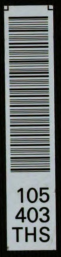

This is to certify that the

dissertation entitled

Site of Digestion of Corn, Barley
or Bromegrass Based Diets in Steers

presented by

Julio Correa-Gumbe

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Animal Science

Werner G. Bergen
Major professor

Date 8/26/87

SITE OF DIGESTION OF CORN, BARLEY OR BROMEGRASS BASED DIETS IN STEERS

By

Julio E. Correa-Gumbe

A DISSERTATION

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

Department of Animal Science

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DEDICATION

To my beloved children Julio, Jorge and Roxana,

who are my life and inspiration.

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ABSTRACTS

SITE OF DIGESTION OF CORN, BARLEY OR BROMEGRASS BASED DIETS IN STEERS

By

Julio E. Correa-Gumbe

Experiment I

Four Holstein steers (475 kg) fitted with T-type cannulas in the proximal duodenum were utilized in a switch back design to study site and extent of digestion of corn-based (C-BD) and barley-based (B-BD) diets. Total tract nitrogen (N) and acid detergent fiber (ADF) apparent digestibility were $P < .05$ and $P < .01$ greater for the C-BD than the B-BD while ruminal starch apparent digestibility was $P < .07$ greater for the B-BD than the C-BD. Intestinal apparent digestibility of dry matter (DM), N and starch were $P < .05$ greater for the C-BD than B-BD. The nonamonia N (NAN) flow exceeded N intake by 15% for both diets. This demonstrates that high concentrate diets with low rumen available N will utilize recycled N for bacterial biomass synthesis. For B-BD, the lower ADF apparent digestibility suggested strong associative effects.

Experiment II

Four Holstein steers (345 kg), fitted with T-type cannulas in the proximal duodenum, were utilized in a 4 x 4 Latin square design to study site and extent of digestion of a low NEg diet supplemented with 33 ppm of either Narasin, Actaplanin or a combination of the two drugs. Total tract dry matter (DM) and acid detergent fiber (ADF) apparent digestibilities were P = .05 greater for the control and narasin steers than for the actaplanin and the combination steers, while ruminal DM and nitrogen (N) apparent digestibilities were P = .05 greater for steers fed control and narasin. Intestinal apparent digestibility of DM and ADF was P = .05 greater for steers fed control and narasin diets than those fed actaplanin and combination diets. Results demonstrate that feeding these additives results, for some of the digestion parameters, in responses similar to those noted for the approved feed additives Rumensin and Bovatec.

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INTRODUCTION

Although barley's feeding value for ruminants is appreciably less in most cases than corn or sorghum, the potential for use of crops such as barley grain in livestock diets has increased in recent years, particularly in Scotland, North Europe and the cooler climates of North America. Therefore, the digestion of nutrients in the gastrointestinal tract of steers fed corn- or barley-based high grain diets was evaluated.

The influence of ionophore feed additives on ruminal and postruminal nutrient digestion and ruminal microbial protein production was also evaluated with other types of ionophores. Previous investigations with monensin showed that protein escape from ruminal degradation (rumen bypass) was enhanced but microbial protein production was depressed.

Adequate site of digestion studies involve digesta passage studies through the length of the gastrointestinal tract. With the proper application of indigestible markers, digestive activities can be partitioned between the rumen-abomasum, small intestine and large intestine.

The objectives of these studies were to examine the site and extent of nutrient digestion of corn- and barley-based diets in the gastrointestinal tract of steers, and to examine

the effects of narasin, actaplanin and ionophore combination on digestive activity in steers fed a low quality diet. Particular attention was given to effects of diets and effects of additives on nitrogen digestion and microbial protein reaching the duodenum.

LITERATURE REVIEW

Rumen Metabolism of Nitrogenous Compounds

The metabolism of nitrogenous compounds in the rumen is very complex. This is due to the many forms of dietary nitrogen and their complex transformations by a large number of microbial species involved. Numerous reviews on nitrogen (N) metabolism in the rumen and in the ruminant have appeared in the literature (Tamminga, 1979; Ørskov, 1982; Owens and Bergen, 1983).

Dietary Nitrogen

Plant N is divided into two main categories, primarily protein and non-protein nitrogen (NPN) in form. True protein makes up about 60 to 80% of the total N in fresh plants, with soluble NPN and a small amount of lignified N making up most of the remainder (Van Soest, 1982).

Plant proteins can be classified into two main groups, leaf and stem proteins, and seed proteins. The seed proteins are the main plant proteins. However, most oil-bearing seeds are low in cystine and methionine and have a variable and usually low lysine content; soybean seeds are an exception in that they are relatively high in lysine content. The protoplasmic proteins of leaves and stems represent the enzymatic

machinery of plant metabolism and are of high quality in contrast to storage proteins of plant seeds (Van Soest, 1982).

The soluble NPN fraction of fresh forage is composed of nitrate, free essential amino acids and non-essential amino acids, with glutamine, asparagine and γ-aminobutyric acid often predominating (Van Soest, 1982). In fermented silages and hays, these may be replaced or added to by ammonia (NH_3) and numerous amines.

The existence of nucleic acids and other insoluble forms of NPN should not be overlooked. Smith and McAllan (1970) and Coelho da Silva et al. (1972) reported results of studies with fresh grass, hay and dried grass containing 5.2 to 9.5% of their total N in deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Fermented products that may be enriched in microbial matter probably contain more nucleic acid N.

Ruminal Protein Degradation

The rumen microflora is highly proteolytic. Dietary protein entering the rumen is extensively degraded by both bacteria and protozoa. Initially, the protein chain is broken by hydrolysis of peptide bonds (proteolysis), resulting in peptides and amino acids, most of which are subsequently further hydrolyzed and deaminated.

The mechanism of protein degradation differs somewhat between bacteria and protozoa. In a review, Tamminga (1979) discussed mechanisms of protein degradation with bacteria and

protozoa. With bacteria the protein chain is broken into smaller parts by hydrolysis of some or all of its peptide bonds. This process takes place outside the bacterial cell. The resulting peptides and amino acids are transported inside the bacterial cells and peptides are hydrolysed further to amino acids. The amino acids in turn are either incorporated into bacterial protein or degraded to volatile fatty acids (VFA), NH_3, carbon dioxide (CO_2), methane (CH_4) and some fermentation heat. End products of this degradation are excreted back into the surrounding medium.

The rumen ciliate protozoa engulf bacteria and use these as a source of amino acids and possible other growth factors (Coleman, 1975). Large species of protozoa may also engulf and use plant proteins directly. Proteolysis of dietary protein takes place inside the protozoal cell. If the resulting amino acids are not incorporated into protozoal protein they are often excreted into the surrounding medium rather than being degraded further (Coleman, 1975).

Information concerning microorganisms responsible for proteolysis and the nature of microbial proteases has been summarized (Hobson and Wallace, 1982). Species of Bacteroides, Butyrivibrio and Selenomonas appear to be the more potent proteolytic rumen bacteria. Rumen bacterial proteases are cell bound and all possess endo- and exo-peptidase activity (enzymes which act to some degree on peptide bonds adjacent to a terminal amino or carboxyl group). Bacterial

proteases are constitutive enzymes which do not appear to be subject to metabolic control, hence, the enzymatic machinery necessary for ruminal degradation can be anticipated to be present under most conditions (Chalupa, 1975).

Proteolytic protozoa include species of Entodinium, Isotrichia, Eudiplodinium and Ophryoscolex, but little is known of the nature of the enzymes (Allison, 1970). Proteolytic enzymes enable rumen protozoa to digest bacterial protein, which is the major source of amino acids for growth of these microbes (Allison, 1970).

Information on ruminal degradation of amino acids has been reviewed by several authors (Blackburn, 1965; Allison, 1970; Bryant, 1970; Leng, 1973). Deaminative activity occurs less frequently in rumen bacterial strains than does proteolytic activity. The more active deaminating bacteria appear to be Selenomonas ruminantium, Bacteroides ruminicola, Megasphaera elsdenii and some strains of Butyrivibrio fibrisolvens. There is evidence of amino acid catabolism by rumen protozoa, but information is limited.

The reason that microorganisms in the rumen hydrolyze dietary protein and further degrade its amino acids is not well understood. Possibly degradation of protein is necessary to provide microbes with required precursors for their own protein synthesis, either NH_3 and presumably α-keto acids or even intact amino acids (Tamminga, 1979). However, degradation is often in excess of these requirements, probably because

degradation of amino acids make VFA, which can be utilized by microbes for their synthetic processes (Tamminga, 1979).

The degradation of dietary protein in the forestomachs of ruminants is influenced by a number of factors, some of which are related to diet, others to the animal. An important dietary factor seems to be the solubility of the protein. Solubility of feed protein is partly determined by the relative amount of soluble albumins and globulins on the one hand, and the less soluble prolamins and glutelins on the other (Tamminga, 1979). Feeds whose major protein fractions are albumins and globulins have a higher protein solubility than feeds containing mainly prolamines and glutelins in their protein (Wohlt et al., 1976). This has a special significance for the ruminant because solubility generally renders the N more available for microbial metabolism.

Solubility of feed protein is further affected by treatments during manufacturing, both of forages and of concentrates. Synthetic means of decreasing protein solubility include heat treatment or treatment with chemical agents such as formaldehyde and tannins, which form ligand-protein complexes. The induction of insoluble protein through heat or by complexing decreases rate of proteolytic hydrolysis, not only through reduced accessibility of the substrate, but also through the formation of linkages resistant to enzymatic attack. Treated proteins subsequently are made available to the host by destruction of these linkages in the acidic abomasum.

However, induction of resistant linkages has the risk that the availability of protein is permanently reduced, and it becomes a part of the ultimately indigestible residue.

Another factor contributing to differences in apparent ruminal degradation of proteins is the length of time protein is retained in the rumen. Ruminal degradation of proteins can be diminished by decreasing retention times in the rumen. Factors known to influence the rate of passage of digesta include level of feed intake, particle size of the dietary ingredients, rate of protein digestion in the rumen, and specific gravity (Balch and Campling, 1965). The quantitative effect of level of feed intake on bypass of feed N was recently studied by Zinn and Owens (1983). In that trial, a high concentrate diet was fed at 1.2, 1.5, 1.8 and 2.1% of body weight to four Angus steers (258 kg) equipped with cannulas in the proximal duodenum and distal ileum. Percentage feed N escaping degradation in the rumen increased from 43.8 to 70.6% as level of feed intake increased. In a study with dairy cows fed mixed diets of long meadow hay and concentrates, Tamminga et al. (1979) also reported that a higher proportion of the dietary N appeared undegraded in the small intestine at the higher level of intake. These studies clearly indicate that increasing intakes result in decreasing protein degradation, probably due to an increased rate of passage of digesta through the forestomachs.

