time by feed additive (P = .8) or supplement type by feed additive (P = .5) interactions for ruminal pH. Bambermycins increased (P = .046) ruminal pH (6.63 vs 6.52) in steers fed both corn and molasses supplements. This effect may be partially caused by a lower rate of fermentation because the total VFA concentration was slightly lower with bambermycins. Ruminal pH apparently was measured with less error than total VFA, hence statistical difference was detected only for pH.

Reported effects of bambermycins on ruminal pH are variable. Bambermycins increased ruminal pH at the end of wk

4, however by the end of wk 9 there was no effect (Murray et al., 1992). Aitchison et al. (1989a) reported that bambermycins increased rumen pH (6.94 vs 6.57) in sheep fed at maintenance. However when animals were given ad libitum access to the same diets, the tendency was the same but not statistically significant (Aitchison et al., 1989b). No effect on pH was found in diets supplemented with bambermycins and different sources of sulfur (Murray et al., 1991), or different concentrations of bambermycins (Murray et al., 1990).

Under these experimental conditions the increase in pH may not be biologically relevant. Mould and Orskow (1983) suggested that bacterial fermentation of fiber may be depressed when pH is below 6.2, but the pH was always above 6.2 in this experiment.

Ruminal volatile fatty acids. Total VFA concentrations exhibited a supplement by time interaction (P = .067), therefore treatment means are presented by time in Table 5-6. The time trends of total ruminal VFA concentration seems to reflect the different rates of degradability of sugar and starch. The peaks of total VFA in ruminal fluid of steers fed corn did not necessarily result in a low pH, probably reflecting salivary buffering with consumption of hay and(or) rumination. Total VFA tended (P = .12) to be higher at 4 h postfeeding in steers fed molasses and it was lower (P = .002) at 16 h postfeeding compared to those fed corn.

There was not a feed additive by time interaction (P = .76) and bambermycins did not affect (P = .41) total VFA concentration. Small trends due to supplement type and feed additive were consistent with results from the performance experiment (Chapter III).

Previously reported effects of bambermycins on total VFA have been variable. Bambermycins decreased the total VFA concentration (65.3 vs 78.5 mM/L) by the end of wk 4, but there was no effect by the end of wk 9 (Murray et al., 1992). Bambermycins increased total VFA when the diet was supplemented with methionine, but it had no effect on total VFA when the diet was supplemented with other sulfur sources (Murray et al., 1991). Bambermycins did not affect total VFA in lucerne (Medicago sativa)-lupin and hay-fishmeal based diets (Murray et al., 1990) or in high quality diet fed at maintenance level (Aitchison et al., 1989a). When sheep where given ad libitum access to these diets, bambermycins decreased total VFA concentration (Aitchison et al., 1989b). In fattening cattle bambermycins did not affect total VFA (Flachowsky and Richter, 1991; Alert et al., 1993). However, higher total VFA concentration were reported in steers fed a 90% concentrate diet with bambermycins (DelCurto et al., 1996).

Acetate molar proportion exhibited a supplement by time interaction (P = .026), therefore treatment means are presented by time in Table 5-7. At 2, 4, and 6 h postfeeding

steers fed corn had higher ($P < .025$) acetate molar percent than those fed molasses. In the performance experiment (Chapter III), animals fed corn had higher acetate proportion than the those fed molasses. Results are difficult to compare, however, because this experiment demonstrates that individual VFA molar proportions change with time after feeding and feeding time was not controlled with molasses supplements in that experiment. There was not a feed additive by time interaction ($P = .5$) and bambermycins tended ($P = .12$) to increase acetate proportion at 2 h postfeeding.

Propionate molar proportion also exhibited a supplement by time interaction ($P = .003$), therefore treatment means are presented by time in Table 5-7. Propionate was higher in steers fed molasses at 2 h ($P = .009$), 4 h ($P = .0004$), and 6 h ($P = .08$) postfeeding than in those fed corn supplements. By 12 h postfeeding, the trend was reversed and animals fed corn tended ($P = .11$) to have a higher ruminal propionate molar proportion. Propionate molar proportion increased shortly after molasses consumption followed by lower propionate proportion 8 h or more postfeeding. In animals fed corn, propionate showed less variation over sampling times. Because the rates of supplement consumption were similar, this trend reflects the faster rate of sugar fermentation. A rapid fermentation rate usually results in more production of H_2. Excess reducing equivalents combined

with low pH has been reported to increase reduction of pyruvate to lactate and propionate (Owens and Goetsch, 1988). Lactic acid (see below) was present shortly after feeding only in animals fed molasses. There was not a feed additive by time interaction (P = .7) and bambermycins did not affect (P = .26) propionate molar proportion.

Butyrate molar proportion also exhibited a supplement by time interaction (P = .012), therefore treatment means are presented by time in Table 5-7. Steers fed molasses tended to have higher butyrate proportions at 2 h (P = .15), 4 h (P = .14), 6 h (P = .065), and 8 h (P = .12) postfeeding than the steers fed corn. Pre-feeding butyrate proportion, however, was higher (P = .097) in steers fed corn. Molasses fermentation has been reported to have a high butyrate proportion (Marty and Preston, 1970; Pate, 1983). Butyrate was also higher in ruminal fluid of cattle fed molasses in the performance experiment (Chapter III).

There was no feed additive by time interaction (P = .49) and bambermycins tended (P = .12) to depress butyrate proportion (averaged across time, Table 5-5). Bambermycins depressed (P < .05) butyrate molar proportion from 12 to 24 h and from 16 to 24 h postfeeding in animals fed corn and molasses, respectively (Table 5-7). Van Nevel and Demeyer (1992) reported that bambermycins decreased butyrate and increased acetate production when the substrate was NDF in

vitro. Murray et al. (1990) also reported a lower butyrate molar proportion in sheep fed bambermycins.

There was no supplement or feed additive by time interaction ($P > .26$) for the minor VFA (Table 5-5). Valerate molar proportion exhibited a supplement by feed additive interaction ($P = .074$). Bambermycins decreased valerate proportion in animals fed molasses but it did not affect valerate proportion in animals fed corn supplements. Valerate can be formed by carbohydrate or amino acid fermentation. Isobutyrate and isovalerate are derived from the fermentation of the amino acids valine and leucine respectively (Russell, 1984).

Isobutyrate and isovalerate molar proportion were affected ($P < .06$) by time and they will be discussed together. Branched chain VFA (BCVFA) were affected by time ($P = .01$) and animals fed molasses tended ($P = .12$) to have lower BCVFA molar proportions. When analyzed by time (data not shown), BCVFA (mol/100 mol) was lower ($P < .06$) in steers fed molasses at 2 h (1.3 vs 1.9), 6 h (.65 vs 1.65), and 16 h (1.19 vs 1.53) postfeeding compared to steers fed corn. Isovalerate molar proportion decreased with sucrose (Huhtanen, 1988; Khalili and Huhtanen, 1991a) and molasses supplementation (Petit and Veira, 1994). They suggested increased utilization of isovalerate for microbial growth. However, BCVFA molar proportion and ruminal ammonia concentration were increased with increasing levels of

soybean meal supplementation (Yang and Russell, 1993b), suggesting increased BCVFA production resulting from ruminal proteolysis and deamination. In the performance experiment (Chapter III), cattle fed molasses had lower BCVFA concentrations in ruminal fluid compared to cattle fed corn supplements. Lower BCVFA may suggest lower feed protein degradation in animals fed molasses. Fiber digesting bacteria may require BCVFA which would be supplied by amino acid degradation (NRC, 1996). Russell et al. (1992) suggested that BCVFA deficiency may occur if high-forage diets are low in true protein and non-protein N is used as supplement.

Bambermycins also affected BCVFA, but the effect was not consistent: it decreased (P = .05) BCVFA proportion at 6 h (.86 vs 1.11 mol/100 mol) and increased BCVFA (P = .03) at 16 h (1.2 vs 1.6 mol/100 mol) after feeding. Bambermycins tended to increase BCVFA molar proportions in the performance experiment (Chapter III). Bambermycins increased extent of in situ CGM CP digestion after 18 h of incubation (see discussion below, Tables 5-10 and 5-11). Leucine and valine comprise 28% of CP in CGM (Cozzi et al., 1994). The effects of bambermycins on CGM digestion appears consistent with increased BCVFA proportion.

Acetate:propionate ratio (C_2:C_3) also exhibited a supplement by time interaction (P = .003), therefore treatment means are presented by time in Table 5-6. At 2 h

(P = .01), 4 h (P = .0001), and 6 h (P = .05) postfeeding, C_2:C_3 was lower in ruminal fluid of steers fed molasses; at 12 h after feeding, however, C_2:C_3 tended (P = .099) to be lower in steers fed corn. In steers fed molasses, acetate and propionate had their lowest and highest values, respectively, at 4 h postfeeding resulting in the lowest C_2:C_3 at this time. This was also coincident with the lowest ruminal pH.

There was no feed additive by time interaction (P = .8). Bambermycins did not affect (P > .36) C_2:C_3, which is consistent with results from the performance experiment (Chapter III) and other reports (Aitchison et al., 1989b; Murray et al., 1991; El-Jack et al., 1986; Fallon et al., 1986). However, Earley et al. (1996) reported that bambermycins depressed C_2:C_3 in cattle fed alfalfa and grass hay.

Lactic acid. With the exception of one sample, lactic acid was detected only in animals consuming molasses (Table 5-8). Lactic acid concentration was not affected (P = .8) by bambermycins. Lactic acid was only detected in 13% of the samples and it was present as a transient peak shortly after feeding, probably related to high rate of intake of molasses. Whether this peak of lactic acid occurs in production situations is not known because the pattern of molasses consumption may be different. As occurred in the experiment with heifers (Chapter IV), molasses intake tended

to be distributed throughout the day. Some animals, however, tended to eat at faster rates shortly after molasses was delivered, consuming considerable amounts that may have caused accumulation of lactic acid.

Table 5-8. Lactic acid concentration (mM) in ruminal fluid of animals fed molasses[a]

Time after feeding	Number of Samples	Mean	Std Dev	Min	Max
2	6	14.79	11.50	.89	33.46
4	5	3.66	2.70	1.31	7.94
6	1	.17	-	-	-
8	2	.54	.49	.19	.89

[a] Except for one sample from corn (4 h, .32 mM), lactic acid was not detected in all other samples from corn or molasses fed animals.

Presence of lactic acid in molasses, but not in corn supplemented cattle, is consistent with a fast rate of sugar fermentation and has been observed in grass silage diets supplemented with sucrose (Khalili and Huhtanen, 1991a) and with molasses (Moloney et al., 1994). Lactic acid concentration may have been underestimated with our sampling schedule because the highest concentrations have been observed at .5 and 1 h postfeeding (Khalili and Huhtanen, 1991a; Moloney et al., 1994). Lactic acid was higher in ruminal fluid of cattle fed sucrose twice daily than in those given a continuous intraruminal sucrose infusion (Khalili and Huhtanen, 1991a), suggesting that the pattern of molasses consumption may dictate the prevalence of lactic acid production.

Ruminal ammonia. Ruminal ammonia N concentration was affected (P = .0001) by time after feeding in all treatments (Figure 5-1). In steers fed corn, ammonia N concentration decreased from 26.5 mg/dL at 2 h to 4.4 mg/dL at 12 h postfeeding. In animals fed molasses, the maximum value (21.3 mg/dL) was observed at 4 h postfeeding and decreased to 3.3 mg/dL at 12 h postfeeding. The small increase after 12 h postfeeding, observed with both supplements, was associated with hay feeding at 12 h, which should also have increased salivary urea input. Because there was a tendency (P = .17) for a supplement type by time interaction, data were also analyzed by time (data not shown). Ammonia N concentrations were higher (P < .07) at 6 h (14.0 vs 10.8 mg/dL), and lower at 12 h (3.3 vs 4.4 mg/dL) and 16 h (5.5 vs 7.0 mg/dL) postfeeding, and pre-feeding (5.1 vs 8.0 mg/dL) in steers fed molasses than in those fed corn. At 2 h postfeeding ammonia concentration tended (P = .11) to be higher in steers fed corn (27 vs 18 mg/dL), suggesting that the ammonia peak may have been greater with corn. The ammonia peak in steers fed corn may have been underestimated because the first sampling was obtained 2 h postfeeding and after that time only a decreasing trend was observed while in those fed molasses ammonia concentration continued to increase up to 4 h postfeeding (Figure 5-1).

There was no feed additive by time interaction (P = .5). Ammonia N concentration averaged over time tended to be

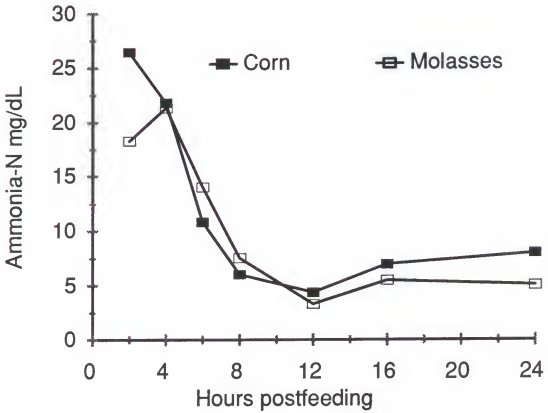

Figure 5-1. Effect of supplement type on ruminal ammonia nitrogen concentrations, means by time after feeding.

lower in animals fed molasses (P = .18) and in those feed bambermycins (P = .19)(Table 5-5). Intake of N estimated from chemical analysis was 154 and 170 g/d for corn and molasses diets, respectively. About 22% of dietary N was provided as non-protein N (urea) in corn, which likely explains the increase of ruminal ammonia N concentration shortly after feeding. Urea N will be hydrolyzed at a fast rate and enter into the ruminal ammonia pool (Owens and Zinn, 1988). Stateler (1993) in his literature review stated that about 60 to 70% of N in molasses is present in relatively simple form. These include amides, albuminoids, amino acids and simple N compounds. Protein and amino acids usually comprise less than 25% of total N and complex N in molasses and they are present mainly as Maillard reaction products. It is conceivable that most of the available N in molasses would be degraded at a fast rate. Rate of degradation of the soluble N fraction in molasses is listed as 350%/h (NRC, 1996). Salivary contribution of urea will also increase during feed ingestion but the relative contribution in corn and molasses diets is not known.

Concentration of ammonia in ruminal fluid is the result of several processes. Degradation of feed N, urea recycling and intraruminal microbial turnover contribute to the ammonia pool. Ammonia is removed from this pool by microbial ammonia N utilization for protein synthesis, ruminal ammonia absorption into the blood, and ammonia outflow to the lower

tract (Obara et al., 1991). Sucrose and molasses supplementation decreased ruminal ammonia concentration, probably reflecting increased microbial ammonia capture when microbial growth was rapid (Rooke et al., 1987; Huhtanen, 1988; Rooke et al., 1989; Khalili and Huhtanen, 1991a; Obara et al., 1991). Ruminal clearance of urea (rate of urea degradation per plasma urea concentration) was increased by dietary sucrose and negatively related to ruminal ammonia concentration (Kennedy, 1980).

Ammonia is absorbed though the rumen wall by passive diffusion and the quantity absorbed is positively related to ruminal ammonia concentration and to rumen pH. Ammonia absorption is depressed at low pH because proportion of NH_4^+ increases and the charged form is absorbed at a lower rate (Merchen, 1988). This suggests that more ammonia may have been absorbed in animals fed corn supplements because the ammonia peak was higher and the pH during the time of highest ruminal ammonia concentration was also higher than in those fed molasses.

Sampling time is an important consideration for plasma urea N (PUN) interpretation (Hammond, 1992; Hammond and Chase, 1996). In the performance experiment (Chapter III), PUN was lower in steers fed the molasses supplement. However, ruminal sampling was conducted 3 to 5 h after feeding corn supplements, which would coincide with high ruminal ammonia concentration. Plasma urea N peaks about an

hour after the ruminal ammonia peaks (Van Soest, 1994). Ruminal ammonia concentration in animals fed molasses was probably lower before sampling because fresh molasses was delivered the day before sampling. Therefore part of the lower PUN concentration may be due to sampling time. Energy intake (1.4% TDN as percent BW) and gain (.6 kg) was similar in animals fed CC and MC, suggesting that supply of ruminal degradable N was not different. Furthermore, PUN concentration in animals fed molasses suggested that a response to additional DIP was not likely (Hammond et al., 1993; Hammond et al., 1994).

It is unlikely that ammonia N availability may have limited microbial growth and ruminal fermentation because the levels were almost always above the suggested 3 to 5 mg/dL levels for microbial growth (Satter and Slyter, 1974). Mehrez et al. (1977) suggested a higher level (23.5 mg/dL) for optimal ruminal fermentation, but Ortega et al. (1979) did not find a benefit in rate of fermentation by increasing ammonia concentration from 6.3 to 27.5 mg/dL.

Bambermycins did not affect (P = .19) ruminal ammonia N concentration, which is consistent with the lack of effect on PUN observed in the performance experiment (Chapter III). The effects of bambermycins on ruminal ammonia have been contradictory in previous research. Bambermycins increased ruminal ammonia concentrations in lambs and adult sheep (Murray et al., 1992). Other reports by the same researchers

showed no effect of bambermycins on ruminal ammonia with diets of different qualities that were supplemented with several sources of sulfur (Murray et al., 1991). When alfalfa-lupin and hay-fishmeal diets were supplemented with bambermycins, ruminal ammonia concentration was decreased only in the hay-fishmeal diet (Murray et al. 1990). Bambermycins added to high or low quality diets fed at maintenance levels increased ruminal ammonia in the high quality diet only (Aitchison et al., 1989a). However, when those diets were fed ad libitum bambermycins reduced ruminal ammonia concentration in the high quality diet (Aitchison et al., 1989b). Bambermycins inclusion in concentrate fed to young calves had no effect on ruminal ammonia concentrations (El-Jack et al., 1986; Fallon et al., 1986). Rowe et al. (1982) also did not find an effect of bambermycins on ruminal ammonia in cattle. Van Nevel and Demeyer (1990) reported that bambermycins did not affect proteolysis or deamination in vitro.

The overall effect of bambermycins on ruminal fermentation evaluated through pH, VFA and ammonia concentration showed only minor changes which would not suffice to explain the increased performance when bambermycins was added to supplements (Chapter III).

Effects of corn and molasses supplements on ruminal fermentation appear more related to timing of events rather than great differences in end products of ruminal

fermentation. This is consistent with similar improvements in performance observed in growing cattle fed CC and MC supplements (Chapter III).

Sodium and potassium. Ruminal fluid Na concentration exhibited a supplement type by time interaction (P = .038). Ruminal Na concentration increased from 8 to 24 h postfeeding in steers fed molasses (Figure 5-2 and Table 5-9). Increased salivary Na input during rumination may be partially responsible for this trend. At all sampling times steers fed corn had higher (P = .0003) ruminal Na concentration than those fed molasses.

There was no supplement type by time (P = .2) or feed additive by time (P = .27) interaction for ruminal K. Ruminal K was affected by time (P = .009), with a decreasing K concentration after feeding for steers fed the molasses supplement (Figure 5-2). At all times K concentration was higher (P = .003) in ruminal fluid of steers fed molasses compared to corn. Thus an inverse relationship between these electrolytes was observed, which is reflected in the Na:K ratios. The sum of Na plus K was not affected by time or diet, suggesting that these electrolytes are regulated together in ruminal fluid. The sum of cations and anions tend to remain constant in saliva. The main cations are Na^+ and K^+, which are inversely related. With normal Na intake, salivary Na:K ratio is about 20:1 and drops below 10:1 in animals with Na deficiency (Morris, 1980). Salivary

Table 5-9. Effect of supplement type and bambermycins on sodium and potassium concentration in ruminal fluid (treatments means)

	Treatment[a]					*P* value for Effect			
Variable	CC	CB	MC	MB	SE	S[b]	A[b]	SxA[b]	T[c]
Na all times[d], mM	103	108	76	80	3.8	.0003	.2786	.9050	.0001
Time after feeding:									
2 h	101	104	78	74	5.8	.0038	.9928	.5976	-
4 h	97	105	67	72	5.0	.0007	.2591	.7858	-
6 h	101	106	67	77	4.9	.0006	.1602	.6221	-
8 h	103	106	72	76	4.1	.0003	.4111	.8106	-
12 h	105	112	77	80	3.5	.0001	.1895	.5795	-
16 h	102	108	80	85	4.0	.0013	.2507	.8854	-
24 h	113	115	92	95	2.6	.0002	.2652	.8710	-
K, mM	41	42	75	67	6.3	.0029	.5456	.5286	.0090
Na + K, mM	144	150	151	147	4.4	.6576	.9071	.3566	.1573
Na:K	3.55	2.87	1.15	1.29	.50	.0069	.6043	.4387	.0418
Intake[e], g/d									
Na	1.4	1.4	4.3	4.2	.09	.0001	.5889	.5889	-
K	74.2	74.2	156.6	153.0	2.81	.0001	.5440	.5440	-

[a] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = Molasses bambermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

[c] Time of sampling after feeding main effect, probability value for time and its interactions are for F with adjusted degrees of freedom (Greenhouse-Geisser).

[d] SxT interaction, P=.0378.

[e] Exclude mineral supplement and water.

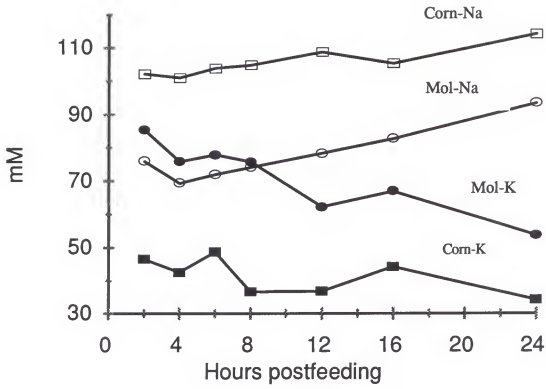

Figure 5-2. Effect of supplement type (corn or molasses) on ruminal sodium and potassium concentrations, means by time after feeding.

concentration of Na and K are regulated by aldosterone (Carter and Grovum, 1990).

Dietary Na could not be assessed because the intake of mineral mix (8% Na) was not measured and water could be an important source of Na. From hay and supplement compositions, it is evident that K and Na intake was higher in animals fed molasses. Corn diets were Na-deficient (.02% Na in DM). Intake of 40 g of mineral supplement would increase Na concentration to .06% DM, which is the minimum requirement (NRC, 1996). Mineral supplement was available at all time and was offered at a rate equivalent of at least 100 g/d.

Sodium is absorbed from the rumen by the Na-K ATPase system. Sodium absorption is increased by increasing ruminal K or Na concentration, and by increasing the osmotic pressure of ruminal fluid (Carter and Growum, 1990).

These electrolytes were measured in an attempt to relate to the performance experiment (Chapter III) because of the interaction of monensin with mineral concentrations. Direct comparison may, however, not be possible because monensin may change the concentration through changes in absorption. Starnes et al. (1984) reported Na:K ratios of 3.7 and 5 in ruminal fluid of sheep fed corn-soybean meal-cottonseed hull diets without and with monensin, respectively. They reported 111 and 122 mM of Na, and 29.5 and 24.3 mM of K for control and monensin diets,

respectively. Monensin increased Na, Mg and P absorption and reduced K concentration and osmolality in ruminal fluid. Magnesium absorption may be depressed in molasses diets because it has been shown that increasing Na:K ratio from .5 to 5 linearly increased Mg absorption (Martens and Rayssiguier, 1980).

Bambermycins did not affect ($P > .28$) Na or K concentrations, which was expected because this antibiotic has not been shown to act by altering membrane permeability to ions.

Ruminal and Total Tract Digestion

In situ degradability of CGM is presented in Tables 5-10 and 5-11, digesta flow in Tables 5-12 and 5-13, and ruminal and total tract digestibility in Tables 5-14 and 5-15 by main effect and treatment, respectively.

