AMMONIUM SALTS OF ORGANIC ACIDS AS SOURCES OF CRUDE PROTEIN FOR FEEDLOT CATTLE

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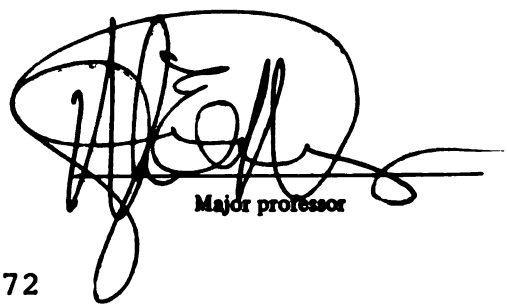

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ABSTRACT

AMMONIUM SALTS OF ORGANIC ACIDS
AS SOURCES OF CRUDE PROTEIN
FOR FEEDLOT CATTLE

By

Charles Keller Allen

The feeding value, metabolism and utilization of supplemented organic acids or ammonium salts of organic acids were studied in four feeding trials and three metabolic studies. The effect of high versus moderate levels of concentrate on the utilization of ammonium salts was also studied.

In Experiment I, ammonium acetate, ammonium lactate, soybean meal and urea were compared in a growth study on a ration composed of 75 per cent concentrates and 25 per cent corn silage. Cattle supplemented with ammonium acetate gained 5.4 per cent faster than cattle receiving soybean meal and 12 per cent faster ($P<.05$) than urea fed steers. Ammonium lactate feed steers gained faster ($P<.05$) than soybean meal (13.5 per cent) or urea (20 per cent) fed groups. Consumption was increased 9.1 per cent and 12.2 per cent for the ammonium lactate steers and 3.1 per cent and 6.0 per cent for the ammonium acetate fed steers compared to those fed soybean meal and urea,

respectively. Similarly, feed efficiency was increased 3.5 per cent and 7.2 per cent with supplementation of ammonium lactate and 2.3 per cent and 6.1 per cent when ammonium acetate was fed.

In Experiment II, ammonium salts of formic, acetic, propionic lactic and butyric acids were compared to soybean meal, urea and a supplement that derived one-half of its protein equivalent from urea and one-half from corn steep water (U-CSW). The nitrogen supplements were added to either a ration of 40 per cent concentrates and 60 per cent corn silage or a ration of 80 per cent concentrates and 20 per cent corn silage.

None of the differences in gains were significant. However, the urea fed cattle had the lowest gains, feed efficiency and DM consumption and produced carcasses that had the lowest grade and the least fat. The performance of all NPN fed cattle except those fed ammonium acetate increased with a higher level of concentrate in the ration. The groups fed NPN were also more efficient on the high concentrate diet but less efficient on the low concentrate diet than those fed soybean meal. The decreasing order of commercial value for the nitrogen supplements was ammonium propionate, soybean meal, ammonium butyrate ammonium lactate, ammonium formate, U-CSW, ammonium acetate and urea.

The gains of cattle on high concentrate diets were 2.9 per cent higher and the feed efficiency was 7 per cent greater than on low concentrate diets. However, the low concentrate ration resulted in more beef per hectare, higher gross returns per hectare and lower cost of gains. Cattle fed the high concentrate diet had higher cracass grades ($P < .05$) and dressing percents ($P < .01$) and were fatter ($P < .01$) than those fed the low concentrate diet.

Experiment III was designed to study the addition of lactic or acetic acid in equalmolar concentrations as the ammonium salts fed in Experiment I. The acid additions were compared on both urea and soybean meal supplemented rations. Adding acetic acid decreased feed efficiency 3.7 per cent but adding lactic acid increased feed efficiency 2.6 per cent. The addition of lactic acid tended to reduce the amount of carcass fat.

Urea fed cattle had a decrease of 4.3 per cent, 2.6 per cent and 1.9 per cent in gain, consumption and feed efficiency, respectively, when compared to soybean meal fed steers. The urea supplemented steers were also trimmer ($p < .05$) than steers fed soybean meal.

In Experiment IV, the addition of acetic or lactic acids to all silage rations was studied. The addition of acetic acid to the ration depressed gain and feed efficiency for all levels of acetic acid. Average daily gain feed

efficiency and consumption were not affected by adding lactic acid to the ration.