Rumen Microbial Protein Synthesis and Nitrogen Passage to the Lower Digestive Tract

The ruminant is unique in its ability to convert dietary N to microbial protein, which can subsequently be utilized by the animal. When dietary protein is supplied by NPN or is of poor amino acid balance, this interchange is advantageous to the animal. However, this cycle is a disadvantage when dietary protein is of high quality. Of the protein reaching the duodenum, 40 to 80% is microbial crude protein (MCP), depending on several dietary and animal factors (Owens and Bergen, 1983).

The preceding section has indicated that in the rumen protein is rapidly hydrolyzed to amino acids, which are then deaminated to NH_3. The rumen microbial population usually forms much of its amino acids from NH_3. If necessary, it can even function entirely free from dietary amino acids. This was emphatically demonstrated by Virtanen (1966) with dairy cows reared on diets containing only urea and ammonium salts as sources of N. Of microbial N in the rumen, 30 to 80% of bacterial N and 25 to 64% of protozoal N may be derived from ruminal NH_3 (Nolan, 1975).

Synthesis of amino acids from NH_3 by rumen microorganisms require the use of NH_3, carbon skeletons and energy. The first stage in the synthesis of microbial amino acids from NH_3 is the uptake of NH_3 from the extracellular fluid. Following uptake into the cell, there are several ways in

which NH_3 might be assimilated into amino acids. The following are the principal reactions of NH_3 fixation in rumen bacteria (Zubay, 1983):

1. α-KETOGLUTARATE + NH_4^+ + NADPH + H^+ → GLUTAMATE + $NADP^+$ + H_2O (CATALYZED BY GLUTAMATE DEHYDROGENASE)

2. GLUTAMATE + NH_4^+ + ATP → GLUTAMINE + ADP + Pi + H^+ (CATALYZED BY GLUTAMINE SYNTHETASE)

3. GLUTAMINE + α-KETOGLUTARATE + NH_4^+ + NADPH + H^+ → 2 GLUTAMATE + $NADP^+$ (CATALYZED BY GLUTAMATE SYNTHASE)

Based on current information, glutamate dehydrogenase is the mayor NH_3 fixation mechanism in ruminal bacteria. However, the pathway involving glutamine synthetase appears to be especially important at low NH_3 concentrations since glutamine synthetase has a greater affinity for NH_3 than does glutamate dehydrogenase, and glutamine synthetase levels increase when NH_3 levels decline (Allison, 1982). An additional mole of ATP is required for each mole of NH_3 fixed via the glutamine synthetase pathway.

Much of the available literature indicates that after NH_3 is assimilated into glutamate, it is then transferred to other carbon skeletons by transaminases. Carbon for amino acid biosynthesis probably comes mainly from intermediates produced during carbohydrate fermentation (especially phosphoenolpyruvate) and from fermentation end products (especially CO_2 and

acetate) (Allison, 1969). However, several rumen bacteria can synthesize amino acids from exogenous precursors, such as the branched-chain VFA phenylacetate (Allison, 1965) and indoleacetate (Allison and Robinson, 1967).

Based on previous results with cell-free extracts of both M. elsdenii and B. ruminicola, carboxylate acetate, isovalerate, 2-methylbutyrate, phenylacetate and indoleacetate to produce the keto acids which are aminated to form alanine, leucine, isoleucine, phenylalanine and tryptophan, respectively, is accomplished by reductive carboxylation reactions similar to those functional with isobutyrate (Allison, 1969). However, carbon skeletons of these amino acids are also synthesized by pathways other than the reductive carboxylation mechanism, and the other pathways (perhaps like those described for aerobic organisms) may be of equal or more importance quantitatively in the mixed microbial population (Allison, 1969). Possibly carbon skeletons of amino acids other than those above are synthesized by reductive carboxylation reactions.

The following proposed sequence of reactions for the reductive carboxylation is based upon information obtained with M. elsdenii extracts and upon studies with "pyruvate synthase" and the "clastic" system in other microorganisms (Allison, 1969):

1. $R\text{-}COOH + ATP \rightarrow R\text{-}CO\text{-}OPO_3H_2$
2. $R\text{-}CO\text{-}OPO_3H_2 + CoASH \rightarrow R\text{-}CO\text{-}S\text{-}CoA$
3. $R\text{-}CO\text{-}S\text{-}CoA + THIAMINE\ PYROPHOSPHATE\ (TPP)\text{-}ENZYME \rightarrow R\text{-}CO\text{-}TPP\text{-}ENZYME + CoASH$
4. $R\text{-}CO\text{-}TPP\text{-}ENZYME + 2FdH \rightarrow R\text{-}CHOH\text{-}TPP\text{-}ENZYME + 2Fd$
5. $RCHOH\text{-}TPP\text{-}ENZYME + CO_2 \rightarrow R\text{-}CO\text{-}COOH + TPP\text{-}ENZYME$

Several studies have indicated that although the mixed bacterial population uses NH_3 as its main nitrogenous nutrient it may also use, in part, preformed amino acids or peptides if these are available (Nolan and Leng, 1972). The degrees to which NH_3, amino acids or even peptides may constitute starting points for synthesis of microbial N in normally fed ruminants have not been ascertained, but could be expected to vary with the nature of the diet and possibly with the particular animals under observation. Pilgrim et al. (1970) concluded that synthesis of microbial protein was more dependent on NH_3 as a starting point with a low-N diet than with a higher-N diet. However, even though bacterial protein synthesis will occur in the rumen on diets in which urea is virtually the only N source, the extent of this synthesis may sometimes be limited by a deficiency of amino acids or other carbon skeletons in a preformed state (Salter et al., 1979). Furthermore, Salter et al. (1979) reported that when adequate supply of preformed units was available (particularly on a high-protein diet) proline (pro), arginine (arg), histidine (his), methionine (met) and phenylalanine (phe) were derived

in this way to a greater extent than the other amino acids, but synthesis of pro, arg and his increased on a low-protein diet, that of met and phi did not. Thus, met and phe may be limiting for baterial growth on diets low in protein and high in NPN.

The protein supply in ruminants is mainly determined by the amount of protein entering the small intestine, which is the result of feed protein escaping microbial degradation, microbial protein synthesized in the forestomachs, and endogeneous protein. In ruminant feeding, an important factor determining the amount of N flowing from the rumen into the duodenum is the level of feed intake. In a study with dairy cows fed mixed diets of long meadow hay and concentrates, Tamminga et al. (1979) reported that at higher feed intake (12.9 kg of DM/day), the flow of N into the small intestine as a proportion of the N ingested was greater than at the lower level of feed intake (8.2 kg of DM/day). The regression equations and the ratio diaminopimelic acid (DAPA)/N in duodenal digesta indicate that increased flow of N into the small intestine mainly resulted from a decreased degradation of dietary protein due to an increased rate of passage of digesta through the forestomachs. More recently, Zinn and Owens (1983) determined the influence of level of feeding on N metabolism in steers fed an 80% concentrate diet. Increasing level of feed intake resulted in linear increases ($P < .01$) in flow of N, nonammonia N (NAN), microbial N and feed N to

the small intestine. The flow of N increased from 57.8 to 141.5 g/d, the NAN flow increased from 52.6 to 132.4 g/d, and the flow of microbial N increased from 25.5 to 49.5 g/d, as the level of feed intake increased from 1.2 to 2.1% of body weight, respectively. Percentage feed N escaping degradation in the rumen increased from 43.8 to 70.6% as level of feed intake increased. As level of feed intake increased from 1.2 to 1.8% of body weight, microbial efficiency increased from 18.7 to 24.7 g of microbial N per kg of organic matter (OM) digested in the rumen. Increasing intake further, however, resulted in a decrease in microbial efficiency to 22.2 g of microbial N per kg of OM digested in the rumen. Consequently, the overall nature of the response of microbial efficiency to level of feeding was cubic ($P < .07$). Lack of linearity suggests that other factor influence microbial growth.

Based on literature reviews on N metabolism, other factors most likely to influence the flow of N into the small intestine are the roughage/concentrate ratio (type of diet), concentration of protein in the diet, and type of protein (Tamminga et al., 1979; Redman et al., 1980; Tamminga, 1981; Zinn et al., 1981).

Corn versus Barley Diets

Cereal grains make up around 80% of animal feed concentrates and these cereal grains are produced by members of the grass family (Gramineae) grown primarily for their seeds. Of these, corn (Zea mays) is by far the most extensively produced cereal grain. A tremendous tonnage is produced in North America and, most is used as animal feed. The important commercial types are dent, sweet and pop corn. Sweet and pop corn are primarily grown for human consumption. Yellow dent corn is the predominant feed grain type. Corn is a very digestible palatable feed relished by all domestic animals.

Barley (Hordeum vulgare) is also a very palatable feed for ruminants and horses, particularly when rolled before feeding, and few digestive problems result from its use. Barley is widely grown in Europe and in the cooler climates of North America and Asia. Although a small amount goes into human food and a substantial amount is used in the brewing industry for the production of malt, most of it is used for animal feed.

Barley has a higher protein content, and except for the leucine and threonine content contains more other essential amino acids than corn (table 1). However, its feeding value for ruminants is appreciably less in most cases than corn.

TABLE 1. CHEMICAL COMPOSITION OF CORN AND BARLEY[a]

Item	Corn, dent	Barley, grain
	% of DM	
Crude protein	10.2	13.0
Crude fiber	2.3	6.0
Ether extract	4.4	1.9
Starch	72.2	64.6
Essential amino acids		
Arginine	0.45	0.53
Cystine	0.09	0.18
Histidine	0.18	0.27
Isoleucine	0.45	0.53
Leucine	0.99	0.80
Lysine	0.18	0.53
Methionine	0.09	0.18
Phenylalanine	0.45	0.62
Threonine	0.36	0.36
Tryptophan	0.09	0.18
Valine	0.36	0.62
Minerals		
Calcium	0.03	0.08
Phosphorus	0.31	0.45
Potassium	0.33	0.55
Magnesium	0.15	0.15

[a]Analytical data taken from NRC publications.

This is in part due to its lower starch and greater fiber content.

Digestion trials have shown that corn diets have a greater nutrient digestibility than barley diets. In a study with crossbred steers (285 kg) fed a basal 84% cracked corn diet, Galyean et al. (1979a) reported values averaging 81.6, 95.5 and 76.8% respectively for total tract dry matter (DM), starch and crude protein (CP) digestion. On the other hand, in a study with Hereford steers (260 kg) fed an 84.7% dry rolled barley diet, Saba et al. (1964) reported values of 74.5, 87.5 and 67.9% for total tract DM, starch and CP digestion respectively. Furthermore, National Research Council (NRC) publications gives respective total digestible nutrients (TDN) value of 91.0% and 80.8 indicating barley has 88.7% the value of corn.

