Utilization of wheat straw in fattening rations for beef steers

by Jerry R Border

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Animal Industry
Montana State University

Abstract:
Forty yearling steers were fed wheat straw as a roughage during a 152-day fattening experiment to determine the feasibility and economy of straw utilization. The animals were randomly divided into four lots of ten head each. Each lot received a basal concentrate ration (barley and wheat mixed feed) fed according to appetite. In addition, two pounds per steer, per day, of a 32 per cent protein supplemental pellet was fed three lots. Similarly a 14 per cent pellet was fed the fourth lot. Pellets differed in constituents. Straw served as roughage for three lots and alfalfa hay fed the fourth lot served as the control roughage. Each roughage was fed ad libitium.

One of the three supplemental pellets fed with straw roughage was designated a control, the other two contained additional ingredients. One contained additional molasses and the other contained yeast and bovirum.

Steers showed a dislike for Straw, which influenced efficiency of feed utilization. Steers fed straw averaged. 12 per cent higher efficiency from this roughage than alfalfa fed steers did from their roughage. The converse was true for concentrate utilization (19 per cent). There were no significant differences between the average daily gains of each lot; however, steers fed alfalfa show 0.3 pound greater average daily gain than those steers fed straw.

The monetary return for steers fed alfalfa hay averaged $5.79 per steer, while each lot fed straw showed an average deficit ranging from $9.26 to $16.87 per steer. The data does indicate, however, that it is entirely possible for wheat straw to be utilized nutritionally and economically in a beef fattening program.

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30

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ABSTRACT

Forty yearling steers were fed wheat straw as a roughage during a 152-day fattening experiment to determine the feasibility and economy of straw utilization. The animals were randomly divided into four lots of ten head each. Each lot received a basal concentrate ration (barley and wheat mixed feed) fed according to appetite. In addition, two pounds per steer, per day, of a 32 per cent protein supplemental pellet was fed three lots. Similarly a 14 per cent pellet was fed the fourth lot. Pellets differed in constituents. Straw served as roughage for three lots and alfalfa hay fed the fourth lot served as the control roughage. Each roughage was fed *ad libitium*.

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UTILIZATION OF WHEAT STRAW IN FATTENING RATIONS FOR BEEF STEERS

INTRODUCTION

The rumen, or first compartment of the ruminant stomach, is one of man's greatest economic assets because of the symbiotic relationship existing between the rumen microorganisms and the host animal. These microorganisms provide enzyme systems enabling conversion of feeds of little value to man into nutrients used by the host animal to produce some of our best food.

Limited amounts of good quality roughages, influenced by climate, and soil, and economic availability, have induced utilization of poorer quality roughages in ruminant rations. With proper supplementation, low quality roughages can be efficiently and economically integrated into the diet of these unique converters.

Many countries have used less desirable roughage foodstuffs for some time because of insufficient supply of hay and/or pasture, thus pointing the way toward new horizons in utilizing readily accessible low quality roughages. More recently, there has been increased interest in utilization of low quality roughages in the United States, not entirely for the same reasons, however. Economic production of livestock and efficient use of products otherwise considered waste materials have been the influence here.

Late-cut hays, straws, corn cobs, corn stover, cottonseed hulls and other materials of high fiber content are often plentiful and available for use in areas where there is considerable production of cattle.

In Montana, there is an abundance of cereal straw--oat, barley, and wheat--which could be used for ruminant consumption. However, most of the cattle fattening has been confined to irrigated areas and communities near the beet pulp industry. Recently, more fattening of cattle has taken place under conditions where dryland farmers and ranchers have access to grains and straws and limited access to alfalfa and grass hays, beet pulp and pasture.

In utilizing low quality roughages, particularly wheat straw, as part of cattle fattening rations, many influencing factors should be borne in mind. Much is yet to be learned and many questions to be answered, such as the following: what specific nutrients, and how much, are needed to meet rumen nutrient requirements? Can low quality roughages, properly supplemented, produce economical gains in cattle? Man's continuing challenge in ruminant nutrition is to learn the nutritive requirements of microorganisms so that more low quality roughages and other feeds can be used efficiently. It is with factors like these our interest lie.

The experiment reported herein was undertaken for the purpose of developing rations which will effectively and economically supplement the deficiencies of wheat straw when used in a cattle fattening program. If these supplements, fed with straw and a barley base concentrate feed, can produce weight gains in fattening cattle as economically as when a high quality roughage is used, then many ranchers in dryland areas may be able to utilize their straw and surplus barley to an advantage in ruminant feeding.

LITERATURE REVIEW

Ruminants are polygastric animals and are vastly different from monogastric animals in their physiology of digestion because of the integral part the bacterial enzymes play in the digestion of the roughages they consume. A thorough knowledge of the biochemical and physiological factors involved in ruminant digestion is essential for efficient use of low quality roughage in the rations of these animals. The understanding of these factors is limited, however, information has shown that use can be made of the rumen bacteria and their enzymes to improve the economy of ruminant feeding. The important contributions of rumen bacteria seem to be: synthesis of vitamins, synthesis of amino acids, and proteins, as well as the digestion of cellulose and production of fatty acids (Davis 1954, Burroughs and Hall 1954).

I. THE RUMEN AND ITS MICROORGANISMS

The rumen is the first of four compartments in a ruminant's compound stomach. After one year of age it contributes approximately 80 per cent of the total stomach volume. Depending upon the size of the animal, an estimate of 20 to 40 gallons is normal rumen capacity for adult cattle (Burroughs and Hall 1954). Emery et al. (1957) estimated the rumen contents of three animals, averaging 1200 pounds each, to be 70 kilograms of liquid. In the rumen, feed is stored, mixed and softened with water and saliva. It is here that most of the digestive activity resulting from bacteria takes place.

The rumen, reticulum, and omasum secrete no digestive enzymes, whereas the abomasum or so called true stomach does. This stomach is similar to the stomach of monogastric animals because it produces digestive enzymes and hydrochloric acid (Burroughs and Hall 1954).

Burroughs et al. (1950) divided into two groups some general factors which involve rumen microbiological digestion. The first, regulated by the physiology and anatomy of the host, is more or less fixed. The second represents variable conditions related to environment of the rumen and indirectly related environment of the host.