In situ. In situ rate of digestion (K_d) of CGM DM was increased by molasses ($P = .034$) and bambermycins ($P = .013$), and bambermycins tended ($P = .13$) to increase K_d of CGM CP. Extent of CGM CP digestion was higher ($P < .08$) at 18 and 24, and 48 h ruminal incubation with molasses supplemented diets. Bambermycins increased ($P < .07$) CGM CP extent of digestion at 18, 24, 36, and 48 h incubation times. Higher rate and extent of digestion with molasses diets may be related to the presence of CGM as an ingredient of this diet. Corn protein should be similar in both, corn

Table 5-10. Main effect of supplement type and bambermycins on in situ rumen digestion characteristics of corn gluten meal

Variable[a]	Supplement		Additive		SE	*P* value for Effect		
	Corn	Molasses	None	Bamb[b]		S[c]	A[c]	SxA[c]
Dry matter								
Fraction A, %	10.7	10.0	10.2	10.5	.29	.1482	.5008	.3952
Fraction B, %	87.2	85.9	86.3	86.6	.83	.3185	.7370	.6684
Fraction C, %	2.2	4.1	3.5	2.8	.83	.1449	.5653	.9029
K_d of fraction B, %/h	2.27	2.78	2.20	2.85	.13	.0342	.0131	.6261
Lag, h	0	.33	.02	.31	.13	.1180	.1586	.1586
Extent of digestion, %								
24 h	42.8	44.9	42.2	45.5	.46	.0176	.0025	.0388
36 h	57.9	62.3	53.0	67.2	3.56	.4165	.0308	.6870
Crude protein								
Fraction A, %	8.4	7.3	7.8	7.9	.63	.2477	.8691	.2600
Fraction B, %	89.1	87.9	88.2	88.9	1.37	.5554	.7249	.5811
Fraction C, %	2.5	4.8	4.0	3.8	1.01	.1521	.5677	.9872
K_d of fraction B, %/h	2.56	2.83	2.17	3.22	.42	.6702	.1289	.2144
Lag, h	7.92	6.64	7.39	7.16	1.86	.6448	.9297	.4106
Extent of digestion, %								
6 h	14.8	14.0	14.1	14.7	.66	.3783	.5777	.3797
12 h	17.9	19.0	18.0	18.9	.99	.4321	.5134	.4196
18 h	21.2	28.9	23.0	27.1	.92	.0010	.0193	.6418
24 h	27.9	31.5	27.6	31.9	.72	.0130	.0054	.0414
36 h	47.2	53.2	41.1	59.3	4.73	.4105	.0347	.6846
48 h	65.7	78.5	65.4	78.9	4.31	.0822	.0689	.3229

[a] Fraction A: Soluble; Fraction B: Fraction degraded at measurable rate; Fraction C: Undigested residue after 60 h in the rumen. K_d: Rate constant of digestion of fraction B.

[b] Bamb = bambermycins.

[c] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

Table 5-11. Effect of supplement type and bambermycins on in situ rumen digestion characteristics of corn gluten meal (treatment means)

Variable[a]	Treatment[b]					*P* value for Effect		
	CC	CB	MC	MB	SE	S[c]	A[c]	SxA[c]
Dry matter								
Fraction A, %	10.7	10.6	9.6	10.3	.41	.1482	.5008	.3952
Fraction B, %	86.8	87.7	86.0	85.9	1.17	.3185	.7370	.6684
Fraction C, %	2.6	1.7	4.4	3.9	1.17	.1449	.5653	.9029
K_d of fraction B, %/h	1.90	2.64	2.50	3.05	.19	.0342	.0131	.6261
Lag, h	0	0	.04	.62	.18	.1180	.1586	.1586
Extent of digestion, %								
24 h	40.3	45.3	44.1	45.7	.66	.0176	.0025	.0388
36 h	49.8	66.0	56.3	68.3	5.03	.4165	.0308	.6870
Crude protein								
Fraction A, %	7.8	9.1	7.8	6.8	.89	.2477	.8691	.2600
Fraction B, %	89.4	88.9	87.0	88.9	1.94	.5554	.7249	.5811
Fraction C, %	2.9	2.0	5.2	4.3	1.43	.1521	.5677	.9872
K_d of fraction B, %/h	1.62	3.51	2.72	2.94	.60	.6702	.1289	.2144
Lag, h	6.87	8.96	7.92	5.35	2.63	.6448	.9297	.4106
Extent of digestion, %								
6 h	15.0	14.7	13.2	14.7	.94	.3783	.5777	.3797
12 h	18.0	17.8	18.0	20.1	1.38	.4321	.5134	.4196
18 h	18.8	23.6	27.2	30.1	1.30	.0010	.0193	.6418
24 h	24.5	31.4	30.7	32.3	1.02	.0130	.0054	.0414
36 h	36.7	57.8	45.5	60.8	6.69	.4105	.0347	.6846
48 h	55.7	75.8	75.0	81.9	6.10	.0822	.0689	.3229

[a] Fraction A: Soluble; Fraction B: Fraction degraded at measurable rate; Fraction C: Undigested residue after 60 h in the rumen. Kd: Rate constant of digestion of fraction B.

[b] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = molasses bambermycins.

[c] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive

and molasses diets. However, processing (in CGM) and organic matrix (in corn) may produce differences in the microbial population that digest the protein from CGM and corn. Loerch et al. (1983) suggested that in situ N disappearance of protein sources may vary with different dietary protein supplements.

Overall mean for the soluble CP fraction was 7.9% in agreement with 7.2% reported for CGM solubilized in sterilized ruminal fluid (Waldo and Goering, 1979). Cozzi et al., 1994) reported 12.3% water soluble CP in CGM. Overall mean for the undegraded fraction at 60 h (used as fraction C) was 4% of CP in CGM, which is similar to the reported 3.7% of CP remaining after 72 h in situ incubation (Cozzi et al., 1994). Van Soest (1994) reported 2% of CP from CGM insoluble in acid detergent, which is an estimate of indigestible CP. Overall mean for K_d was 2.7%/h which compares well with 2.87%/h reported by Cozzi et al. (1994). Bacterial contamination is one potential problem with estimation of CP degradability in situ (Nocek, 1988). Microbial CP contamination of CGM was 4.5, 6.7, 9.3, 2.3, .2, 0, and 0% for 8, 12, 16, 24, 48, 72 and 120 h of in situ incubation (Cozzi et al., 1994). Underestimation of extent of digestion may be expected in our data because correction for bacterial contamination was not done. Bias in treatment comparisons could result if treatments affect differentially bacterial attachment to CGM. The in situ method probably

underestimates CP degradability of CGM due to hydrophobic properties of CGM protein (Stern and Satter, 1982; Cozzi et al., 1993).

The practical significance of changes in degradability may be assessed using the NRC (1985) equations. Using PR from Table 5-3 (G4G1 model), degraded CGM crude protein concentrations were 46 and 52% for corn and molasses, and 45 and 53% for control and bambermycins, respectively. When PR was fixed at 4%/h, corresponding values were 42 and 44%, and 38 and 48%, respectively, which would suggest that supplement type had less impact than feed additive. These values agree with estimated 57% ± 11 escape value from in vivo estimation by regression technique (Stern et al., 1983).

Degradability measured with nylon bags really measures disappearance from the bag. Degradation of insoluble protein to ammonia by ruminal microbes include attachment of bacteria to protein, proteolysis to polypeptides, further hydrolysis to oligopeptides, dipeptides and amino acids, and deamination with production of ammonia (Broderick et al., 1991). Protein may disappear from bags as soluble peptides and amino acids, which could be further degraded or pass out of the rumen with the fluid phase contributing to metabolizable protein. The trend for decreased NANMN flow (Table 5-17) for MB compared to MC tends to support that more dietary protein was degraded in the rumen in steers fed

MB. The lack of effect of bambermycins on ruminal ammonia concentration does not support increased deamination. Comparison between in situ and in vivo estimates of CP degradability is difficult because the treatment effect on hay CP is unknown and changes in particle PR dramatically alter extent of rumen degradability.

In vivo ruminal digestion. Dry matter intake was similar for corn and molasses diets (Table 5-12) because molasses had less DM than expected, resulting in higher OM intake from corn diets. Total N intake was different between supplements by design, as the diets were balanced for DIP and UIP. Because of these differences, digesta flow data presented in Tables 5-12 and 5-13 will not be emphasized. Instead, digestibility will be discussed (Tables 5-14 and 5-15).

Apparent ruminal DM (P = .13) and OM (P = .1) digestibility tended to be higher in steers fed the molasses supplement. Ruminal NDF digestibility was not affected by supplement type or feed additive. Steers fed corn had 10.2 percentage units higher (P = .015) ruminal feed CP digestibility. Ammonia has been considered as the only protein degradation product absorbed through the forestomach epithelium. However according to recent research the stomach may be capable of amino acid and peptide absorption (Webb et al., 1992). In vitro studies with ruminal and omasal epithelial tissue have shown that both tissues have the

Table 5-12. Main effect of supplement type and bambermycins on intake, duodenal flow, and fecal output

	Supplement		Additive			*P* value for Effect		
Variable	Corn	Molasses	None	Bamb[a]	SE	S[b]	A[b]	SxA[b]
Intake, g/d								
DM	8008	7999	8030	7976	92	.9484	.6959	.3257
OM	7535	7259	7441	7353	81	.0517	.4660	.4660
NDF	4215	3929	4096	4048	35	.0012	.3640	.3640
N	154	170	163	161	2	.0006	.4191	.4191
Duodenal flow, g/d								
DM	5727	5483	5701	5509	87	.0936	.1690	.1813
OM	4562	4157	4417	4303	84	.0146	.3756	.3541
NDF	1734	1637	1692	1679	58	.2782	.8738	.4780
Total N	177	191	189	179	4	.0361	.1058	.3390
Fecal output, g/d								
DM	2766	2942	2849	2859	50	.0460	.8965	.4213
OM	2412	2575	2488	2498	41	.0308	.8583	.4332
NDF	1638	1646	1645	1639	27	.8505	.8724	.3930
N	54	64	59	59	1	.0004	.7470	.8100

[a] Bamb = bambermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive

Table 5-13. Effect of supplement type and bambermycins on intake, duodenal flow and fecal output (treatment means)

	Treatment[a]					*P* value for Effect		
Variable	CC	CB	MC	MB	SE	S[b]	A[b]	SxA[b]
Intake, g/d								
DM	7965	8050	8095	7903	130	.9484	.6959	.3257
OM	7535	7355	7348	7170	114	.0517	.4660	.4660
NDF	4215	4215	3978	3880	50	.0012	.3640	.3640
N	154	154	172	168	2	.0006	.4191	.4191
Duodenal flow, g/d								
DM	5730	5724	5671	5295	122	.0936	.1690	.1813
OM	4559	4565	4274	4041	119	.0146	.3756	.3541
NDF	1710	1758	1674	1599	82	.2782	.8738	.4780
Total N	179	175	199	183	5	.0361	.1058	.3390
Fecal output, g/d								
DM	2731	2801	2968	2917	70	.0460	.8965	.4213
OM	2382	2441	2594	2556	58	.0308	.8583	.4332
NDF	1624	1653	1666	1625	38	.8505	.8724	.3930
N	54	54	64	64	1	.0004	.7470	.8100

[a] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = molasses bambermycins.
[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive

Table 5-14. Main effect of supplement type and bambermycins on ruminal, intestinal and total tract digestibility

	Supplement		Additive			*P* value for Effect		
Variable	Corn	Molasses	None	Bamb[a]	SE	S[b]	A[b]	SxA[b]
Ruminal, % of intake								
DM	28.4	31.4	29.3	30.8	1.30	.1288	.4475	.5391
OM								
Apparent	39.4	42.9	40.9	41.4	1.28	.0976	.8144	.5687
True	55.1	57.9	56.6	56.4	1.22	.1549	.9136	.3236
NDF	58.7	58.4	58.7	58.4	1.48	.8867	.9038	.6438
Feed CP	69.2	58.9	63.7	64.4	2.13	.0145	.8274	.1228
Ruminal, % of total tract								
OM								
Apparent	57.7	66.4	61.4	62.7	1.86	.0161	.6320	.6019
True	80.9	89.6	85.0	85.5	1.92	.0186	.8508	.3847
NDF	96.3	100.4	98.2	98.4	2.67	.3269	.9716	.7175
Intestinal, % of entering								
DM	50.6	45.5	49.1	47.0	1.03	.0126	.1945	.6760
OM	46.0	37.4	42.8	40.6	1.43	.0051	.3304	.8560
NDF	5.0	-.9	2.3	1.8	3.97	.3301	.9199	.8437
CP	68.7	65.9	67.9	66.8	.48	.0057	.1673	.0829
Total tract, % of intake								
DM	65.4	63.2	64.6	64.1	.49	.0184	.5452	.8570
OM	68.0	64.5	66.6	65.9	.41	.0011	.3150	.6987
NDF	61.0	58.1	59.8	59.4	.43	.0030	.5758	.6241
CP	64.8	62.1	63.6	63.3	.68	.0348	.7622	.4847

[a] Bamb = bambermycins.

[b] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

Table 5-15. Effect of supplement type and bambermycins on ruminal, intestinal and total tract digestibility (treatment means)

	Treatment[a]					*P* value for Effect		
Variable	CC	CB	MC	MB	SE	S[b]	A[b]	SxA[b]
Ruminal, % of intake								
DM	28.3	28.6	30.3	33.0	1.84	.1288	.4475	.5391
OM								
Apparent	39.7	39.0	42.1	43.7	1.80	.0976	.8144	.5687
True	56.1	54.0	57.0	58.7	1.72	.1549	.9136	.3236
NDF	59.5	58.1	58.0	58.8	2.09	.8867	.9038	.6438
Feed CP	71.5	66.8	55.9	62.0	3.01	.0145	.8274	.1228
Ruminal, % of total tract								
OM								
Apparent	57.8	57.6	65.0	67.8	2.63	.0161	.6320	.6019
True	81.9	79.9	88.1	91.2	2.72	.0186	.8508	.3847
NDF	96.9	95.7	99.5	101	3.78	.3269	.9716	.7175
Intestinal, % of entering								
DM	51.4	49.9	46.9	44.2	1.45	.0126	.1945	.6760
OM	46.9	45.2	38.6	36.1	2.02	.0051	.3304	.8560
NDF	4.7	5.3	-.05	-1.8	5.61	.3301	.9199	.8437
CP	68.6[c]	68.9[c]	67.1[c]	64.7[d]	.68	.0057	.1673	.0829
Total tract, % of intake								
DM	65.7	65.2	63.4	63.1	.69	.0184	.5452	.8570
OM	68.4	67.5	64.7	64.3	.58	.0011	.3150	.6987
NDF	61.4	60.7	58.2	58.1	.60	.0030	.5758	.6241
CP	64.6	65.0	62.7	61.6	.96	.0348	.7622	.4847

[a] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = molasses bambermycins.

[b] S=Supplement main effect, corn or molasses; A=Feed additive main effect, none or bambermycins, SxA= Interaction of supplement by feed additive

[cd] Means within a row with different superscripts differ ($P < .05$). Probability values for main effect means should be used for all other variables.

ability to absorb and transfer amino acids and dipeptides (Matthews and Webb, 1995). The importance of this absorption in the diets used in the present experiment is unknown. For this discussion, feed CP disappearance in the rumen can be interpreted as passage of feed N to ammonia pool and absorption through the rumen wall, which is the fate of excess ruminal ammonia. Excess ammonia may result from non-protein N and highly degradable feed protein, especially if readily available energy is limiting. Feed CP can be captured by ruminal microbes as peptides, amino acids or ammonia for microbial protein synthesis. Ruminal ammonia N concentration and microbial N flow were higher in steers fed corn supplements. Higher disappearance of feed N from the rumen with corn diets may be explained by increased ruminal ammonia pool, increased absorption to blood, and increased capture in microbial protein.

Ruminal apparent (66.4 vs 57.7%) and true OM (89.6 vs 80.9%) digestibility expressed as percent of the total tract were higher ($P < .02$) in steers fed the molasses supplement. Alternative expression of same effect is the increased ($P = .015$) duodenal OM (4.56 vs 4.16 kg/d) flow in steers fed the corn supplement (Table 5-12).

Eighty to 90% of the digested OM disappeared in the rumen. Intestinal digestion would be proportionally lower at restricted intake because of long ruminal retention time. Increasing the level of intake would shift the site of

digestion to the intestine and that effect would be greater with high concentrate and mixed diets as opposed to long hay (Galyean and Owens, 1991). Firkins et al. (1986) reported small but significant increases in ruminal NDF digestibility (as percent of intake and as percent of total tract) when intake of chopped and ground prairie hay was reduced from 1.6 to 1.1% BW.

With bermudagrass and corn diets, true rumen OM digestibility (as percent of intake) was 53.4 (Brake et al., 1989), 50.7 (Galloway et al., 1993a), 57.8 (Galloway et al., 1993b), and 52.9 (Galloway et al., 1992). Ruminal true OM digestibility expressed as percent of total tract digestion calculated from data presented in these reports ranged from 80 to 98%.

Estimation of feed CP ruminal digestion by the difference method should be taken with caution because errors could be great (Stern and Satter, 1980). Estimates of feed protein entering the duodenum were 8 and 47% higher than predicted by the NRC Model Level 2 (NRC, 1996) for CC and MC treatments, respectively. Only 20% of the difference can be explained by assuming that 15% of N in molasses is indigestible (Stateler, 1993). Other possible explanations are that protein from CGM passed out of the rumen faster than corn protein and(or) that molasses depressed hay protein degradability. Passage rate of CGM was higher than soybean meal and distiller grains (Stern and Satter, 1980)

and molasses has been shown to depress ruminal CP degradability in silage (Huhtanen, 1988; Petit and Veira, 1994). Molasses increased in situ extent of digestion of CGM CP. However this effect was expressed after 18 h of incubation. If PR of CGM was high, the effect of molasses would probably disappear.

Bambermycins apparently affected dietary CP degradability in opposite directions in each supplement (interaction, $P = .12$), but differences within each diet were only numerical. Reports on the effect of bambermycins on ruminal digestion are limited. The few reports available show that bambermycins did not affect in situ cellulose degradation in cattle (Rowe et al., 1982), or NDF, starch, and casein degradation in vitro (Van Nevel and Demeyer, 1990; Van Nevel and Demeyer, 1992). In situ rate of digestion was not affected by addition of bambermycins or ionophores to alfalfa-hay diets fed to steers (Earley et al., 1996). In contrast, Poppe et al. (1993) reported that bambermycins decreased OM, CP and CF digestibility in the rumen.

Intestinal digestion. Steers fed corn had higher intestinal digestion (as % entering) of DM ($P = .013$) and OM ($P = .005$), suggesting that starch was not completely digested in the rumen. Intestinal total N digestibility exhibited an interaction ($P = .08$) of supplement by feed additive, due to no effect of bambermycins in corn but

lowering ($P < .05$) total intestinal N digestion in molasses supplements. This effect could be related to a numerical increase in feed N digestion in the rumen resulting in less available feed N entering the small intestine of steers fed MB.

Intestinal digestibility of NDF was not affected by supplement type ($P = .33$) or feed additive ($P = .9$).

Total tract digestion. Steers fed corn had higher total tract DM ($P = .018$), OM ($P = .001$), NDF ($P = .002$), and CP ($P = .035$) digestibility than those fed molasses (Table 5-14). Although steers fed corn supplements had lower ruminal true OM digestibility (55.1 vs 57.9 %) than steers fed molasses supplements, the intestinal OM digestibility (46.0 vs 37.4% of OM entering the duodenum), and total tract OM digestibility (68.0 vs 64.5%) were higher. Ruminal NDF digestibility was similar (58.7 vs 58.4%) between corn and molasses supplemented steers but intestinal NDF digestibility was numerically higher in corn supplemented steers (5.0 vs -.9%) with a high SE. Total tract NDF digestibility had a low SE and steers supplemented with corn had a higher total tract NDF digestibility (61.0 vs 58.1%) than steers supplemented with molasses. Hsu et al. (1987) reported that 71 and 9% of NDF was digested pre- and post-duodenum, respectively, in sheep fed corn fiber. Molasses or sucrose supplementation depressed NDF digestibility in several studies (Brown et al., 1987; Brown, 1993; Khalili,

1993; Khalili and Huhtanen, 1991b; Kalmbacher et al., 1995). Royes (1996) compared the effect of corn and molasses supplements fed at 15 or 30% of the diet on total tract digestibility in steers fed ammoniated stargrass hay. Digestibility of OM and NDF was lower with molasses than with corn when supplement comprised 15% of the diet (50.9 vs 54.7 % OM, and 50.7 vs 56.9% NDF), but OM and NDF digestibility was similar when supplements were 30% of the diet.

When the same supplements were fed with ad libitum hay intake (Chapter IV), NDF digestibility was lower with corn diets. Apparently there was more depression in fiber digestibility because of higher corn than molasses intake. Royes (1996) reported that steers fed .43% BW of molasses had a ruminal pH similar to those fed ammoniated stargrass hay. However, steers fed .52% BW of corn had a ruminal pH significantly lower than steers fed ammoniated stargrass hay. Apparently this pH reflected the feeding habits of steers (corn consumed in 30 min and molasses consumed in 12 to 24 h), which were similar to patterns of supplement consumption described in Chapter IV. Hay intake was also higher in heifers fed molasses. More fermentable OM entering the large intestine with corn may explain the tendency for lower CP digestibility observed in heifers given ad libitum access to hay. High intake of mixed diets has been shown to

shift the site of digestion, increasing intestinal digestion (Galyean and Owens, 1991).

Differences in total tract CP digestibility were numerically small between supplements (Table 5-15), suggesting that animals fed molasses could partially compensate for lower ruminal protein degradability. Pate (1983) suggested that feeding moderate to high levels of molasses reduces the apparent digestibility of crude protein in the range of 5 to 15%. Depression of intestinal microbial or dietary protein digestibility and(or) increased metabolic fecal N excretion have been suggested as possible explanations. In this experiment, this difference can be accounted for by the estimated 15% (7 g N) indigestible N from molasses (Stateler, 1993).

However, consideration of fecal N is relevant. Cattle do not have intestinal sucrase (Merchen, 1988). It is generally assumed that soluble sugars are completely fermented in the rumen. At medium to high levels of molasses supplementation, part of the sucrose may exit the rumen dissolved in the ruminal fluid. Oldham et al. (1977) estimated that only 6 to 9% of sucrose ingested with molasses reached the duodenum in sheep fed 60% molasses. Using the upper limit, it can be estimated that up to 90 g of sucrose may reach the duodenum in cattle fed molasses in this experiment. The fate of this sucrose would likely be to support microbial fermentation in the large intestine. An

increase of fermentable substrate at this site would result in increased ammonia capture for microbial growth with the net result of increased fecal N (Orskov et al. 1972). Sucrose supplementation increased fecal N in grass silage diets. Fecal output of N was closely related to the excretion of RNA in feces indicating increased hindgut fermentation (Khalili and Huhtanen, 1991a).

Bambermycins did not affect DM, OM, NDF or CP total tract digestibility. In contrast, bambermycins tended to increase N digestibility in heifers (Chapter IV). One of the mechanisms, lower intestinal cell turnover, suggested as an explanation may be not as important here. Animals fed at maintenance have lower visceral metabolism and tissue mass (Ferrell and Jenkins, 1985). Reported effects of bambermycins on total tract digestion have been variable as discussed in Chapter IV.

Nitrogen Flow and Microbial Efficiency

Total N intake, duodenal total N, duodenal ammonia N, and duodenal NAN flows (g/d) were higher ($P < .07$) in steers fed molasses compared to those fed corn (Table 5-16). Steers fed bambermycins had 10.9 g/d lower ($P = .077$) NAN flow than those fed control supplements. Flow of NAN expressed as percent of N intake was not affected by supplement type ($P = .4$) or feed additive ($P = .35$). Total duodenal N flow was 22.6 and 20.9 g/d higher than N intake in steers fed corn and molasses supplements, respectively. Recycled N causes

daily duodenal N flow to exceed N intake when diets contain below 13 to 15% CP (Owens and Zinn, 1988). Total diet CP was 12 and 13.3% in corn and molasses, respectively. Duodenal flows (g/d) of NANMN and undegraded feed N exhibited a supplement type by feed additive interaction ($P < .08$). Steers fed MC had higher ($P < .05$) NANMN and undegraded feed N than those fed CC or CB. Steers fed MB had higher ($P < .05$) flows of these N fractions than steers fed CC but similar to the those fed CB (Table 5-17). When expressed as percent of intake, steers fed molasses had higher ($P < .051$) NANMN and undegraded feed N flow than the ones fed corn.