The available literature suggests that diets containing corn are fermented in the rumen to a much lesser extent than are barley diets. Ørskov et al. (1971) obtained results which suggest that greater quantity of dietary protein escaped the rumen undegraded with corn diets than with barley diets. This may be due to the lower DAPA/N ratio in abomasal fluid obtained when the lambs were given corn in place of barley, and also to the tendency of a closer similarity between the amino acid composition of the diet and that of the abomasal fluid for corn-fed than for barley-fed lambs. If the concentration of DAPA can be taken as some measure of the

proportion of microbial protein, then barley feeding leads to a higher proportion of microbial protein in abomasal fluid than does corn feeding.

Ionophores

An ionophore is any molecule that increases the permeability of cell membranes to a specific ion (as defined in Dorland's Illustrated Medical Dictionary). As applied to animal agriculture ionophores constitute a group of compounds presently used as feed additives for several purposes in various animals. Monensin, a polyether ionophore, has been extensively tested in cattle for efficacy and has been widely used in feedlot cattle since 1975. Lasalocid, another polyether ionophore, is now being marketed for use as a ruminant feed additive. References to monensin and lasalocid will be made subsequently in this review.

Two newer ionophores recently cleared for commercial feeding of cattle, salinomycin and narasin, have received limited research attention. Salinomycin has improved beef cattle performance (McClure et al., 1980) and produced changes in rumen VFA similar to those produced by monensin (Fontenot et al., 1980). Narasin is also similar to monensin (Potter et al., 1979), but appears to be more potent than monensin.

Although not an ionophore, avoparcin is a glycopeptide antibiotic that has improved efficiency of gain in feedlot cattle by 5% (Owens and Gill, 1981). Actaplanin, a compound similar to avoparcin, is currently being tested as an additive

to increase level and efficiency of milk production by dairy cows (McGuffey et al., 1983a,b). Neither of these two glycopeptides is yet approved for use in the U.S., although avoparcin is widely used in Europe as a feed additive.

Other chemical agents such as the halogen-containing chemicals, diaryliodonium chemicals, certain antibiotics, agricultural chemicals and antiprotozoal agents, are discussed in a review by Chalupa (1980). However, due to their intensive investigation in recent years, only the effects of monensin and lasalocid will be examined in this review. Throughout the remainder of this review, the terms monensin and lasalocid will be used to represent the sodium salt of monensin and lasalocid.

Effects on Performance of Feedlot Cattle

Responses in feed efficiency and (or) growth to monensin and lasalocid in cattle under feedlot conditions have been consistent. The addition of monensin to feedlot diets has improved feed efficiency by reducing feed intake without adversely affecting growth rate (Raun et al., 1976; Boling et al., 1977). Feedlot cattle diets that contain lasalocid also have reduced feed intake while causing either no change or an increase in growth rate (Berger et al., 1981).

Although limited data are available, responses in performance to monensin and lasalocid in cattle under pasture conditions have also been consistent. Potter et al. (1976) conducted three grazing trails with steers and fed 0, 100, 200

or 400 mg monensin/head/day in the first trial, 0, 50, 100 or 200 mg monensin/head/day in the second trial and 0, 50, 100, 200, 300 or 400 mg monensin/head/day in a third trial. Average daily gains of cattle fed 100 or 200 mg monensin/head/day were greater ($P < .01$) than gains for control cattle. Spears and Harvey (1984) fed steers 0, 200 or 300 mg lasalocid/head/day in .91 kg of ground corn while grazing a mixture of tall fescue, orchard grass and ladino clover pasture. All lasalocid fed cattle gained faster ($P < .05$) than controls. Lasalocid at levels of 200 and 300 mg/d improved gains by 18.9 and 13.5%, respectively, when compared with the control treatment. No significant difference was found between 200 and 300 mg/d lasalocid.

Results clearly indicate that monensin and lasalocid will increase gains in growing beef steers grazing pasture. However, because forage intake was not measured in any of the above trials, no inference can be made as to whether the improvement in gain observed resulted from an increased efficiency, increased forage intake or a combination of these two factors.

Effects on Ruminal Fermentation

Monensin and lasalocid effectively alter rumen fermentation. Richardson et al. (1976) demonstrated that monensin increased molar proportion of propionate and decreased molar proportions of both acetate and butyrate in ruminal fermentation. Like monensin, lasalocid has been shown to decrease

acetate and increase propionate concentrations, leading to a decreased acetate: propionate (A:P) ratio (Bartley et al., 1979; Fuller and Johnson, 1981). This modification of VFA has been theorized as being beneficial to the efficiency of production in ruminants (Bergen and Bates, 1984).

Propionate fermentation is more energetically efficient and theoretically reduces the large loss of CH_4 associated with the production of acetate and butyrate (Hungate, 1966). Apart from the energy savings associated with the fermentation which yields propionate, the efficiency of utilization of propionate in the ruminant tissues has been reported to be greater than that of acetate (Blaxter, 1962), but is now known to be equal. Also, propionate may sometimes be used for gluconeogenesis in addition to direct oxidation by the citric acid cycle. This would also increase the efficiency of absorbed amino acids. Having more substrate for glycolysis may provide significant energetic advantages to the ruminant at certain times by generating more reduced coenzyme outside the metochondrial membrane (Schelling, 1984). However, this has been demonstrated only when [^{3}H]-propionate was infused alone.

Is unlikely that the effect on VFA production could account for all of the animal performance response normally observed. An improvement in N utilization may account for some of the benefits of feeding monensin. In vitro and in vivo studies have indicated that monensin significantly

reduces feed protein degradation and NH_3 production in the rumen (Van Nevel and Demeyer, 1977; Poos et al., 1979). This suggests that monensin may spare dietary protein by decreasing ruminal proteolysis, hence, altering the final site of protein digestion in the animal (Isichei and Bergen, 1980). However, this could only happen if an improved array of amino acids were absorbed and available for anabolism.

Monensin feeding has also been shown to decrease the efficiency of rumen microbial protein synthesis (Isichei and Bergen, 1980). Monensin addition decreased bacterial N and increased plant N reaching the abomasum of steers fed brewers dried grains (BDG) and urea supplemented diets (Poos et al., 1979). This effect could be a disadvantage depending on the nature of the diet and the amount of protein escaping rumen degradation. The effect of lasalocid on intraruminal N metabolism has been less extensively studied although Darden et al. (1985) found no significant effect of lasalocid on extent of degradation of feed protein or efficiency of bacterial protein synthesis in the rumen of beef steers.

Another effect of monensin and lasalocid on rumen fermentation is depressed CH_4 production. In a series of in vitro studies Bartley et al. (1979) demonstrated that monensin and lasalocid inhibited gas production and decreased rumen CH_4 production. However, Chalupa et al. (1980) reported that monensin reduced methanogenesis only slightly (15 to 40%). Van Nevel and Demeyer (1977) concluded that the

methane-depressing property of monensin is due to an inhibition of organisms decomposing formate to CO_2 and H_2. These gases are by far the most important substrates for CH_4 bacteria (Hungate, 1966). Furthermore, Chalupa et al. (1980) reported that monensin decreased CO_2 production by approximately 10% with no accumulation of gaseous hydrogen.

Monensin and lasalocid effectively increased pH and substantially lowered lactate concentration during in vitro fermentation of various sugars and ground grains with rumen fluid from either hay- or grain-fed cattle (Dennis et al., (1981b). Furthermore, Dennis et al (1981a) reported that monensin or lasalocid inhibited most of the lactate-producing rumen bacteria (like S. bovis). Among the lactate producers, those that produce succinate as a major end product were not inhibited by monensin or lasalocid however. Also, none of the major lactate fermenters were inhibited by monensin or lasalocid. Therefore, the increase in propionate in monensin- or lasalocid-fed cattle may result from selection for succinate producers and lactate fermenters. These results suggest that monensin or lasalocid may be used to prevent lactic acidosis in ruminants (Bergen and Bates, 1984).

While the previously mentioned effects of monensin on rumen fermentation are well established, and perhaps even account for most of the performance response, the effect on rumen turnover rates has only been studied to a limited extent. Lemenager et al. (1978) reported that liquid

and solids turnover rates were 31% ($P < .10$) and 44% ($P < .01$) slower, respectively, when monensin was fed. The decreased rumen turnover rate could partially account for decreased feed intakes observed and reduced rumen turnover would decrease feed intake if bulk fill limits intake (Lemenager et al., 1978). However, this is probably not true with high concentrate diets.

Effects on Nutrient Digestion

The available data indicates an influence of monensin on digestibility. The results have been variable however, particularly when unadapted animals were used. In a study with lambs fed diets based on ground corn cobs and grain sorghum, Poos et al. (1979) found that DM and acid detergent fiber (ADF) digestibilities were significantly reduced by monensin, but by days 40 to 46 these parameters approached those of the control indicating a possible adaptation effect. Simpson (1978) also found that monensin decreased in vitro cellulose digestibility when inoculum from unadapted animals was used. However, Dinius et al. (1976) found no reduction in cellulose digestibility when animals had been adapted to monensin for a 21-day period.

Muntifering et al. (1980) reported that monensin had no effect ($P > .05$) on apparent digestibility of DM, gross energy or starch when fed with a 90% corn diet (10.5% CP, DM basis) and allowed a 3-week adjustment period. Monensin in this corn-based diet tended to increase CP digestibility (63.4 vs

61.3%) however. Similarly, in metabolism trials with a 76% sorghum grain diet (11.7% CP, DM basis), monensin improved apparent digestibility of CP ($P < .05$) but not DM or gross energy ($P > .05$) (Muntifering et al., 1980). Other researchers (Dinius et al., 1976) reported that there were no significant differences in apparent digestibility of CP when steers had been fed monensin in a 90% chopped orchardgrass hay diet (12.8% CP, DM basis), however CP digestibility tended to be greater for steers fed monensin. A tendency for higher N retention was observed when cattle were fed high grain or high roughage diets with monensin (Dinius et al., 1976; Muntifering et al., 1980). Another report indicates inconsistent N retention responses, but this may have been caused by a rather high level of monensin (44 ppm) fed in one of the trials (Poos et al., 1979).

The effects of lasalocid have been less extensively studied although increases in apparent N digestibility and retention have been reported in lambs fed lasalocid (Paterson et al., 1983; Ricke et al., 1984).

Basic Mode of Action

The underlying mode of action of ionophores is on transmembrane ion fluxes and the dissipation of cation and proton gradients (Bergen and Bates, 1984). This action destroys primary membrane transport of cells, thereby interfering with cellular solute uptake coupled to primary transport systems (Bergen and Bates, 1984). Cells dependent

on substrate level phosphorylation for ATP (gram positive bacteria) are inhibited by ionophores since they cannot adequately generate ATP to maintain transmembrane proton gradients and intracellular pH solute. Gram negative bacteria which generate ATP via electron transport chain linked phosphorylation and concomitant proton extrusion, in the rumen are enriched (Bergen and Bates, 1984). Some claim that all of the observable ionophore effects are secondary phenomena caused by the disruption of normal membrane physiology (Bergen and Bates, 1984). This view is strengthened when related to the fact that lactate producers are mostly gram positive while propionate production is associated with the gram negative organisms.