Group I-	Temperature Moisture Saliva and its buffering action Salts in saliva Anaerobiosis	Absorption of organic acids through the rumen wall Rumen motion Possibly exclusion of light
Group II-	Types of microorganisms Nutrients available to bacteria present Hydrogen ion concentration	Total salt concentration Oxidation-reduction potential Possible synergistic relations of organisms

Another important factor is the length of time ingested feed remains in the rumen. Feeds entering the rumen of cattle must be acted upon in a very short time. According to Burroughs et al. (1946), feeds must be acted upon within periods averaging 24 hours or less. Again in 1954, Burroughs and Hall stated that feed may remain in the rumen 60 to 72 hours; the majority of it remaining much less. Compared with other forms of microbiological decomposition, i.e. organic matter break down in the soil, sewage disposal and industrial fermentations of fibrous materials, this is an extremely short period for fiber digestion. The rate of fermentation is hastened by rumen temperature (Burroughs et al. 1950c) although fermentation is nearly constant throughout a 24-hour day. Little differences in temperature exist between breeds of cattle.

Monroe and Perkins (1939) stated that one of the requirements for optimal bacterial activity is maintenance of a proper hydrogen ion concentration. No doubt nature regulates the rumen pH reaction by some means, however it is probable that extremes in feeding have an influence. Fattening or high production rations where heavy grain feeding or excessive use of corn or silage may affect the pH balance (Monroe and Perkins).

Dukes (1937) states, "the reaction of the rumen content of the ox is always alkaline; the average is pH 8.89 (Gabriel)." It is because of the highly alkaline saliva secreted by ruminants there is such a constant reaction, Dukes explains. When hay or straw was fed with oats or bran, or hay alone, Stalfors (1926) noted an alkaline rumen reaction. In 1926, Swarz and Stremnitzer found upon slaughtering eleven animals, an average pH of 8.28 (reported by Monroe and Perkins 1939). These animals were fed a ration consisting of hay and straw. Higher alkaline rumen values were found when alfalfa hay was fed, also variations in pH were noted during the day. Kick _et al_. (1938) found that pH values were not the same in all parts of the rumen and that the greatest variations were found soon after the steers consumed their rations.

It has been assumed that the bacteria present in sheep and cattle would be different because of Hasting's statement that the pH in the rumen of the sheep is the higher of the two species. In their studies, when both species were fed the same type of ration, Gall _et al_. (1949) found the pH was similar, as was the bacterial population.

Rumen microorganisms appear to be able to tolerate a higher pH better than a low pH (Cheng et al. 1955). These workers also state it is very likely that different animals fed different rations also differ to some extent in their rumen microfloral activity.

Although the classification of the rumen microorganisms is imcomplete, bacteria, protozoa and yeast are the three general groups of microorganisms present in the rumen (Burroughs and Hall 1954). These workers also related that incomplete classification of rumen microorganisms exists partially because of the many species and types of microflora and microfauna in the rumen. Environmental rumen conditions have some influence upon the predominant types of microorganisms at a specific time. An example of this is, microorganisms from the water and feed consumed add to the complexity and confusion of identifying the native rumen population.

Protozoa are the most primitive members of the animal Kingdom, being microscopic in size, yet much larger than bacteria. Some of the larger protozoa may be 100,000 times larger in volume than some genera of bacteria (Heald and Oxford 1953). Protozoa possess a definite nucleus, celia, vacuoles and can ingest solid food but must absorb their nutrients in solution.

Mowry and Becker (1930) maintain that much importance is attached to the amount and kind of feed consumed in regulation of the number of organisms present in the rumen. They remarked that, under normal feeding conditions, approximately 1,000,000 microorganisms per cubic centimeter were present in the rumen. By direct count methods, Van Der Wath (1948) found an average of one to two billion microorganisms per milliliter of rumen contents.

Hungate (1947) stated that species and breed within species played no specific role in influencing rumen flora. High grain rations encouraged an increase in a type of organism already present in moderate numbers in the rumen, instead of an entirely different type of bacteria. Hungate also noted, that animals on pasture had greater numbers of bacteria in their rumen.

Gall et al. (1949) made direct counts of the rumen bacteria of cattle and sheep on pasture and reported numbers as high as 96×10^9 cells per gram of rumen contents. The numbers were somewhat lower in animals on wintering type rations.

Burroughs and Hall (1954) in describing yeast said, "yeasts resemble bacteria in being unicellular, non-motile, devoid of chlorophyll and require food material in a soluble form which can pass through the cell wall by diffusion. Yeasts differ from bacteria in their modes of reproduction and are generally much larger. Yeast cells also possess distinct nuclei and vacuoles of various kinds. It appears that yeasts are a relatively insignificant group of microorganisms in the rumen."

Resulting from their unique and dependent relationship, the ruminant supplies the material and the rumen microorganisms break down these substances so the nutrients can be utilized by the animal. These rumen microorganisms grow and multiply, and a great many of them are digested as they pass through the lower digestive tract (Burroughs and Hall 1954).

Early workers found that cellulose was decomposed by ruminants. They offered as evidence of rumen microbial cellulolytic activity, the lack of cellulase in the fore-stomach of ruminants (Burroughs and Hall 1954).

Hungate (1947) while working with high dilutions of rumen contents succeeded in isolating cellulose-digesting bacteria. It is now common knowledge that bacteria breakdown and digest cellulose (Bryant and Doetch 1955, Burroughs and Hall 1954); however, little is known of protozoan function within the rumen. Cellulolytic properties have been atributed to these microorganisms by some workers, (Burroughs and Hall 1954); nevertheless, it is not known whether protozoa or the bacteria ingested by the protozoa, digest the cellulose. Soluble carbohydrates are stored within protozoan cytoplasm (Burroughs and Hall 1954) as complex polysacharide vacuoles. Protozoa also become available to the animal in the lower digestive tract and serve as food for the host animal. Becker et al. (1929) removed the protozoa from the rumen of goats and the feed utilization was compared between these and normal animals. While possessing normal bacterial flora and having an absence of protozoa Becker et al. found no difference in the digestion coefficients of the feed nutrients in the treated and untreated animals.