Experiment V involved stomach pumping and bleeding cattle previously on Experiments I and III. The rumen ammonia concentrations were highest at $T_{2.5}$ for urea, ammonium acetate and ammonium lactate. Ammonium lactate fed cattle also had higher ($P < .05$) rumen ammonia levels at T_5 and T_{10}. Blood urea levels were higher at all for cattle fed ammonium salts than for cattle fed urea or soybean meal at all sampling times.

Rumen acetate concentration was higher at all determinations for cattle fed ammonium lactate than for cattle receiving ammonium acetate or urea and higher for steers fed ammonium salts at T_2 than for those fed soybean meal or urea. Rumen propionate levels were higher for the steers fed soybean meal and ammonium lactate. Rumen butyrate was not detected in rumen fluid samples of the ammonium lactate fed steers.

When lactic acid was added to the ration, rumen ammonia and blood urea levels were higher at all sampling times. Cattle receiving acetic acid in the diet had the highest rumen acetate at $T_{2.5}$. Lactic acid fed steers had the highest rumen acetate (except $T_{2.5}$) and highest rumen propionate at all sampling times.

In Experiment VI, nitrogen balance and metabolic studies were conducted with fistulated steers fed the same rations as Experiment I. Rumen ammonia and blood urea levels of the urea fed steers were higher at all sampling times except T_{10} than for soybean meal or ammonium salt fet cattle. Supplementation with ammonium lactate increased the levels of rumen acetate and propionate. Rumen butyrate levels were higher for steers feed ammonium salts than for steers fed urea or soybean meal.

Steers fed ammonium salts had greater nitrogen intake but did not lose any more nitrogen in the feces or urine than the soybean meal and urea fed steers. This resulted in an increased quantity of nitrogen digested and higher ($P < .01$) nitrogen balance for the steers fed ammonium salts.

Experiment VII was a nitrogen balance and metabolic study of the nitrogen supplements fed in Experiment II on the low concentrate ration. Rumen ammonia concentrations were maximized at T_2 and were highest for ammonium lactate and ammonium acetate fed steers. There was no significant difference among the various nitrogen sources tested for blood urea levels.

Rumen acetate concentrations were higher for ammonium acetate fed steers at T_2 but lower than soybean meal, ammonium lactate, U-CSW, ammonium formate and ammonium butyrate at T_4. Supplementing the diets with soybean

meal or ammonium lactate resulted in elevated rumen propionate levels. Rumen butyrate was higher at T_2, T_4 and T_6 for the ammonium butyrate fed steers.

None of the differences in DM intake, DM digestibility or the nitrogen parameters studied were significant. Daily nitrogen intake was highest for the U-CSW fed steers, lowest for the soybean meal steers and intermediate for cattle fed urea or ammonium salts.

The results of these experiments indicate that ammonium salts of organic acids are superior to urea and in many cases equal or superior to soybean meal in promoting efficient beef gains and positive nitrogen balance.

The acid portion of ammonium salts is an efficient energy source and does not, with the exception of ammonium acetate, effect DM consumption.

AMMONIUM SALTS OF ORGANIC ACIDS AS SOURCES OF CRUDE PROTEIN FOR FEEDLOT CATTLE

By

Charles Keller Allen

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INTRODUCTION

Recent studies indicate that if present relative rates of population growth continue, it is probable that the excess of cereal grains and natural proteins, which are now available for use as animal feeds, will be critically diminished. More efficient utilization of natural protein and cereal grains can be made if they are consumed directly by man instead of being processed into meat by animals. Only animals which are the most efficient in the utilization of these feeds will be used to convert them into more nutritionally complete food. In this respect, ruminants are the least efficient of farm animals and beef cattle are the least efficient ruminants that are in commercial production.

However, ruminants survive and are economical when fed materials that are non-edible by man and other monogastrics. This results from a digestive system which includes a symbiotic relationship with a massive microbial population capable of digesting fibrous plant material that is high in cellulose and not digestible by simple stomach animals. The final products of this digestive process are volatile fatty acids which can provide most of the energy needed by the host animal. In

addition, rumen microorganisms synthesize protein from non-protein nitrogen compounds, vitamin K and all of the B-complex vitamins. The protein is synthesized in the form of the microbial body and is transported to the small intestine where it is utilized in the same manner as in monogastric animals.