Extensive studies have been conducted with monensin in target animals and laboratory animals to determine monensin concentrations in tissues, route of elimination, metabolism and pharmacokinetics of monensin. In a review, Donoho (1984) reported that monensin administered orally is absorbed, conjugated and excreted in the bile and eliminated in the feces by the several species examined. Donoho (1984) also reported that when fed to cattle and chickens according to recommended practices, monensin was not detected (less than .05 ppm) in edible tissues. However, Fahim and Pressman (1981) stressed that the potential to exceed the metabolic clearing mechanism is a possibility and may cause toxicity syndromes or possibly death of certain animals feeding on

treated feed or man consuming monensin-fed beef. Environmental studies indicate that monensin is biodegradable in manure and soil (Donoho, 1984).

Markers in Ruminant Nutrition Studies

Marker, indicator, tracer, reference substance and index substance are terms applied in nutrition and physiology to a number of materials used in the qualitative or quantitative estimation of nutritional or physiological phenomena. The scope of this review will be limited to specific intestinal markers (hereafter called markers) commonly used in animal nutrition studies.

One use of markers is to indicate the time taken for digesta to pass along the tract and as inert reference substances whose concentration in digesta can be used to measure changes along the gastrointestinal tract. Kotb and Luckey (1972) reported that for a substance to qualify as a marker in nutritional studies, it should: be inert with no toxic, physiological or psychological effects; be neither absorbed nor metabolized within the alimentary tract and therefore be completely recovered from either raw or processed food; have no appreciable bulk; mix intimately with the usual food and remain uniformly distributed in the digesta; have no influence on alimentary secretion, digestion, absorption, normal motility of the digestive tract or excretion; have no influence on the microflora of the alimentary tract which is of significance to the host; have qualities that allow ready,

precise quantitative measurements; and have physical-chemical properties which make it discernible throughout the digestive process. Because no one marker meets all these requirements, a mental decision by the researcher must be made when selecting a material (marker). External markers commonly selected for ruminant nutrition studies are mentioned below.

Particulate-Phase Markers

Chromium sesquioxide (Cr_2O_3). This compound is probably the most commonly used marker in nutrition studies today. It is light to dark green in color and practically insoluble in water, alcohol or acetone, but slightly soluble in acid and alkali (Merck Index, 1968). In ruminants best results are obtained when the marker is given in sustained-release form by mixing with a suitable carrier (Kotb and Luckey, 1972). The available data indicates that Cr_2O_3 when added at the rate of 0.5% to the diet of sheep and cattle is almost quantitatively recovered from the feces.

Rare earth elements. Several elements of the rare earths and other inert metals have been qualified as fecal markers and used in studies of passage and absorption of nutrients. Included in this group are the radioactive nuclides cerium (^{144}Ce), scandium (^{46}Sc, ^{47}Sc), zirconium (^{95}Zr), lanthanum (^{140}La), yttrium (^{91}Y), ruthenium (^{106}Ru) and gold (^{198}Au). Yterbium (Yb), dysprosium (Dy), europium (Eu) and gold are non-radioactive members of this group. At very low concentrations (below $10^{-11}M$) rare earth elements

exhibit radiocolloidal behavior, i.e. strong adsorbtive properties (Schweitzer and Jackson, 1952). These adherence properties suggested to researchers in the USA that the rare earth elements could be used as particulate markers.

Liquid-Phase Markers

Polyethylene glycol (PEG). Sperber et al. (1953) reported the use of PEG as a reference substance in studies of ruminant digestion and found that it was neither absorbed nor destroyed to any considerable extent in the digestive tract and more than 90% was recovered in the feces. However, because PEG associates itself with the liquid phase and not the solid phase of digesta, its use to study digestibility is doubtful (Kotb and Luckey, 1972). Furthermore, Kotb and Luckey (1972) reported that the lack of a specific, sensitive and accurate method for the analysis of PEG may partially explain the occasional failure to achieve complete recovery or reproducible results.

Chromium ethylenediaminetetraacetic acid (Cr-EDTA). In a review, Kotb and Luckey (1972) presented a summary of papers which concluded that both Cr-EDTA and ^{51}Cr-EDTA are satisfactory soluble markers in spite of slight absorption and subsequent excretion in the urine. The estimation of both markers is simple, accurate and specific. The ability to account for the small urinary excretion makes it possible to apply simple corrections in digestion experiments.

EXPERIMENT I

Introduction

Although barley's feeding value for ruminants is appreciably less in most cases than corn or sorghum, the potential for use of crops such as barley grain in livestock diets has increased in recent years, particularly in Scotland, North Europe and the cooler climates of North America. It has been tentatively accepted that diets containing ground corn are fermented to a lesser extent in the rumen than are barley diets, that more dietary protein escapes the rumen undegraded with corn diets than with barley diets and that the efficiency of microbial cell yield is greater for barley diets than for corn diets. The objective of this experiment was to evaluate the digestion of nutrients in the gastrointestinal tract, the quantity of plant and microbial protein reaching the duodenum, and the efficiency of microbial cell yield in the rumen of steers fed corn- or barley-based high grain diets.

Materials and Methods

Four Holstein steers (avg. wt. 475 kg), fitted with T-type cannulas in the proximal duodenum, were utilized in a switchback design (4 animals- 2 treatments- 2 periods). Two grain mixtures (table 2), one consisting mainly of corn and the other barley, were fed in combination with wheat straw to

TABLE 2. INGREDIENT COMPOSITION OF GRAIN MIXTURES[a]

Ingredient	Corn-based	Barley-based
	%	
Corn grain, ground (IFN 4-02-931)	83.0	-
Barley grain, ground (IFN 4-00-549)	-	91.5
Soybean seeds, solvent-extracted (IFN 5-04-604)	13.5	5.0
Sugercane molasses (IFN 4-04-696)	2.0	2.0
Limestone, ground (IFN 6-02-632)	1.0	1.0
Salt, trace-mineralized[b]	0.5	0.5
Vitamin A (30,000 IU/g)	0.005	0.007
Vitamin D (3,000 IU/g)	0.009	0.009
Diet		
Grain Mixture	80.0	85.0
Wheat Straw (IFN 1-05-175)	20.0	15.0
Crude Protein	12.0	12.0
Starch	40.5	40.5
Acid Detergent Fiber	15.0	15.0

[a]Dry matter basis.

[b]Composition (%): NaCl (98.5); Zn (.35); Fe (.34); Mn (.20); Cu (.033); I (.007), and Co (.005).

make up two complete diets (corn-based diet (C-BD) and barley-based diet (B-BD)) containing 12% CP, 40.5% starch and 15% ADF. Steers were housed in individual pens in an environmentally controlled room under continuous lighting and were fed 8 equally spaced and equalized meals daily by means of automatic feeders in order to establish somewhat steady-state conditions in the gastrointestinal tract. Water was available ad libitum. Cr_2O_3 at .4% of DM intake (32 g/head/day), was used as a nonabsorbable digesta flow marker. Grain mixtures and wheat straw were individually weighed and mixed for each animal daily before placing in the automatic feeder. Average daily DM intake was 8.15 kg (1.7% of body weight).

Steers were allowed 2 to 3 weeks to adapt to diets initially. Thereafter, each experimental period lasted 14 d in duration with the first 10 d serving as an adjustment period, followed by a 4-d period for sampling feedstuffs, feed refusals, duodenal digesta and feces. Spot samples of duodenal digesta (500 ml) and grab samples of feces (200 g wet basis) were taken three times daily during the 4-d collection period in a sampling scheme (table 3) such that animals were sampled on every even hour of a 24-h period. Twelve digesta and fecal samples were composited (equal weight basis) for each steer in each period.

Feedstuffs, feed refusals and feces were dried at 60° C prior to processing. Duodenal composites were subsampled and an aliquot (500 ml) of the fresh material was frozen for analyses of fresh digesta. The remainder of the duodenal

TABLE 3. SAMPLING SCHEME

Day	Time		
1	12:00 am	8:00 am	4:00 pm
2	2:00 am	10:00 am	6:00 pm
3	4:00 am	12:00 pm	8:00 pm
4	6:00 am	2:00 pm	10:00 pm

composite was freeze-dried. Feedstuffs, feed refusals, freeze-dried duodenal digesta and feces were ground in a Wiley mill through a 1-mm screen. Dry matter of feedstuffs, feed refusals, duodenal digesta and feces was determined by oven drying at 60°C for approximately 96 h. Starch determination was done at Colorado State University and ADF determination was done using the procedure of Goering and Van Soest (1970). Total N concentration was determined on feedstuffs, feed refusals, fresh duodenal contents and feces by the Missouri-Technicon Auto-Analyzer block digestor method (Wall and Gehrke, 1975).

Duodenal fluid was analyzed for NH_3-N concentration by the procedure of Wall and Gehrke (1975) and freeze-dried duodenal digesta was analyzed for RNA concentration by using the following procedure:

1. Weigh .5 g of dry duodenal content and add 10 ml of 10% TCA in ethanol. Mix and place samples in the cold room for at least 12 h.
2. Centrifuge mixed samples at 19,000 rpm for 20 minutes. Discard supernatant and save the pellet.
3. Wash the pellet with 10 ml of 5% TCA in water and recentrifuge. Then add 10 ml of 5% TCA, vortex and place it in boiling water bath (95°+) for 30 minutes.
4. Allow samples to cool and centrifuge at 19,000 rpm for 20 minutes. Save the supernatant and discard the pellet.

5. To 1 ml of supernatant add 9 ml of DH_2O and mix. From this dilution take .1 ml and add 1.9 ml of DH_2O.
6. To the latter dilution add 2 ml of orcinol reagent. Orcinol reagent: 1 g of recrystallized orcinol is dissolved immediately before use in 100 ml of concentrated HCl containing .5 g of $FeCl_3$ (hydrated form).
7. Cover the test tube with a marble and heat 20 minutes in a boiling water bath. Cool, then read and record the absorbance immediately with a Gilford STASAR II at 660 nm.
8. Standards are prepared by diluting a stock solution of RNA (Sigma Ribonucleic acid from Bakers yeast # R-6750) to a concentration of .005, .010, .020, .040, .080 and .100 mg/ml of RNA. To 2 ml of the diluted standards add 2 ml of orcinol reagent. Cover with a marble and heat 20 minutes in a boiling water bath. Cool, then read and record the absorbance immediately at 660 nm. This should be done along with the samples.
9. With the data obtained (concentration RNA mg/ml vs absorbance) from standards, a linear regression ($Y = mx + b$) is calculated. The absorbance recorded for the unknowns is converted to concentration using the linear equation, and divided by sample weight to obtain the concentration of RNA in the sample; e.g.,: RNA in sample (mg/g) = $[mx + b]/w$, where m = slope of standard curve, x = OD of sample, b = Y intercept of standard curve and w = sample weight in grams.