II. FACTORS AFFECTING ROUGHAGE UTILIZATION BY MICROORGANISMS

It is a general concept that rumen microorganisms have nutritional requirements, and if efficient roughage (cellulose) digestion is to take place, these requirements must be fulfilled. Good quality roughages have ample quantities of these nutrients, while inadequate amounts are present in some poor quality roughages. Burroughs et al. (1949a, 1949b, 1949c, and 1950a, 1950b, 1950c) furnished additional support to this concept. Their results indicate the presence or absence of certain nutrients, needed by rumen organisms, affect the efficiency of digestion of roughage dry matter.

The nutrient requirement for the mixed rumen microflora appears to be relatively simple because they have such a large and varied synthesizing ability. There is evidence that the types of nutrients required by rumen microorganisms may fall into four general classifications (Davis 1954):

Type A. Energy - Nutrients related to energy, which are primarily soluble carbohydrates (presumably the motivation force of the digestion of compounds such as cellulose by rumen bacteria).

Type B. Protein- A nitrogen source related to protein (urea, ammonium salts etc.) or protein elements which can be synthesized into protein material.

Type C. Minerals-(major and minor minerals) Inorganic nutrients believed to be part of enzyme systems.

Type D. Factors- Unidentified stimulatory factors.

A. ENERGY

1. CELLULOSE AND FATTY ACIDS. Belasco (1956) stated that, "cellulose digestion in the ruminant is dependent on the nutritive status and requirements of the rumen microorganisms." He emphasized how carbohydrates yield fatty acids. Fatty acids are essential as energy, intermediates for tissue biosynthesis and milk production. The composition of feed ingredients have a direct bearing on the amount and distribution of volatile fatty acids in the rumen (Gray _et al_. 1951, El-Shazly 1952). Belasco (1956) stated that the amount and type of carbohydrate used, affects the amount and distribution of fatty acids.

Burroughs and Hall (1954) said, "the end products of cellulose decomposition consist primarily of acetic, proprionic and butyric acids." One pathway of cellulose breakdown is by way of cellobiase to glucose and then to volatile fatty acids perhaps by way of pyruvic or lactic acid (Phillipson

1947). Other carbohydrates, such as starch and sugars are broken down to these same fatty acids. Acetic acid is usually produced in greatest quantity, followed by propionic and butyric acid, depending upon the type of carbohydrate fermented (Phillipson 1947).

As indicated by the large amount of volatile fatty acids in the rumen the reticulum and relatively smaller amounts in the abomasum, these acids are absorbed from the rumen (Burroughs and Hall 1954). Phillipson and McAanally (as reported by Burroughs and Hall 1954) showed that blood draining the rumen, reticulum, omasum and caecum contained a higher concentration of volatile fatty acids than peripheral blood. This was good evidence that absorption was occuring from the rumen.

These volatile acids may enter various metabolic pathways. Propionic acid is converted to glycogen (Deuel et al. 1935, Doetch et al. 1952). Acetic acid after combining with coenzyme A to form acetyl coenzyme A, may be used in forming fat. It may be converted to sugar or glycogen, going through the intermediates of the krebs cycle to malate, from which it is converted to phosphoenolpyruvate, then to sugar. Because of the dynamic effect of feeds in ruminants, a great deal of the acetic acid is thought to be oxidized to $CO_2 + H_2O$ directly (Burroughs and Hall 1954).

Cellulose digesting bacterium, Bacteriodes succinogenes, have been shown to require branched and straight chain fatty acids (Bryant and Doetch 1955). Bently (1954) reported that valeric and caproic acids increased cellulose digestion in the artificial rumen and that some of the fatty acids stimulate fermentation by mixed rumen bacteria in vitro. Hungate and Dyer (1956) suggest that small amounts of appropriate acids might improve utilization of poor quality roughages. However, their results show no significant difference in weight gains, and rumen microbial activity between these steers fed with or without small amounts of valeric and isovaleric acids. These steers were fed a high wheat straw ration. Hungate and Dyer felt that the reason for this negative result might be due to lack of sufficient digestible carbohydrate in the ration. Those steers receiving the acid did display a stimulated appetite.

2. STARCH. Starch disturbs roughage digestion in ruminants in a manner probably related to the alimentary tract in habitation of biological microorganisms. An exact explanation of this necessitates direct bacteriological study.

As reported by Burroughs et al. (1949c) investigators, (Kellner and Hamilton) suggest when steers are fed a carbohydrate ration, the alimentary microorganisms might break down the simpler carbohydrates. Burroughs et al. (1949a, b) indicated starch and roughage are acted upon together by rumen microorganisms and that the addition of starch in their studies was found to decrease the apparent digestibility of crude fiber, throughout a wide range in protein intake.

Arias et al. (1951) observed that high levels of readily available carbohydrates decrease cellulose digestion. They suggested that in the interval between the time when the cellulose is broken down to a form which is utilizable by the cell, (glucose) some readily available energy is needed. If too much of the soluble carbohydrate is supplied, then the energy requirement of the bacteria will be satisfied and they no longer need to break down cellulose for energy.

From pH measurements taken right after feeding, Burroughs and Gerlaugh (1949a) found the attack on starch either precedes or takes place at a faster rate than it does when roughage replaces starch. Monroe and Perkins (1939) showed that the pH value decreases immediately two to four hours following feeding. Lower pH values are obtained in a shorter period of time when the starch to roughage ratio is increased in a ration (Burroughs *et al*. (1949c). These same workers noted that four pounds of starch decreased corn cob digestion appreciably. When the same amount of starch was added to alfalfa hay, no effect was noted. They stated that alfalfa hay contained more essential nutrients for promoting growth of microorganisms than did corn cobs. The alfalfa hay had adequate nutrients to withstand starch fermentation and enough left to promote growth of rouchage digesting microorganisms.

3. FAT. The level of fat was indicated to have a critical effect upon cellulose breakdown by sheep microbial organisms, as interpreted by Brooks *et al*. (1953) in seven trials with 130 artificial rumina. In these trials, 10 milligrams of corn oil added to the basal ration increased cellulose breakdown an average of 8 per cent. Cellulose digestion was decreased 4.8 per cent by adding 20 milligrams of oil and decreased 35 per cent by adding 40 milligrams of oil.

Erwin *et al*. (1955) found that fat significantly increased the digestibility of dry matter and crude fiber of steer rations. Tillman *et al*. (1956) conducted study using 141 sheep, involving the effect of fat and/or alfalfa ash upon the utilization of different types of rations containing low quality roughages. The levels of fat were 2.5 and 15 per cent, combined with varying amounts of low quality roughages. These data support the idea that under certain conditions even small amounts of supplemental fat may decrease the value of certain rations for sheep.