Urea was used to provide the same amount of DIP in both diets, which resulted in 34 and 5 g of dietary N contributed from urea in corn and molasses diets, respectively. Urea and most of the CP from molasses has a similar rate of fermentation (400 and 350%/h, NRC, 1996). However the rate of fermentation of starch and sugar differ greatly (15 to 35 vs 300%/h, NRC, 1986). It would be expected that the N entering the ruminal ammonia pool would be utilized more efficiently in molasses diets, through incorporation into microbial protein. Ruminal ammonia concentration was higher in corn, which may imply that part of accumulated ammonia was absorbed through the rumen wall. Partition of NAN flow was different between corn and molasses because bacterial N flow was higher ($P = .053$) in steers fed corn. The lower

Table 5-16. Main effect of supplement type and bambermycins on nitrogen flow and bacterial nitrogen efficiency

Variable[a]	Supplement		Additive		SE	*P* value for Effect		
	Corn	Molasses	None	Bamb[b]		S[c]	A[c]	SxA[c]
N intake, g/d	154.2	170.2	163.2	161.1	1.71	.0006	.4191	.4191
Flow to duodenum:								
Total N, g/d	176.8	191.1	189.0	178.9	3.74	.0361	.1059	.3391
Ammonia-N, g/d	7.1	8.0	7.1	8.0	.29	.0682	.0934	.8781
NAN, g/d	169.7	183.1	181.8	170.9	3.61	.0401	.0772	.3284
NAN, % of intake	110.8	107.6	111.1	107.3	2.65	.4328	.3488	.6212
Microbial N, g/d	100.0	91.1	98.5	92.6	2.67	.0533	.1639	.2578
NANMN, g/d	69.7	92.0	83.3	78.4	3.89	.0035	.3461	.0786
NANMN, % of intake	45.8	53.9	50.3	49.4	2.27	.0506	.8080	.1405
Feed N, g/d	46.8	70.1	60.5	56.4	3.10	.0018	.3829	.0760
Feed N, % of intake	30.8	41.1	36.3	35.6	2.13	.0145	.8274	.1228
Total fecal N, g/d	53.3	63.5	58.7	58.1	1.00	.0004	.6877	.8567
N digested, g/d	100.9	106.7	104.5	103.0	1.99	.0858	.6128	.4333
Rumen OM digestion								
Apparent, g/d	2973	3101	3024	3050	126	.4991	.8904	.8668
True, g/d	4158	4187	4193	4152	129	.8804	.8275	.6925
Microbial efficiency, Ruminal:								
App., g N/100 g OM	3.59	2.99	3.38	3.19	.14	.0185	.3504	.5144
True, g N/100 g OM	2.47	2.19	2.37	2.28	.07	.0330	.4284	.5833
True, g MCP/100 g OM	15.4	13.7	14.8	14.3	.45	.0330	.4284	.5833
Total tract:								
MCP/100 g DOMI	12.2	12.1	12.4	11.9	.36	.9315	.3888	.2261

[a] NAN = non ammonia N; NANMN = NAN non microbial N; MCP = microbial CP; DOMI = digestible OM intake.
[b] Bamb = bambermycins.
[c] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

Table 5-17. Effect of supplement type and bambermycins on nitrogen flow and bacterial nitrogen efficiency (treatment means)

	Treatment[b]					*P* value for Effect		
Variable[a]	CC	CB	MC	MB	SE	S[c]	A[c]	SxA[c]
N intake, g/d	154.2	154.2	172.3	168.1	2.42	.0006	.4191	.4191
Flow to duodenum:								
Total N, g/d	179.1	174.6	198.9	183.3	5.29	.0361	.1059	.3391
Ammonia-N, g/d	6.7	7.5	7.6	8.4	.41	.0682	.0934	.8781
NAN, g/d	172.4	167.0	191.2	174.9	5.11	.0401	.0772	.3284
NAN, % of intake	111.7	109.8	110.5	104.7	3.75	.4328	.3488	.6212
Microbial N, g/d	105.4	94.7	91.7	90.4	3.77	.0533	.1639	.2578
NANMN, g/d	67.1	72.4	99.5	84.5	4.79	.0035	.3461	.0786
NANMN, % of intake	43.4	48.2	57.2	56.7	3.35	.0506	.8080	.1405
Feed N, g/d	44.2	49.5	76.8	63.3	4.39	.0018	.3829	.0760
Feed N, % of intake	28.5	33.2	44.1	38.0	3.01	.0145	.8274	.1228
Total fecal N, g/d	53.7	52.9	63.7	63.3	1.41	.0004	.6877	.8567
N digested, g/d	100.5	101.3	108.6	104.7	2.82	.0858	.6128	.4333
Rumen OM digestion								
Apparent, g/d	2976	2970	3073	3129	178	.4991	.8904	.8668
True, g/d	4217	4100	4170	4204	182	.8804	.8275	.6925
Microbial efficiency, Ruminal:								
App., g/100 g OM	3.76	3.43	3.00	2.95	.19	.0185	.3504	.5144
True, g/100 g OM	2.54	2.40	2.20	2.17	.11	.0330	.4284	.5833
True, g MCP/100 g OM	15.9	15.0	13.8	13.6	.64	.0330	.4284	.5833
Total tract:								
MCP/100 g DOMI	12.5	11.6	12.0	12.2	.51	.9315	.3888	.2261

[a] NAN = non ammonia N; NANMN = NAN non microbial N; MCP = microbial CP; DOMI = digestible OM intake.

[b] CC = corn control; CB = corn bambermycins; MC = molasses control; MB = molasses bambermycins.

[c] S = Supplement main effect, corn or molasses; A = Feed additive main effect, none or bambermycins, SxA = Interaction of supplement by feed additive.

bacterial N flow in steers fed molasses is not consistent with benefits of synchronization of protein and carbohydrate fermentation in the rumen.

Apparent and true OM fermented in the rumen (g/d) was not affected by supplement type ($P > .5$) or feed additive ($P > .8$). Efficiency of microbial N synthesis was higher in steers fed corn, expressed as apparently (3.59 vs 2.99 g N/100 g OM, $P = .019$) or as truly (2.47 vs 2.19 g N/100 g OM, $P = .033$) fermented OM.

Bacterial efficiency expressed as percent of OM digested in the total tract was not affected by supplement type ($P > .5$) or feed additive ($P > .26$). The NRC (1996) committee used this form of expression of microbial efficiency and a value of 13% of TDN is recommended for use with most diets. The total tract efficiency of MCP was similar for both diets because increased postruminal digestion decreases efficiency with corn supplement.

Apparent microbial N efficiency found in this trial was similar to mean value (2.7 ± .99 g N/100 g OM) reported by Stern and Hoover (1979). True microbial N efficiencies were higher than reported values (1.38 to 1.63 g N/100 g OM) measured with bermudagrass and corn diets consumed at comparable intake levels (Galloway et al., 1992, 1993b; Brake et al., 1989), and similar to values (2.7% g N/100 g OM) measured in steers fed prairie hay at 1.1 to 1.6% BW (Firkins et al., 1986).

Microbial protein synthesis may be affected by dilution rate, ruminal N concentration, N source, carbohydrate source, sulfur to N ratio, and feeding frequency (Stern and Hoover, 1979). The last two factors were not likely factors because S was added to the corn supplement and molasses is high in S (.47% DM, NRC, 1996), and frequency of feeding was similar between supplements. Dilution rate was numerically lower, but not significantly different, in steers fed molasses than in those fed corn.

Mixed ruminal bacteria that were incubated in vitro produced 50% less protein at pH 5.7 than at 6.7 (Strobel and Russell, 1986). Because pH was similar in corn and molasses diets, pH per se can not explain the lower efficiency observed with molasses diets. The transient presence of lactic acid in all steers fed molasses suggests that bacteria may have had increased use of the acrylate pathway. Propionate synthesized through the acrylate pathway yields less ATP than when it is synthesized through the randomized pathway (Russell and Wallace, 1988).

Although ruminal ammonia N concentration was lower in molasses-fed animals, it was above the minimum of 3 to 5 mg/dL required for maximum bacterial growth (Satter and Slyter, 1974). The NRC (1996) Model Level 2 predicted +14 and -18 g bacterial N balance for corn and molasses diets, respectively. However these estimates are driven by predicted bacterial CP synthesis. Calculated recycled N

(NRC, 1985) was 37 and 33 g/d for corn and molasses diets, respectively. Flow of NAN was higher than N intake in all diets suggesting that recycled N was captured into microbial protein. Most of the DIP should have originated from readily available non-protein N (urea and simple N compounds from molasses), with true feed protein contributing at later postfeeding times because of lower rates of degradation. Recycled N can supply ruminal ammonia, but not ruminal peptides. Steers fed molasses had higher duodenal NANMN flow and lower BCVFA molar proportion in ruminal fluid, suggesting a decreased feed protein degradation. Amino acids and peptides are needed for optimum bacterial protein synthesis (Russell et al., 1992), although according to NRC (1996) a lack of amino acids or peptides is unlikely to be a problem in typical diets for beef cattle. However, this generalization may not be applicable to the molasses-supplemented diets in this experiment. Molasses provided 44% of the total TDN with a high degradation rate of the energy substrate. The main N source for bacterial growth when soluble sugars were fermented should have been derived from non-protein N rather than from true feed protein, which may have implication in the efficiency of microbial growth. Bates and Denham (1990) emphasized that different sources of CP degraded in the rumen are not necessarily equivalent in capacity to support efficient microbial protein synthesis.

Energy source deserves careful consideration because it differs between diets. In his review, Pate (1983) found evidence that sugars, and particularly sucrose, were less effective than starch in promoting microbial synthesis from urea. Nitrogen retention was also lower for molasses-urea than for corn-urea diets. He inferred that if the biological value of all microbial protein is similar, then the higher urinary-N losses observed in animals fed molasses-urea indicate that urea-N was less efficiently synthesized into microbial protein.

Khalili and Huhtanen (1991a) reported increased duodenal NAN flow and dilution rate in cattle fed grass silage supplemented with sucrose. However, the efficiency of microbial N synthesis was not significantly increased by sucrose supplementation. Obara et al. (1991) reported increased N balance and a reduced ruminal ammonia concentration in sheep infused with sucrose intrarruminally. There was no increase in ammonia incorporation into microbial N suggesting that less feed N was degraded and calculation from data presented shows that efficiency of microbial N synthesis was 4.03 and 2.75 g N/100 g OM digested, with basal diet and basal plus sucrose infusion, respectively. No difference was observed in the protozoal population. Rowe et al. (1980) also reported low efficiency of microbial synthesis with molasses-based diets, and efficiency was increased with the addition of starch. They

suggested that addition of starch provided a more uniform supply of fermentable energy for the rumen bacteria. Combination of barley-urea increased duodenal amino acid flow more than the combination of molasses-urea when sheep were given cereal straw, suggesting a better efficiency of ammonia capture in microbial protein when starch was the energy source (Oldham et el., 1977).

In vitro experiments indicated that bacteria use energy for purposes other than growth (energy spilling), and a variety of pathways for energy spilling have been proposed (Russell and Cook, 1995). Fermentation of energy-rich substrate can continue with VFA and ATP production, but without the increase in microbial mass. A pulse of glucose added to glucose-limited cultures of S. ruminantium and P. ruminicola (formely B. ruminicola) caused an immediate doubling of heat production and little increase in cell protein (Russell, 1986). Energy spilling appears to be a phenomenon that can occur any time bacteria have excess energy (Russell and Cook, 1995). Van Kessel and Russell (1996) reported that when growth rate of the predominant ruminal bacteria was being regulated by the limited ammonia concentration, the impact of energy spilling was very great, and additional ammonia caused a large increase in yield. This probably was not the situation observed in the present experiment because ammonia appears to be in excess during molasses fermentation. However, when energy-excess batch

cultures were provided with amino N, the growth rate was increased and less energy was spilled (Van Kessel and Russell, 1996). It is therefore likely that during sugar fermentation the supply of amino N (peptides, amino acids) may have been insufficient to balance the anabolic and catabolic rates of fast growing bacteria. Consequently, part of the energy available from fermentation may have been spilled. Rooke et al. (1987) reported that the efficiency of microbial N synthesis was unchanged by infusion of casein, urea or glucose syrup in cattle fed a grass silage diet. However, when glucose syrup and casein were infused together the efficiency increased from 2.6 to 3.8 g N/100 g OM digested.

Inclusion of a protein source of high ruminal degradability in the molasses slurry may increase microbial protein flow to duodenum through availability of growth factors, amino acids, and peptides. Good responses to escape protein may result from lower than expected microbial protein contribution. More information about effects of different N sources on microbial growth in diets supplemented with molasses would allow evaluation of different feeding strategies to meet metabolizable protein (MP) requirements.

The NRC (1996) Model Level 2 predicted 534 and 728 g bacterial protein for CC and MC treatments, respectively. Estimated bacterial CP flows in this experiment were 659 and

569 g for CC and MC treatments. It should be noted that model estimates are for steady state conditions, which may not be applicable to restriction of intake imposed in this experiment. Animals fed molasses, for example, showed ruminal characteristics associated with active ruminal fermentation for only 6 to 8 h postfeeding and the bulk of the nutrients were consumed in two hours or less after feeding.

Metabolizable protein is the composite of bacterial and feed protein. Steers fed molasses had higher NAN (g/d) flow than the ones fed corn. However, if the calculated unavailable N originating from molasses is subtracted, the NAN flows in both, corn and molasses are close (170 vs 176 g/d). Predicted MP (NRC, 1996) was 548 and 612 g/d for CC and MC in the performance experiment (Chapter III). This MP protein would allow .92 kg of gain in animals fed corn, which indicates that energy and not MP was limiting. Under these circumstances, the lower efficiency of microbial growth may not be relevant because after discounting for lower microbial N efficiency, an estimated 570 g MP would be available in animals fed molasses.

Amount of N digested in the total tract tended (P = .086) to be higher in steers fed molasses. Fecal N was also higher (P = .0004) which resulted in the lower apparent CP digestibility discussed above.

Bambermycins tended to (P = .16) decrease microbial N flow and did not affect (P = .4) microbial efficiency. In vitro, bambermycins did not affect microbial yield (Van Nevel and Demeyer 1992). Report of effects of bambermycins on microbial growth in vivo could not be found.

In summary, bambermycins had minor biologically relevant effects on ruminal or total tract digestibility. The effect on pH was small but consistent and may be more important at higher feed intakes. The increased gain observed in the performance experiment (Chapter III) can not be explained by digestibility alone. Bambermycins had a variable effect on hay intake in that experiment. Bambermycins increased total DM intake and tended to increase hay DM intake when heifers where given ad libitum access to hay. However, these effects could not be explained by changes in digesta kinetics or digestibility (Chapter IV). The effect of bambermycins on animal performance may be also mediated postruminally. This possible mode of action, however, is difficult to reconcile with variability of response, not only in these experiments but also in the available literature. If in fact bambermycins lowered maintenance energy and protein requirements through lower intestinal tissue turnover, a dietary effect would not be expected. Experiments with different levels of feeding to estimate maintenance requirement and efficiency of energy utilization may be one way to test effects on energy

utilization. Measurement of variables associated with gut metabolism (cell turnover, oxygen consumption) and N balance would be indicated also.

Molasses and corn supplements appear to elicit a slightly different response in digestibility, and this effect appears dependent on level of intake. Rate of supplement consumption may be relevant in some of the responses. This aspect has rarely been addressed in the literature and may warrant further research. Diets including corn and molasses apparently provided excess of MP, therefore energy may have been the nutrient limiting gain (Chapter III). Animal performance was similar in CC and MC indicating that the energy from corn and molasses supplements was used with similar efficiency. Apparent lower ruminal digestibility of feed CP with molasses and the apparent contradiction with in situ degradation may warrant further research. The lower efficiency of microbial growth detected with molasses merits additional research. Effects of non-protein N and amino N on microbial growth efficiency should be evaluated with molasses supplements.

CHAPTER VI
SUMMARY AND CONCLUSIONS

Experiment 1 - Animal Performance (Chapter III)

Yearling cattle fed bermudagrass hay during two winters and supplemented with corn DM at .65% of BW gained .047 kg/d more (P = .005) than those supplemented with molasses DM at .74% of BW, due to greater efficacy of feed additives in corn than in molasses supplements. Cattle fed corn (CC) and molasses (MC) without antibiotics gained .621 and .616 kg/d, increased height 6.18 and 5.9 cm, increased BCS .28 and .30, and consumed 1.54 and 1.64% BW of hay DM, respectively. This indicates that the energy (1.57 and 1.56 kg TDN/d) provided by corn and molasses based supplements was used with similar efficiency when no antibiotic was added.

Addition of 200 mg of monensin tended to produce different ADG response when fed with corn and molasses (monensin by supplement interaction, P = .11). Monensin increased ADG .035 kg in corn and decreased ADG .029 kg in molasses supplements. Animals fed CM had .067 kg higher ADG than those fed MM.

Addition of 20 mg of bambermycins tended to produce different ADG when fed with corn and molasses (bambermycins

by supplement interaction, $P = .10$). Bambermycins increased ADG .106 and .042 kg in corn and molasses supplements, respectively. Cattle fed CB gained .063 kg/d more than those fed MB.

Cattle fed monensin consumed .14% of BW less ($P = .024$) hay DM than those fed control supplements. Cattle fed bambermycins consumed 1.62% of BW hay DM, similar ($P = .64$) to 1.59% of BW hay DM consumed by those fed control supplements. Bambermycins increased ($P = .07$) hay intake in Year 1 and had no effect ($P = .4$) in Year 2.

Monensin did not affect ($P = .49$) height change or BCS change ($P = .67$) while bambermycins did not affect ($P = .49$) height change but tended ($P = .12$) to increase BCS change (.14), when compared to control supplements.

Monensin tended ($P = .13$) to interact with supplement type for efficiency of feed utilization. Monensin increased ($P = .004$) by .102 and .026 kg the difference between observed and predicted gain in corn and molasses supplements, respectively. Bambermycins increased ($P = .013$) by .063 and .041 kg the difference between observed and predicted gain in corn and molasses supplements, respectively. However, the increased efficiency with bambermycins was most apparent in Year 2.

Animals fed supplements gained .4 kg/d more ($P = .0001$), had 1.9 cm more growth in height ($P = .0001$), and .72 more increase in BCS ($P = .0001$) than those fed hay

alone. Cattle fed supplements consumed less (P = .0001) hay, [.47% BW (CB) to .70% BW (CM)], than those fed hay alone.

Animals fed corn had higher (P = .0001) ruminal VFA concentrations (70.1 vs 58.7 mM), higher (P < .0001) molar proportion of branched-chain VFA (BCVFA)(1.35 vs .51 mol/100 mol), lower (P = .0001) butyrate molar proportion (9.7 vs 11.3 mol/100 mol), and a 6% higher (P = .008) acetate:propionate ratio (C_2:C_3) than those fed molasses supplements.

There was a trend (P = .118) toward a monensin by supplement type interaction for total VFA. Monensin tended to increase by 3% total VFA in corn and to decrease by 7% total VFA in molasses supplements. Bambermycins decreased (P = .011) by 13 and 3% total VFA in corn and molasses supplements, respectively. Monensin decreased (P = .0001) by 5%, while bambermycins did not affect (P = .38) acetate molar proportion in both corn and molasses supplements.

There was a monensin by supplement type interaction (P = .0006) for propionate molar proportion. Monensin increased propionate molar proportion by 39% in corn and 17% in molasses supplements. Bambermycins did not affect (P = .84) propionate proportions.

There was a monensin by supplement type interaction (P = .003) for butyrate proportions. Monensin decreased butyrate in corn by 16% and it did not affect butyrate in molasses supplements. Bambermycins did not affect (P = .45)

butyrate molar proportions in any type of supplement. Monensin did not affect ($P > .8$) BCVFA molar proportion and bambermycins tended ($P = .07$) to increase by 61% molar proportion of BCVFA in both corn and molasses supplements.

There was a monensin by supplement interaction ($P = .005$) for $C_2:C_3$. Monensin decreased $C_2:C_3$ by 44% in animals fed corn and by 21% in those fed molasses. Bambermycins did not affect ($P = .9$) $C_2:C_3$ but tended ($P = .098$) to interact with supplement type. Acetate:propionate (treatment) were: 4.14 (CC), 2.88 (CM), 4.33 (CB), 3.81 (MC), 3.17 (MM), 3.64 (MB), and 4.41 (hay alone). All supplements decreased ($P = .0001$) $C_2:C_3$ when compared with hay alone.

Cattle fed corn had 2.13 mg/dL higher ($P = .0001$) plasma urea N (PUN) concentration than those fed molasses supplements but part of this difference may be related to sampling time after feeding. There was a trend ($P = .10$) toward a monensin by supplement interaction and bambermycins had no effect ($P = .9$) on PUN concentrations. Animals fed supplements had higher ($P = .0001$) PUN concentration than those fed hay alone (10.9 vs 8.0 mg/dL). Minimum mean values of 7.86 (Year 1, February) and 6.07 (Year 2, March) suggest that performance may have been limited by ruminal degradable CP in animals fed hay alone.

Monensin consistently suppressed ($P < .0004$) coccidia counts in both corn and molasses supplements and bambermycins had no effect ($P > .2$) on coccidia counts.

Experiment 2 - Intake and Digestibility (Chapter IV)

Heifers fed molasses consumed .15% of BW more (P = .007) total DM and .28% of BW more (P = .001) hay DM, and .13% of BW less (P = .098) supplement DM than those fed corn. Heifers fed bambermycins consumed .08% of BW more (P = .073) total DM and tended to consume .08% of BW more (P = .14) hay DM than those fed control supplements. Effects of bambermycins on hay intake resembled those observed in Year 1. Pattern of corn and molasses consumption was different, with molasses consumption distributed throughout the day while 80% of the corn was consumed in 2 h after feeding.

Apparent digestibility of DM and OM was not affected by supplement type (P > .18) or feed additive (P > .8). Heifers fed molasses had 4.6 percentage units higher (P = .027) NDF and 3.9 percentage units higher (P = .084) CP digestibility than those fed corn. Heifers fed molasses had .29% of BW higher (P = .098) intake of digestible OM than those fed corn, reflecting the higher total DM intake and the lower negative associative effect on fiber digestion when molasses was fed. Bambermycins did not affect NDF (P = .9) and CP (P = .2) digestibility or digestible OM intake (P = .35). Increased efficiency of feed utilization due to bambermycins (Chapter III) can not be explained by changes in total tract digestibility.

Heifers fed corn had 34% faster (P = .065) marked-hay

particle passage rate out of the rumen, tended to have 32% longer (P = .13) fast compartment MRT, had 20% shorter (P = .049) slow compartment and 6% shorter (P = .028) total tract MRT, and tended to have .11% of BW higher (P = .11) hay DM fill of the fast compartment than heifers fed molasses. Higher hay intake in animals fed molasses may be related to a trend (P = .13) for shorter hay particles MRT in the age-dependent pool (mixing, rumination, comminution, fermentation), a trend for .16% BW higher ruminal fill (P = .17), and longer ruminal (P = .049) and total tract MRT (P = .028). Higher intake was not associated with higher ruminal passage rate of undigested hay DM.

Bambermycins depressed (P = .018) ruminal passage rate by 11% and increased (P = .006; 1.5 h) ruminal MRT by 7% in heifers fed the corn supplement (supplement by bambemycins interaction, $P < .09$). This effect on digesta kinetics was small, it was detected only with the linear model, and is probably biologically non relevant. Increased intake in growing cattle fed bambermycins can not be explained by digesta kinetics or digestion. In general, trends in digesta kinetics due to bambermycins were greater in heifers fed corn compared to those fed molasses.

Experiment 3-Rumen Function and Digestibility (Chapter V)

Pattern of corn and molasses consumption was similar, probably due to feed restriction.

Steers fed molasses had 1.1% of BW higher (P = .055) ruminal volume and .19% of BW higher (P = .019) total hay DM fill than those fed corn, suggesting less ruminal motility. There was no effect (P > .17) of bambermycins on fluid or hay particles kinetics, except that it tended (P = .095, supplement by bambermycins interaction) to decrease ruminal DM fill .29% of BW in steers fed corn and to increase ruminal DM fill .21% of BW in those fed molasses.

Ruminal pH, total VFA, acetate, propionate, butyrate molar proportions and acetate to propionate ratios exhibited a supplement type by time of sampling interaction (P < .07). Postprandial changes reflected the different rates of digestion of sugars (faster) and starch (slower). Steers fed molasses had lower (P < .025) acetate molar proportions at 2, 4, and 6 h postfeeding, higher (P < .08) propionate molar proportions at 2, 4, and 6 h postfeeding, lower (P < .05) acetate to propionate ratios at 2, 4, and 6 h postfeeding, compared to those fed corn. Butyrate molar proportion was higher (P = .065) in steers fed molasses at 6 h postfeeding but lower (P = .096) at 24 h postfeeding compared to those fed corn. Averaged across time, steers fed molasses tended (P = .11) to have lower acetate (71.3 vs 72.9 mol/100 mol), had higher (P = .08) propionate (16.1 vs 14.8 mol/100 mol), had lower (P =.097) acetate to propionate ratios (4.57 vs 4.99), and tended (P = .12) to have lower branched-chain VFA (1.31 vs 1.61 mol/100 mol) than those fed corn supplements.