Determination of Cr_2O_3 in feed refusals, duodenal samples and feces was made by atomic emission spectrophotometry following a wet ash procedure. This procedure consists of the following steps:

1. Weigh approximately .3 g of sample into a 250 ml capacity Phillips beaker. Then add 7.0 ml of nitric acid (HNO_3) and 3.5 ml of perchloric acid ($HClO_4$). This and future steps must be done under the hood specifically for $HClO_4$ digestion.
2. Place the beaker containing the sample on a hot plate, set the temperature at 3.5 (approximately 320°C) and cover it with a watch glass. Avoid using the middle of the plate.
3. When all the organic matter is in solution, remove the watch glass from the beaker. Red fumes will be emitted immediately.
4. When red fumes have changed to white dense fumes, place the watch glass back on the beaker. If the sample has dried, add .5 ml of HNO_3.
5. Immediately after the watch glass has been placed back on the beaker, the sample will begin to turn orange. If change in color is delayed, raise the temperature of the hot plate to 4.5.
6. As soon as the orange color appears, remove the beaker from the hot plate and allow it to cool under the $HClO_4$ hood.

7. When cool, add to the sample approximately 100 ml of DH_2O and mix thoroughly. If the concentration of Cr in the sample is too high, further dilution will be necessary before final reading.
8. Standards are prepared by diluting a stock solution of Cr to a concentration of 1, 2, 3, 4 and 5 ppm of Cr.
9. With an atomic emission spectrophotometer, read and record first, the concentration of the standards and then the concentration (ppm) of the diluted sample.

Flow of DM at the duodenum was calculated by dividing the daily Cr_2O_3 intake by the concentration of Cr_2O_3 in the duodenal DM. Flow of individual nutrients was calculated by multiplying the percentage of the given nutrient in duodenal DM by the DM flow at the duodenum. Microbial N flow to the duodenum was determined by dividing daily N flow to the duodenum by the N:RNA-N ratio of the duodenal sample and multiplying by the N:RNA-N ratio of rumen bacterial isolates collected from animals fed a similar diet. Efficiency of microbial CP synthesis (E_{MCP}; g microbial CP/100 g rumen digested organic matter) was calculated after correcting rumen digested organic matter (RDOM) for microbial OM (microbial N x 6.25/.5).

Statistical analyses were performed using a one way analysis of variance from the procedure of Snedecor and Cochran (1967). This procedure was chosen because during the

second period one of the steers died, and another steer was utilized instead in two other separate periods, hence, not allowing the application of the switch back statistical design.

EXPERIMENT II

Introduction

The ionophores constitute a group of compounds enjoying considerable success as feed additives for several purposes in various animals. These compounds are produced by various strains of Streptomyces and include monensin, lasalocid, salinomycin and narasin. Monensin has been widely used as an anticoccidial drug in the poultry industry and to promote feed efficiency in the cattle industry. Previous work with monensin showed that protein escape from ruminal degradation was enhanced but microbial protein production was depressed. The objective of this experiment was to evaluate the influence of ionophore feed additives on ruminal and postruminal nutrient digestion and ruminal microbial protein production with two ionophores.

Materials and Methods

Four Holstein steers (avg. wt. 345 kg), fitted with permanent T-type cannulas in the proximal duodenum, as used in Experiment I, were utilized in a 4 x 4 Latin square design. The diet (table 4) consisted (DM basis) of 85% bromegrass (Bromus inermis) hay and 15% supplement, balanced to provide 15% CP, 40.5% ADF, .4% calcium and .2% phosphorus in the

TABLE 4. INGREDIENT COMPOSITION OF EXPERIMENTAL DIET[a]

Ingredient	% of diet[a]
Brome, smooth, hay, s-c, grnd (IFN 2-00-364)	85.0
Supplement	15.0
Soybean, seeds, solv-extd, grnd (IFN 5-04-604)	91.0
Limestone, grnd (IFN 6-02-632)	3.0
Dicalcium phosphate	3.0
Salt, trace-mineralized[b]	3.0
Vitamin A	0.05
Vitamin D	0.06
Diet	
Crude Protein[c]	15.0
Acid Detergent Fiber[c]	40.5

[a]Dry matter basis.

[b]Composition (%): NaCl (98.5); Zn (.35); Fe (.34); Mn (.20); Cu (.033); I (.007), and Co (.005).

[c]Based on chemical analysis.

total diet. The calculated net energy for gain (NEg) of the diet was approximately .5 Mcal/kg. Dietary treatments included a control and diets containing narasin, actaplanin or combination of ionophores (narasin (13) + actaplanin (20)) at 33 mg/kg of DM intake. Steers were housed in individual pens in an environmentally controlled room under continuous lighting and were fed equal amounts of the appropriate diet on every even hour of the day (12 feedings/day) by means of automatic feeders in order to establish steady-state conditions in the gastrointestinal tract. Water was available ad libitum. The Cr_2O_3 at .5% of DM intake (36 g/head/day), was used as a non-absorbable digesta flow marker. Hay and supplement were individually weighed and mixed for each animal daily and the proper portion placed in the automatic feeder. Average daily DM intake was 7.2 kg (2.0% of body weight).

Table 5 illustrates the sequence of events in each experimental period. Spot samples of duodenal digesta (500 ml) and grab samples of feces (200 g wet basis) were taken four times daily during the 3-d collection period in a sampling scheme (table 6) such that animals were sampled on every even hour of a 24-h period. Twelve digesta and fecal samples were composited (equal weight basis) for each steer in each period.

The preparation of all samples prior to analyses and the determination of DM, ADF, total N, NH_3-N, RNA and Cr_2O_3 were performed as described in Experiment I. Flow of DM, individual nutrients, microbial N at the duodenum and E_{MCP} was also calculated as described in Experiment I.

TABLE 5. SEQUENCE OF EVENTS IN EACH EXPERIMENTAL PERIOD

Day	Action
1	Started on feed.
1-6	Adapt to desired level of ionophore per day.
6	Started multiple per-day-equal feeding.
6-20	Adjustment to diet.
14	Started feeding marker (Cr_2O_3).
22-24	Collection of duodenal and fecal samples at 6 h intervals on a rotating basis.
25-32	Animal recovery, then restarted.

TABLE 6. SAMPLING SCHEME II

Day	Time			
1	12:00 am	6:00 am	12:00 pm	6:00 pm
2	2:00 am	8:00 am	2:00 pm	8:00 pm
3	4:00 am	10:00 am	4:00 pm	10:00 pm

Statistical analyses were performed using Latin square analysis of variance and effects of treatments were analyzed by single degree of freedom comparisons (Steel and Torrie, 1960). Comparisons made were: control vs narasin, actaplanin, combination; narasin vs actaplanin, combination; and actaplanin vs combination.

RESULTS AND DISCUSSION

Experiment I

Digestion parameters for dry matter (DM), nitrogen (N), acid detergent fiber (ADF) are shown in table 7. Total tract DM digestibility (DMD) was not significantly different among diets. However, total tract DMD was slightly greater for the corn-based diet (C-BD) than for the barley-based diet (B-BD). A similar pattern was observed for total tract starch digestibility. On the other hand, total tract N digestibility was lower ($P < .05$) for the B-BD (54.0%) than for the C-BD (63.0%). The low total tract N digestion coefficient obtained in the B-BD may be attributed to a low intestinal N digestion. Total tract ADF digestibility was also lower ($P < .01$) for the B-BD (15.3%) than for the C-BD (41.2%). The total tract ADF digestion coefficient obtained with the B-BD was very low, which may be attributed to a low ADF digestion in the rumen.

Steers fed the C-BD had a greater ($P < .01$) ruminal ADF digestibility (44.7%) than those fed the B-BD (19.7%). The low ruminal ADF digestion coefficient obtained with the B-BD may be attributed to a faster starch digestion rate in the rumen. Van Soest (1982) suggested that another variable that affects digestibility is the change in rate of fermentation due to rumen pH or the competitive presence of a starch

TABLE 7. APPARENT RUMINAL, INTESTINAL AND TOTAL TRACT DIGESTIBILITY IN STEERS FED CORN- OR BARLEY-BASED DIETS[a]

Item	Diets		SEM[d]
	C-BD[b]	B-BD[c]	
Apparent ruminal digestibility			
Dry matter	29.4	32.9	6.0
Nitrogen	-14.6	-16.9	8.4
Starch[g]	50.1	76.8	8.3
Acid detergent fiber[e]	44.7	19.7	4.0
Apparent intestinal digestibility			
Dry matter[f]	53.4	37.9	3.9
Nitrogen[f]	67.1	60.7	1.7
Starch[f]	35.6	6.1	7.6
Acid detergent fiber	-6.5	-6.0	3.1
Apparent total tract digestibility			
Dry matter	92.1	89.1	1.0
Nitrogen[f]	63.0	54.0	2.7
Starch	85.7	82.9	2.6
Acid detergent fiber[e]	41.2	15.3	2.9

[a]All values are means of four observations.

[b]Corn-based diet.

[c]Barley-based diet.

[d]Standard error of the mean.

[e]Significant diet effect ($P < .01$).

[f]Significant diet effect ($P < .05$).

[g]Significant diet effect ($P < .07$).

substrate. Ruminal starch digestibility was significantly greater ($P < .07$) for the B-BD (76.8%) than for the C-BD (50.1%). Zinn and Owens (1983) observed greater ruminal starch digestibilities in steers fed a C-BD at levels of 1.2, 1.5, 1.8 and 2.1% of body weight. In their study, values of 79.6, 80.2, 84.9 and 91.0% were obtained at 1.2, 1.5, 1.8 and 2.1% feeding rate, respectively. However, Hibberd et al. (1985) obtained ruminal starch digestibility values of 71.1, 60.2 and 75.2% in steers fed dry-rolled hetero-yellow, red and brown sorghums, respectively. The low ruminal starch digestion coefficient obtained in the present study with the C-BD may be attributed to the small size of the grain particle after processing. Beever et al. (1970) noted that large quantities of starch passed beyond the rumen with ground corn.