Willey et al. (1954) observed a faster rate of gain with increased feed efficiency when yearling steers were fed 5 per cent tallow in their ration.

Steers fed pellets containing alfalfa were noted to have increased rates of gain when 7 per cent fat (bleachable fancy tallow) was added to their ration (Erwin et al. 1956a). Steers consuming wheat straw showed a reduced rate of gain with the same level of fat. These differences may be explained (Erwin et al. 1956a) in that fat tends to reduce crude fiber breakdown, and wheat straw has a higher crude fiber content than alfalfa hay (Morrison 1956).

Brooks and fellow workers (1954) observed a reduction in cellulose digestion in vitro from the addition of fat. Ruminant feedstuffs could be affected considerably by fat because a large part is composed of cellulose. In the work done by Swift et al. (1948), digestibility of fat was increased as the level of fat increased in the ration. However, a trend was noticed toward decreasing dry matter digestibility as fat increased in the ration. Erwin, et al. (1956b) reported 7 per cent fat added in steer rations fed alfalfa and straw reduced the digestibility of the dry matter and crude fiber.

Erwin et al. (1956b) stated, "The mode of action of fat in reducing the digestibility of certain nutrients in the ration has not been definitely established. A possibility exists that the depressing effect is physical - that is, by coating the fiber so that the cellulolytic microorganisms cannot fully degradate the fiber."

4. MOLASSES. High levels of molasses produce a varied effect with different rations. Low levels of molasses appear to stimulate cellulose digestion with some rations and have no effect with others (Davis 1954). Molasses will usually increase the palatability of any roughage on which it is fed. It may be used to increase intakes and allow ruminants to obtain more nutrients from roughages. However, it must be remembered that this treatment will not turn poor-quality roughages into a higher class rations.

Molasses has been used as feed for at least sixty years and perhaps longer in the United States. Early work, as reported by Bohman et al. (1954) indicated that molasses was not an adequate carbohydrate for urea utilization, when fed with little or no starchy carbohydrate. As determined by nitrogen balance data, adequate synthesis of protein from urea did not occur in these rations. Further, the digestibility of dry matter, organic matter, either extract and crude fiber was found to be depressed by molasses.

Molasses competes directly with grains and mill feeds as a source of nutrients for livestock. However, Allan (1954) stated that molasses is an extremely poor source of protein.

Steer calves fed poor quality hay and two levels of protein showed an increased liveweight upon supplementing with molasses or trace minerals (Klosterman et al. 1956). These workers found that one pound of cane molasses per head, daily, improved the carcass grade of the finished cattle as well as their rate of gain.

The value of molasses has been associated with poor quality feeds. An investigation at Cornell indicates maximum value of molasses may be realized only when used with the best quality feeds, according to Fry (1956).

B. PROTEIN AND AMMONIATED PRODUCTS.

1. PROTEIN. Early work concerning ruminant synthesis of protein dates as far back as 1891. Improved digestibility by the addition of protein supplements to ruminants' rations have been observed by many. Watson et al. (1947), Swift et al., (1947), Gallup and Briggs (1948) and Morrison (1956) are a few of the many who have noted the influence of protein upon digestibility in ruminants. Davis (1954) recognized that for optimum function of rumen bacteria, there is need for some natural protein and a specific source of energy.

Because the bacterial cell is approximately fifty per cent protein, a nitrogen source is extremely important if they are to multiply. The following steps are involved in protein utilization by ruminants: (1) bacterial breakdown of a large part of the protein and non-protein nitrogen in the ration to ammonia, (2) incorporation of ammonia nitrogen into bacterial protein, (3) digestion of the bacterial protein as it passes through the lower digestive tract. Protozoa are known to ingest large numbers of bacteria and they in turn are digested by the animal (Burroughs and Hall 1954). Bacterial and protozoan protein has been found to have a biological value of 81 and 80 respectively and a true digestibility of 74 and 91 per cent (McNaught et al. 1954).

Burroughs et al. (1949b) stated that the decrease in protein digestibility of low protein rations is more apparent than real because fecal metabolic nitrogen is not taken into account. However, a decrease in non-protein digestibility may impair the digestive actions of the microorganisms in the rumen and digestive activity of these microorganisms. Proteins presumably serve two physiological functions when fed to ruminants (Burroughs _et al_. 1949b).

Function I - Pertains to growth and development of roughage digesting microorganisms, and amino acid and B-vitamin synthesis.

Function II - Relates to growth in the ruminant body proper.

Because the same feed-protein serves both functions, the total minimum protein required for maximum production depends upon which functional need is greatest. This production is difficult because under different conditions the protein requirement is variable in both instances. For example, the requirement for growth of body tissue protein for growing and fattening cattle decreases as the animal becomes older. More starchy feeds are consumed compared to roughage while fattening these animals, which in turn increases the protein requirement for roughage digestion. When corn cobs are fed in the absence of starch, the protein requirement for efficient utilization is as little as four per cent (Burroughs _et al_. 1949b).

Feeding grain in addition to roughage may furnish enough protein for body needs, yet may furnish insufficient protein to maintain efficient roughage utilization. This type of protein deficiency would affect mostly cattle being fattened, particularly older animals.

Because of the incomplete understanding of the role starch plays an increasing protein requirements in roughage digestion, an accurate minimal protein level has not been established. It is suggested, however, that this level falls between eight and twelve per cent protein. (Burroughs et al. 1949b). Burroughs et al. (1950b) again reported an apparent need for a minimal amount of protein in cattle rations to facilitate maximum roughage digestion. At times, they said, it appeared this level exceeded eleven per cent protein.

In the absence of starchy feeds or when a roughage is fed alone, the importance of protein per se to roughage digestion is quite small. Burroughs et al. (1950a) maintain that as starchy grains are reduced in a ration, apparently so is the protein requirement for efficient roughage digestion. As stated by Burroughs et al. (1950a), "this should not be inferred to mean that this small amount of protein in a roughage is ample in meeting the needs of cattle because requirements for roughage digestion and body needs are distinct and not additive even though ration protein jointly serves the two requirements."