Lactic acid was detected only in animals consuming molasses and it was present as a transient peak shortly after feeding, probably related to high rate of intake of molasses and high rate of sugar fermentation.

Steers fed bambermycins had higher ($P = .046$) pH (6.63 vs 6.52) averaged across time and lower ($P < .05$) butyrate molar proportions at 12, 16, and 24 h postfeeding compared to those fed control supplements. Averaged across time steers fed bambermycins tended ($P = .12$) to have lower butyrate (9.8 vs 10.6 mol/100 mol) than those fed control supplements. Bambermycins did not affect ($P = .88$) acetate to propionate ratio.

Ruminal ammonia N decreased with time after feeding. Postprandial peak of ammonia N was earlier and tended to be higher ($P = .12$) in steers fed corn compared to those fed molasses (27 mg/dL at 2 h vs 21 mg/dL at 4 h postfeeding). The lowest ammonia N concentrations were observed at 12 h postfeeding with both corn and molasses, and were lower ($P = .08$) in animals fed molasses (3.3 vs 4.4 mg/dL) than in those fed corn. Ammonia N concentration was also lower ($P < .05$) at 20 h (5.5 vs 7.0 mg/dL) and 24 h (5.1 vs 8.0 mg/dL) postfeeding in animals fed molasses.

Effect of supplemental energy source on ruminal fermentation appears more related to timing of events rather than great differences in total VFA concentration or VFA molar proportions. This is consistent with similar gains

observed in animals fed CC and MC (Exp. 1).

Overall, effects of bambermycins on ruminal fermentation evaluated though pH, VFA and ammonia concentration showed only minor changes which would not suffice to explain the increased performance observed when bambermycins was added to supplements in Exp. 1.

Animals fed molasses had lower (P = .0003) ruminal Na (78 vs 105 mM) and higher (P = .003) ruminal K (71 vs 42 mM) concentrations than those fed corn. Ruminal Na increased and ruminal K decreased with time after feeding in steers fed molasses.

Rate of DM digestion of CGM was higher when incubated in situ in animals fed molasses (P = .034) or bambermycins (P = .013) than when incubated in steers fed corn or control supplements. Bambermycins tend (P = .13) to increase CP rate of degradation compared to control supplements (2.17 vs 3.22). Extent of CP degradation was higher (P < .08) after 18, 24, and 48 h of ruminal incubation in animals fed molasses compared to those fed corn. Bambermycins increased (P < .07) the extent of CP degradation after 18, 24, 36, and 48 h of ruminal incubation compared to control supplements.

Apparent ruminal OM digestibility was higher (P = .098) in steers fed molasses than in those fed the corn supplement (42.9 vs 39.4%). Ruminal NDF digestibility was not affected by supplement type (P = .89) or bambermycins (P = .9). Steers fed corn had higher (P = .015) ruminal feed CP

degradability (69.2 vs 58.9%). Pre-duodenal apparent and true OM digestion (% of total tract) was higher ($P < .02$) in steers fed molasses than in those fed corn. Steers fed corn had higher ($P < .013$) intestinal digestion (% entering) of DM and OM than those fed molasses. Steers fed corn had higher ($P < .035$) total tract DM (65.4 vs 63.2%), OM (68.0 vs 64.5%), NDF (61.0 vs 58.1%), and CP (64.8 vs 62.1%) digestibility than those fed molasses.

Bambermycins did not affect ($P > .2$) DM, OM, NDF or CP ruminal or total tract digestibility. However, bambermycins tended to increase ruminal feed CP degradability (62.0 vs 55.9 %) and decreased ($P < .05$) intestinal CP digestibility (64.7 vs 67.1%) in molasses but not in corn.

Non-ammonia N flow was higher than N intake in all treatments indicating that recycled N was captured in microbial protein. Flow of NAN expressed as percent of N intake was not affected by supplement type ($P = .43$) or feed additive ($P = .35$).

Steers fed molasses had higher ($P = .05$) NANMN (53.9 vs 45.8%) and higher ($P = .015$) undegraded feed N flow (41.1 vs 30.8%) than those fed corn, expressed as percent of intake.

Bacterial N flow was higher ($P = .053$) in steers fed corn than in those fed molasses (100 vs 91.1 g/d). Lower bacterial N flow in steers fed molasses is not consistent with benefits of synchronization of N availability and carbohydrate fermentation in the rumen.

Bambermycins tended (P = .11) to decrease total duodenal N flow (179 vs 189 g/d), increased (P = .093) ammonia N flow (8.0 vs 7.1 g/d), and decreased (P = .077) NAN flow (171 vs 182 g/d) compared to control supplements.

Steers fed corn had higher (P = .019) apparent (3.59 vs 2.99 g N/100 OM) and higher (P = .033) true (2.47 vs 2.19 g N/100 OM) microbial N efficiency (g N/100 OM fermented in the rumen). Microbial N efficiency expressed as percent of OM digested in the total tract or as percent of calculated TDN intake was not affected by supplement type (P > .5) or bambermycins (P > .26). It is likely that during sugar fermentation the supply of amino N (peptides, amino acids) may have been insufficient to balance the anabolic and catabolic rates of fast growing bacteria under excess energy conditions. Consequently, part of the energy available from fermentation may have been spilled.

Prediction of MP supply from diets used in Exp. 1 indicates that energy, not protein was limiting gain. Under these circumstances, the lower efficiency of microbial growth may not be relevant.

Bambermycins tended (P = .16) to decrease microbial N flow and did not affect microbial N efficiency. Bambermycins had minor biologically significant effects on ruminal or total tract digestibility. The effect on pH was small but consistent and may be important at higher feed intake. The effect of bambermycins of increasing situ extent of

digestion at long incubation times, higher ruminal feed N digestion, and lower bacterial N flow may be relevant in diets that include molasses. The increased gain due to bambermycins in Exp. 1 can not be explained by digestibility. Effect of bambermycins on animal performance may be mediated postruminally. More research is needed to elucidate the mechanism of action of bambermycins.

Conclusions

Supplemental energy supplied by corn and molasses without feed additives was used with similar efficiency for gain.

Monensin was not effective for improving gain in growing cattle fed bermudagrass hay and supplemented with molasses slurry DM at .7% of BW.

Bambermycins improved gain by 17% and 7% when included in corn and molasses supplements, respectively. Because of a trend toward a supplement by bambermycins interaction, definitive conclusions on the efficacy of bambermycins to improve gain in molasses supplemented-diets can not be made and further research is needed.

Monensin depressed hay intake while bambermycins either had no effect or tended to increase hay intake, which indicates that bambermycins should be used when maximum use of forage resource is the objective.

Monensin and bambermycins improved feed efficiency.

However, bambermycins increased gain by increasing hay intake and feed efficiency in Year 1, and by increasing feed efficiency in Year 2.

Effect of bambermycins on gain does not appear mediated through notable changes in ruminal fermentation, digesta kinetics or digestibility. Increased ruminal pH and extent of CP degradation in situ, and decreased butyrate molar proportion were the only significant effects of feeding bambermycins.

Steers fed molasses had higher ruminal propionate and butyrate, lower acetate and branched-chain VFA molar proportions, lower acetate to propionate ratio, and lower ruminal ammonia concentrations than those fed corn supplements.

Ruminal feed CP digestibility, duodenal microbial N flow, and microbial N efficiency were lower in cattle fed molasses-based supplements compared to cattle fed corn-based supplements. Lactic acid was present only in animals fed molasses. Ruminal fluid volume and DM fill were higher in animals fed molasses. More research is needed to evaluate these changes in animals fed at production levels of intake.

Ruminal Na concentration was lower and K was higher in animals fed molasses than in those fed corn.

At restricted intake, total tract nutrient digestibility was higher in animals fed corn than those fed molasses. At ad libitum hay intake, NDF digestibility was

higher in animals fed molasses. However, this conclusion is hindered by lower molasses than corn intakes when animals were given ad libitum access to hay.

APPENDIX A
TABLES

Table A-1. Monensin concentration (g/ton) in supplements - Exp. 1

Date sampled	Corn[a]		Corn gluten meal[a]	
	Expected	Analysis	Expected	Analysis
Year 1				
Dec-14-94	84	91	640	645
Dec-29-94	84	80	640	639
Jan-16-95	84	105	640	575
Jan-26-95	84	74	640	685
Feb-07-95	84	83	640	636
Feb-19-95	84	83	640	555
Mar-07-95	84	84	640	549
Mar-20-95	84	88	640	629
Year 2				
Jan-04-96	84	85	640	623
Jan-18-96	84	83	-	-
Feb-01-96	84	86	640	570
Feb-15-96	84	82	640	586
Mar-05-96	84	82	640	611
Mar-14-96	84	91	640	606
Apr-01-96	84	77	-	-

[a] Year 1: Corn mixed on 11-30-94, 12-13-94,1-4-95, 1-19-95, 1-31-95, 2-21-95, and 3-14-95. Corn gluten meal mixed on 11-30-94, 15-15-94, and 1-12-95. Corn gluten meal was 10.4% of molasses slurry.
Year 2: Corn mixed on 12-14-95, 1-4-96, 1-24-96, 2-14-96, 3-7-96, and 3-28-96. Corn gluten meal mixed on 12-14-95 and 2-1-96. Corn gluten meal was 10.4% of molasses slurry.

Table A-2. Bambermycins concentration (g/ton) in supplements - Exp. 1, Year 1.

	Corn[a]		Corn gluten meal[a]		
Date sampled	Expected	Analysis	Expected	First analysis	Second analysis
Dec-14-94	8.4	6.7	64	7.1	53.4
Dec-29-94	8.4	6.7	64	7.5	52.8
Jan-16-95	8.4	7.5	64	7.2	52.3
Jan-26-95	8.4	6.9	64	7.6	51.7
Feb-07-95	8.4	7.0	64	7.2	52.8
Feb-19-95	8.4	7.3	64	7.3	52.3
Mar-07-95	8.4	6.8	64	7.5	51.7
Mar-20-95	8.4	7.5	64	7.6	52.3

[a] Corm mixed on 11-30-94, 12-13-94,1-4-95, 1-19-95, 1-31-95, 2-21-95, and 3-14-95. Corn gluten meal mixed on 11-30-94, 15-15-94, and 1-12-95. Corn gluten meal was 10.4% of molasses slurry.
Original drug premix analyzed in June/96 tested 100% effective.

Table A-3. Bambermycins concentration (g/ton) in supplements - Exp. 1, Year 2.

	Corn[a]			Corn Gluten meal[a]	
Date sampled	Expected	First analysis	Second analysis	Expected	First and second analysis
Jan-04-96	8.4	< 2.5	7.9	64	< 25
Jan-18-96	8.4	< 2.5	8.0	64	< 25
Feb-01-96	8.4	< 2.5	7.7	64	< 25
Feb-15-96	8.4	< 2.5	< 2.5	64	< 25
Mar-05-96	8.4	< 2.5	< 2.5	64	< 25
Mar-14-96	8.4	< 2.5	< 2.5	64	< 25
Apr-01-96	8.4	< 2.5	< 2.5	64	< 25

[a] Corn mixed on 12-14-95, 1-4-96, 1-24-96, 2-14-96, 3-7-96, and 3-28-96. Corn gluten meal mixed on 12-14-95 and 2-1-96. Corn gluten meal was 10.4% of molasses slurry.
Original drug premix analyzed in June/96 tested 100% effective.

Table A-4. Bambermycins concentration (g/ton) in supplements - Exp. 2

	Corn[a]			Corn gluten meal[a]		
Period	Expec	First analysis	Second analysis	Expec	First analysis	Second analysis
1 old	9	8.3	-	71	< 25	-
1 new	9	< 2.5	-	71	< 25	-
2	9	< 2.5	8.5	71	< 25	< 25
3	9	< 2.5	-	71	< 25	-
4	9	< 2.5	-	71	< 25	-

[a] Corn mixed on 9-30-95 and 11-14-95. Corn gluten meal mixed on 10-1-95, 11-20-95, and 12-27-95. Expec = expected concentration. Original drug premix analyzed in June/96 tested 100% effective.

Table A-5. Bambermycins concentration (g/ton) in supplements - Exp. 3

	Corn[a]			Corn gluten meal[a]		
Period	Expec	First analysis	Second analysis	Expec	First analysis	Second analysis
1	9	8.3	-	71	62.9	-
2	9	8.4	8.9	71	64.2	-
3 old	9	8.3	-	71	62.9	-
3 new	9	< 2.5	-	71	< 25	-
4	9	< 2.5	8.5	71	< 25	64.8

[a] Corn mixed on 9-30-95 and 11-14-95. Corn gluten meal mixed on 10-1-95, 11-20-95, and 12-27-95. Expec = expected concentration. Original drug premix analyzed in June/96 tested 100% effective.

Table A-6. Animal performance, means by treatments - Year 1

	Corn			Molasses				
Item	Control	Monensin	Bamb[a]	Control	Monensin	Bamb[a]	Hay	SE
Initial BW, kg	244	247	242	248	238	242	243	4.3
Initial BCS	5.43	5.52	5.43	5.38	5.40	5.53	5.67	.113
Initial height, cm	119	119	119	120	118	118	119	1.1
Shrunk ADG, kg	.532	.612	.658	.514	.498	.572	.166	.021
Height change, cm	6.75	6.83	7.42	7.11	7.13	7.62	4.65	.368
BCS change	.22	.35	.46	.27	.05	.37	-.57	.128
Hay intake,								
kg DM/d	3.78	3.57	4.34	3.94	3.42	4.14	5.03	.201
DM, % BW	1.38	1.27	1.56	1.42	1.29	1.51	1.99	.070
Change % BW	-.607	-.715	-.432	-.565	-.701	-.475	-	.070
Supplement intake,								
kg DM/d	1.86	1.86	1.86	2.09	2.06	2.09	0	.11
DM, % BW	.68	.66	.67	.76	.78	.76	0	.009
% of total DM	33.1	34.3	30.1	34.9	37.7	33.6	0	.98
kg TDN[b]/d	1.57	1.57	1.57	1.53	1.51	1.54	0	.009
% of total TDN[b]	43.6	44.9	40.2	42.2	45.1	40.7	0	1.06
Total TDN[b], kg/d	3.61	3.50	3.94	3.66	3.77	3.77	2.72	.102
Total TDN[b], % BW	1.32	1.25	1.40	1.32	1.26	1.38	1.07	.04

[a] Bamb = bambermycins.

[b] Total TDN intakes for hay calculated assuming 54% TDN (back calculation of TDN from gain on hay alone treatment using NRC, 1996). For supplement, tables values were used (NRC, 1984).

Table A-7. Volatile fatty acid, plasma urea-N, and parasites. Means by treatments - Year 1

Item[a]	Corn			Molasses			Hay	
	Control	Monensin	Bamb[b]	Control	Monensin	Bamb[b]	Alone	SE
Total VFA, mM								
All dates	82.9	82.2	71.1	67.4	59.1	61.7	66.4	2.99
Dec	84.7	71.0	75.4	60.6	56.3	57.3	67.6	3.91
Jan	71.1	81.6	59.2	69.6	54.9	56.8	57.9	5.28
Feb	79.9	85.4	74.7	67.3	55.6	56.2	63.6	4.80
Mar	95.8	90.2	75.2	72.1	69.6	76.4	76.4	5.57
Acetic:Propionic								
All dates	4.40	2.88	4.38	3.96	3.58	3.98	4.70	.12
Dec	4.05	2.86	4.26	3.84	3.31	4.09	4.62	.16
Jan	3.94	2.12	3.61	2.94	2.61	2.84	3.84	.18
Feb	4.46	3.12	4.36	4.27	4.19	4.08	4.79	.25
Mar	5.16	3.41	5.28	4.80	4.20	4.90	5.56	.20
PUN, mg/dL								
All dates	13.08	13.30	12.31	10.17	11.89	10.73	9.41	.52
Dec	13.84	12.57	12.27	9.51	9.92	8.66	9.45	.67
Jan	12.65	13.40	12.68	11.16	11.60	11.58	11.66	.50
Feb	12.56	13.82	12.74	9.59	13.99	11.74	7.86	.92
Mar	13.27	13.40	11.54	10.41	12.05	10.97	8.69	.88
Parasite counts								
Coccidia, o/5 g	626	6	1057	881	6	805	827	149
Nematoda, e/5 g	15	11	8	12	10	28	29	6.17

[a] No treatment x time interaction for VFA total, acetic:propionic, and parasites. Time ($P = .0089$) and Treatment x time ($P = .0016$) effect for PUN. Time effect: for VFA total (Mar > than all others); for acetic:propionic all dates differ from one another. No time effect for parasite counts interaction.

[b] Bamb = bambermycins.

Table A-8. Probability values for effects and contrasts - Year 1

Variable	Contrast[a]						Effect	
	C1	C2	C3	C4	C5	C6	Time (T)	T x Trt
Shrunk ADG, kg	.0001	.1481	.0003	.0346	.1254	.0001	-	-
Height change, cm	.3523	.8926	.1206	.9287	.8279	.0001	-	-
BCS change	.2801	.7196	.1919	.1889	.5976	.0001	-	-
Hay intake,								
kg DM/d	.7090	.0867	.0744	.4541	.3900	.0001	-	-
DM, % BW	.9435	.0986	.0731	.8466	.5524	.0001	-	-
Change, % BW	.9435	.0986	.0731	.8466	.5524	.0001	-	-
Supplement intake,								
kg DM/d	.0001	.2999	.9238	.2999	.9238	-	-	-
kg DM, % BW	.0001	.9308	.8151	.0652	.2962	-	-	-
% of total DM	.0031	.0767	.0540	.4684	.4339	-	-	-
kg TDN/d	.0001	.2999	.9238	.2999	.9238	-	-	-
% of total TDN	.8340	.0757	.0495	.4853	.3977	-	-	-
Total TDN, kg/d	.3650	.0535	.0540	.3619	.3545	-	-	-
Total TDN, % BW	.9569	.1021	.0873	.8508	.7058	-	-	-
Total VFA, mM	.0001	.1472	.0079	.2147	.3262	.1883	.0001	.1692
Acetic:Propionic	.6231	.0001	.9578	.0001	.8723	.0001	.0001	.2289
PUN all dates	-	-	-	-	-	-	.0089	.0016
Dec	.0001	.5325	.0853	.2233	.5950	.0310	-	-
Jan	.0016	.2500	.6613	.7601	.7005	.3486	-	-
Feb	.1066	.0059	.2221	.1037	.2985	.0002	-	-
Mar	.0384	.3264	.5144	.4012	.2091	.0026	-	-

[a] Contrasts: C1 = corn vs molasses; C2 = monensin vs control; C3 = bambermycins vs control; C4 = monensin by supplement; C5 = bambermycins vs supplement; C6 = supplements vs hay alone.

Table A-9 . Animal performance, means by treatment - Year 2

	Corn			Molasses			Hay	
Item	Control	Monensin	Bamb[a]	Control	Monensin	Bamb[a]	Alone	SE
Initial BW, kg	259	266	259	265	265	260	269	2.94
Initial BCS	5.31	5.31	5.23	5.34	5.20	5.30	5.21	.113
Initial height, cm	118	118	118	117	118	116	119	.644
Shrunk ADG, kg	.710	.699	.797	.719	.680	.744	.324	.031
Height change, cm	5.62	5.70	5.58	4.68	5.65	4.78	4.15	.648
BCS change	.34	.45	.48	.34	.48	.40	-.16	.102
Hay intake,								
kg DM/d	5.08	4.61	5.16	5.65	5.17	5.14	6.33	.287
DM, % BW	1.71	1.52	1.71	1.86	1.72	1.71	2.22	.094
Change, % BW	-.507	-.694	-.508	-.353	-.497	-.503	-	-
Supplement intke,								
kg DM/d	1.86	1.86	1.86	2.15	2.13	2.15	0	.012
DM, % BW	.63	.62	.62	.71	.71	.72	0	.009
% of total DM	27.1	28.9	26.9	27.8	29.2	29.7	0	1.29
kg TDN[b]/d	1.57	1.57	1.57	1.58	1.56	1.58	0	.009
% of total TDN[b]	36.7	38.8	36.5	34.3	35.9	36.4	0	1.48
Total TDN[b], kg/d	4.31	4.06	4.35	4.63	4.35	4.35	3.41	.180
Total TDN[b], % BW	1.45	1.34	1.44	1.53	1.45	1.45	1.20	.051

[b] Total TDN intakes for hay calculated assuming 54% TDN (back calculation of TDN from gain on hay alone treatment using NRC, 1996). For supplement, tables values were used.

[a] Bamb = bambermycins.

Table A-10. Volatile fatty acid, plasma urea-N, and parasites. Means by treatments - Year 2

Item[a]	Corn			Molasses			Hay	
	Control	Monensin	Bamb[b]	Control	Monensin	Bamb[b]	Alone	SE
Total VFA, mM								
All dates	62.0	67.4	55.2	54.4	53.9	56.1	54.2	3.04
Jan	63.7	73.0	55.7	53.3	62.8	65.5	65.4	4.66
Mar	60.2	61.8	54.6	55.5	45.1	46.6	53.1	4.10
Acetic:Propionic								
All dates	3.87	2.88	4.28	3.65	2.77	3.32	4.12	.18
Jan	4.33	2.86	4.77	4.07	2.83	3.68	4.70	.21
Mar	3.41	2.90	3.80	3.23	2.71	2.97	3.54	.23
PUN, mg/dL								
All dates	11.15	10.75	11.65	8.45	9.76	8.24	6.77	.86
Jan	9.63	9.63	10.52	9.03	8.70	8.44	6.49	.87
Feb	13.45	13.10	12.81	8.61	11.38	9.23	7.73	1.40
Mar	10.38	9.45	11.61	7.71	9.20	7.04	6.07	1.26
Parasite								
Coccidia[c]	.78	.25	1.03	.78	.23	.72	.78	.09
Nematoda, e/5 g	0	.25	.10	1.97	.94	.25	.25	.53

[a] No treatment x time interaction for VFA total and PUN.
Time (P= .0001) and Treatment x time (P= .0324) interaction for acetic:propionic ratio.
Time effect for acetic:propionic and total VFA (Mar > than Jan). For Pun, Feb > than Jan and Mar.

[b] Bamb = bambermycins.

[c] Scores (0=none present, 4=heavy infestation).

Table A-11. Probability values for effects and contrasts - Year 2

	Contrast[b]						Effect	
Variable[a]	C1	C2	C3	C4	C5	C6	Time (T)	T x Trt
Shrunk ADG, kg	.4272	.4393	.0939	.6606	.3404	.0001	-	-
Height change, cm	.2789	.4326	.9683	.5042	.9206	.1133	-	-
BCS change	.8413	.2563	.3622	.8754	.6883	.0001	-	-
Hay intake,								
kg DM/d	.1896	.1672	.5227	.9998	.3868	.0032	-	-
DM, % BW	.1440	.0993	.4341	.8221	.4431	.0002	-	-
Change, % BW	.1440	.0993	.4341	.8221	.4431	.0002	-	-
Supplement intake,								
kg DM/d	.0001	.0050	1.000	.0050	1.000	-	-	-
kg DM, % BW	.0001	.4246	.9444	.6835	.3751	-	-	-
% of total DM	.2853	.2646	.5320	.8811	.4726	-	-	-
kg TDN/d	.3723	.0050	1.000	.0050	1.000	-	-	-
% of total TDN	.1893	.2591	.5487	.8602	.4773	-	-	-
Total TDN, kg/d	.1932	.1611	.5295	.9602	.3948	-	-	-
Total TDN, % BW	.1298	.0632	.3991	.7581	.5031	-	-	-
Total VFA, mM	.0132	.4237	.4058	.3404	.1782	.2425	.0050	.1520
Acetic:Propionic								
Jan	.0142	.0001	.9168	.5877	.0649	.0005	-	-
March	.0468	.0371	.7988	.9737	.1737	.1563	-	-
PUN all dates	.0028	.6047	.8708	.3294	.6841	.0022	.0004	.7480

* Sex effect (*P*= .0337) for ADG, Height change (*P*= .0899), BCS change (*P*= .1643) and Hay intake (*P*= .6583), and Sex x Treatment P=.8018;.2379; .2318; and .2174 for ADG, Height change, BCS change, hay intake, respectively. No Sex x Treatment effect in any variable. Sex and Sex x Treatment deleted from model for VFA, Ac:Pr, and PUN. Acetic:Propionic ratio all dates: Treatment x Time (P=.0324).