Ruminal DMD was not significantly different among diets. Since ruminal DMD was low for both the C-BD and the B-BD, one might expect increased intestinal DM digestion. Indeed, both diets showed a high intestinal DM digestion. However, intestinal DMD was greater ($P < .05$) for the C-BD (53.4%) than for the B-BD (37.9%). Intestinal N digestibility was also greater ($P < .05$) for the C-BD (67.1%) than for the B-BD (60.7%). These estimates agree with those of Hibberd et al. (1985) who also reported values for total N digestibility in small intestine ranging from 58.0 to 63.4% when the diet was 88% sorghum. However, Zinn and Owens (1983) obtained a slightly greater value (69%) on a diet containing 63% dry-rolled corn.

Steers fed the C-BD had a greater ($P < .05$) intestinal starch digestibility (35.6%) than those fed the B-BD (6.1%). Although the intestinal starch digestion coefficient obtained in the present study with the C-BD was very high, the observation mentioned above agrees with values obtained by Ørskov et al. (1971). In their study, sheep fed a 93.3% corn diet had a greater starch disappearance in the small intestine than sheep fed a 92.8% barley diet (16.6% vs 7.3%).

The N intakes and passage of duodenal N fractions are in table 8. The amount of N passing to the duodenum was greater than N intake with both the C-BD and B-BD. This suggests that more extensive recycling of N had occurred on both experimental diets. Nitrogen recycling values of a similar magnitude have been observed previously when steers were fed a high concentrate diet at 1.8 and 2.1% of body weight (Zinn and Owens, 1983).

Nonammonia N (NAN) accounted for about 99.8% of total duodenal N passage on both the C-BD and B-BD. Microbial N and escape N comprised approximately 56 and 44%, respectively, of the duodenal NAN on the C-BD, and comprised approximately 70 and 30%, respectively, of the duodenal NAN on the B-BD. These results indicate that barley feeding leads to a higher proportion of microbial protein in duodenal fluid than does corn feeding. They also confirm the work of Ørskov et al. (1971), that diets containing corn were fermented in the rumen to a much lesser extent than were barley diets, resulting in less

TABLE 8. PASSAGE OF DUODENAL NITROGEN FRACTIONS IN STEERS FED CORN- OR BARLEY- BASED DIETS[a]

Item	Diets		SEM[d]
	C-BD[b]	B-BD[c]	
N[e] intake, g/d	153.5	153.5	1.5
Duodenal N, g/d	178.8	176.5	12.4
Ammonia N, g/d	0.4	0.3	0.1
Nonammonia N, g/d	178.4	176.2	12.4
Microbial N, g/d	100.1	123.4	2.6
Escape N, g/d	78.3	52.8	2.3
E^{f}_{MCP}, g/100 g RDOM[g]	17.9	18.0	0.9

[a]All values are means of four observations.

[b]Corn-based diet.

[c]Barley-based diet.

[d]Standard error of the mean.

[e]N=Nitrogen.

[f]E_{MCP}=Efficiency of microbial crude protein synthesis.

[g]RDOM=Rumen digested organic matter.

microbial cell growth. However, the E_{MCP} is not different when corrected for microbial OM flow. Corn protein is relatively rich in zein which is known to be degraded very slowly in rumen fluid (McDonald, 1952; Annison, 1956), while barley proteins are easily fermented.

EXPERIMENT II

Intakes, flow rates and digestion parameters for DM are in table 9. Steers fed actaplanin and the combination had lower (P = .05) total tract DMD (67.9 and 67.5% respectively) than those fed the control (70.4%) and narasin (70.1%) rations. However, the addition of narasin to the diet had no effect on total tract DMD. Similarly, Dinius et al. (1976) reported that monensin fed with forage had no effect on apparent digestibility of DM in steers. The slight decrease in total tract DMD by steers fed actaplanin and the combination in the present experiment may be due to a reduction in extent of intestinal DM digestion.

On the other hand, steers fed narasin had a lower (P = .05) ruminal DMD (52.9%) than those fed the control (57.3%), actaplanin (57.5%) or the combination (58.1%). These results are inversely related to the DM flow at the duodenum. Steers fed narasin had a greater (P = .05) DM flow (3411 g/d) than those fed the control (3090 g/d), actaplanin (3076 g/d) or the combination (3032 g/d). Poos et al. (1979) reported DM flow values of 2965 and 3353 g/d in steers fed 0 and 200 mg monensin per head per day, respectively, with a diet based on ground corn cobs and milo supplemented with BDG. In the present experiment, the addition of actaplanin and the combination to the diet had no significant effect on DM flow

TABLE 9. SITE AND EXTENT OF DRY MATTER DIGESTION IN STEERS ON A BROMEGRASS DIET WITH NARASIN, ACTAPLANIN ALONE OR IN A COMBINATION[a]

Item	Control	Narasin	Actaplanin	Nar + Act	SEM[b]
DM[f] intake, g/d	7244[c]	7244[c]	7244[c]	7244[c]	0.0
DM flow at duodenum, g/d	3090[c]	3411[d]	3076[c]	3032[c]	45.6
Apparent ruminal digestion, g/d	4153[c]	3832[d]	4167[c]	4212[c]	38.2
% of intake	57.3[c]	52.9[d]	57.5[c]	58.1[c]	0.6
True ruminal digestion[e] g/d	4884[cd]	4594[d]	4928[cd]	4956[c]	31.7
% of intake	67.4[cd]	63.4[d]	68.0[cd]	68.4[c]	0.6
Apparent intestinal digestion, g/d	947[cd]	1243[d]	751[c]	674[c]	58.1
% of flow at duodenum	30.6[cd]	36.3[d]	24.6[c]	22.5[c]	1.2
Apparent DM digestibility, % of intake	70.4[c]	70.1[c]	67.9[d]	67.5[d]	0.3

[a]All values are means of four observations.

[b]Standard error of the mean.

[c,d]Means in the same row that do not have a common superscript differ (P = .05).

[e]Apparent ruminal digestion + microbial OM.

[f]DM = Dry matter.

at the duodenum nor on ruminal DMD. The decrease in ruminal DMD observed with the addition of narasin to the diet may be due to a depression in digestion rate.

No statistical difference in intestinal DM digestion were observed between the control and the three additives. However, steers fed actaplanin (24.6%) and the combination (22.5%) had significantly lower (P = .05) intestinal DMD than those fed narasin (36.3%). There is no available data comparing the extent of intestinal DMD with these three additives. However, Darden et al. (1985) observed no differences in the site of organic matter (OM) digestion in the gastrointestinal tracts of steers fed monensin, lasalocid or avoparcin with a diet based on ground corn and chopped alfalfa-brome hay.

Intakes, flow rates and digestion parameters for ADF are shown in table 10. Total tract ADF digestibility was largely unaffected by the presence of narasin in the diet. This observation agrees with that of Ricke et al. (1984), who observed that the addition of monensin or lasalocid to a 56.3% alfalfa diet had no effect on digestibility of ADF by lambs. Furthermore, in vitro studies using rumen fluid from animals adapted to monensin show only a slight depression in cellulose digestibility (Dinius et al., 1976). Because steers in the present experiment were on treatment for a certain period of time before collection, they may have adapted sufficiently to mask any decrease in ADF digestibility due to initial rumen exposure to narasin. However, actaplanin and the combination

TABLE 10. SITE AND EXTENT OF ACID DETERGENT FIBER DIGESTION IN STEERS ON A BROMEGRASS DIET WITH NARASIN, ACTAPLANIN ALONE OR IN A COMBINATION[a]

Item	Control	Narasin	Actaplanin	Nar + Act	SEM[b]
ADF[f] intake, g/d	2933[c]	2933[c]	2933[c]	2933[c]	0.0
ADF flow at duodenum, g/d	931[c]	1056[c]	978[c]	979[c]	19.5
Apparent ruminal digestion, g/d	2002[c]	1877[c]	1954[c]	1953[c]	20.7
% of intake	68.1[c]	63.6[c]	66.4[c]	66.4[c]	0.7
Apparent intestinal digestion, g/d	106[cd]	186[c]	1[d]	-50[d]	25.7
% of flow at duodenum	9.9[cd]	16.3[cx]	0.2[de]	-5.2[ey]	1.9
Apparent ADF digestibility, % of intake	71.8[c]	70.2[cd]	66.3[de]	64.6[e]	0.6

[a]All values are means of four observations.

[b]Standard error of the mean.

[c,d,e]Means in the same row that do not have a common superscript differ (P = .05).

[x,y]Means in the same row that do not have a common superscript differ (P = .01).

[f]ADF = Acid detergent fiber.

caused a reduction on total tract ADF digestibility. Steers fed actaplanin (66.3%) and the combination (64.6%) had significantly lower (P = .05) total tract ADF digestion coefficients than those fed the control (71.8%). Furthermore, steers fed the combination had a significantly lower (P = .05) total tract ADF digestion coefficient than those fed narasin (70.2%).

No statistical differences were detected among treatments on ruminal ADF digestibility and in the amounts of ADF reaching the duodenum. However, steers fed narasin had a higher ADF flow and a slightly lower ruminal ADF digestion coefficient than steers fed the control, actaplanin and the combination. This observation clearly indicates that steers fed narasin will have more ADF available for intestinal digestion than those fed the control, actaplanin and the combination. Hence, steers fed narasin are expected to have a higher intestinal ADF digestion due to the fact that increase in fermentable carbohydrate promotes postgastric fermentation.

Indeed, steers fed narasin digested more ADF than those fed the control, actaplanin and the combination. However, there was a great variation among treatments on intestinal ADF digestibility. This may have been caused by the marker used to estimate flow. The extent of ruminal ADF digestion may have been overestimated, while the ADF flow at the duodenum may have been underestimated.

Intakes, flow rates and digestion parameters for N are shown on table 11. Total tract digestibility of N was similar for all treatments. This observation is in agreement with that of Darden et al. (1985), who observed that the polyether ionophores monensin and lasalocid, and the glycopeptide avoparcin had no effect on apparent N digestibility of steers. However, Ricke et al. (1984) reported that lambs fed lasalocid digested more N than control and monensin-fed lambs. The reason for this variation is not clear.

In the present experiment, steers fed the combination had a significantly greater (P = .05) ruminal N digestion (49.2%) than those fed the control (41.5%) and narasin (41.6%). Although there were no statistical differences, steers fed actaplanin (46.4%) had a greater ruminal N digestion than steers fed the control and narasin, but had a slightly lower ruminal N digestion than those fed the combination. These results are inversely related to the N flow at the duodenum. Steers fed the combination had a significantly lower (P = .05) N flow (88.7 g/d) than those fed the control (102.8 g/d) and narasin (102.8 g/d). Although there were no statistical differences, steers fed actaplanin had a lower N flow (93.9 g/d) than steers fed the control and narasin, but had a slightly greater N flow than those fed the combination. The addition of narasin to the diet had no effect at all on the N flow at the duodenum. This observation is in agreement with that of Poos et al. (1979), who reported that the addition of monensin did not significantly affect the above mentioned parameter.