The theory that protein aids roughage digestion by furnishing an essential nutrient for rumen bacteria was offered by Burroughs et al. (1949c). Following this thinking, Burroughs suggested that protein requirements for roughage digestion is actually the protein (nitrogen) requirements for rumen bacterial growth. As observed in these same studies, sufficient numbers of rumen bacteria were present when adequate protein was fed and roughage digestion was good. The predominating types of bacteria differed morphologically and culturally from those found when roughage digestion was poor.

Urea provides a satisfactory source of nitrogen for mature ruminants when thirty per cent or less of the total crude protein is furnished by urea (Davis 1954). In their *in vitro* studies of urea utilization by ruminants, Pearson and Smith (1943) found the first step in the use of urea to be its conversion to ammonia. Greater conversion was noted occurring at temperatures around 40° to 50° C. and hydrogen ion concentrations between 7 and 9. The second step was the incorporation of ammonia-nitrogen into protein. Pearson and Smith suggested this conversion was done by bacteria.

Burroughs *et al*. (1951) and McDonald (1951), as reported by Burroughs and Hall 1954, have both suggested that ammonia is the important intermediate in the digestion or utilization of protein or non-protein nitrogen by rumen bacteria. Bentley *et al*. (1953) found that urea (which is partially converted to ammonia) in combination with minerals and glucose gave great increases in *in vitro* cellulolytic activity.

Davis (1954) remarked there is a need for a more satisfactory source of non-protein nitrogen for ruminant feeding. Urea is rapidly broken down to carbon dioxide and ammonia which quickly escapes from the rumen. This action apparently occurs before the bacteria have an opportunity to use it completely for the synthesis of amino acids and protein.

Non-protein nitrogen was released enzymatically proportionate to the growth of the rumen bacteria which were synthesizing protein. This would appear to be a more useful source of nitrogen than urea. According to Davis (1954), a way to provide for the slow release of urea nitrogen in the form of ammonia is now under consideration. Several non-protein nitrogen compounds containing soluble ammonia or ammonia made available through enzymatic breakdown, provide good sources of nitrogen (Belasco 1954). His work was done *in vitro*. Magruder and Knodt (1954) indicated a compound called dicyanodiamide may provide a useful source of non-protein nitrogen for ruminants. Its nitrogen content is 66 per cent.

Results in their study (Burroughs et al. 1950b) with cattle indicate protein influenced favorable roughage digestion when roughages were fed in rations containing starch. Substantially the same results were observed by Burroughs et al. (1949a and 1949b) in which soybean oil meal and skim milk both increased the digestion of roughage. They also studied the effect of soybean oil meal upon corn cob and timothy hay dry matter digestion in a fattening ration. An average increase of about fifteen per cent in dry matter digestion occurred with the soybean oil meal addition.

Practical significance can be attached to the improvement in roughage digestion resulting from adding soybean oil meal to a low protein fattening ration. It is entirely possible that soybean oil meal might contribute some beneficial nutritional property to the ration other than protein. (Burroughs and Gerlaugh 1949a, b and c).

Extensive studies with artificial rumina showed that many protein rich feeds increased cellulose digestion by rumen bacteria (Burroughs et al. 1950d).

2. AMMONIATED PRODUCTS. The production of ammonia in the rumen at a greater rate than can be utilized by rumen microorganisms is an important problem in feeding non-protein nitrogen compounds to ruminants. Hale and King (1955) proclaim accumulation of ammonia in the rumen is undesirable and may be detrimental; and that among other things available carbohydrates are required for ammonia utilization.

Methods have been developed that may release ammoniated nitrogen in the rumen near the rate which complex carbohydrates are hydrolyzed and become available for protein synthesis. This is done by impregnating several agricultural products with ammonia-inducing chemical combinations, thus reducing its release to about the correct rate. Many feeds and industrial by-products have been ammoniated under varying temperatures and pressure. Understanding of the chemical combinations occurring from these reactions are not well understood (Tillman et al. 1957). In several ammoniated products, much of the nitrogen might be unavailable to rumen bacteria because of its form (Davis 1954).

Ten to fifteen per cent ammoniated molasses has been fed as a substitute in grain rations for cottonseed oil meal and with no adverse effects (Fry 1956). When the level of ammoniated molasses was increased to 25 per cent, undesirable symptoms were observed, such as excited condition, muscular tremors, twisted jaw, head turned sideways, closed or staring eyes, running in circles or jumping at top speed when startled by the slightest noise or movement. High levels of ammoniated molasses may react or combine with certain compounds in the rumen or intestine to produce a specific compound which might cause this abnormal stimulation.

Tillman et al. (1957) reported that cattle fed a high-test ammoniated molasses (32 per cent protein equivalent) at two pounds per day, had a peculiar reaction within five to six days. For short periods, these cattle reacted with violence and injured themselves by running into fences and attempting to climb them. It was also noted by these investigators, that utilization of nitrogen was not efficient from ammoniated cow manure or ammoniated furfural residue. Similar results are recorded from digestion and nitrogen balance trials with fattening-type rations. Wintering trials with cattle on winter range or wheat straw supplemented with ammoniated cow manure extract revealed both inefficient and efficient utilization of nitrogen.

C. MINERALS AND ASH.

1. MINERALS. The mineral requirement of the ruminant is generally assumed to be more complex than for monogastric animals because of additional mineral needs for bacterial activity in the rumen. McNaught et al. (1950) reported that iron, cobalt, copper, zinc, and manganese stimulated the utilization of non-protein nitrogen by rumen bacteria. Gall et al. (1949) found a marked difference in types and number of bacteria in the rumen of cobalt-deficient sheep.

Studies with a purified type of steer ration reveals that mature timothy hay did not supply enough cobalt. Results indicated the lack of cobalt was critical. Thus, the possibility of border-line deficiencies of trace minerals for cattle and sheep are most likely to occur when they are fed poor quality roughages, such as corn cobs, corn stover, and mature and rained-on hays, particularly those high in grasses. Corn is low in trace minerals (Bentley and Klosterman 1953).

There are several known physiological functions of trace minerals, especially in blood formation. However, the role of trace minerals in ruminant metabolism may have added significance because of their influence on the activity of the rumen microorganisms. A good example is the tie-up between the trace mineral cobalt and vitamin B_{12} synthesis. It is thought that cobalt has an effect on the activity of the rumen organisms (Bentley and Klosterman 1953).