[a] Contrasts: C1 = corn vs molasses; C2 = monensin vs control; C3 = bambermycins vs control; C4 = monensin by supplement; C5 = bambermycins vs supplement; C6 = supplement vs hay alone.

APPENDIX B
RAW DATA

Data Codes for Performance Experiment

ID = cattle ear tag number
YEAR
1 = Dec-1994 to Mar-1995, at Pine Acres
2 = Dec-1995 to Apr-1996, at Santa Fe
TRT = treatment
1 = corn control
2 = corn monensin
3 = corn bambermycins
4 = molasses control
5 = molasses monensin
6 = molasses bambermycins
7 = hay alone
BRD = breed
SWT1KG = initial shrunk body weight in kg
SWT2KG = final shrunk body weight in kg
HT1 = initial hip height in cm
HT2 = final hip height in cm
CS1 = initial body condition score (1 to 9 scale)
CS2 = final body condition score (1 to 9 scale)

ADG = average daily gain in kg
AVGWT = average shrunk body weight (initial + final)/2, kg
HAYDM = hay dry matter intake in kg
SUPPDM = supplement dry matter intake in kg
PRDADG = predicted average daily gain from NRC (1996), kg

ACET = acetate molar proportion in rumen fluid
PROP = propionate molar proportion in rumen fluid
BUTY = butyrate molar proportion in rumen fluid
RATIO = acetate to propionate molar ratio
TOTAL = total volatile fatty acids in rumen fluid, mM

PUN = plasma urea nitrogen in mg/dL

Data Codes for Intake and Digestibility - Heifers

PER = period of the Latin Square
AN = animal number
SUPP = supplement type:
c = corn
m = molasses
ADD = bambermycins
c = control, no bambermycins
b = 20 mg bambermycins

TDMI = total dry matter intake, kg
TOMI = total organic matter intake, kg
TNDFI = total neutral detergent fiber intake, kg
TCPI = total crude protein intake, kg
TTDNI = total digestible nutrients intake, kg

SDMI = supplement dry matter intake, kg
SOMI = supplement organic matter intake, kg
SNDFI = supplement neutral detergent fiber intake, kg
SCPI = supplement crude protein intake, kg
STDNI = supplement digestible nutrients intake, kg

FDMOUT = fecal dry matter output, kg
FOMOUT = fecal organic matter output, kg
FNDFOUT = fecal neutral detergent fiber output, kg
FCPOUT = fecal crude protein output, kg

CZERO = ytterbium concentration at time = 0
LAMBDA = passage rate parameter of marker from the age-dependent compartment
Ks = passage rate of marker from the age-independent compartment
DOSE = ytterbium dosed, mg
TD = time delay for first appearance of marker in feces, hours
K-LN = passage rate of marker from the rumen estimated with linear model (slope of regression)

Data Codes for Rumen Function and Digestibility - Steers

PER = period of the Latin Square
AN = animal number
SUPP = supplement type:
c = corn
m = molasses
ADD = bambermycins
c = control, no bambermycins
b = 30 mg bambermycins

DMI = total dry matter intake, kg
OMI = total organic matter intake, kg
NDFI = total neutral detergent fiber intake, kg
NI = total nitrogen intake, g
DMFW = dry matter flow at duodenum, g
OMFW = organic matter flow at duodenum, g
NDFFW = neutral detergent fiber flow at duodenum, g
TNFW = total nitrogen flow at duodenum, g
NH3FW = ammonia nitrogen flow at duodenum, g
MNFW = microbial nitrogen flow at duodenum, g

DMOUT = fecal dry matter output, kg
OMOUT = fecal organic matter output, kg
NDFOUT = fecal neutral detergent fiber output, kg
NOUT = fecal nitrogen output, kg

CZERO = ytterbium concentration at time = 0
LAMBDA = passage rate parameter of marker from the age-dependent compartment
Ks = passage rate of marker from the age-independent compartment
DOSE = ytterbium dosed, mg
TD = time delay for first appearance of marker in feces, hours

Raw Data Performance Experiment

ID	YEAR	TRT	PEN	BRD	SEX	SWT1KG	SWT2KG	HT1	HT2	CS1	CS2
3940040	1	1	2	2.5	1	282	358	124.5	133.4	5.8	5.0
3940093	1	1	2	4.0	1	225	278	118.1	124.8	5.5	5.5
3940103	1	1	2	4.0	2	249	292	125.4	131.1	5.2	5.8
3940115	1	1	2	1.0	2	220	284	111.5	119.1	5.2	4.8
3940174	1	1	2	3.0	1	241	307	116.5	124.5	5.4	5.5
3940906	1	1	2	2.0	2	215	272	111.5	115.9	5.2	6.0
3940008	1	1	6	2.0	2	305	363	128.0	132.7	5.0	6.2
3940025	1	1	6	1.0	1	224	314	113.0	122.3	5.8	5.5
3940027	1	1	6	4.0	2	266	308	121.3	126.4	6.2	6.2
3940069	1	1	6	4.0	1	288	317	122.6	130.2	6.8	5.8
3940142	1	1	6	2.5	1	218	268	118.1	125.1	5.0	5.2
3940909	1	1	6	2.0	2	236	305	122.6	126.1	5.6	5.5
3940004	1	1	20	2.0	1	301	372	129.5	136.9	4.8	5.5
3940137	1	1	20	3.0	1	248	307	128.0	133.7	5.8	5.2
3940169	1	1	20	2.0	2	190	258	108.9	118.1	5.0	5.2
3940180	1	1	20	5.0	1	222	266	121.3	129.2	5.0	5.5
3940908	1	1	20	5.0	2	213	264	115.9	123.2	6.2	6.0
3940910	1	1	20	2.0	2	322	373	127.6	128.9	6.2	6.5
3940012	1	1	28	1.0	2	247	333	114.6	122.3	5.2	6.2
3940014	1	1	28	4.0	1	300	356	128.9	134.0	4.8	5.8
3940088	1	1	28	2.5	2	222	298	115.6	122.3	5.0	6.0
3940106	1	1	28	4.0	2	208	268	115.3	127.0	5.5	6.2
3940131	1	1	28	1.0	1	223	298	114.0	122.9	4.8	5.2
3940903	1	1	28	2.0	2	193	227	110.8	115.6	5.2	5.2
3940047	1	2	10	2.0	2	296	373	120.7	128.0	6.0	.
3940092	1	2	10	1.0	1	236	313	118.1	124.8	5.0	4.8
3940096	1	2	10	3.0	2	277	341	121.9	127.0	6.5	6.0
3940108	1	2	10	3.0	1	227	298	122.6	129.9	5.0	5.0
3940117	1	2	10	5.0	1	241	300	118.7	124.8	6.0	6.2
3940907	1	2	10	5.0	2	260	319	118.7	126.7	5.5	5.8
3940016	1	2	14	3.0	1	283	353	123.2	130.8	5.2	6.2
3940024	1	2	14	4.0	2	266	322	127.0	133.0	6.0	6.2
3940028	1	2	14	3.0	2	282	345	117.5	123.5	6.5	6.5
3940046	1	2	14	1.0	1	234	307	113.0	120.0	4.8	5.2
3940189	1	2	14	5.0	1	184	232	117.8	125.1	5.2	5.2
3940901	1	2	14	2.0	2	265	313	114.3	120.0	5.3	5.5
3940098	1	2	22	2.5	2	259	342	122.3	126.4	5.4	6.5
3940099	1	2	22	5.0	2	203	251	119.1	122.3	4.8	5.8
3940104	1	2	22	4.0	1	253	317	120.7	127.0	5.7	5.5
3940107	1	2	22	1.0	2	249	335	116.2	122.3	4.8	6.0
3940114	1	2	22	3.0	2	278	346	116.5	127.3	5.8	6.5
3940126	1	2	22	2.5	1	221	283	113.7	123.2	5.7	5.5
3940026	1	2	24	1.0	2	237	324	114.9	121.9	5.0	5.8
3940065	1	2	24	2.5	2	251	318	117.2	122.9	6.2	6.5
3940078	1	2	24	2.5	1	290	412	130.2	137.5	5.5	6.5
3940171	1	2	24	3.0	2	200	272	113.0	121.9	4.8	6.0
3940188	1	2	24	4.0	1	205	282	116.2	124.2	5.2	5.8
3940911	1	2	24	5.0	2	228	273	116.5	123.5	6.5	5.8
3940017	1	3	12	3.0	2	298	354	127.0	131.8	6.2	6.2
3940037	1	3	12	4.0	1	286	350	124.2	128.9	5.7	6.0
3940038	1	3	12	1.0	2	248	334	119.4	122.9	5.5	6.5
3940147	1	3	12	4.0	2	222	283	117.2	125.1	5.5	6.2
3940152	1	3	12	2.5	1	257	331	130.8	136.9	5.2	4.8
3940160	1	3	12	2.5	1	209	275	114.6	123.8	5.2	5.2
3940018	1	3	17	1.0	1	249	337	114.9	123.2	5.8	5.8
3940035	1	3	17	1.0	2	233	312	114.9	121.9	5.1	6.2
3940120	1	3	17	5.0	2	208	261	116.8	120.7	5.8	5.5

Raw Data Performance Experiment

ID	YEAR	TRT	PEN	BRD	SEX	SWT1KG	SWT2KG	HT1	HT2	CS1	CS2
3940125	1	3	17	3.0	2	231	313	117.8	124.8	6.2	6.2
3940136	1	3	17	5.0	1	297	373	123.2	131.8	6.0	6.5
3940146	1	3	17	3.0	1	232	307	126.4	135.3	4.8	4.2
3940075	1	3	19	1.0	2	198	289	108.3	117.5	4.8	5.2
3940091	1	3	19	4.0	1	298	385	128.9	136.2	5.6	6.5
3940110	1	3	19	3.0	2	228	285	108.6	111.5	5.8	6.0
3940116	1	3	19	2.0	1	244	327	119.4	129.5	5.0	5.5
3940155	1	3	19	4.0	2	210	276	113.0	120.3	5.5	6.5
3940162	1	3	19	2.5	1	220	286	110.2	120.0	5.6	6.0
3940170	1	3	27	1.0	2	213	297	110.8	117.8	5.2	6.2
3940005	1	3	27	2.5	2	288	349	123.5	130.8	5.2	5.8
3940070	1	3	27	5.0	1	276	355	124.5	133.7	5.4	6.2
3940076	1	3	27	3.0	2	232	311	120.7	126.4	4.3	6.5
3940077	1	3	27	1.0	1	198	295	112.4	125.1	4.7	5.5
3940170	1	3	27	4.0	2	233	295	116.8	126.7	6.2	6.2
3940048	1	4	4	3.0	2	305	357	128.9	135.0	6.2	6.5
3940062	1	4	4	2.5	1	272	351	123.5	132.7	5.2	5.5
3940068	1	4	4	3.0	1	258	331	119.7	127.0	6.0	5.8
3940074	1	4	4	1.0	2	211	243	110.5	117.5	5.2	5.2
3940165	1	4	4	4.0	1	229	290	120.7	129.5	5.6	6.2
3940913	1	4	4	5.0	2	240	280	120.3	126.1	5.8	5.8
3940020	1	4	7	2.0	2	260	319	117.8	123.8	6.2	6.0
3940049	1	4	7	1.0	1	280	346	121.6	130.5	5.0	5.5
3940101	1	4	7	3.0	1	266	320	118.4	126.7	5.2	5.8
3940135	1	4	7	4.0	2	238	307	119.7	128.6	5.5	5.8
3940158	1	4	7	5.0	1	214	268	118.1	121.9	5.8	5.8
3940914	1	4	7	2.0	2	214	279	110.2	117.5	5.2	5.2
3940010	1	4	9	3.0	2	299	360	124.8	129.2	6.5	6.5
3940029	1	4	9	1.0	2	210	268	110.2	118.7	4.5	4.8
3940041	1	4	9	5.0	1	242	282	122.6	129.2	4.5	5.2
3940061	1	4	9	2.5	1	281	344	127.3	133.0	5.2	5.5
3940175	1	4	9	5.0	2	208	245	121.0	126.1	5.2	5.2
3940185	1	4	9	3.0	1	220	284	120.7	130.0	4.7	4.8
3940011	1	4	26	2.5	2	259	330	119.1	123.8	4.8	5.8
3940081	1	4	26	2.0	2	271	311	120.3	126.7	4.5	5.5
3940100	1	4	26	1.0	1	240	321	117.2	123.5	5.6	5.5
3940121	1	4	26	2.0	2	252	308	112.1	123.2	5.8	5.8
3940195	1	4	26	5.0	1	223	268	118.1	126.7	5.7	6.0
3940905	1	4	26	5.0	2	255	315	124.8	131.1	5.2	5.8
1940020	1	5	5	1.0	2	256	313	113.4	119.4	5.2	5.8
3940056	1	5	5	3.0	1	254	319	125.1	132.7	5.5	5.2
3940084	1	5	5	5.0	2	210	245	113.0	120.3	5.2	5.5
3940128	1	5	5	2.5	1	237	298	119.1	129.7	5.5	4.8
3940129	1	5	5	3.0	2	221	261	116.2	122.3	5.7	5.8
3940199	1	5	5	5.0	2	208	277	118.1	126.7	5.0	5.8
1940173	1	5	8	1.0	1	230	288	116.8	124.5	5.8	4.8
3940051	1	5	8	4.0	2	284	313	123.2	129.5	6.0	5.5
3940066	1	5	8	3.0	2	225	288	117.8	122.9	5.7	5.8
3940113	1	5	8	2.0	2	256	326	121.3	127.6	5.8	6.2
3940179	1	5	8	3.0	1	224	282	122.9	132.1	4.2	4.2
3940183	1	5	8	4.0	1	236	277	113.4	127.3	5.8	5.8
3940039	1	5	13	2.5	1	240	310	121.3	128.6	5.2	5.2
3940054	1	5	13	2.0	2	298	363	123.5	129.9	5.0	5.5
3940094	1	5	13	5.0	2	233	262	122.6	128.0	5.4	5.2
3940097	1	5	13	3.0	2	221	261	104.8	108.0	6.5	6.2
3940141	1	5	13	3.0	1	225	307	117.5	126.1	4.5	5.2
3940145	1	5	13	4.0	1	259	337	125.1	130.5	4.2	5.0

Raw Data Performance Experiment

ID	YEAR	TRT	PEN	BRD	SEX	SWT1KG	SWT2KG	HT1	HT2	CS1	CS2
1940037	1	5	21	1.0	2	210	271	111.1	119.7	4.8	5.0
3940006	1	5	21	3.0	2	316	356	127.0	131.8	5.7	6.2
3940055	1	5	21	1.0	1	217	271	114.0	121.3	5.5	5.0
3940086	1	5	21	3.0	1	222	294	116.8	122.6	5.8	5.2
3940148	1	5	21	4.0	2	215	268	111.5	118.1	6.2	6.0
3940154	1	5	21	5.0	1	225	272	120.7	127.6	5.4	5.8
1940028	1	6	3	1.0	2	258	316	117.5	122.9	5.7	5.8
3940032	1	6	3	1.0	1	252	309	112.1	121.6	6.5	6.5
3940036	1	6	3	3.0	2	244	312	121.0	128.0	5.4	5.2
3940105	1	6	3	4.0	1	212	280	109.2	118.1	5.8	6.2
3940109	1	6	3	5.0	2	209	282	117.5	123.5	5.5	6.5
3940172	1	6	3	3.0	1	240	325	123.5	133.4	5.2	5.8
1940009	1	6	11	1.0	2	251	321	112.4	124.2	5.0	5.5
3940045	1	6	11	3.0	2	264	317	119.4	128.6	6.5	6.2
3940060	1	6	11	2.0	1	305	366	126.7	131.4	6.2	6.2
3940130	1	6	11	5.0	1	236	285	120.0	128.3	5.0	5.2
3940143	1	6	11	4.0	2	221	258	119.4	128.6	5.8	5.2
3940149	1	6	11	3.0	1	251	321	114.0	122.6	6.2	6.5
3940089	1	6	15	1.0	2	260	323	118.1	122.9	5.0	6.0
3940112	1	6	15	4.0	2	238	302	121.3	130.5	5.8	6.2
3940127	1	6	15	3.0	2	188	273	108.6	119.7	4.2	5.5
3940153	1	6	15	2.5	1	238	313	120.7	129.5	5.2	5.5
3940164	1	6	15	5.0	1	229	280	123.2	126.4	5.5	6.2
3940177	1	6	15	3.0	1	229	298	121.0	129.5	5.2	5.2
3940003	1	6	25	2.0	2	306	377	121.6	127.3	5.8	6.8
3940033	1	6	25	1.0	2	186	256	110.2	115.9	4.5	5.5
3940042	1	6	25	3.0	2	298	351	122.9	126.7	6.5	6.5
3940059	1	6	25	2.5	1	254	317	120.7	124.8	5.5	6.0
3940111	1	6	25	4.0	2	221	278	116.5	124.8	5.8	5.8
3940132	1	6	25	4.0	1	221	288	113.0	124.2	4.8	5.5
3940013	1	7	1	1.0	1	238	259	121.0	127.0	5.2	4.5
3940015	1	7	1	4.0	2	269	295	121.6	128.6	6.2	5.8
3940022	1	7	1	2.0	2	281	295	115.9	121.0	6.5	6.2
3940124	1	7	1	5.0	1	250	262	126.1	132.9	5.5	5.5
3940187	1	7	1	3.0	1	201	218	118.1	123.2	5.2	4.2
3940902	1	7	1	2.0	2	239	231	118.7	121.0	5.2	4.5
3940031	1	7	16	4.0	1	276	286	119.4	123.2	5.8	5.8
3940072	1	7	16	3.0	2	261	277	121.9	123.8	6.8	5.8
3940073	1	7	16	2.0	2	249	265	119.4	127.6	5.0	5.0
3940159	1	7	16	2.0	1	208	226	113.4	117.5	5.8	4.5
3940163	1	7	16	5.0	2	201	215	113.7	119.4	6.2	5.0
3940167	1	7	16	3.0	1	211	234	111.1	117.5	5.2	4.5
3940021	1	7	18	1.0	1	269	287	121.0	124.8	5.0	4.8
3940043	1	7	18	2.0	2	281	294	120.0	126.4	5.8	5.8
3940083	1	7	18	4.0	2	239	263	129.2	132.4	4.5	4.5
3940151	1	7	18	5.0	1	244	259	124.8	127.3	6.5	5.5
3940166	1	7	18	3.0	2	203	235	110.5	114.9	5.7	5.5
3940191	1	7	18	3.0	1	267	290	127.0	131.8	4.8	4.2
3940002	1	7	23	2.0	2	302	330	121.3	126.7	6.2	6.0
3940009	1	7	23	3.0	2	255	284	111.8	115.6	6.2	5.5
3940063	1	7	23	2.5	2	238	258	113.4	116.5	5.5	5.0
3940082	1	7	23	1.0	1	250	272	111.8	118.1	6.2	4.5
3940123	1	7	23	5.0	2	233	254	123.2	125.7	6.2	5.5
3940190	1	7	23	4.0	1	173	199	110.5	113.4	4.8	4.2
908	2	1	14	2.0	2	308	406	121.6	127.6	5.5	6.0
910	2	1	14	2.0	2	231	302	118.1	125.4	4.8	5.2

Raw Data Performance Experiment

ID	YEAR	TRT	PEN	BRD	SEX	SWT1KG	SWT2KG	HT1	HT2	CS1	CS2
922	2	1	14	1.0	2	240	313	113.0	114.3	5.5	6.2
3950030	2	1	14	5.0	2	265	329	121.3	125.7	6.2	6.5
3950033	2	1	14	3.0	2	295	349	121.0	123.5	5.2	5.8
3950081	2	1	14	6.0	2	259	329	114.0	118.7	5.5	5.8
917	2	1	19	1.0	2	209	277	109.6	115.3	5.0	5.5
3950042	2	1	19	2.0	2	259	340	112.4	116.5	5.5	6.2
3950080	2	1	19	3.0	2	231	283	115.3	116.8	4.8	5.5
3950136	2	1	19	2	2	277	356	114.0	119.4	5.8	6.0
3950139	2	1	19	4	2	283	333	122.6	126.4	6.0	6.5
3950170	2	1	19	3	2	249	317	122.6	128.3	4.8	5.8
3950044	2	1	22	5	3	272	345	121.6	130.2	5.8	5.6
3950115	2	1	22	4	3	274	349	117.8	127.6	4.5	4.6
3950132	2	1	22	6	3	245	308	112.1	120.7	5.5	5.8
3950134	2	1	22	2	3	272	367	121.6	128.0	4.8	5.4
3950177	2	1	22	3	3	261	342	119.7	125.4	5.2	5.4
3950203	2	1	22	3	3	231	308	113.0	123.2	5.2	5.0
3950041	2	1	25	3	3	297	376	115.6	121.0	5.8	5.5
3950059	2	1	25	3	3	252	347	117.2	121.6	5.5	5.5
3950148	2	1	25	2	3	227	327	116.5	121.6	5.0	5.5
3950166	2	1	25	4	3	288	351	124.8	130.8	5.3	5.6
3950173	2	1	25	1	3	238	315	109.9	117.2	5.0	5.2
3950205	2	1	25	5	3	259	340	126.7	131.4	5.2	5.5
3950016	2	2	3	6	2	231	297	111.5	118.4	5.3	5.4
3950020	2	2	3	3	2	283	374	122.3	127.3	5.0	5.8
3950038	2	2	3	4	2	254	297	120.7	120.7	5.8	5.8
3950077	2	2	3	3	2	243	288	119.1	144.5	5.0	5.5
3950108	2	2	3	2	2	268	340	114.3	117.5	5.5	6.2
3950126	2	2	3	2	2	286	354	118.7	122.9	6.2	6.2
907	2	2	5	2	2	274	347	116.2	120.7	4.8	5.8
911	2	2	5	2	2	274	354	122.3	125.1	5.2	5.8
3950011	2	2	5	4	2	288	354	120.0	124.5	5.8	6.0
3950028	2	2	5	1	2	249	351	120.0	126.4	4.8	5.5
3950061	2	2	5	3	2	209	277	117.8	119.7	4.5	5.0
3950175	2	2	5	3	2	249	345	115.9	125.1	5.2	6.0
3950067	2	2	7	2	3	238	329	115.9	124.2	5.5	5.6
3950069	2	2	7	3	3	256	317	117.8	124.8	5.2	5.4
3950121	2	2	7	2	3	272	356	116.5	120.0	5.8	5.8
3950146	2	2	7	5	3	299	374	122.3	128.3	6.2	6.2
3950154	2	2	7	3	3	272	367	121.6	130.2	5.0	6.0
3950155	2	2	7	4	3	286	363	117.5	121.9	5.8	6.0
3950015	2	2	12	3	3	320	367	121.6	124.2	5.5	5.8
3950034	2	2	12	6	3	279	354	113.0	117.5	5.8	5.8
3950053	2	2	12	2	3	272	349	113.0	118.4	5.0	5.8
3950066	2	2	12	4	3	234	324	118.1	123.8	4.5	5.5
3950098	2	2	12	4	3	277	345	119.7	123.2	5.0	5.8
3950140	2	2	12	3	3	259	311	122.3	125.7	5.0	5.4
3950027	2	3	9	2	2	304	410	122.9	124.2	6.2	6.2
3950047	2	3	9	6	2	229	306	113.4	121.0	5.0	5.3
3950078	2	3	9	2	2	277	363	116.5	122.9	5.8	6.0
3950117	2	3	9	3	2	306	374	121.9	127.0	5.4	6.0
3950182	2	3	9	3	2	238	299	112.7	117.5	5.5	5.5
3950193	2	3	9	5	2	231	295	123.2	127.0	4.8	5.5
909	2	3	18	2	2	299	399	123.2	127.6	5.0	6.2
3950024	2	3	18	2	2	231	308	111.1	116.5	5.2	6.2
3950092	2	3	18	2	2	259	354	119.1	121.9	4.8	5.3
3950120	2	3	18	3	2	290	374	121.9	127.6	4.8	6.0