Less than 10 per cent (1.0 billion hectare) of the total world land surface is planted to crops that produce food for human consumption. There is an additional 19 per cent (2.6 billion hectare) in permanent pastures and meadows, but it is improbable that all of this could be converted to crops edible by man. The world's forest lands yield approximately two-thirds of the total carbohydrate produced each year on the land surface. The remaining one-third comes from all other types of land plants; the majority of which is cellulose which cannot be utilized by man. Much of the cellulose now produced is poorly utilized even by ruminants primarily because of its high lignin content. However, methods are being developed for hydrolyzing the lignocellulose bonds and making the cellulose more available to the rumen microorganisms. It seems reasonable that, in time, these methods will be improved and/or new methods devised that will make it practical to prepare these feeds for ruminant consumption.

In the harvesting of cereal grain and legume seeds, the stalks and leaves are left in the field in spite of the fact that, in some cases such as with corn, they contain up to 50 per cent of the total plant gross energy. Residues from other crops such as tubers could be converted by ruminants into high quality foods which would otherwise not be available to man.

Another potential source of feed for ruminants are by-products of the food processing industries. Many of these energy sources are not only being wasted, but also pollute the environment.

These energy sources are mostly deficient in protein and contain only low levels of the B-complex vitamins. Supplementation with non-protein nitrogen and feeding them to ruminants would result in their conversion to nutritious food for human consumption that has a high concentration of protein and B-complex vitamins. Non-protein nitrogen compounds can also be used by ruminants for improving the efficiency of conversion of plant protein to food for man.

The widespread use of non-protein nitrogen compounds in ruminant nutrition is relatively recent and has been primarily restricted to urea. Urea can make up approximately 50 per cent of the protein required by beef cattle and feeders use it to reduce feed cost. Poorer performance and toxicity frequently result when urea

exceeds 50 per cent of the total crude protein intake. Therefore, there has been a search for non-protein nitrogen compounds that can safely and economically meet a larger proportion of the protein requirements of ruminants.

Extensive research conducted at the Michigan station with non-protein nitrogen addition to corn silage established that much of this nitrogen was combined with organic acids that resulted from fermentation to form ammonium salts. The performance of cattle fed non-protein nitrogen treated silages compared to untreated silages supplemented with soybean meal indicated a high availability of ammonium salts for feedlot cattle. In addition, it was hypothesized that these compounds could be produced by ammoniating organic acids produced from the fermentation of substances now considered waste products.

Therefore, the objectives of this study were to:

(1) Compare ammonium salts of organic acids, soybean meal, and urea as sources of supplemental curde protein for feedlot cattle.

(2) Determine the effect on nitrogen metabolism by adding organic acids to feedlot rations supplemented with urea and soybean meal.

(3) Describe the rumen and blood parameters associated with the digestion and metabolism of ammonium salts of organic acids.

(4) Determine the effect of high versus moderate levels of concentrate on the utilization of ammonium salts of organic acids.

(5) Assess the potential of ammonium salts as nitrogen supplements and justification of future studies on methods of commercial production of ammonium salts of organic acids.

LITERATURE REVIEW

Historical Development of Protein Nutrition

Protein is the most abundant nitrogenous compound in the diet and in the body. Consequently, the early history of protein metabolism is linked to the discovery of nitrogen and its distribution in nature. Munro (1964) and Stangel (1967) have reviewed early protein biochemistry.

Daniel Rutherford is generally attributed with the discovery of nitrogen gas in 1772 but the name nitrogen was not given to the new material until 1790. The French chemist Antoine Lavoisier reported in 1790 that nitrogen gas played no part in the metabolism of the mammalian organism. A system of organic analysis for nitrogen by treating the organic material with potassium chlorate was devised by Gay-Lussac in 1810. In addition, this period also saw the isolation of several compounds of considerable interest in the later study of protein metabolism. Urea was identified in the urine by H. M. Rouelle in 1773. In 1823, Pre'vost and Dumas demonstrated that urea accumulated in the blood when the kidneys were removed and led to their suggestion that the liver was the site of urea formation. By 1824, Proust made the

first accurate analysis of urea and determined its empirical formula. In 1828, Wohler demonstrated the synthesis of urea from inorganic substances. Amino acids were isolated in 1810 by Wollaston and acid hydrolysis was first employed for disintegration of proteins by Braconnot in 1820. Advances in the knowledge of protein metabolism from the late 1820's until the turn of the century were hampered by inadequate analytical techniques and controversy over the relationship of dietary compounds to those found in the body. The major contributions included the recognition of protein as a component of animal and plant tissues (Muder, 1838 as reported by Stangel, 1967) and the development of nitrogen balance as a technique for the study of protein metabolism by Voit.