Using _in vitro_ studies, Farris _et al_. (1955) showed reduced cellulose digestion when each of the following minerals were removed from the media: sodium, potassium, phosphorus, magnesium, manganese, iron, and sulphur. These workers found high levels of copper, zinc, and cobalt inhibited cellulose digestion, also that a wide range of certain mineral concentrations could be tolerated by rumen microorganisms.

The beneficial effect of adding minerals (Chappel _et al_. 1955) in the form of alfalfa ash or synthetic ash, may be due to:

I - The addition of some other essential micro-nutrient contained in the natural ash and present as a constituent in the salts;

II - An increase in the total ash content of a low ash ration with a subsequent favorable effect of undetermined nature on the rumen bacteria;

III - Some combination of known nutrients which are present in inadequate or unbalanced amount.

Alfalfa ash may promote better appetite by virtue of its higher alkalinity. Similarly, natural alfalfa ash which also has a high pH, might also have its favorable influence on appetite for the same reason (Chappel _et al_. 1955). In addition, these workers found the presence of alfalfa ash or a synthetic alfalfa ash in lamb rations increased the crude fiber and organic matter digestion significantly. Appetite of the lambs was also improved by either of these mineral additions. It was concluded that there was little advantage in providing extra protein without added trace minerals. The trace minerals also had a sparing effect on protein requirements.

Bentley and Klosterman (1953) suggested that in any program in which poor quality roughage is used, it would be advisable to feed mineralized salt. If plenty of good quality, high-legume roughage is being fed, it is doubtful if trace mineral supplements are necessary. In addition, it should be emphasized that trace minerals, plus poor quality roughages, will not replace good quality hay in a feeding program where roughage supplies the major portion of the nutrients. They added that there is a possibility of feeding too high a concentration of trace minerals.

2. ASH. Swift and co-workers (1951) suggested that alfalfa ash increased fermentation in the rumen, making available more feed energy to the animal, even after paying for the overhead (methane), as they put it. This observed increased production of methane supports Burroughs et al. in their theory of how alfalfa ash aids roughage digestion.

Tillman et al. (1956) said a large part of the increased utilization of low quality roughage, because of adding alfalfa ash, was due to the major minerals of the ash (salts of calcium, phosphorus, sodium, potassium, chlorine and magnesium). Iron and/or copper content of the forage appeared to be responsible for a small part of the increase. Bentley and Klosterman (1953) showed that molasses ash could be replaced with a mixture of copper, cobalt, zinc, manganese, and iron.

Some of the beneficial results of alfalfa ash was due to its action on the added fat in the ration (Tillman et al. 1954). However, no beneficial results occurred from the action of alfalfa ash upon added fat in their experimental work.

Burroughs et al. (1950b) showed the addition of alfalfa ash promoted greater digestibility of corn cobs. Alfalfa ash was postulated to enhance greater utilization of crude fiber and other constituents in the ration.

Steers fed poor quality hay were noted to have gained significantly more when the ash of dehydrated alfalfa meal was added to their ration (Klosterman 1953).

Tillman et al. (1954) found the addition of alfalfa ash to a semi-purified sheep ration improved the digestibility of all the ration components. Cottonseed hulls supplied all the minerals in the ration except calcium, phosphorus, sodium, chlorine and sulphur. They suggested the total ash and trace mineral content may be major considerations in the explanation why alfalfa ash increases the digestibility of some roughages and is of no value in others. Tillman and workers also found neither alfalfa ash nor a complete mineral mixture improved the apparent digestibility of the ration or any of its proximate components.

Bentley and Moxon (1952) reported that poor quality timothy hay was low in cobalt and that either alfalfa ash or a cobalt-containing salt mixture corrected this deficiency.

Bentley et al. (1953) observed that alfalfa or molasses ash doubled the rate of cellulose digestion.

D. FACTORS.

1. UNIDENTIFIED FACTORS. Many natural substances are known to enhance rumen microbial activity *in vitro*. Attempts to explain the stimulatory properties of such substances on the basis of known chemical composition have failed thus far (Burroughs et al. 1950e). Certain feedstuffs and other material contribute additional factors, thought to be unidentified bacterial nutrients, that help improve rumen fermentation (Ruf et al. 1953). Burroughs et al. (1949 and 1950), Hungate (1950) and Doetch et al. (1952)

demonstrated a need for materials of unknown nature for optimal growth of rumen bacteria.

Some of these natural substances which increase microbial activity in vitro are rumen liquor, yeast extract, manure extract, oil meals, alfalfa meal, and molasses. Burroughs et al. (1950c) found that manure extract, plus a complex mineral mixture and available nitrogen, greatly increases the breakdown of poor quality roughages in the artificial rumen. Addition of distillers dried solubles, soybean oil meal, cane molasses, corn, wheat bran, and cottonseed meal were found to be stimulatory.

Part of the stimulatory action of some of these feed substances may be explained by known chemical constituents. For example, it is known that the mineral content of alfalfa meal will stimulate cellulose digestion (Burroughs et al. 1950d). The soluble carbohydrate content of rumen liquor will also contribute to cellulose digestion. Bentley et al. (1954) indicated that five and six carbon fatty acids are a major component of the stimulatory factors in rumen liquor. However, when all of these known constituents are included in a medium, additions of the natural substances still result in a further increase in micorbial activity. Klosterman et al. (1956) also surmised an unidentified factor to be in hay of good quality, other than trace minerals or protein. Studies of these unidentified factors have shown that they often occur in largest quantities in feeds either rich in protein or in natural feeds rich in non-protein nitrogen.

Unknown nutrients present in rumen juice, dried distillers residues, grass juice, yeast, cow manure extract and other sources required by rumen bacteria were detected by Burroughs et al. (1950), Ruf et al. (1953), Bentley et al. (1953). Davis (1954) reported it has been indicated that the presence of alfalfa in the ration improves non-protein nitrogen utilization. Whether this is a direct effect or a general stimulation to the rumen flora is not known. Bentley et al. (1953) found in addition to rumen juice, factor(s) present in dried yeast and hot water extract of alfalfa leaf meal or hay.