Raw Data Performance Experiment

ID	YEAR	TRT	PEN	BRD	SEX	SWT1KG	SWT2KG	HT1	HT2	CS1	CS2
3950131	2	3	18	6	2	249	351	118.7	120.7	4.8	6.2
3950171	2	3	18	4	2	249	333	121.6	125.4	4.5	5.4
3950090	2	3	23	6	3	283	397	119.4	128.0	5.2	6.0
3950107	2	3	23	3	3	272	356	118.7	123.8	5.5	5.5
3950127	2	3	23	1	3	240	329	112.7	119.7	5.2	5.4
3950135	2	3	23	4	3	290	363	122.6	126.4	5.8	5.8
3950165	2	3	23	5	3	268	342	124.2	128.9	6.0	6.0
3950179	2	3	23	3	3	231	308	111.8	129.5	5.5	5.6
3950036	2	3	27	4	3	279	358	119.7	120.3	5.5	5.4
3950110	2	3	27	6	3	288	381	118.4	123.5	4.8	5.8
3950141	2	3	27	1	3	204	306	104.8	115.3	4.8	5.6
3950143	2	3	27	3	3	243	311	117.2	118.7	5.5	5.4
3950218	2	3	27	4	3	215	283	113.0	123.5	4.8	5.2
3950013	2	4	2	2	2	277	388	123.8	132.4	4.8	5.4
3950055	2	4	2	3	2	279	356	115.3	119.4	6.2	6.2
3950147	2	4	2	2	2	268	354	115.9	120.7	5.4	5.8
3950162	2	4	2	4	2	249	324	119.4	125.1	4.8	5.2
3950176	2	4	2	6	2	254	290	110.8	112.1	5.8	5.8
3950187	2	4	2	1	2	202	265	105.4	108.3	5.2	5.2
3950019	2	4	20	2	2	317	413	123.8	126.7	5.8	6.0
3950083	2	4	20	1	2	238	311	107.6	111.1	5.5	5.8
3950104	2	4	20	3	2	288	329	118.1	118.7	5.6	5.2
3950119	2	4	20	2	2	268	345	117.8	122.9	4.8	5.6
3950161	2	4	20	5	2	259	327	123.8	127.6	5.2	5.5
3950201	2	4	20	3	2	206	270	110.8	114.3	5.2	5.8
3950031	2	4	24	4	3	274	358	123.2	129.9	4.8	5.8
3950065	2	4	24	3	3	299	397	121.3	127.3	6.0	5.8
3950076	2	4	24	6	3	249	333	113.7	118.4	5.8	6.2
3950129	2	4	24	1	3	259	313	110.8	115.3	5.2	5.5
3950157	2	4	24	5	3	252	324	121.6	126.4	5.2	5.6
3950167	2	4	24	4	3	297	367	119.7	125.4	5.2	5.5
3950039	2	4	28	6	3	288	365	121.3	125.7	5.0	5.8
3950064	2	4	28	4	3	279	361	120.3	129.9	4.8	5.6
3950091	2	4	28	3	3	293	381	115.3	118.7	5.2	5.8
3950124	2	4	28	1	3	204	286	106.0	114.9	5.2	5.5
3950130	2	4	28	4	3	327	413	124.5	126.4	6.0	6.0
3950172	2	4	28	4	3	238	306	114.6	119.7	5.5	5.8
912	2	5	4	2	2	259	320	120.7	123.8	5.3	5.5
920	2	5	4	1	2	220	268	112.1	115.3		5.5
3950040	2	5	4	2	2	281	374	115.6	119.1	5.5	6.2
3950068	2	5	4	3	2	215	308	115.3	125.1	4.8	5.2
3950086	2	5	4	3	2	324	372	125.7	126.4	5.8	5.2
3950198	2	5	4	4	2	234	311	119.7	126.4	4.8	5.5
913	2	5	13	2	2	277	358	126.7	132.1	4.8	5.4
3950026	2	5	13	4	2	297	349	110.5	124.2	5.8	6.2
3950057	2	5	13	3	2	231	297	114.6	115.9	4.8	5.2
3950058	2	5	13	6	2	224	317	112.7	120.0	4.8	5.5
3950084	2	5	13	2	2	283	345	112.4	117.8	5.5	5.5
3950163	2	5	13	3	2	274	338	123.8	126.4	5.2	5.8
3950029	2	5	17	3	3	327	401	117.5	117.8	5.8	6.2
3950056	2	5	17	3	3	247	333	126.7	134.0	4.8	5.5
3950122	2	5	17	1	3	277	356	113.4	119.1	5.2	6.0
3950169	2	5	17	6	3	279	370	120.0	128.6	5.5	6.1
3950183	2	5	17	5	3	220	290	120.7	126.4	5.2	6.2
3950184	2	5	17	4	3	252	311	115.9	120.3	5.5	5.8
3950087	2	5	26	6	3	311	390	127.0	131.1	4.8	5.8

Raw Data Performance Experiment

ID	YEAR	TRT	PEN	BRD	SEX	SWT1KG	SWT2KG	HT1	HT2	CS1	CS2
3950093	2	5	26	3	3	279	342	116.2	119.7	5.2	6.2
3950105	2	5	26	2	3	288	356	118.1	121.0	5.0	5.6
3950137	2	5	26	4	3	286	349	120.7	126.7	5.2	5.2
3950138	2	5	26	3	3	243	327	116.2	134.6	5.5	5.6
3950181	2	5	26	4	3	238	297	118.1	124.2	4.8	5.4
3950009	2	6	1	2	2	299	365	117.5	118.4	6.2	6.2
3950017	2	6	1	1	2	229	290	107.6	115.3	5.5	5.5
3950022	2	6	1	3	2	286	356	124.2	128.3	5.2	5.3
3950095	2	6	1	6	2	306	358	122.3	124.5	5.8	5.8
3950099	2	6	1	2	2	236	302	106.7	110.2	5.5	6.0
3950195	2	6	1	4	2	227	283	116.5	124.2	5.5	5.8
914	2	6	6	2	2	299	395	122.9	126.7	4.8	5.5
926	2	6	6	2	2	268	351	111.8	116.5	5.2	6.2
3950025	2	6	6	3	2	243	320	119.7	121.3	4.8	5.7
3950133	2	6	6	3	2	213	295	103.5	106.7	5.8	6.0
3950153	2	6	6	1	2	234	295	105.4	108.3	5.5	5.5
3950164	2	6	6	4	2	249	342	122.3	127.6	5.0	6.0
3950049	2	6	10	2	3	247	349	113.0	117.5	5.0	5.4
3950088	2	6	10	4	3	263	324	118.7	121.3	5.2	5.4
3950113	2	6	10	4	3	331	429	125.4	134.3	.	5.6
3950152	2	6	10	3	3	288	383	120.7	124.2	5.2	5.8
3950160	2	6	10	5	3	222	274	118.1	122.6	4.5	5.1
3950208	2	6	10	6	3	231	320	120.3	127.0	5.5	5.2
3950096	2	6	16	6	3	327	417	122.6	128.6	6.0	6.2
3950101	2	6	16	4	3	297	356	125.4	131.4	5.8	5.6
3950125	2	6	16	1	3	213	304	109.6	115.6	5.0	5.5
3950149	2	6	16	4	3	313	424	118.7	127.0	5.5	6.5
3950189	2	6	16	2	3	229	297	109.2	114.0	5.0	5.5
3950221	2	6	16	4	3	197	293	109.6	114.9	4.5	5.5
925	2	7	8	1	2	222	265	108.0	109.9	5.0	5.2
3950006	2	7	8	3	2	272	304	114.0	116.2	5.2	5.4
3950008	2	7	8	6	2	272	299	120.0	125.7	5.0	4.8
3950014	2	7	8	2	2	299	333	120.3	120.7	6.0	5.7
3950074	2	7	8	5	2	254	277	124.2	128.0	5.2	4.8
3950144	2	7	8	2	2	254	274	112.7	139.7	5.5	5.5
919	2	7	11	2	2	254	306	117.8	118.1	4.8	5.2
3950005	2	7	11	1	2	197	218	107.6	109.6	4.5	4.8
3950018	2	7	11	2	2	286	340	119.4	127.3	5.0	5.2
3950052	2	7	11	6	2	322	340	120.3	124.2	6.0	5.2
3950097	2	7	11	3	2	293	306	125.4	128.9	4.5	4.7
3950142	2	7	11	5	2	238	277	119.7	121.3	5.2	5.4
3950037	2	7	15	6	3	311	342	126.1	128.0	6.0	4.8
3950089	2	7	15	2	3	261	299	116.5	117.2	5.0	4.8
3950103	2	7	15	4	3	295	333	125.7	128.3	5.5	5.2
3950109	2	7	15	3	3	254	295	118.1	120.3	5.2	5.5
3950159	2	7	15	3	3	286	336	121.3	123.2	5.2	4.5
3950210	2	7	15	5	3	229	268	116.8	122.9	5.2	4.8
3950021	2	7	21	2	3	302	331	114.6	117.8	5.8	4.8
3950046	2	7	21	6	3	240	283	119.4	123.2	5.0	4.8
3950112	2	7	21	4	3	283	322	120.3	120.7	5.5	5.5
3950114	2	7	21	5	3	322	345	128.9	138.4	5.0	4.5
3950123	2	7	21	3	3	268	295	119.7	122.6	5.2	5.0
3950145	2	7	21	3	3	238	279	116.8	121.6	4.5	5.0

Performance Experiment: Intake, observed and predicted gain

OBS	YEAR	TRT	PEN	SEX	ADG	AVGWT	HAYDM	SUPPDM	PRDADG
1	1	1	2	.	.535	269	3.56	1.86	.545
2	1	1	6	.	.506	284	3.72	1.86	.520
3	1	1	20	.	.512	278	4.32	1.86	.640
4	1	1	28	.	.576	264	3.52	1.86	.555
5	1	2	10	.	.606	290	3.30	1.86	.425
6	1	2	14	.	.533	282	3.63	1.86	.515
7	1	2	22	.	.611	278	3.81	1.86	.555
8	1	2	24	.	.699	274	3.54	1.86	.525
9	1	3	12	.	.606	287	4.19	1.86	.590
10	1	3	17	.	.672	279	4.69	1.86	.700
11	1	3	19	.	.670	270	4.27	1.86	.660
12	1	3	27	.	.685	278	4.19	1.86	.620
13	1	4	4	.	.503	281	4.25	2.12	.565
14	1	4	7	.	.548	276	4.37	2.05	.590
15	1	4	9	.	.478	270	3.06	2.04	.385
16	1	4	26	.	.526	280	4.07	2.15	.560
17	1	5	5	.	.487	258	3.10	2.06	.435
18	1	5	8	.	.475	269	3.24	2.07	.430
19	1	5	13	.	.539	276	3.44	2.04	.435
20	1	5	21	.	.490	261	3.92	2.08	.580
21	1	6	3	.	.609	270	4.38	2.07	.620
22	1	6	11	.	.505	283	3.89	2.10	.505
23	1	6	15	.	.607	264	4.17	2.07	.610
24	1	6	25	.	.568	280	4.12	2.13	.560
25	1	7	1	.	.120	253	5.13	0.00	.170
26	1	7	16	.	.143	242	4.18	0.00	.030
27	1	7	18	.	.184	261	5.62	0.00	.255
28	1	7	23	.	.217	254	5.19	0.00	.195
29	2	1	14	2	.680	302	5.67	1.86	.740
30	2	1	19	2	.633	285	3.99	1.86	.540
31	2	1	22	3	.738	298	5.21	1.86	.730
32	2	1	25	3	.788	301	5.46	1.86	.760
33	2	2	3	2	.612	293	4.16	1.86	.540
34	2	2	5	2	.767	298	4.30	1.86	.550
35	2	2	7	3	.767	311	5.09	1.86	.670
36	2	2	12	3	.651	307	4.86	1.86	.650
37	2	3	9	2	.734	303	5.60	1.86	.730
38	2	3	18	2	.860	308	6.23	1.86	.800
39	2	3	23	3	.810	307	4.92	1.86	.650
40	2	3	27	3	.782	287	3.90	1.86	.560
41	2	4	2	2	.713	292	5.90	2.15	.780
42	2	4	20	2	.662	297	4.60	2.15	.570
43	2	4	24	3	.734	310	5.82	2.15	.750
44	2	4	28	3	.767	312	6.26	2.15	.810
45	2	5	4	2	.666	290	5.16	2.11	.660
46	2	5	13	2	.662	299	4.97	2.15	.620
47	2	5	17	3	.731	305	5.56	2.13	.720
48	2	5	26	3	.662	309	4.99	2.11	.620
49	2	6	1	2	.590	295	4.33	2.15	.530
50	2	6	6	2	.781	292	4.98	2.15	.640
51	2	6	10	3	.788	305	5.57	2.15	.730
52	2	6	16	3	.817	306	5.66	2.15	.740
53	2	7	8	2	.284	277	6.97	0.00	.420
54	2	7	11	2	.313	281	5.53	0.00	.180
55	2	7	15	3	.378	292	6.55	0.00	.330
56	2	7	21	3	.320	292	6.26	0.00	.290

Performance Experiment: Volatile Fatty Acids

OBS	YEAR	TIME	TRT	PEN	ACET	PROP	BUTY	RATIO	TOTAL
1	1	1	1	2	65.8	15.7	8.2	4.32	91.5
2	1	1	1	6	63.0	15.3	8.5	4.11	88.5
3	1	1	1	20	55.2	15.3	7.3	3.77	79.4
4	1	1	1	28	54.8	14.1	9.2	3.99	79.4
5	1	1	2	10	52.1	21.1	5.1	2.49	80.2
6	1	1	2	14	46.5	15.4	6.2	3.12	69.8
7	1	1	2	22	46.6	15.4	5.1	3.03	68.3
8	1	1	2	24	43.2	16.7	4.7	2.82	65.5
9	1	1	3	12	57.1	12.3	7.7	4.64	78.7
10	1	1	3	17	45.6	10.7	5.7	4.24	63.3
11	1	1	3	19	50.6	12.5	6.2	4.07	70.8
12	1	1	3	27	62.4	15.5	8.9	4.10	88.7
13	1	1	4	4	50.1	13.6	7.1	3.72	71.4
14	1	1	4	7	42.0	10.1	6.0	4.14	58.9
15	1	1	4	9	38.0	9.3	5.9	4.13	54.0
16	1	1	4	26	39.6	11.7	6.9	3.39	58.7
17	1	1	5	5	39.1	10.9	6.0	3.60	56.7
18	1	1	5	8	35.6	12.0	6.5	2.96	54.9
19	1	1	5	13	40.0	10.9	6.6	3.77	58.1
20	1	1	5	21	36.4	13.9	4.5	2.90	55.6
21	1	1	6	3	53.0	11.7	6.8	4.52	72.5
22	1	1	6	11	36.4	9.0	5.8	4.06	51.9
23	1	1	6	15	35.7	9.1	5.5	3.93	50.9
24	1	1	6	25	37.8	10.1	5.6	3.84	54.1
25	1	1	7	1	49.9	11.0	5.0	4.55	67.0
26	1	1	7	16	41.1	9.2	4.7	4.50	56.3
27	1	1	7	18	55.1	11.0	5.3	4.96	72.4
28	1	1	7	23	55.0	12.3	6.0	4.45	74.6
29	1	2	1	2	64.2	14.7	9.4	4.37	90.0
30	1	2	1	6	43.1	13.7	8.9	3.16	67.7
31	1	2	1	20	45.5	10.3	6.9	4.43	64.6
32	1	2	1	28	40.8	10.8	9.1	3.79	62.3
33	1	2	2	10	47.7	23.6	6.9	2.03	80.1
34	1	2	2	14	49.2	19.6	5.9	2.54	76.3
35	1	2	2	22	47.3	24.2	5.8	1.98	78.6
36	1	2	2	24	55.4	28.6	5.9	1.94	91.3
37	1	2	3	12	36.9	9.4	7.4	3.93	56.0
38	1	2	3	17	31.5	11.5	4.9	3.25	49.1
39	1	2	3	19	41.5	11.3	6.6	3.68	61.4
40	1	2	3	27	47.8	13.7	6.6	3.58	70.5
41	1	2	4	4	54.5	20.9	11.2	2.62	88.1
42	1	2	4	7	48.5	14.4	9.3	3.35	74.3
43	1	2	4	9	39.0	13.8	7.9	2.82	61.8
44	1	2	4	26	34.3	11.6	7.5	2.97	54.2
45	1	2	5	5	43.1	15.1	7.8	2.86	67.0
46	1	2	5	8	32.0	12.4	7.2	2.59	52.5
47	1	2	5	13	28.1	9.9	5.3	2.84	43.8
48	1	2	5	21	32.2	15.5	7.3	2.14	56.2
49	1	2	6	3	46.1	17.6	9.0	2.73	73.5
50	1	2	6	11	32.0	9.8	6.1	3.26	48.7
51	1	2	6	15	31.3	10.6	7.0	2.97	49.6
52	1	2	6	25	33.1	13.7	7.7	2.41	55.2
53	1	2	7	1	45.3	11.6	6.4	3.90	65.2
54	1	2	7	16	39.5	10.3	6.3	3.82	58.1
55	1	2	7	18	34.0	8.5	4.7	4.00	48.7
56	1	2	7	23	41.5	11.3	5.4	3.63	59.7

Performance Experiment: Volatile Fatty Acids

OBS	YEAR	TIME	TRT	PEN	ACET	PROP	BUTY	RATIO	TOTAL
57	1	3	1	2	62.7	14.8	6.8	4.38	85.9
58	1	3	1	6	68.4	17.8	8.7	3.85	96.9
59	1	3	1	20	45.3	9.9	6.4	4.57	63.4
60	1	3	1	28	54.2	10.6	7.4	5.06	73.6
61	1	3	2	10	57.2	22.3	6.1	2.58	87.5
62	1	3	2	14	62.2	16.5	7.0	3.82	87.6
63	1	3	2	22	55.5	17.5	5.5	3.19	80.1
64	1	3	2	24	59.1	20.5	5.6	2.89	86.5
65	1	3	3	12	50.8	11.6	6.2	4.64	70.4
66	1	3	3	17	55.1	13.4	7.0	4.17	77.2
67	1	3	3	19	59.8	12.9	8.0	4.79	83.1
68	1	3	3	27	48.3	12.7	5.5	3.83	68.0
69	1	3	4	4	51.0	11.1	6.8	4.72	70.0
70	1	3	4	7	52.4	13.9	7.7	3.78	75.0
71	1	3	4	9	46.2	10.1	6.4	4.55	63.6
72	1	3	4	26	42.6	10.9	6.4	4.05	60.5
73	1	3	5	5	51.7	14.5	6.4	3.56	74.0
74	1	3	5	8	29.4	5.5	2.6	5.35	38.4
75	1	3	5	13	33.3	8.2	4.4	4.14	46.1
76	1	3	5	21	45.0	12.2	5.3	3.70	63.9
77	1	3	6	3	38.4	9.7	6.1	4.16	55.0
78	1	3	6	11	44.5	10.4	6.8	4.30	62.4
79	1	3	6	15	40.8	11.7	6.8	3.50	60.4
80	1	3	6	25	33.7	7.9	4.8	4.35	46.9
81	1	3	7	1	45.3	9.4	4.7	4.80	60.6
82	1	3	7	16	49.5	10.0	6.0	4.97	66.9
83	1	3	7	18	43.6	9.2	4.8	4.75	58.9
84	1	3	7	23	49.9	10.7	5.6	4.67	67.7
85	1	4	1	2	74.5	13.8	9.1	5.43	98.4
86	1	4	1	6	67.2	14.7	8.7	4.57	92.0
87	1	4	1	20	61.3	11.8	8.7	5.17	82.8
88	1	4	1	28	81.0	14.7	12.4	5.47	109.9
89	1	4	2	10	78.4	28.6	7.9	2.75	116.2
90	1	4	2	14	65.6	19.1	7.3	3.43	93.9
91	1	4	2	22	54.2	14.3	5.9	3.78	75.6
92	1	4	2	24	55.4	15.0	6.1	3.69	78.0
93	1	4	3	12	47.7	9.3	6.8	5.11	77.5
94	1	4	3	17	47.5	9.3	5.8	5.11	63.2
95	1	4	3	19	55.2	10.3	7.2	5.36	73.8
96	1	4	3	27	64.9	11.8	7.7	5.53	86.3
97	1	4	4	4	53.2	11.5	8.3	4.70	74.1
98	1	4	4	7	50.9	9.2	7.0	5.50	67.4
99	1	4	4	9	57.3	12.3	7.9	4.66	77.9
100	1	4	4	26	48.9	11.3	8.0	4.33	68.9
101	1	4	5	5	48.1	10.1	6.2	4.80	65.1
102	1	4	5	8	51.3	15.5	9.6	3.32	77.0
103	1	4	5	13	54.7	12.3	7.7	4.44	75.5
104	1	4	5	21	43.8	10.3	6.2	4.23	61.0
105	1	4	6	3	59.2	12.4	9.3	4.78	81.1
106	1	4	6	11	55.1	10.8	7.8	5.12	74.7
107	1	4	6	15	50.1	10.8	8.1	4.72	69.4
108	1	4	6	25	60.1	12.1	8.1	4.98	80.3
109	1	4	7	1	50.7	9.2	5.4	5.52	65.5
110	1	4	7	16	60.5	10.9	7.4	5.54	79.7
111	1	4	7	18	70.9	13.2	7.9	5.36	94.1

Performance Experiment: Volatile Fatty Acids

OBS	YEAR	TIME	TRT	PEN	ACET	PROP	BUTY	RATIO	TOTAL
112	1	4	7	23	51.6	8.8	5.4	5.84	66.1
113	2	1	1	14	50.8	14.4	8.6	3.53	76.2
114	2	1	1	19	41.8	9.3	6.9	4.52	59.9
115	2	1	1	22	36.7	8.0	5.4	4.64	51.6
116	2	1	1	25	48.1	10.4	7.1	4.64	67.2
117	2	1	2	3	49.2	20.5	6.4	2.43	77.7
118	2	1	2	5	50.8	15.8	8.0	3.21	76.6
119	2	1	2	7	50.3	17.4	5.6	2.96	75.6
120	2	1	2	12	40.7	14.4	5.7	2.84	62.2
121	2	1	3	9	36.7	7.4	6.2	4.96	51.5
122	2	1	3	18	40.7	8.4	6.9	4.85	57.6
123	2	1	3	23	40.7	8.8	5.3	4.65	55.8
124	2	1	3	27	41.8	9.1	5.9	4.61	57.8
125	2	1	4	2	40.7	11.6	6.4	3.51	59.6
126	2	1	4	20	40.8	10.4	6.6	3.91	58.8
127	2	1	4	24	41.5	10.3	7.2	4.03	60.2
128	2	1	4	28	25.7	5.4	3.4	4.81	34.7
129	2	1	5	4	43.1	16.2	9.3	2.73	69.5
130	2	1	5	13	40.9	14.2	8.1	2.89	63.7
131	2	1	5	17	36.1	12.0	5.9	3.01	54.8
132	2	1	5	26	39.7	14.9	7.8	2.69	63.0
133	2	1	6	1	48.4	17.3	10.3	2.82	77.5
134	2	1	6	6	47.3	12.6	8.1	3.75	69.7
135	2	1	6	10	44.2	12.1	8.9	3.65	66.5
136	2	1	6	16	33.1	7.4	6.1	4.48	48.4
137	2	1	7	8	35.3	7.1	4.1	4.91	47.3
138	2	1	7	11	34.6	7.1	4.0	4.90	47.0
139	2	1	7	15	47.1	10.8	6.5	4.39	65.9
140	2	1	7	21	44.5	9.8	5.6	4.59	61.1
141	2	2	1	14	34.3	10.2	4.4	3.35	49.1
142	2	2	1	19	50.6	14.1	9.0	3.58	73.9
143	2	2	1	22	42.0	11.6	7.4	3.62	60.9
144	2	2	1	25	37.7	12.2	7.0	3.10	56.9
145	2	2	2	3	40.1	17.0	4.3	2.37	61.4
146	2	2	2	5	49.1	18.5	8.0	2.73	75.6
147	2	2	2	7	35.3	15.0	4.3	2.35	54.6
148	2	2	2	12	40.4	11.3	3.9	4.16	55.7
149	2	2	3	9	38.4	9.7	6.6	3.94	54.7
150	2	2	3	18	40.0	10.9	6.8	3.66	57.8
151	2	2	3	23	33.4	9.1	6.4	3.64	49.2
152	2	2	3	27	40.1	10.2	6.6	3.94	56.9
153	2	2	4	2	37.1	13.9	8.9	2.82	59.9
154	2	2	4	20	38.5	11.7	7.2	3.28	57.4
155	2	2	4	24	32.9	8.7	2.7	3.79	44.3
156	2	2	4	28	39.3	13.0	8.0	3.05	60.4
157	2	2	5	4	29.9	10.7	4.0	2.74	44.8
158	2	2	5	13	32.7	11.1	5.1	2.85	48.8
159	2	2	5	17	25.1	10.4	4.4	2.42	39.9
160	2	2	5	26	31.2	11.0	4.5	2.82	46.7
161	2	2	6	1	30.4	11.5	6.8	2.65	48.7
162	2	2	6	6	34.3	13.6	8.5	2.52	56.6
163	2	2	6	10	27.7	9.3	6.7	2.96	43.7
164	2	2	6	16	27.6	7.3	2.5	3.75	37.4
165	2	2	7	8	51.0	12.4	2.6	4.11	66.0
166	2	2	7	11	31.4	9.5	2.8	3.23	43.8
167	2	2	7	15	30.3	9.2	4.9	3.30	44.4
168	2	2	7	21	41.4	11.9	4.8	3.51	58.1