In 1900, a partial quantitative analysis of individual isolated proteins was made possible by the method of Kossel and Kutcher who observed wide divergence in the amino acid content of different proteins. The establishment of a link between defects in the nutritive value of a protein and its amino acid composition was made by Willcock and Hopkins in 1906 (Munro, 1964). Rose (1938) replaced dietary protein with mixtures of purified amino acids and culminated his study with the classification of amino acids as essential or non-essential for

both the rat and man. This preceded studies by Osborne et al. (1919), Mitchell (1923-24), Block and Mitchell (1946), Oser (1951), Miller and Bender (1955), and Bender and Doell (1957) that devised methods of evaluating protein quality for non-ruminants. These methods involved the utilization of proteins by growing animals or by protein depleted animals. Chemical methods for determination of the amino acid content of the protein were also developed.

Nitrogen Metabolism in the Ruminant

Nitrogen metabolism in the ruminant has been the subject of several reviews (Blackburn, 1965; Hungate, 1966; Waldo, 1968; Chalupa, 1968; Conrad and Hibbs, 1968; Smith, 1969; Kay, 1969; McDonald, 1968 and Purser, 1970a, b).

Microbes in the rumen degrade a major portion of the dietary and endogenous nitrogenous compounds. Some of the degradation products may be absorbed directly from the rumen or from the lower alimentary tract. However, most are used in the synthesis of microbial protein. The nitrogenous substances presented to the abomasum and intestine of the ruminant consist of those present in the

microorganisms and, to a limited extent, those that escape degradation and absorption in the rumen (Smith, 1969 and Chalupa et al., 1972).

Hutton et al. (1971) estimated that 50 per cent of the total nitrogen leaving the abomasum was bacterial nitrogen. Jackson et al. (1971) noted that about half of the nitrogen that passed to the duodenum was α-amino nitrogen. In addition, Black (1971) suggested that the complete degradation of dietary protein in the rumen would result in about 50 per cent less absorbed protein from the small intestine than in a non-ruminating lamb.

Most of the nitrogenous material ingested by ruminants receiving natural feeds consist of proteins. These are usually broken down by the rumen bacteria to yield amino acids and then ammonia (Blackburn, 1965 and Hungate, 1966). Many individual species of rumen bacteria use ammonia as a nitrogen source in preference to amino acids and some species have an absolute requirement for ammonia (Smith, 1969). In contrast, the protozoa in the rumen are mainly ciliates (Hungate, 1966) and ciliates in general have an absolute requirement for amino acids (Kidder, 1967, as reported by Smith, 1969).

Al-Rabbat et al. (1971a, b) reported a procedure for estimating rumen microbial synthesis from ammonia. It was estimated that 61 per cent of the microbial nitrogen was derived from ammonia (Al-Rabbat et al., 1971a) and that the formation of microbial cells from ammonia was dependent on energy intake and independent of nitrogen intake (Al-Rabbat et al., 1971b). In this study they estimated that between 42 and 100 per cent of the total microbial nitrogen could be derived from ammonia. Beever et al. (1971) fed low-nitrogen rye grass hay to sheep and also concluded that available energy rather than nitrogen limited microbial protein synthesis. Mathison and Milligan (1971) found that 50 to 65 per cent of the bacterial nitrogen and 31 to 55 per cent of the protozoal nitrogen were derived from ammonia.

Diets consumed by ruminants normally contain appreciable nitrogenous material other than proteins. Pasture plants contain about 20-30 per cent of their total nitrogen as non-protein nitrogen or NPN (Ferguson and Terry, 1954 and Hogan, 1964) and corn silage contains a much greater proportion (Henderson et al., 1971a). Most of the compounds in the NPN fraction are rapidly degraded in the rumen and form ammonia (Smith, 1969). Apart from NPN derived from natural feeds, ammonia compounds or other nitrogenous compounds such as urea are added to ruminant rations.