Burroughs and associates (1949) imply factors other than protein intake were responsible for increased digestion of dry matter by addition of soybean oil meal. Missouri workers (Brooks et al. 1954) have indicated that certain steroid compounds such as cholesterol stimulate cellulose digestion. Other substances such as feather meal, hair, and drackett protein have stimulatory properties when subjected to mild hydrolysis. The stimulatory properties of these protein hydrolyzates appear to be fully as active in autoclaved rumen liquor in stimulating cellulose digestion by rumen microorganisms (Burroughs et al. 1950d).

The identification of the factor which favorably influences cellulose digestion is not known. Its significance to the nutrition of cattle and sheep also cannot be fully appraised (Ruf et al. 1953). Ruf suggests the factor is beneficial in maintaining appetite and rate of gain in lambs. Yeast supplies an unidentified factor helpful to cellulose digestion by rumen microorganisms. Ruf relates this material is quite generally distributed in the major feeds consumed by cattle and sheep. However, this widespread distribution does not preclude the possibility of inadequacy in present day ruminant rations, both concentrates and roughages. Yeast and manure extract were particularly rich sources of the material.

The factor is heat-stable and soluble in water and low concentrations of ethanol. Ashing destroyed the factor, indicating that the active material was not a mineral but rather an organic substance. The factors did not appear to be a B-complex vitamin or protein because the removal of proteins by precipitation failed to remove the active principle, and various B-vitamins and amino acid supplements failed to stimulate cellulose digestion (Ruf et al. 1953).

Yeast supplements added to a ration high in corn cobs and soybean oil meal improved liveweight gains in cattle (Beeson and Perry 1951). Thompson and Tosic (1949) showed a stimulation from yeast upon the rate of gain in sheep consuming a semi-purified and a natural ration respectively.

Hall et al. (1953, 1955) found no combination of B-vitamins which stimulated cellulose digestion as much as that obtained from yeast extract and autoclaved rumen liquid. These substances, no doubt, contain unidentified factors stimulatory to cellulose digestion in addition to the B-vitamins. The complete answer to unidentified cellulolytic factors is not B-vitamins; however, they may be partially responsible for the cellulolytic properties of yeast extract rumen liquid and possible other sources of factors.

2. VITAMINS. There is much experimental work showing microbial synthesis of thiamine, biotin, folic acid, nicotinic acid, pantothenic acid, pyridoxine and riboflavin (McNaught and Smith 1947). Vitamin B_{12} is also known to be synthesized by rumen bacteria (Bentley and Klosterman 1953). Vitamin K is the only fat soluble vitamin produced in the rumen (Davis 1954 and Burroughs and Hall 1954).

Until 1954, all the work on vitamin synthesis was qualitative. No work has been done on total vitamin production as related to metabolic requirements (Burroughs and Hall 1954). Normally no visible signs of deficiency of the B-vitamins and Vitamin K occur in the ruminant; therefore, it is assumed that vitamins are produced in sufficient quantities to meet body demands (Davis 1954, Burroughs and Hall 1953 and Hall et al. 1955). While on certain types of rations it is possible some of these vitamins may not be produced in large enough numbers for the animal's best performance. Following this thinking, several B-vitamins have been shown to enhance cellulose digestion in vitro (Burroughs and Hall 1954). For example, Hall et al. (1953) used washed suspensions of rumen microorganisms, found Vitamin B_{12}, biotin, pyridoxine, folic acid, para amino benzoic acid and riboflavin stimulated cellulose digestion. These workers also found that of the combinations of vitamins studied, B_{12} and biotin were the only vitamins which had synergistic action. A greater stimulation of cellulose digestion was observed from a combination of these two vitamins than any other single vitamin or combination.

Hall et al. (1955) later stated that no significant increase in cellulose digestion resulted from adding chlorine chloride, inositol, niacin, pantothenic acid or thiamine at levels ranging from 1 to 100 micrograms in a basal medium containing no vitamins and 0.5 per cent cellulose.

Bentley (1953) found that the stimulatory effect of rumen juice could be partially replaced by adding nine B-vitamins and adenine, uracil, and xanthine. A combination of B-vitamins and alfalfa ash was thought to be responsible for most of the increased cellulolytic activity. However, neither B-vitamins nor ash showed much activity. In 1955, Hall, et al. remarked that it is not known whether or not B-vitamins stimulating cellulose digestion in vitro, perform similarly in vivo. It may possibly be these B-vitamins required by cellulolytic microorganisms may be synthetically supplied by other microbes. These symbiotic relationships undoubtedly exist in the normal rumen.

Hunt et al. (1954) found that starch increased the synthesis of riboflavin, niacin, pantothenic acid and vitamin B_{12} in vitro. They also found that rumen inoculum from steers eating good quality alfalfa hay synthesized more B_{12} than inoculum from steers fed poor hay. Hallis et al. (1954) reported that the addition of soybean oil meal or urea (as a source of nitrogen) to corn caused a sharp increase in the synthesis of vitamins by those animals fed prairie hay as a basal ration. In addition, they found alfalfa ash and corn cobs as the main roughage, also resulted in an increased synthesis of all vitamins.

Dietary vitamin C is not required by ruminants. It is felt that this vitamin is produced by the tissue rather than by the microbes. Also, there is no evidence for synthesis of vitamin C by rumen bacteria (Burroughs and Hall 1954).

3. ANTIBIOTICS. Neumann et al. (1951) reported chloretetracycline had no beneficial effect on performance of beef heifers fed a fattening ration composed of corn silage, ground yellow corn, linseed meal and salt. Bridges et al. (1953) fed 1.1 to 15 milligrams of chlortetracycline per pound of feed to lambs weighing from 56 to 64 pounds without observing any significant increase in the rate of gain.

Dairy heifers fed rations containing 51 per cent ground corn cobs showed increase gains when aureomycin was added to their feed (Harshborger 1955). Rates of gain were significantly increased by adding aureomycin to alfalfa or wheat straw, making up 50 to 83 per cent of the roughage in beef cattle rations (Erwin _et al_. 1956a). Aureomycin fed at five milligrams per pound did not affect the amount of feed consumed or the efficiency of utilization. It did decrease, insignificantly, the dry matter and crude fiber digestibility. Earlier work by Erwin _et al_. (1955) with beef cattle showed that chlortetracycline significantly increased the digestibility of ether extract. Erwin and workers (1956) could not explain the increase in gain. They remarked the rapid weight gains may be supported by antibiotic alteration of rumen microflora.