Performance Experiment: Plasma Urea Nitrogen

OBS	YEAR	MONTH	TRT	PEN	PUN
1	1	DEC	1	2	12.23
2	1	DEC	1	6	13.45
3	1	DEC	1	20	13.37
4	1	DEC	1	28	16.32
5	1	DEC	2	10	11.93
6	1	DEC	2	14	14.35
7	1	DEC	2	22	11.04
8	1	DEC	2	24	12.97
9	1	DEC	3	12	11.29
10	1	DEC	3	17	12.18
11	1	DEC	3	19	11.38
12	1	DEC	3	27	14.22
13	1	DEC	4	4	8.72
14	1	DEC	4	7	8.75
15	1	DEC	4	9	11.08
16	1	DEC	4	26	9.48
17	1	DEC	5	5	11.28
18	1	DEC	5	8	10.94
19	1	DEC	5	13	9.74
20	1	DEC	5	21	7.74
21	1	DEC	6	3	8.00
22	1	DEC	6	11	8.81
23	1	DEC	6	15	8.03
24	1	DEC	6	25	9.78
25	1	DEC	7	1	9.01
26	1	DEC	7	16	11.12
27	1	DEC	7	18	9.00
28	1	DEC	7	23	8.68
29	1	FEB	1	2	12.75
30	1	FEB	1	6	12.88
31	1	FEB	1	20	12.02
32	1	FEB	1	28	12.60
33	1	FEB	2	10	14.25
34	1	FEB	2	14	15.68
35	1	FEB	2	22	12.85
36	1	FEB	2	24	12.50
37	1	FEB	3	12	11.28
38	1	FEB	3	17	13.12
39	1	FEB	3	19	14.50
40	1	FEB	3	27	12.06
41	1	FEB	4	4	10.31
42	1	FEB	4	7	11.34
43	1	FEB	4	9	7.94
44	1	FEB	4	26	8.78
45	1	FEB	5	5	15.90
46	1	FEB	5	8	16.08
47	1	FEB	5	13	14.80
48	1	FEB	5	21	9.16
49	1	FEB	6	3	11.44
50	1	FEB	6	11	11.67
51	1	FEB	6	15	14.77
52	1	FEB	6	25	9.06
53	1	FEB	7	1	8.58
54	1	FEB	7	16	8.60
55	1	FEB	7	18	6.27
56	1	FEB	7	23	7.98

Performance Experiment: Plasma Urea Nitrogen

OBS	YEAR	MONTH	TRT	PEN	PUN
57	1	JAN	1	2	13.02
58	1	JAN	1	6	11.60
59	1	JAN	1	20	14.03
60	1	JAN	1	28	11.97
61	1	JAN	2	10	13.93
62	1	JAN	2	14	13.38
63	1	JAN	2	22	12.45
64	1	JAN	2	24	13.82
65	1	JAN	3	12	11.61
66	1	JAN	3	17	13.33
67	1	JAN	3	19	11.80
68	1	JAN	3	27	13.98
69	1	JAN	4	4	11.19
70	1	JAN	4	7	10.90
71	1	JAN	4	9	11.34
72	1	JAN	4	26	11.22
73	1	JAN	5	5	12.07
74	1	JAN	5	8	12.50
75	1	JAN	5	13	11.70
76	1	JAN	5	21	10.11
77	1	JAN	6	3	11.28
78	1	JAN	6	11	11.70
79	1	JAN	6	15	11.82
80	1	JAN	6	25	11.50
81	1	JAN	7	1	9.25
82	1	JAN	7	16	12.31
83	1	JAN	7	18	12.13
84	1	JAN	7	23	12.97
85	1	MAR	1	2	12.13
86	1	MAR	1	6	14.47
87	1	MAR	1	20	13.50
88	1	MAR	1	28	12.97
89	1	MAR	2	10	14.88
90	1	MAR	2	14	14.52
91	1	MAR	2	22	12.33
92	1	MAR	2	24	11.85
93	1	MAR	3	12	13.81
94	1	MAR	3	17	9.66
95	1	MAR	3	19	10.43
96	1	MAR	3	27	12.27
97	1	MAR	4	4	10.59
98	1	MAR	4	7	10.58
99	1	MAR	4	9	10.81
100	1	MAR	4	26	9.67
101	1	MAR	5	5	12.93
102	1	MAR	5	8	14.20
103	1	MAR	5	13	12.40
104	1	MAR	5	21	8.68
105	1	MAR	6	3	12.17
106	1	MAR	6	11	12.17
107	1	MAR	6	15	10.06
108	1	MAR	6	25	9.49
109	1	MAR	7	1	6.18
110	1	MAR	7	16	12.26
111	1	MAR	7	18	7.23
112	1	MAR	7	23	9.09

Performance Experiment: Plasma Urea Nitrogen

OBS	YEAR	MONTH	TRT	PEN	PUN
113	2	FEB	1	14	15.83
114	2	FEB	1	19	15.90
115	2	FEB	1	22	8.68
116	2	FEB	1	25	13.40
117	2	FEB	2	3	12.60
118	2	FEB	2	5	15.33
119	2	FEB	2	7	12.83
120	2	FEB	2	12	11.88
121	2	FEB	3	9	18.53
122	2	FEB	3	18	10.30
123	2	FEB	3	23	13.43
124	2	FEB	3	27	8.97
125	2	FEB	4	2	9.40
126	2	FEB	4	20	9.56
127	2	FEB	4	24	7.28
128	2	FEB	4	28	8.20
129	2	FEB	5	4	11.56
130	2	FEB	5	13	12.57
131	2	FEB	5	17	12.52
132	2	FEB	5	26	8.86
133	2	FEB	6	1	6.98
134	2	FEB	6	6	7.26
135	2	FEB	6	10	8.11
136	2	FEB	6	16	14.57
137	2	FEB	7	8	7.49
138	2	FEB	7	11	9.13
139	2	FEB	7	15	4.36
140	2	FEB	7	21	9.95
141	2	JAN	1	14	12.52
142	2	JAN	1	19	7.26
143	2	JAN	1	22	8.42
144	2	JAN	1	25	10.31
145	2	JAN	2	3	8.25
146	2	JAN	2	5	12.09
147	2	JAN	2	7	8.94
148	2	JAN	2	12	9.23
149	2	JAN	3	9	10.92
150	2	JAN	3	18	8.39
151	2	JAN	3	23	11.13
152	2	JAN	3	27	11.63
153	2	JAN	4	2	7.31
154	2	JAN	4	20	8.42
155	2	JAN	4	24	12.37
156	2	JAN	4	28	8.02
157	2	JAN	5	4	9.08
158	2	JAN	5	13	8.44
159	2	JAN	5	17	9.32
160	2	JAN	5	26	7.98
161	2	JAN	6	1	7.57
162	2	JAN	6	6	6.93
163	2	JAN	6	10	10.89
164	2	JAN	6	16	8.37
165	2	JAN	7	8	6.10
166	2	JAN	7	11	8.76
167	2	JAN	7	15	5.92
168	2	JAN	7	21	5.19

Performance Experiment: Plasma Urea Nitrogen

OBS	YEAR	MONTH	TRT	PEN	PUN
169	2	MAR	1	14	10.83
170	2	MAR	1	19	7.77
171	2	MAR	1	22	9.43
172	2	MAR	1	25	13.50
173	2	MAR	2	3	7.26
174	2	MAR	2	5	11.53
175	2	MAR	2	7	8.22
176	2	MAR	2	12	10.80
177	2	MAR	3	9	12.51
178	2	MAR	3	18	7.77
179	2	MAR	3	23	15.00
180	2	MAR	3	27	11.18
181	2	MAR	4	2	11.48
182	2	MAR	4	20	9.23
183	2	MAR	4	24	4.99
184	2	MAR	4	28	5.14
185	2	MAR	5	4	7.29
186	2	MAR	5	13	8.62
187	2	MAR	5	17	13.43
188	2	MAR	5	26	7.44
189	2	MAR	6	1	5.55
190	2	MAR	6	6	6.25
191	2	MAR	6	10	6.05
192	2	MAR	6	16	10.31
193	2	MAR	7	8	4.30
194	2	MAR	7	11	5.60
195	2	MAR	7	15	6.81
196	2	MAR	7	21	7.59

Heifers: Total Intake

OBS	PER	AN	SUPP	ADD	TDMI	TOMI	TNDFI	TCPI	TTDNI
1	0	1	0	0	4.610	4.370	3.350	0.520	2.440
2	0	2	0	0	6.020	5.690	4.400	0.640	3.190
3	0	3	0	0	5.330	5.070	3.890	0.580	2.820
4	0	4	0	0	5.060	5.100	3.930	0.580	2.680
5	1	1	m	c	6.136	5.630	3.599	0.714	3.439
6	1	2	m	b	7.312	6.681	4.116	0.877	4.158
7	1	3	c	c	5.627	5.290	3.139	0.656	3.404
8	1	4	c	b	6.848	6.433	4.071	0.766	4.031
9	2	1	m	b	5.776	5.390	3.597	0.742	3.220
10	2	2	c	b	6.717	6.385	4.082	0.788	3.966
11	2	3	m	c	5.355	5.088	3.876	0.692	2.827
12	2	4	c	c	6.197	5.889	3.750	0.734	3.675
13	3	1	c	c	6.465	6.096	3.570	0.713	3.937
14	3	2	m	c	8.403	7.738	4.668	0.948	4.520
15	3	3	c	b	6.471	6.157	3.624	0.718	3.940
16	3	4	m	b	8.504	7.832	4.728	0.941	4.888
17	4	1	c	b	6.750	6.419	3.995	0.750	4.046
18	4	2	c	c	7.631	7.255	4.556	0.807	4.548
19	4	3	m	b	6.613	6.251	4.703	0.757	3.514
20	4	4	m	c	8.633	7.999	5.114	0.970	4.881

Heifers: Supplement Intake

OBS	PER	AN	SUPP	ADD	SDMI	SOMI	SNDFI	SCPI	STDNI
1	0	1	0	0	0.000	0.000	0.000	0.000	0.000
2	0	2	0	0	0.000	0.000	0.000	0.000	0.000
3	0	3	0	0	0.000	0.000	0.000	0.000	0.000
4	0	4	0	0	0.000	0.000	0.000	0.000	0.000
5	1	1	m	c	1.285	1.080	0.008	0.234	0.947
6	1	2	m	b	1.795	1.509	0.011	0.327	1.323
7	1	3	c	c	1.553	1.476	0.144	0.242	1.311
8	1	4	c	b	1.553	1.476	0.144	0.242	1.311
9	2	1	m	b	1.229	1.064	0.022	0.273	0.936
10	2	2	c	b	1.734	1.647	0.161	0.270	1.463
11	2	3	m	c	0.455	0.417	0.015	0.198	0.366
12	2	4	c	c	1.647	1.565	0.153	0.256	1.390
13	3	1	c	c	1.734	1.647	0.161	0.270	1.463
14	3	2	m	c	1.990	1.701	0.028	0.358	1.167
15	3	3	c	b	1.734	1.647	0.161	0.270	1.463
16	3	4	m	b	1.918	1.641	0.028	0.346	1.445
17	4	1	c	b	1.907	1.812	0.177	0.297	1.610
18	4	2	c	c	2.081	1.977	0.194	0.324	1.756
19	4	3	m	b	0.671	0.599	0.016	0.238	0.525
20	4	4	m	c	2.165	1.850	0.030	0.395	1.628

Heifers: Fecal Outputs

OBS	PER	AN	SUPP	ADD	FDMOUT	FOMOUT	FNDFOUT	FCPOUT
1	0	1	0	0	1.500	1.395	1.018	0.180
2	0	2	0	0	1.874	1.738	1.271	0.226
3	0	3	0	0	2.064	1.893	1.361	0.243
4	0	4	0	0	1.815	1.684	1.262	0.214
5	1	1	m	c	1.804	1.661	1.211	0.205
6	1	2	m	b	2.255	2.057	1.489	0.266
7	1	3	c	c	2.046	1.847	1.349	0.259
8	1	4	c	b	2.969	2.656	2.021	0.328
9	2	1	m	b	1.829	1.704	1.200	0.256
10	2	2	c	b	2.134	1.968	1.414	0.287
11	2	3	m	c	1.889	1.734	1.260	0.250
12	2	4	c	c	2.338	2.114	1.444	0.316
13	3	1	c	c	2.166	2.025	1.515	0.252
14	3	2	m	c	2.819	2.596	1.840	0.377
15	3	3	c	b	2.370	2.157	1.562	0.271
16	3	4	m	b	2.774	2.550	1.834	0.338
17	4	1	c	b	1.921	1.771	1.268	0.238
18	4	2	c	c	2.664	2.441	1.703	0.379
19	4	3	m	b	2.385	2.172	1.597	0.283
20	4	4	m	c	2.786	2.559	1.811	0.382

Heifers: Parameter from G2G1 and Log models

OBS	PER	AN	SUPP	ADD	CZERO	LAMBDA	KS	DOSE	TD	K-LN
1	1	1	m	c	361.1	0.21879	0.039228	688	13.0	0.043624
2	1	2	m	b	274.1	0.14299	0.037868	680	9.6	0.038138
3	1	3	c	c	426.1	0.09062	0.090558	401	4.7	0.059858
4	1	4	c	b	270.7	0.24736	0.049136	681	12.6	0.047758
5	2	1	m	b	372.8	0.25555	0.038045	747	12.2	0.041925
6	2	2	c	b	359.2	0.14050	0.042876	745	10.0	0.039801
7	2	3	m	c	339.4	0.26937	0.035678	747	10.6	0.047902
8	2	4	c	c	470.0	0.14489	0.061949	739	11.5	0.052897
9	3	1	c	c	462.2	0.14396	0.052313	797	10.2	0.054026
10	3	2	m	c	269.0	0.15638	0.039459	799	10.5	0.042670
11	3	3	c	b	590.6	0.10101	0.077357	754	8.7	0.053254
12	3	4	m	b	398.9	0.17379	0.057870	793	12.2	0.050056
13	4	1	c	b	573.6	0.18110	0.044373	1035	11.4	0.045289
14	4	2	c	c	330.1	0.15561	0.035578	1030	9.7	0.041431
15	4	3	m	b	417.3	0.17421	0.040853	1015	9.9	0.047559
16	4	4	m	c	430.5	0.14647	0.050709	985	10.7	0.047898

Fistulated: Parameter from G4G1 model

OBS	PER	AN	SUPP	ADD	CZERO	LAMBDA	KS	TD	DOSE
1	1	1	m	c	283	0.10824	0.037480	1.23	2200
2	1	2	m	b	246	0.12879	0.023867	0.00	2200
3	1	3	c	c	289	0.14926	0.030032	0.00	2200
4	1	4	c	b	282	0.18904	0.023300	0.00	2200
5	2	1	m	b	180	0.16229	0.013652	1.96	1800
6	2	2	c	b	651	0.08993	0.088586	3.13	1800
7	2	3	m	c	249	0.16577	0.020055	5.47	1800
8	2	4	c	c	254	0.16681	0.023322	0.00	1800
9	3	1	c	c	158	0.39839	0.015257	12.15	1800
10	3	2	m	c	236	0.12543	0.030940	0.00	1800
11	3	3	c	b	193	0.32114	0.026416	7.31	1800
12	3	4	m	b	219	0.16423	0.025055	1.00	1800
13	4	1	c	b	243	0.16623	0.032718	0.01	1800
14	4	2	c	c	203	0.24695	0.035246	1.05	1800
15	4	3	m	b	198	0.14900	0.030196	0.00	1800
16	4	4	m	c	222	0.20987	0.039950	3.04	1800

Fistulated: Nutrient intake

OBS	PER	AN	SUPP	ADD	DMI	OMI	NDFI	NI
1	1	1	m	c	7.96	7.21	3.87	173.09
2	1	2	m	b	7.96	7.21	3.87	173.09
3	1	3	c	c	7.75	7.32	4.10	154.73
4	1	4	c	b	7.75	7.32	4.10	154.73
5	2	1	m	b	7.70	6.94	3.69	155.32
6	2	2	c	b	7.75	7.05	3.92	136.97
7	2	3	m	c	7.41	6.71	3.69	150.81
8	2	4	c	c	7.48	7.05	3.92	136.97
9	3	1	c	c	8.28	7.93	4.61	161.81
10	3	2	m	c	8.54	7.78	4.36	181.91
11	3	3	c	b	8.35	7.93	4.61	161.81
12	3	4	m	b	8.54	7.78	4.36	181.91
13	4	1	c	b	8.35	7.84	4.23	163.20
14	4	2	c	c	8.35	7.84	4.23	163.20
15	4	3	m	b	7.41	6.75	3.60	161.99
16	4	4	m	c	8.47	7.69	3.99	183.30

Fistulated: Duodenal flow

OBS	PER	AN	SUPP	ADD	DMFW	OMFW	NDFFW	TNFW	NH3FW	MNFW
1	1	1	m	c	5652	4119	1388	189	7.09	77.0
2	1	2	m	b	5519	4213	1753	199	6.32	86.9
3	1	3	c	c	4135	3372	1585	116	5.02	71.6
4	1	4	c	b	5917	4817	1999	166	7.24	81.6
5	2	1	m	b	6007	4458	1436	210	10.93	91.2
6	2	2	c	b	6374	4974	1630	212	7.40	95.9
7	2	3	m	c	4275	3326	1637	159	6.54	86.1
8	2	4	c	c	5700	4457	1745	172	7.37	102.9
9	3	1	c	c	6363	5157	1857	195	7.81	113.2
10	3	2	m	c	6474	4907	1835	234	7.38	97.4
11	3	3	c	b	4378	3480	1629	130	7.23	96.6
12	3	4	m	b	5464	4217	1708	168	9.45	90.4
13	4	1	c	b	6225	4988	1775	190	8.28	104.6
14	4	2	c	c	6723	5251	1652	233	6.44	133.8
15	4	3	m	b	4189	3274	1498	157	6.80	93.3
16	4	4	m	c	6284	4745	1837	214	9.50	106.3

Fistulated: Fecal outputs

OBS	PER	AN	SUPP	ADD	DMOUT	OMOUT	NDFOUT	NOUT
1	1	1	m	c	2799	2426	1554	62.1
2	1	2	m	b	3020	2610	1719	65.8
3	1	3	c	c	2415	2086	1477	45.4
4	1	4	c	b	2707	2362	1659	52.0
5	2	1	m	b	2868	2507	1566	66.5
6	2	2	c	b	2940	2507	1628	58.8
7	2	3	m	c	2665	2334	1492	61.0
8	2	4	c	c	2735	2356	1594	56.9
9	3	1	c	c	2678	2378	1622	48.2
10	3	2	m	c	3094	2730	1835	57.2
11	3	3	c	b	2850	2510	1720	45.0
12	3	4	m	b	3053	2718	1782	55.9
13	4	1	c	b	2707	2386	1604	58.5
14	4	2	c	c	3095	2707	1805	67.2
15	4	3	m	b	2725	2387	1434	67.9
16	4	4	m	c	3313	2884	1785	76.2

In situ digestion: Percent left

OBS	PER	AN	TIME	SUPP	ADD	DM	CP
1	1	1	0	m	c	92.22	93.66
2	1	1	1	m	c	86.83	85.97
3	1	1	2	m	c	84.12	86.98
4	1	1	4	m	c	83.36	87.27
5	1	1	6	m	c	80.80	84.31
6	1	1	12	m	c	74.56	82.56
7	1	1	18	m	c	64.26	78.01
8	1	1	24	m	c	63.43	78.26
9	1	1	36	m	c	47.85	59.58
10	1	1	48	m	c	37.62	45.24
11	1	1	60	m	c	12.13	14.79
12	1	2	0	m	b	92.10	94.27
13	1	2	1	m	b	86.22	87.92
14	1	2	2	m	b	85.20	87.30
15	1	2	4	m	b	80.27	86.90
16	1	2	6	m	b	79.63	85.89
17	1	2	12	m	b	68.58	81.71
18	1	2	18	m	b	59.78	73.44
19	1	2	24	m	b	59.29	73.15
20	1	2	36	m	b	39.75	49.50
21	1	2	48	m	b	31.73	39.60
22	1	2	60	m	b	9.11	10.63
23	1	3	0	c	c	91.85	95.76
24	1	3	1	c	c	86.69	92.62
25	1	3	2	c	c	84.68	89.51
26	1	3	4	c	c	77.03	84.66
27	1	3	6	c	c	74.53	85.74
28	1	3	12	c	c	66.12	79.16
29	1	3	18	c	c	60.21	75.56
30	1	3	24	c	c	55.02	69.71
31	1	3	36	c	c	38.28	47.48
32	1	3	48	c	c	18.16	22.10
33	1	3	60	c	c	0.67	0.81
34	1	4	0	c	b	91.74	92.32
35	1	4	1	c	b	84.97	89.92
36	1	4	2	c	b	82.54	88.13
37	1	4	4	c	b	76.98	83.91
38	1	4	6	c	b	72.64	83.86
39	1	4	12	c	b	67.89	83.60
40	1	4	18	c	b	59.41	76.13
41	1	4	24	c	b	55.51	69.70
42	1	4	36	c	b	40.79	51.63
43	1	4	48	c	b	19.49	22.85
44	1	4	60	c	b	0.05	0.06
45	2	1	0	m	b	87.91	91.25
46	2	1	1	m	b	85.89	91.90
47	2	1	2	m	b	83.70	89.64
48	2	1	4	m	b	80.38	90.57
49	2	1	6	m	b	78.84	88.20
50	2	1	12	m	b	75.49	89.39
51	2	1	18	m	b	61.32	78.04
52	2	1	24	m	b	62.05	77.49
53	2	1	36	m	b	44.02	54.89
54	2	1	48	m	b	24.48	29.63
55	2	1	60	m	b	5.93	6.33
56	2	2	0	c	b	89.18	91.73

In situ digestion: Percent left

OBS	PER	AN	TIME	SUPP	ADD	DM	CP
57	2	2	1	c	b	84.26	92.87
58	2	2	2	c	b	82.59	90.48
59	2	2	4	c	b	78.62	88.95
60	2	2	6	c	b	76.68	89.43
61	2	2	12	c	b	73.26	87.21
62	2	2	18	c	b	64.60	77.40
63	2	2	24	c	b	57.64	71.80
64	2	2	36	c	b	34.02	41.05
65	2	2	48	c	b	21.27	25.62
66	2	2	60	c	b	5.18	5.91
67	2	3	0	m	c	88.58	89.66
68	2	3	1	m	c	84.96	89.11
69	2	3	2	m	c	82.36	87.70
70	2	3	4	m	c	80.07	87.54
71	2	3	6	m	c	75.52	89.49
72	2	3	12	m	c	70.80	83.97
73	2	3	18	m	c	56.41	66.60
74	2	3	24	m	c	52.86	66.07
75	2	3	36	m	c	49.22	60.92
76	2	3	48	m	c	22.12	26.38
77	2	3	60	m	c	2.07	2.09
78	2	4	0	c	c	89.67	89.09
79	2	4	1	c	c	84.71	89.76
80	2	4	2	c	c	81.78	88.80
81	2	4	4	c	c	79.09	89.24
82	2	4	6	c	c	77.53	87.34
83	2	4	12	c	c	72.09	83.71
84	2	4	18	c	c	68.41	85.20
85	2	4	24	c	c	61.37	77.94
86	2	4	36	c	c	59.68	76.53
87	2	4	48	c	c	43.60	55.25
88	2	4	60	c	c	2.68	2.97
89	3	1	0	c	c	88.66	91.82
90	3	1	1	c	c	87.60	96.64
91	3	1	2	c	c	84.73	93.70
92	3	1	4	c	c	79.17	89.97
93	3	1	6	c	c	77.61	86.99
94	3	1	12	c	c	68.74	84.09
95	3	1	18	c	c	69.14	86.04
96	3	1	24	c	c	61.85	78.28
97	3	1	36	c	c	52.51	65.60
98	3	1	48	c	c	32.95	40.46
99	3	1	60	c	c	5.62	5.89
100	3	2	0	m	c	91.95	94.31
101	3	2	1	m	c	87.48	93.16
102	3	2	2	m	c	85.75	87.93
103	3	2	4	m	c	83.40	90.03
104	3	2	6	m	c	80.82	87.44
105	3	2	12	m	c	72.18	86.72
106	3	2	18	m	c	61.13	75.99
107	3	2	24	m	c	56.53	70.60
108	3	2	36	m	c	51.55	64.95
109	3	2	48	m	c	11.60	13.62
110	3	2	60	m	c	3.26	3.83
111	3	3	0	c	b	89.67	90.75
112	3	3	1	c	b	85.76	92.03