Post-Ruminal Metabolism of Protein

The digestion and absorption of protein in the small intestine of the ruminant is very similar to that found in non-ruminants and has been reviewed by (Gitler, 1964). The hydrogen ion concentration in the abomasum permits the autocatylytic conversion of pepsinogen to pepsin. Rennin, the milk coagulating enzyme, is also found in the abomasum of the young calf. The object of proteolysis in the stomach appears to be one of splitting certain bonds in preparation for further hydrolysis by that proteases of the small intestine. It is also probable that secondary linkages in proteins are broken by the acidity of the abomasum and result in denaturation (Gitler, 1964).

The presence of acid, peptides and fats in the pyloric area of the abomasum and the duodenum induces the release of secretin and pancreozymin from the duodenal mucosa which stimulates secretion by the pancreas and by the Brunner's glands (Harper, 1959). The combined action of the proteolytic enzymes of the pancreatic juice and intestinal mucosa result in further digestion of exogenous nitrogen from the stomach (Geiger, 1951; Chen et al., 1962). The absorption of the greast part of the protein

from the stomach occurs in the distal duodenum and proximal half of the jejunum (Schlussle, 1959).

The main end-products of protein digestion that are absorbed across the mucosal membrane are amino acids (Gitler, 1964). Whole proteins are absorbed in the very young ruminant as a means of establishing passive immunity from disease (McCance and Widdowson, 1964). There is disagreement concerning the absorption of small peptides across the mucosal membrane.

Amino Acid Supply and Requirements of Ruminants

There appears to be no significant discrepancy between ruminants and non-ruminant mammals in the essential chemical pathways of nitrogen metabolism in the various tissues of the body (McDonald, 1968 and Hogan and Weston, 1970). Black et al. (1952, 1957) and Downes (1961) demonstrated by using isotope techniques that sheep and cattle are not able to synthesize essential amino acids (EAA) at the tissue level. This has also been shown for man, rats and dogs. Rose (1938) made it clear that EAA are indispensable for maintenance and optimum growth. They must be provided in the diet or at the absorption sites for ruminants in adequate amounts to meet requirements.

Rumen bacteria and protozoa influence the amino acid supply to the animal by degrading dietary protein and by synthesizing microbial proteins (Bryant and Robinson, 1961, Hungate, 1966 and Allison, 1969). The quantitative supply of amino acids is also influenced by nitrogen intake (Clarke, et al., 1966 and Williams et al., 1953), nitrogen source in the diet (Little and Mitchell, 1967) and the microbial population in the rumen (Bergen and Purser, 1968 and Bergen et al., 1968).

After absorption amino acids are transported to the liver where they are used for protein synthesis and gluconeogenesis. Some may also be transferred to the circulating plasma pool (Purser, 1970a). The use of amino acids for gluconeogenesis in sheep was estimated to account for about one-fourth of the total plasma glucose (Reilly and Ford, 1971 and Wolff et al., 1971). Several workers have interpreted an increase in plasma amino acid concentration as being indicative of improved protein status, but Zimmerman and Scott (1967) showed that an improved balance of amino acid led to a decrease in plasma amino acid concentration.

There has been considerable research conducted to describe precisely the amino acid supply to the ruminant for metabolism but very little has been done to determine the adequacy of the supply (Purser, 1970a). Bergen (1967) examined the effect of ration on the protein quality of

rumen microorganisms. The data showed that rations did not significantly effect the amino acid composition of the rumen bacteria and rumen protozoa. Bergen et al. (1968) concluded that histidine and cystine were the limiting amino acids of rumen protozoal and bacterial protines after feeding these proteins to rats as the only nitrogen source. Leucine, arginine and lysine were also in short supply. Leibholz (1971) used in vitro techniques to determine that L-histidine and glycine were transferred across the rumen epithelium in sheep.

Methionine may be a limiting amino acid for ruminants (Nimrick et al., 1971 and Wright, 1971). It is suggested that the hydroxy analog of methionine may escape rumen degradation and increase the amount of metnionine available to the animal. Results to date have been variable. Methionine hydroxy analog (MHA) has been shown to increase cellulose digestion in the rumen (Salsbury et al., 1964, 1967, 1970) and increase nitrogen retention (Polan et al., 1970 and Salas, 1971). There have been reports of increased daily gain of steers fed MHA (Salas et al., 1971 and Burroughs et al., 1969b, 1969c) as well as reports in which MHA had no effect on daily gain of beef steers (Gosset et al., 1962; Beeson et al., 1970; Hale et al., 1970a, 1970b; and Lofgreen, 1970). Other workers have reported a benefit (Ternus et al., 1971) or no benefit (Peter et al.,; Ternus et al., 1971 and Wilson et al., 1971) from feeding MHA to sheep.