TABLE 11. SITE AND EXTENT OF NITROGEN DIGESTION IN STEERS ON A BROMEGRASS DIET WITH NARASIN, ACTAPLANIN ALONE OR IN A COMBINATION[a]

Item	Control	Narasin	Actaplanin	Nar + Act	SEM
N[f] intake, g/d	175.6[c]	175.6[c]	175.6[c]	175.6[c]	0.0
N flow at duodenum, g/d	102.8[c]	102.8[c]	93.9[cd]	88.7[d]	1.3
Apparent ruminal digestion, g/d	72.8[c]	72.7[c]	81.7[cd]	86.8[d]	1.0
% of intake	41.5[c]	41.6[c]	46.4[cd]	49.2[d]	0.7
Apparent intestinal digestion, g/d	64.9[cd]	66.3[c]	54.6[de]	53.0[e]	1.6
% of flow at duodenum	63.3[c]	64.5[c]	58.0[c]	60.0[c]	0.9
Apparent N digestibility, % of intake	78.5[c]	79.3[c]	77.8[c]	79.6[c]	0.3

[a]All values are means of four observations.

[b]Standard error of the mean.

[c,d,e]Means in the same row that do not have a common superscript differ (P = 0.5).

[f]N = Nitrogen.

Narasin, actaplanin or the combination of ionophores did not affect apparent intestinal digestion of N in the present experiment. There are no available data comparing the extent of intestinal N digestion among these three additives. However, actaplanin and the combination caused a slight numerical decrease on intestinal N digestion in the present experiment.

The N intakes and duodenal N fractions passage are reported in table 12. As for the total N flow, previously discussed, steers fed the combination had a significantly lower (P = .05) NAN flow (88.3 g/d) than those fed the control (102.4 g/d) and narasin (102.4 g/d). Although there were no statistical differences, steers fed actaplanin had a lower NAN flow (93.5 g/d) than steers fed the control and narasin, but had a slightly greater NAN flow than those fed the combination. However, the addition of narasin to the diet had no effect at all on the NAN flow. This observation agrees with that of Darden et al. (1985), who reported that the addition of monensin, lasalocid or avoparcin did not significantly affect the NAN flow to the duodenum.

No statistical differences in the amounts of microbial N reaching the duodenum were detected between the control and the three additives. This observation is in agreement with that of Darden et al. (1985), who observed that the addition of monensin, lasalocid or avoparcin did not affect the bacertial N reaching the duodenum. However, these observations are in contrast with those of Poos et al. (1979), and

TABLE 12. PASSAGE OF DUODENAL NITROGEN FRACTIONS IN STEERS ON A BROMEGRASS DIET WITH NARASIN, ACTAPLANIN ALONE OR IN A COMBINATION[a]

Item	Control	Narasin	Actaplanin	Nar + Act	SEM
N[e] intake, g/d	175.6[c]	175.6[c]	175.6[c]	175.6[c]	0.0
Duodenal N, g/d	102.8[c]	102.8[c]	92.9[cd]	88.7[d]	1.3
Ammonia N, g/d	0.4[c]	0.4[c]	0.4[c]	0.4[c]	0.0
Nonammonia N, g/d	102.4[c]	102.4[c]	93.5[cd]	88.3[d]	1.3
Microbial N, g/d	58.4[c]	60.9[c]	60.9[c]	59.5[c]	1.1
Escape N, g/d	44.0[c]	41.5[c]	32.6[c]	28.8[c]	1.2
E^{f}_{MCP}, g/100 g RDOM[g]	7.5[c]	8.4[c]	7.8[c]	7.5[c]	0.4

[a]All values are means of four observations.

[b]Standard error of the mean.

[c,d]Means in the same row that do not have a common superscript differ (P = .05).

[e]N = Nitrogen.

[f]E_{MCP} = Efficiency of microbial crude protein synthesis.

[g]RDOM = Rumen digested organic matter.

Isichei and Bergen (1980) who noted decreased bacterial N flow to the duodenum when monensin was fed.

The addition of narasin, actaplanin and the combination of ionophores decreased the amounts of undegraded dietary N reaching the duodenum. These results are in contrast with those of Poos et al. (1979), who noted increased flow of dietary N to the duodenum when monensin was fed. On the other hand, Darden et al. (1985) reported that there were no statistical differences detected among treatments (control, monensin, lasalocid and avoparcin) in the amounts of apparently undegraded dietary N reaching the duodenum. The results obtained in the present experiment may be due to a big net rumen N loss, despite the high overall DMD, and difference in mode of action of the additives compared.

Efficiency of microbial CP synthesis was not affected by treatment. Values for efficiency of microbial CP synthesis are somewhat lower than those reported in a number of studies reivewed by Stern and Hoover (1979) and those reported by Darden et al. (1985) with other ionophores.

CONCLUSIONS

Experiment I

1. A greater proportion of ground barley DM is fermented in the rumen while a greater proportion of ground corn DM is digested in the intestines.
2. Duodenal NAN flow was equal for both diets and exceeded N intake by 15%.
3. High concentrate diets with low rumen available N will utilize recycled N for bacterial biomass synthesis resulting in NAN flow greater than N intake.
4. For the corn-based diet (C-BD), the lower rumen starch apparent digestibility suggests that particle size was extremely small after processing.
5. For the barley-based diet (B-BD), the lower rumen ADF apparent digestibility suggests a strong associative effect.
6. Laboratory analysis indicate that the duodenal digesta from B-BD contained more RNA indicating greater microbial protein flow.
7. There was no difference in efficiency of microbial crude protein synthesis (E_{MCP}) among diets.

Experiment II

1. The addition of actaplanin or a combination of narasin + actaplanin at 33 ppm to a high roughage diet causes a decrease in total tract DM and ADF digestibility, and NAN and escape N flow to the duodenum of steers.
2. Narasin added to a high roughage diet decreases ruminal DMD and the flow of escape N to the duodenum.
3. There were no differences in E_{MCP} among treatments.
4. These three additives cause, in some of the parameters, responses similar to those of monensin, lasalocid and avoparcin. However, effect of dosage of all three compounds, the activity of various combinations and complete characterization of their activity in various types of diets has not been adequately investigated.

LITERATURE CITED

Allison, M.J. 1965. Phenylalanine biosynthesis from phenylacetic acid by anaerobic bacteria from the rumen. Biochem. Biophys. Res. Commun. 18:30.

Allison, M.J. and I.M. Robinson. 1967. Tryptophan biosynthesis from indole-3 acetic acid by anaerobic bacteria from the rumen. Biochem. J. 102:36P.

Allison, M.J. 1969. Biosynthesis of amino acids by ruminal microorganisms. J. Anim. Sci. 29:797.

Allison, M.J. 1970. Nitrogen metabolism of ruminal microorganisms. In: A.T. Phillipson, ed. Physiology of Digestion in the Ruminant. Oriel Press Ltd. Newcastle upon Tyne, England.

Allison, M.J. 1982. Nitrogen requirements of ruminal bacteria. In: Protein Requirements for Cattle: Symposium. MP-109 Division of Agriculture, Oklahoma State University. P. 128.

Annison, E.F. 1956. As cited by Ørskov, E.R., C. Fraser and I. McDonald. 1971. Digestion of concentrates in sheep. 3. Effects of rumen fermentation of barley and maize diets on protein digestion. Br. J. Nutr. 26:477.

Balch, C.C. and R.C. Campling. 1965. Rate of passage of digesta through the ruminant digestive tract. In: R.W. Dougherty, ed. Physiology of Digestion in the Ruminant. Butterworths, Washington. P. 108.

Bartley, E.E., E.L. Herod, R.M. Bechtle, D.A. Sapienza, B.E. Brent and A. Davidovich. 1979. Effect of monensin or lasalocid, with and without niacin or amicloral, on rumen fermentation and feed efficiency. J. Anim. Sci. 49:1066.

Beever, D.E., J.F. Coehlo da Silva and D.G. Armstrong. 1970. The effect of processing maize on its digestion in sheep. Proc. Nutr. Soc. 29:43A.

Bergen, W.G. and D.B. Bates. 1984. Ionophores: Their effect on production efficiency and mode of action. J. Anim. Sci. 58:1465.

Berger, L.L., S.C. Ricke and G.C. Fahey, Jr. 1981. Comparison of two forms and two levels of lasalocid with monoensin on feedlot cattle performance. J. Anim. Sci. 53:1440.

Blackburn, T.H. 1965. Nitrogen metabolism in the rumen. In: R.W. Dougherty, ed. Physiology of Digestion in the Ruminant. Butterworths, Washington. P. 322.

Blaxter, K.L. 1962. As cited by L.F. Richardson, A.P. Raun, E.L. Potter, C.O. Cooley and R.P. Rathmacher. 1976. Effect of monensin on rumen fermentation in vitro and in vivo. J. Anim. Sci. 43:657.

Boling, J.A., N.W. Bradley and L.D. Campbell. 1977. Monensin levels for growing and finishing steers. J. Anim. Sci. 44:867.

Bryant, M.P. 1970. Microbiology of the rumen. In: E.J. Swenson, ed. Duke's Physiology of Domestic Animals, 8th ed. Cornell University Press, Ithaca, N.Y. P. 484.

Coelho da Silva, J.F., R.C. Seely, D.E. Beever, J.H.D. Prescott and D.G. Armstrong. 1972. The effect in sheep of physical form and stage of growth on the sites of digestion of dried grass. Br. J. Nutr. 28:357.

Coleman, G.S. 1975. The interrelationship between rumen ciliate protozoa and bacteria. In: I.W. McDonald and A.C.I. Warner (Ed.) Digestion and Metabolism in the Ruminant. The Univ. of New England Publishing Unit, Armidale. P. 149.

Chalupa, W. 1975. Rumen bypass and protection of proteins and amino acids. Symposium: Protein and Amino Acid Nutrition. J. Dairy Sci. 58:1198.

Chalupa, W. 1980. Chemical control of rumen microbial metabolism. In: Y. Ruckebusch and P. Thivend (Ed.) Digestive Physiology and Metabolism in Ruminants. MTP Press Ltd., Lancaster, England. P. 325.

Chalupa, W., W. Corbett and J.R. Brethour. 1980. Effects of monensin and amicloral on rumen fermentation. J. Anim. Sci. 51:170.

Darden, D.E., N.R. Merchen, L.L. Berger, G.C. Fahey, Jr. and J.W. Spears. 1985. Effects of avoparcin, lasalocid and monensin on sites of nutrient digestion in beef steers. Nutrition Reports International. 31:979.

Dennis, S.M., T.G. Nagaraja and E.E. Bartley. 1981a. Effects of lasalocid or monensin on lactate-producing or -using rumen bacteria. J. Anim. Sci. 52:418.