In situ digestion: Percent left

OBS	PER	AN	TIME	SUPP	ADD	DM	CP
113	3	3	2	c	b	82.48	89.67
114	3	3	4	c	b	74.24	84.33
115	3	3	6	c	b	70.68	85.33
116	3	3	12	c	b	61.51	77.60
117	3	3	18	c	b	57.45	73.49
118	3	3	24	c	b	47.11	57.92
119	3	3	36	c	b	16.52	19.68
120	3	3	48	c	b	5.93	6.98
121	3	3	60	c	b	0.59	0.69
122	3	4	0	m	b	90.17	96.39
123	3	4	1	m	b	85.65	92.99
124	3	4	2	m	b	83.38	90.87
125	3	4	4	m	b	79.70	84.39
126	3	4	6	m	b	77.84	86.20
127	3	4	12	m	b	60.34	74.37
128	3	4	18	m	b	53.52	67.99
129	3	4	24	m	b	49.94	63.26
130	3	4	36	m	b	19.93	24.38
131	3	4	48	m	b	2.00	2.44
132	3	4	60	m	b	0.21	0.26
133	4	1	0	c	b	86.96	89.00
134	4	1	1	c	b	80.60	86.78
135	4	1	2	c	b	77.77	85.20
136	4	1	4	c	b	75.06	83.70
137	4	1	6	c	b	72.41	82.68
138	4	1	12	c	b	68.11	80.55
139	4	1	18	c	b	62.74	78.71
140	4	1	24	c	b	58.59	74.88
141	4	1	36	c	b	44.58	56.59
142	4	1	48	c	b	32.93	41.44
143	4	1	60	c	b	1.13	1.42
144	4	2	0	c	c	87.04	92.15
145	4	2	1	c	c	81.68	89.40
146	4	2	2	c	c	78.86	89.08
147	4	2	4	c	c	75.20	85.99
148	4	2	6	c	c	74.16	79.88
149	4	2	12	c	c	66.35	81.00
150	4	2	18	c	c	65.04	77.90
151	4	2	24	c	c	60.68	76.22
152	4	2	36	c	c	50.53	63.52
153	4	2	48	c	c	47.41	59.35
154	4	2	60	c	c	1.42	1.77
155	4	3	0	m	b	88.60	90.84
156	4	3	1	m	b	81.81	86.34
157	4	3	2	m	b	81.06	84.32
158	4	3	4	m	b	74.97	82.05
159	4	3	6	m	b	72.73	81.02
160	4	3	12	m	b	61.32	74.01
161	4	3	18	m	b	48.32	57.87
162	4	3	24	m	b	45.97	56.73
163	4	3	36	m	b	23.15	27.91
164	4	3	48	m	b	0.52	0.63
165	4	3	60	m	b	0.13	0.16
166	4	4	0	m	c	88.73	91.32
167	4	4	1	m	c	81.81	86.79
168	4	4	2	m	c	79.45	87.56

In situ digestion: Percent left

OBS	PER	AN	TIME	SUPP	ADD	DM	CP
169	4	4	4	m	c	78.19	83.57
170	4	4	6	m	c	77.78	85.82
171	4	4	12	m	c	61.34	74.89
172	4	4	18	m	c	57.01	70.64
173	4	4	24	m	c	50.64	62.46
174	4	4	36	m	c	26.28	32.58
175	4	4	48	m	c	11.96	14.77
176	4	4	60	m	c	0.17	0.21

Rumen Fluid: pH, ammonia, sodium and potassium

OBS	PER	AN	SUPP	ADD	TIME	PH	NH3	NA_mM	K_mM
1	1	1	m	c	2	6.00	23.66	56.5	110.0
2	1	1	m	c	4	6.28	17.52	43.5	81.8
3	1	1	m	c	6	6.37	11.55	47.8	74.2
4	1	1	m	c	8	6.57	5.62	60.9	84.4
5	1	1	m	c	12	6.71	2.71	69.6	58.8
6	1	1	m	c	16	6.61	4.12	73.9	56.3
7	1	1	m	c	24	6.87	3.61	91.3	38.4
8	1	2	m	b	2	6.16	22.20	43.5	94.6
9	1	2	m	b	4	6.35	15.61	34.8	81.8
10	1	2	m	b	6	6.52	7.40	43.5	74.2
11	1	2	m	b	8	6.53	1.10	47.8	61.4
12	1	2	m	b	12	6.78	1.71	47.8	48.6
13	1	2	m	b	16	6.59	3.95	60.9	61.4
14	1	2	m	b	24	6.68	4.09	60.9	56.3
15	1	3	c	c	2	6.75	24.40	113.1	38.4
16	1	3	c	c	4	6.69	18.93	113.1	38.4
17	1	3	c	c	6	6.69	9.83	113.1	35.8
18	1	3	c	c	8	6.41	4.27	108.7	33.2
19	1	3	c	c	12	6.57	5.41	113.1	43.5
20	1	3	c	c	16	6.42	5.75	121.8	38.4
21	1	3	c	c	24	6.64	7.66	126.1	23.0
22	1	4	c	b	2	6.85	9.84	108.7	35.8
23	1	4	c	b	4	6.71	14.25	113.1	46.0
24	1	4	c	b	6	6.53	2.39	113.1	30.7
25	1	4	c	b	8	6.46	1.59	108.7	25.6
26	1	4	c	b	12	6.59	5.76	117.4	38.4
27	1	4	c	b	16	6.65	4.95	113.1	33.2
28	1	4	c	b	24	6.81	6.92	126.1	28.1
29	2	1	m	b	2	6.15	18.68	69.6	84.4
30	2	1	m	b	4	6.56	19.55	78.3	71.6
31	2	1	m	b	6	6.65	14.45	87.0	74.2
32	2	1	m	b	8	6.79	8.06	91.3	71.6
33	2	1	m	b	12	6.81	3.39	91.3	51.2
34	2	1	m	b	16	6.82	6.79	100.0	58.8
35	2	1	m	b	24	6.94	5.09	113.1	40.9
36	2	2	c	b	2	6.77	30.33	87.0	61.4
37	2	2	c	b	4	6.59	18.92	78.3	43.5
38	2	2	c	b	6	6.48	10.45	82.6	51.2
39	2	2	c	b	8	6.23	3.58	87.0	40.9
40	2	2	c	b	12	6.45	3.77	87.0	30.7
41	2	2	c	b	16	6.47	6.97	95.7	53.7
42	2	2	c	b	24	6.61	8.55	82.6	38.4
43	2	3	m	c	2	6.66	10.39	108.7	53.7
44	2	3	m	c	4	6.47	46.80	104.4	66.5
45	2	3	m	c	6	6.40	19.98	91.3	61.4
46	2	3	m	c	8	6.28	14.17	95.7	66.5
47	2	3	m	c	12	6.20	6.34	91.3	58.8
48	2	3	m	c	16	6.29	4.18	100.0	56.3
49	2	3	m	c	24	6.65	8.80	108.7	51.2
50	2	4	c	c	2	6.88	9.83	117.4	35.8
51	2	4	c	c	4	6.68	23.82	113.1	30.7
52	2	4	c	c	6	6.51	16.43	113.1	25.6
53	2	4	c	c	8	6.46	11.37	117.4	23.0
54	2	4	c	c	12	6.51	6.57	121.8	23.0
55	2	4	c	c	16	6.46	9.12	108.7	33.2
56	2	4	c	c	24	6.72	7.52	121.8	28.1
57	3	1	c	c	2	6.92	30.51	108.7	35.8

Rumen Fluid: pH, ammonia, sodium and potassium

OBS	PER	AN	SUPP	ADD	TIME	PH	NH3	NA_mM	K_mM
58	3	1	c	c	4	6.88	30.18	104.4	25.6
59	3	1	c	c	6	6.69	15.72	113.1	23.0
60	3	1	c	c	8	6.47	6.21	117.4	25.6
61	3	1	c	c	12	6.69	4.41	113.1	23.0
62	3	1	c	c	16	6.65	9.52	108.7	38.4
63	3	1	c	c	24	6.69	8.77	121.8	7.7
64	3	2	m	c	2	6.34	21.46	52.2	99.7
65	3	2	m	c	4	6.14	17.55	43.5	89.5
66	3	2	m	c	6	6.31	12.29	43.5	94.6
67	3	2	m	c	8	6.43	5.86	47.8	99.7
68	3	2	m	c	12	6.48	3.42	52.2	102.3
69	3	2	m	c	16	6.58	7.23	52.2	104.9
70	3	2	m	c	24	6.73	5.75	60.9	102.3
71	3	3	c	b	2	6.89	17.80	113.1	43.5
72	3	3	c	b	4	6.90	21.92	113.1	40.9
73	3	3	c	b	6	6.74	14.34	117.4	120.2
74	3	3	c	b	8	6.64	16.28	113.1	40.9
75	3	3	c	b	12	6.57	3.90	117.4	35.8
76	3	3	c	b	16	6.56	8.81	113.1	46.0
77	3	3	c	b	24	6.92	6.98	121.8	35.8
78	3	4	m	b	2	6.54	22.81	82.6	89.5
79	3	4	m	b	4	6.46	21.64	82.6	89.5
80	3	4	m	b	6	6.58	12.18	82.6	84.4
81	3	4	m	b	8	6.64	5.74	78.3	71.6
82	3	4	m	b	12	6.74	3.06	82.6	53.7
83	3	4	m	b	16	6.80	7.47	87.0	81.8
84	3	4	m	b	24	6.95	4.82	100.0	46.0
85	4	1	c	b	2	7.02	47.58	108.7	43.5
86	4	1	c	b	4	6.51	23.11	113.1	38.4
87	4	1	c	b	6	6.53	7.21	113.1	33.2
88	4	1	c	b	8	6.43	1.48	113.1	30.7
89	4	1	c	b	12	6.41	3.69	126.1	28.1
90	4	1	c	b	16	6.49	6.61	113.1	38.4
91	4	1	c	b	24	6.71	12.95	126.1	30.7
92	4	2	c	c	2	6.79	41.55	60.9	76.7
93	4	2	c	c	4	6.25	23.34	60.9	76.7
94	4	2	c	c	6	6.10	10.33	65.2	74.2
95	4	2	c	c	8	5.96	3.46	69.6	74.2
96	4	2	c	c	12	6.12	1.58	69.6	69.1
97	4	2	c	c	16	6.16	3.91	69.6	76.7
98	4	2	c	c	24	6.50	4.42	78.3	81.8
99	4	3	m	b	2	6.92	7.15	104.4	56.3
100	4	3	m	b	4	6.62	14.11	91.3	51.2
101	4	3	m	b	6	6.46	22.66	100.0	81.8
102	4	3	m	b	8	6.45	14.10	87.0	74.2
103	4	3	m	b	12	6.71	3.23	95.7	66.5
104	4	3	m	b	16	6.61	5.33	91.3	53.7
105	4	3	m	b	24	6.76	4.48	108.7	46.0
106	4	4	m	c	2	6.53	20.06	91.3	92.1
107	4	4	m	c	4	6.48	17.91	78.3	76.7
108	4	4	m	c	6	6.48	11.68	82.6	76.7
109	4	4	m	c	8	6.51	5.72	82.6	76.7
110	4	4	m	c	12	6.80	2.78	91.3	58.8
111	4	4	m	c	16	6.66	4.87	95.7	61.4
112	4	4	m	c	24	6.83	3.80	104.4	48.6

PERIOD	ANIMAL	TIME	SUPPL	ADDIT	ACETIC	PROPIO	BUTYRI	ISOBUT	VALERI	ISOVAL	TOTAL
1	1	2	MOL	CON	69.4	17.2	12.2	0.13	0.54	0.54	105
1	1	4	MOL	CON	59.0	24.6	12.5	1.20	1.43	1.25	120
1	1	6	MOL	CON	68.6	17.2	12.6	0.32	0.80	0.40	73
1	1	8	MOL	CON	58.6	23.1	12.7	1.97	1.87	1.78	114
1	1	12	MOL	CON	65.9	16.9	10.4	1.81	2.28	2.71	94
1	1	16	MOL	CON	66.2	19.0	12.2	0.70	1.01	0.94	100
1	1	24	MOL	CON	58.9	21.7	11.1	2.64	2.36	3.24	110
1	2	2	MOL	BAM	64.9	19.7	13.6	0.23	1.06	0.58	117
1	2	4	MOL	BAM	65.9	18.9	13.5	0.27	1.01	0.50	92
1	2	6	MOL	BAM	68.6	17.3	12.8	0.11	0.99	0.23	87
1	2	8	MOL	BAM	70.0	15.9	11.6	0.35	1.44	0.68	83
1	2	12	MOL	BAM	75.7	13.3	9.7	0.05	0.79	0.45	58
1	2	16	MOL	BAM	71.1	16.7	9.4	0.77	0.96	0.95	107
1	2	24	MOL	BAM	77.0	13.9	6.8	0.64	0.62	1.03	80
1	3	2	COR	CON	70.3	16.7	9.5	0.99	1.20	1.24	142
1	3	4	COR	CON	73.9	14.0	10.0	0.73	0.60	0.74	101
1	3	6	COR	CON	70.8	15.9	10.3	0.87	0.96	1.18	108
1	3	8	COR	CON	69.1	17.9	10.1	0.59	1.11	1.21	112
1	3	12	COR	CON	69.7	17.3	10.2	0.84	0.91	1.10	112
1	3	16	COR	CON	69.1	16.7	11.2	0.81	1.05	1.16	126
1	3	24	COR	CON	71.7	14.9	10.3	0.91	0.88	1.34	109
1	4	2	COR	BAM	72.3	15.7	8.5	0.96	1.12	1.31	100
1	4	4	COR	BAM	75.2	14.6	7.8	0.70	0.79	0.87	104
1	4	6	COR	BAM	75.0	15.6	7.8	0.16	0.71	0.74	117
1	4	8	COR	BAM	73.8	16.3	7.7	0.50	0.71	0.90	107
1	4	12	COR	BAM	74.0	15.9	7.9	0.55	0.69	0.90	100
1	4	16	COR	BAM	71.2	16.6	8.6	0.99	1.23	1.44	108
1	4	24	COR	BAM	75.1	15.4	6.9	0.61	0.60	1.43	98
2	1	2	MOL	BAM	66.4	18.6	11.5	0.89	1.34	1.24	114
2	1	4	MOL	BAM	66.5	18.7	12.6	0.59	0.89	0.67	117
2	1	6	MOL	BAM	70.2	15.6	13.3	0.25	0.69	0.05	105
2	1	8	MOL	BAM	71.1	14.2	13.1	0.37	0.81	0.44	88
2	1	12	MOL	BAM	73.2	13.5	11.3	0.44	0.86	0.62	79
2	1	16	MOL	BAM	76.5	11.7	9.9	0.47	0.73	0.71	90
2	1	24	MOL	BAM	71.8	14.9	8.8	1.24	1.08	2.13	69
2	2	2	COR	BAM	75.4	12.9	9.1	0.76	1.01	0.91	95
2	2	4	COR	BAM	74.8	13.4	9.7	0.69	0.65	0.77	72
2	2	6	COR	BAM	74.6	15.6	8.8	0.43	0.44	0.13	89
2	2	8	COR	BAM	71.5	18.3	9.1	0.34	0.26	0.56	92
2	2	12	COR	BAM	70.5	18.0	9.8	0.53	0.44	0.78	72
2	2	16	COR	BAM	72.7	15.6	9.7	0.61	0.68	0.74	99
2	2	24	COR	BAM	70.4	16.6	9.6	0.99	0.96	1.42	112
2	3	2	MOL	CON	72.7	14.1	10.6	0.65	0.92	1.07	87
2	3	4	MOL	CON	69.2	17.4	10.5	0.70	1.04	1.15	124
2	3	6	MOL	CON	68.0	19.2	10.7	0.41	0.79	0.85	99
2	3	8	MOL	CON	69.7	18.0	10.7	0.28	0.72	0.67	115
2	3	12	MOL	CON	70.9	16.8	10.9	0.15	0.70	0.52	114
2	3	16	MOL	CON	71.0	16.2	11.1	0.11	0.88	0.75	109
2	3	24	MOL	CON	72.7	14.7	10.0	0.58	0.90	1.05	102
2	4	2	COR	CON	72.8	12.6	11.7	0.77	0.94	1.18	85
2	4	4	COR	CON	72.6	12.6	12.3	0.65	0.82	0.94	82
2	4	6	COR	CON	72.1	13.5	12.3	0.63	0.71	0.79	87
2	4	8	COR	CON	70.7	14.5	12.6	0.66	0.70	0.84	93
2	4	12	COR	CON	71.3	14.1	12.6	0.53	0.60	0.84	87

Data of Individual (M/100 M) and Total VFA (M)

PERIOD	ANIMAL	TIME	SUPPLEMENT	ADDITIVE	ACETIC	PROPIONIC	BUTYRIC	ISOBUTYRIC	VALERIC	ISOVALERIC	TOTAL
2	4	16	COR	CON	72.9	14.1	12.3	0.64	0.00	0.00	100
2	4	24	COR	CON	71.7	13.9	11.5	0.86	0.71	1.28	85
3	1	2	COR	CON	74.1	12.8	10.0	0.88	0.97	1.25	89
3	1	4	COR	CON	70.9	14.3	11.4	1.04	1.00	1.42	82
3	1	6	COR	CON	70.8	15.5	11.3	0.76	0.74	1.03	99
3	1	8	COR	CON	70.4	15.0	12.4	0.66	0.58	0.97	96
3	1	12	COR	CON	69.2	14.3	14.0	0.78	0.47	1.17	81
3	1	16	COR	CON	70.4	13.9	13.1	0.71	0.79	1.07	104
3	1	24	COR	CON	72.2	13.3	11.4	0.97	0.64	1.55	94
3	2	2	MOL	CON	69.4	18.1	10.6	0.35	0.84	0.66	104
3	2	4	MOL	CON	67.2	18.2	11.8	0.69	1.12	1.00	91
3	2	6	MOL	CON	70.8	16.5	11.4	0.24	0.90	0.23	91
3	2	8	MOL	CON	72.9	14.6	11.4	0.20	0.82	0.19	91
3	2	12	MOL	CON	73.7	14.1	11.0	0.21	0.75	0.30	96
3	2	16	MOL	CON	75.6	12.7	10.1	0.31	0.86	0.52	97
3	2	24	MOL	CON	75.0	13.7	9.0	0.61	0.69	1.03	87
3	3	2	COR	BAM	74.9	12.7	9.6	0.64	0.87	1.26	99
3	3	4	COR	BAM	74.3	12.4	10.7	0.88	0.66	1.03	81
3	3	6	COR	BAM	73.5	13.1	11.0	0.79	0.60	0.96	91
3	3	8	COR	BAM	71.7	14.5	11.5	0.66	0.66	0.96	99
3	3	12	COR	BAM	70.6	16.4	11.1	0.45	0.52	0.91	105
3	3	16	COR	BAM	71.1	16.1	10.8	0.38	0.68	0.88	127
3	3	24	COR	BAM	71.9	14.7	10.6	0.86	0.65	1.29	95
3	4	2	MOL	BAM	69.3	19.0	9.9	0.41	0.70	0.64	99
3	4	4	MOL	BAM	69.3	19.3	9.9	0.29	0.76	0.45	128
3	4	6	MOL	BAM	69.9	17.9	10.8	0.29	0.73	0.35	106
3	4	8	MOL	BAM	71.7	16.3	10.9	0.21	0.53	0.32	95
3	4	12	MOL	BAM	72.9	14.8	10.9	0.32	0.62	0.45	89
3	4	16	MOL	BAM	71.5	15.7	10.9	0.47	0.77	0.72	85
3	4	24	MOL	BAM	75.1	14.0	8.8	0.35	0.58	1.13	86
4	1	2	COR	BAM	74.9	13.8	8.7	0.76	0.67	1.18	85
4	1	4	COR	BAM	74.2	15.0	8.7	0.58	0.58	0.89	93
4	1	6	COR	BAM	73.4	16.3	8.5	0.45	0.45	0.86	89
4	1	8	COR	BAM	72.9	16.9	8.5	0.36	0.48	0.91	97
4	1	12	COR	BAM	72.7	16.2	9.1	0.39	0.45	1.09	102
4	1	16	COR	BAM	72.5	15.6	9.3	0.74	0.61	1.24	104
4	1	24	COR	BAM	76.0	13.2	8.3	0.61	0.49	1.44	90
4	2	2	COR	CON	77.5	12.4	8.5	0.33	0.51	0.78	111
4	2	4	COR	CON	76.7	13.3	8.6	0.34	0.39	0.66	106
4	2	6	COR	CON	76.7	13.9	8.3	0.24	0.33	0.51	100
4	2	8	COR	CON	76.4	14.2	8.3	0.25	0.29	0.56	108
4	2	12	COR	CON	75.3	14.2	9.2	0.33	0.31	0.70	101
4	2	16	COR	CON	76.2	13.6	9.0	0.18	0.39	0.66	109
4	2	24	COR	CON	77.5	13.0	7.9	0.38	0.36	0.91	98
4	3	2	MOL	BAM	77.4	13.5	7.2	0.68	0.00	1.27	81
4	3	4	MOL	BAM	74.6	15.1	8.4	0.40	0.55	1.04	94
4	3	6	MOL	BAM	73.2	15.9	9.3	0.21	0.51	0.84	99
4	3	8	MOL	BAM	72.8	16.2	9.5	0.19	0.46	0.77	104
4	3	12	MOL	BAM	75.8	13.8	9.1	0.20	0.38	0.74	89
4	3	16	MOL	BAM	75.9	13.8	8.3	0.49	0.59	0.91	102
4	3	24	MOL	BAM	75.9	14.3	7.1	0.67	0.61	1.41	97
4	4	2	MOL	CON	74.4	15.0	9.4	0.26	0.50	0.48	96

Data of Individual (M/100 M) and Total VFA (M)

PERIOD	ANIMAL	TIME	SUBSTRATE	ACID	ACETIC	PROPIONIC	BUTYRIC	VALERIC	ISOVALERIC	TOTAL
4	4	4	MOL	CON	72.1	16.7	10.1	0.23	0.53	0.31	94
4	4	6	MOL	CON	74.6	14.8	9.8	0.16	0.37	0.23	99
4	4	8	MOL	CON	75.8	13.8	9.6	0.21	0.43	0.22	90
4	4	12	MOL	CON	76.8	13.0	9.0	0.31	0.47	0.48	78
4	4	16	MOL	CON	79.0	11.8	8.0	0.22	0.49	0.50	90
4	4	24	MOL	CON	79.2	12.6	6.3	0.45	0.49	0.92	79

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BIOGRAPHICAL SKETCH

Osvaldo Balbuena was born April 18, 1955, in Avellaneda, Buenos Aires Province, Argentina. He grew up in the rural community of Ita Ibate, Corrientes Province, Argentina. He attended high school and college at Corrientes City. He received his veterinary medicine degree from the Universidad Nacional del Nordeste in 1978. The following year he was awarded a scholarship to learn research techniques in ruminant pathology at the Instituto Nacional de Tecnologia Agropecuaria (INTA). He has been permanent researcher at INTA since 1983 and has worked in mineral deficiencies of beef cattle in Formosa and Chaco provinces. He later came to the University of Florida and in 1988 he received his M.S. degree under Dr. L.R. McDowell. After his return to Argentina he continued his work with mineral deficiencies and started to conduct on-farm research with protein-energy supplementation of beef cattle grazing rangelands. He has been a research coordinator at Colonia Benitez Experimental Station since 1989.

In December 1993 he was awarded a thirty-month scholarship from INTA and came back to Florida, with his family, to pursue the Ph.D. degree under Dr. W.E. Kunkle.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William E. Kunkle, Chair
Professor of Animal Science

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