In several studies MHA was fed to dairy cows and equally conflicting results were obtained. Griel et al. (1968), McCarthy et al. (1969), Polan et al. (1970) and Bishop (1971) reported increased milk production with supplemental MHA. In contrast, there have been several reports that MHA had no effect on milk production (Williams et al., 1970; Grugaugh and Olson, 1971; Kim et al., 1971 and Hutjens and Schultz, 1971). Rosser et al. (1971) suggested that MHA may enhance triglyceride transport into the mammary gland. Both increased milk fat production (Bishop, 1971 and Kim et al, 1971) and no improvement in milk fat production (Hutjens and Schultz, 1971 and Grubaugh and Olson, 1971) have resulted with MHA supplementation. On the average, it appears that the feeding of MHA was not beneficial. However, there may be special circumstances that result in an increased need for methionine in ruminants.

Urea as a Nitrogen Source in Ruminants

The recognition that microorganisms in the rumen play a unique role in the nutrition of the host animal was reported independently by Zunte and Hageman in 1891 (reported by Stangel, 1967). Hageman pointed out that the confusion in experimental results found when testing the nutrative value of NPN compounds could be explained by the role that microorganisms play in the digestive system of

herbivorous animals. For the next 35 years, the ability of rumen organisms to utilize NPN was explored. Morgan et al., in a series of experiments from 1907 to 1924, showed that 30 to 40 per cent of the protein in sheep rations could be replaced by urea (reported by Stangel, 1967). The first work in the United States on urea utilization was not conducted until the 1930's (Chalupa, 1968; Beeson, 1969 and Church et al., 1970). Hart et al. (1938, 1939) concluded that ruminants could use simple nitrogen compounds through the action of rumen microorganisms. They also reported diuresis, increased blood urea and some kidney damage in animals on rations with over 60 per cent of the protein equivalent as urea.

Bartlett and Cotton (1938) showed that dairy heifers could use urea effectively. The substitution of urea in the rations of producing dairy cows was reported by Owen (1941) and Owen et al. (1943). The supplementation of urea was found to have no effect on the percentage of protein, fat, lactose or total milk solids of the milk. The amount of urea in the milk never exceeded that of the blood.

Loosli et al. (1949) obtained substantial growth over a three-month period with lambs and goats fed a purified diet devoid of amino acids in which all of the nitrogen was provided by urea. In the same experiment, EAA were 9 to 20 times greater in the rumen and in the

feces than in the feeds fed. Loosli et al. concluded that all EAA were synthesized by rumen microorganisms and this was later confirmed by Duncan et al. (1953).

Other feeding trials with cattle (Rupel et al., 1943; Willet et al., 1946; Briggs et al., 1947; Dinning et al., 1949 and Brown et al., 1956) have conclusively demonstrated the usefulness of urea for partially meeting the protein needs of ruminants. Nitrogen balance experiments (Harris and Mitchell, 1941; Johnson et al., 1942; Harris et al., 1943; Hamilton et al., 1948 and Arias et al., 1951) have added further information, showing that limited amounts of urea can be converted into protein. Urea is particularly suited as a feed ingredient since it is an economical, odorless material of high nitrogen content and biological availability (Belasco, 1954).

Numerous studies at the Michigan Station (Henderson et al., 1960; 1968a , b; 1970) have shown that urea can not only replace part of the supplemental protein but also substantially reduce the total feed cost for feedlot steers. Other workers (Ewing and Burroughs, 1963 and Martin et al., 1968) have shown that urea can also be used in the rations of breeding cattle to reduce feed costs without sacrificing optimal performance.

In contrast, experiments in Oklahoma have shown that urea is not as efficiently utilized as natural proteins for wintering cattle on native grass. This was true

for both steers (Nelson et al., 1961) and for lactating cows (Miller et al., 1958 and Williams et al., 1968). Williams et al. (1968) thought that the reason that previous Oklahoma work had failed to show good urea utilization was due to the low level of energy in the ration. Allen (1972) found that a liquid protein supplement that derived 20 per cent of its crude protein equivalent from natural protein and 80 per cent from urea was more efficient than a supplement that derived all of its protein equivalent from urea. This was true for both yearling steers, and for calves nursing cows that grazed frosted winter pastures in Argentina. Newland et al. (1961) reported a slight depression in gains and feed efficiency when urea made up 100 per cent of the supplemental nitrogen for cattle.