Hungate _et al_. (1955) found rumen biota were modified by as little as five milligrams of chlortetracycline per pound of feed. He also found certain microorganisms, while in the presence of aureomycin, apparently select themselves on the basis of their resistance to it, and they are at least equally as active in its presence.

Tillman and Mac Vicar (1956) stated no effect upon ration digestibility was observed when 11.8 milligrams of chlortetracycline per 100 pounds of body weight was fed sheep. When the level of chlortetracycline was increased to 15.4 milligrams per 100 pounds of body weight, there was significant reduction in digestibility of dry matter, crude protein, crude fiber, nitrogen-free-extract and energy. The addition of either level of antibiotic had no effect upon nitrogen retention.

It is apparent from the literature that aureomycin exerts different effects upon different nutritional regimes. The stage of rumen development in relation to rumen biota and the type of ration fed appears to influence the effects of chlortetracycline on ruminants (Neumann _et al_. 1951).

4. HORMONES. Brooks _et al_. (1953) found the addition of diethylstilbestrol to _in vitro_ fermentation resulted in a substantial increase in cellulose digestion. Stilbestrol did not significantly affect the digestibility of either dry matter, crude fiber, crude protein or ether extract in steer rations. Erwin _et al_. (1956).

When lambs were fed either high or low protein rations it was shown that nitrogen retention was increased significantly by stilbestrol feeding only in rations containing high protein (14 and 20 per cent). Stilbestrol had little effect upon the nitrogen retention in the low protein (8 per cent) ration. There was no effect upon the digestibility of protein and dry matter from feeding stilbestrol regardless of its influence upon nitrogen retention (Struempler and Burroughs 1956).

Many workers have noted the increased rate of gain and efficiency of feed utilization when diethylstilbestrol is incorporated into a fattening steer ration or when implanted (Burroughs _et al_. 1954, Luther _et al_. 1954 and Perry _et al_. 1955).

According to Brooks _et al_. (1954) stilbestrol's contribution to accelerated weight gains may be due to an increased digestion of crude fiber. However, the mode of action of stilbestrol has not been definitely established.

Erwin _et al_. (1956b) witnessed interaction between fat and stilbestrol and fat and chlortetracycline in reducing the digestibility of crude fiber. In addition, they report there was no interaction between chlortetracycline and diethylstilbestrol.

III. LOW QUALITY ROUGHAGE

Low quality roughages utilized all over the world have characteristics in common. A comparison of the chemical composition of some good quality roughages with some poor quality roughages is made in Table I.

As pointed out, in Table I, the low quality roughages are inferior to high quality roughages in many factors. Franklin et al. (1955) discussed the effects of some of the deficiencies found on low quality pastures in New South Wales, Australia. Those mentioned in this report were vitamin D deficiency and protein deficiency. Also, severe occurrences of hypocalcaemia and hypophosphotemia were noted with the occurrence of clinical rickets. In Morrison's description of feed straw, he says, "The straw, which consists of the mature stems and leaves, without the seeds, has relatively little protein, starch, or fat, while the content of fiber and lignin is high." Straw is also low in calcium and phosphorus and in most vitamins, especially in vitamin A content. Straw generally contains considerable vitamin D.

"When low quality feeds are used, extra digestible protein must be used in the ration (Davis 1954). Dyer et al. (1957) reported that protein was apparently the first limiting factor of wheat straw in their observations with pregnant beef heifers and effects of various constituents on roughage utilization. They substantiated this by the observation that feeding minerals without nitrogen resulted in no weight gains in heifers.

The efficiency with which cellulose is utilized in roughage fed to

Table 1. Chemical Composition of Various Roughages. 1/, 2/

Roughage	C.P.	D.P.	E.E.	C.F.	N.F.E.	Ash	Ca.	Phos.	Est. Net Energy
	%	%	%	%	%	%	%	%	Therm/cwt.
				Good quality roughages					
Alfalfa hay, very leafy	17.5	12.8	2.4	22.7	39.5	8.4	1.61	0.24	43.5
Alfalfa hay, all analysis	15.3	10.9	1.9	28.6	36.7	8.0	1.07	0.24	40.6
Clover hay, Ladino before bloom	21.4	16.5	1.4	18.6	36.6	10.4	---	---	48.2
Timothy hay, before bloom	9.7	6.1	2.7	27.9	42.2	6.5	0	0	44.1
				Poor quality roughages					
Timothy hay, late seed	5.3	1.9	2.3	31.2	45.7	4.5	0.14	.15	27.2
Corn cobs, ground	2.3	0	0.4	32.1	54.0	1.6	0.11	.04	40.1*
Wheat straw	3.9	0.3	1.5	37.0	41.9	8.3	0.15	.07	10.0
Cotton seed hulls	3.9	0	0.9	45.0	38.4	2.6	0.13	.06	29.3

1/ Davis, 1954
2/ From Morrison (1956)
* Fed with efficient supplements

cattle and sheep is primarily dependent upon the degree of lignification in plant tissue and whether the conditions (pH, microflora, etc.) are favorable in the rumen for efficient cellulose digestion (Crampton and Maynard 1938). The crude fiber increased as much as sixty per cent in low quality roughages, and with this increase its character changed (Forbes 1948). As plants mature, there is an appreciable increase in lignin. This increase is important because of the indigestibility of lignin and because of the decrease of other nutrient digestibility as the lignin increases.

Davis (1954) suggested that because of the deficient mineral and protein content of poor quality roughage the utilization of the nitrogen-free-extract is generally decreased, although poor quality roughages have a higher nitrogen-free-extract than higher quality roughages. A good indication of a good or poor quality roughage is its estimated net energy. Low quality roughages measured by any of these yardsticks should not be expected to provide results compared with first-class feeds.

IV. FACTORS AFFECTING COMPOSITION OF ROUGHAGES

As reported by Dent (1957), W. M. Ashton examined the chemical composition of straw and grain of three varieties of oats. His conclusion was that little variation exists between varieties at the ripe stage, when grown under similar conditions. He also found that straws harvested at a relatively immature stage at higher altitudes had a superior chemical composition when compared with straw harvested at the normal stage of ripeness at the same altitude, and the digestibility of the crude protein was also higher.

Dent (1957) maintained that environment made a great difference in