Dennis, S.M., T.G. Nagaraja and E.E. Bartley. 1981b. Effect of lasalocid or monensin on lactate production from in vitro rumen fermentation of various carbohydrates. J. Dairy Sci. 64:2350.

Dinius, D.A., M.E. Simpson and P.B. Marsh. 1976. Effect of monensin fed with forage on digestion and the ruminal ecosystem of steers. J. Anim. Sci. 42:229.

Donoho, A.L. 1984. Biochemical studies on the fate of monensin in animals and in the environment. J. Anim. Sci. 58:1528.

Fahim, M. and B.C. Pressman. 1981. As cited by Bergen, W.G. and D.B. Bates. 1984. Ionophores: Their effect on production efficiency and mode of action. J. Anim. Sci. 58:1465.

Fontenot, J.P., K.E. Webb and D.M. Lucas. 1980. Effect of salinomycin on in vitro and in vivo ruminal volatile fatty acids. J. Anim. Sci. 51 (Suppl. 1):360.

Fuller, J.R. and D.E. Johnson. 1981. Monensin and lasalocid effects on fermentation in vitro. J. Anim. Sci. 53:1574.

Galyean, M.L., D.G. Wagner and F.N. Owens. 1979a. Level of feed intake and site and extent of digestion of high concentrate diets by steers. J. Anim. Sci. 49:199.

Goering, H.K. and P.J. Van Soest. 1970. Forage Fiber Analyses. Apparatus, Reagents, Procedures and Some Applications. ARS, USDA Agr. Handbook No. 379.

Hibberd, C.A., D.G. Wagner, R.L. Hintz and D.D. Griffin. 1985. Effect of sorghum grain variety and reconstitution on site and extent of starch and protein digestion in steers. J. Anim. Sci. 61:702.

Hobson, P.N. and R.J. Wallace. 1982. Microbial ecology and activities in the rumen: Part II. CRC Critical Reviews in Microbiology. May:264.

Hungate, R.E. 1966. The Rumen and Its Microbes. Academic Press Inc., New York, New York.

Isichei, C.O. and W.G. Bergen. 1980. The effect of monensin on the composition of abomasal nitrogen flow in steers fed grain and silage ration. J. Anim. Sci. 51 (Suppl. 1):371.

Kotb, A.R. and T.D. Luckey. 1972. Markers in Nutrition. Nutr. Abstr. Rev. 42:813.

Lemenager, R.P., F.N. Owens, B.J. Shockey, K.S. Lusby and R. Totusek. 1978. Monensin effects on rumen turnover rate, twenty-four hour VFA pattern, nitrogen components and cellulose disappearance. J. Anim. Sci. 47:255.

Leng, R.A. 1973. Salient features of the digestion of pasture by ruminants and other herbivores. In: G.W. Butler and R.W. Bailey, ed. Chemistry and Biochemistry of Herbage, Vol. 3. Academic Press, New York. P. 81.

Merck Index. 1968. Merck and Co., Rahway, N.J., USA.

McClure, W.H., J.P. Fontenot, K.E. Webb and D.M. Lucas. 1980. Feedlot performance of cattle fed different salinomycin levels. J. Anim. Sci. 51 (Suppl. 1): 380.

McDonald, I.W. 1952. As cited by Ørskov, E.R., C. Fraser and I. McDonald. 1971. Digestion of concentrates in sheep. 3. Effects of rumen fermentation of barley and maize diets on protein digestion. Br. J. Nutr. 26:477.

McGuffey, R.K., H.B. Green, R.P. Basson and E.L. Potter. 1983a. Actaplanin for lactating dairy cows. J. Dairy Sci. 66 (Suppl. 1):198.

McGuffey, R.K., R.P. Basson, H.B. Green and N.G. Shoaff. R.S. Emery, D.E. Harmon, C.L. McLaughlin, A.H. Rakes and J.E. Shirley. 1983b. Actaplanin for lactating dairy cows. Field studies. J. Dairy Sci. 66 (Suppl. 1):198.

Muntifering, R.B., B. Theurer, R.S. Swingle and W.H. Hale. 1980. Effect of monensin on nitrogen utilization and digestibility of concentrate diets by steers. J. Anim. Sci. 50:930.

Nolan, J.V. and R.A. Leng. 1972. Dynamic aspects of ammonia and urea metabolism in sheep. Br. J. Nutr. 27:177.

Nolan, J.V. 1975. Quantitative models of nitrogen metabolism in sheep. In: Digestion and Metabolism in the Ruminant. McDonald, I.W. and A.C.I. Warner, Eds., Univ. N. England Publishing Unit, Armidale, Aust. P. 416.

Ørskov, E.R., C. Fraser and I. McDonald. 1971. Digestion of concentrates in sheep. 3. Effects of rumen fermentation of barley and maize diets on protein digestion. Br. J. Nutr. 26:477.

Ørskov, E.R. 1982. Protein Nutrition in Ruminants. Academic Press Inc., New York, New York.

Owens, F.N. and D.R. Gill. 1981. Avoparcin, monensin and implants for growing heifers. Okla. Agr. Exp. Sta. Res. Rep. MP- 108:125.

Owens, F.N. and W.G. Bergen. 1983. Nitrogen metabolism of ruminants animals: Historical perspective, current understanding and future implications. J. Anim. Sci. 57 (Suppl. 2):498.

Paterson, J.A., B.M. Anderson, D.K. Bowman, R.L. Morrison and J.E. Williams. 1983. Effect of protein source and lasalocid on nitrogen digestibility and growth by ruminants. J. Anim. Sci. 57:1537.

Pilgrim, A.F., F.V. Gray, R.A. Weller and C.B. Belling. 1970. Synthesis of microbial protein from ammonia in the sheep's rumen and the proportion of dietary nitrogen converted into microbial nitrogen. Br. J. Nutr. 24:589.

Potter, E.L., C.O. Cooley, L.F. Richardson, A.P. Raun and R.P. Rathmacher. 1976. Effect of monensin on performance of cattle fed forage. J. Anim. Sci. 43:665.

Potter, E.L., C.O. Cooley and L.F. Richardson. 1979. Effect of narasin upon the performance of feedlot cattle. J. Anim. Sci. 49 (Suppl. 1):397.

Poos, M.I., T.L. Hanson and T.J. Klopfenstein. 1979. Monensin effects on diet digestibility, ruminal protein bypass and microbial protein synthesis. J. Anim. Sci. 48:1516.

Raun, A.P., C.O. Cooley, E.L. Potter, R.P. Rathmacher and L.F. Richardson. 1976. Effect of monensin on feed efficiency of feedlot cattle. J. Anim. Sci. 43:670.

Redman, R.G., R.C. Kellaway and J. Leibholz. 1980. Utilization of low quality roughages: effects of urea and protein supplements of differing solubility on digesta flows, intake and growth rate of cattle eating oaten chaff. Br. J. Nutr. 44:343.

Richardson, L.F., A.P. Raun, E.L. Potter, C.O. Cooley and R.P. Rathmacher. 1976. Effect of monensin on rumen fermentation in vitro and in vivo. J. Anim. Sci. 43:657.

Ricke, S.C., L.L. Berger, P.J. van der Aar and G.C. Fahey, Jr. 1984. Effects of lasalocid and monensin on nutrient digestion, metabolism and rumen characteristics of sheep. J. Anim. Sci. 58:194.

Saba, W.J., W.H. Hale, F. Hubbert, Jr., J. Kiernat and B. Taylor. 1964. Digestion of milo and barley by cattle. J. Anim. Sci. 23:533.

Salter, D.N., K. Daneshvar and R.H. Smith. 1979. The origin of nitrogen incorporated into compounds in the rumen bacteria of steers given protein- and urea-containing diets. Br. J. Nutr. 41:197.

Shelling, G.T. 1984. Monensin mode of action in the rumen. J. Anim. Sci. 58:1518.

Schweitzer, G.K. and M. Jackson. 1952. As cited by McRae, J.C. 1974. The use of intestinal markers to measure digestive function in ruminants. Proc. Nutr. Soc. 33:147.

Simpson, M.E. 1978. Effects of certain antibiotics on in vitro cellulose digestibility and volatile fatty acids production by ruminal microorganisms. J. Anim. Sci. 47 (Suppl. 1):429.

Smith, R.H. and A.B. McAllan. 1970. Nucleic acid metabolism in the ruminant. Br. J. Nutr. 24:545.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical Methods. Iowa State University Press, Ames, Iowa.

Spears, J.W. and R.W. Harvey. 1984. Performance, ruminal and serum characteristics of steers fed lasalocid on pasture. J. Anim. Sci. 58:460.

Sperber, I., S. Hyden and J. Ekman. 1953. As cited by Kotb, A.R. and T.D. Luckey. 1972. Markers in nutrition. Nutr. Abstr. Rev. 42:813.

Steel, R.G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York.

Stern, M.D. and Hoover, W.H. 1979. Methods for determining and factors affecting microbial protein synthesis: A Review. J. Anim. Sci. 49:1590.

Tamminga, S. 1979. Protein degradation in the forestomachs of ruminants. J. Anim. Sci. 49:1615.

Tamminga, S., C.J. Van der Koelen and A.M. Van Vuuren. 1979. The effectof the level of feed intake on nitrogen entering the small intestine of dairy cows. Livest. Prod. Sci. 6:255.

Tamminga, S. 1981. Effect of the roughage/concentrate ratio on nitrogen entering the small intestine of dairy cows. Neth. J. Agric. Sci. 29:273.

Van Nevel, C.J. and D.I. Demeyer. 1977. Effect of monensin on rumen metabolism in vitro. Appl. Environ. Microbiol. 34:251.

Van Soest, P.J. 1982. Forms of feed nitrogen. In: Nutritional Ecology of the Ruminant. Oregon: O and B Books, Inc. P. 230.

Van Soest, P.J. 1982. Leaf proteins. In: Nutritional Ecology of the Ruminant. Oregon: O and B Books, Inc. P. 232.

Virtanen, A.I. 1966. Milk production of cows on protein-free feed. Science. 153:1603.

Wall, Sr., L.L. and C.W. Gehrke. 1975. An automated total protein nitrogen method. J. of the A.O.A.C. 58:1221.

Wohlt, J.E., C.J. Sniffen, W.H. Hoover, L.L. Johnson and C.K. Walker. 1976. Nitrogen metabolism in wethers as affected by dietary protein solubility and amino acid profile. J. Anim. Sci. 42:1280.

Zinn, R.A., L.S. Bull and R.W. Hemke. 1981. Degradation of supplemental proteins in the rumen. J. Anim. Sci. 52:857.

Zinn, R.A. and F.N. Owens. 1983. Influence of feed intake level on site of digestion in steers fed a high concentrate diet. J. Anim. Sci. 56:471.

Zubay, G.L. 1983. Biochemistry. Addison-Wesley Publishing Company, Inc. Reading, Massachusetts.