In order to make the most efficient use of urea as a nitrogen supplement to poor quality roughages, a readily available source of carbohydrate appears necessary (McKnaught and Smith, 1947; Bell et al., 1953; Reid, 1953 and Belasco, 1956). Arias et al. (1951) reported that increasing the energy content of the fermentation mixture resulted in an increased urea utilization with all sources of energy tested. This was true regardless of whether the energy source was a soluble carbohydrate such as dextrose or sucrose, or whether the carbohydrate was more complex such as the cellulose of a high fiber feed.

Potter et al. (1971) compared quantities of amino acids reaching the abomasum and plasma amino acids of steers fed different sources of protein. Only 79.4 per cent as much nitrogen reached the abomasum for steers fed urea compared to steers fed soybean meal. When 2.5 per cent molasses was added to the urea ration, the amount of nitrogen reaching the abomasum was 92.5 per cent of that when soybean meal was fed.

Commercial liquid supplements of molasses, urea, phosphorus, trace minerals and vitamins were first introduced to the United States in 1951 (Beeson and Perry, 1970). Feedlot tests with beef steers (Perry et al., 1967b; Gay and Vetter, 1967 and Kercher and Paulus, 1967) have shown no significant difference in the nutrative value or cattle response to high-urea dry or liquid supplements provided the supplements and/or rations contain the same essential nutrients in the proper balance.

Workers at Purdue (Beeson et al., 1964 a, b, 1968; Beeson and Perry, 1969, 1970; Perry and Beeson, 1968 and Perry et al., 1969) reported the existence of unidentified urea protein factors (UPF) in cattle fed high urea rations. The addition of both dehydrated alfalfa meal and distillers grain solubles increased nitrogen retention, feed efficiency and average daily gain with urea supplements. Perry et al. (1969) found a slight but non-significant increased daily gain by adding fish solubles to a high

urea liquid supplement. Burroughs et al. (1969a) also reported improved performance when fish solubles were added to high urea liquid supplements, but found no advantage to adding fish solubles to high urea dry supplements.

Burroughs et al. (1972) reported that converting the nitrogen in the ration to crude protein equivalent using the 6.25 multiplication factor for the nitrogen present in all feed stuffs, irrespective of the type of nitrogen present, may at times lead to inaccurate protein evaluation when applied to NPN in the diet. They cited attempts to measure quantitative protein requirements of feedlot cattle that resulted in widely divergent values.

Burroughs et al. (1971a) proposed a new system for defining protein requirements and the value of various cattle feed ingredients. The measurements employed were designated as metabolizable amino acids or metabolizable protein and were defined as the quantity of protein digested or amino acids absorbed in the post-ruminant portion of the digestive tract of ruminants. The amount of metabolizable protein required is calculated as the amount of protein required for maintenance plus the amount of protein deposited during growth times 1.667. The factor 1.667 is used to account for the 40 per cent loss of amino acids during metabolism.

A measure of the amount of urea that can be useful in any given cattle ration was a second part of the metabolizable protein system (Burroughs et al., 1971b). The urea fermentation potential (UFP) was defined as the estimated grams of urea per kilogram of feed dry matter consumed that is useful in fermentation by microorganisms in the fore part of the digestive tract of ruminants. The basis for establishing UFP values involves the amount of fermentable energy present in the feed and the amount of ammonia formed from protein degradation due to rumen fermentation of that feed. Burroughs et al. (1972) cited several instances in which the metabolizable protein system predicted accurately the cattle performance while the 6.25 multiplicative system did not make an accurate prediction.

Urea as an Additive to Corn Silage

Urea added to corn silage is hydrolyzed by urease contained in the fresh chopped corn plant resulting in higher levels of ammonia than untreated corn silage (Hastings, 1944 and Karr et al., 1965). The latter workers reported that 28 to 50 per cent of the urea added to corn silage at ensiling was hydrolyzed. Most of the hydrolyzed urea is recovered in the form of ammonia (Huber et al., 1968 b; Henderson, Purser and Geasler, 1970; and Lopez et al., 1970). Urea recovery from treated silage has

varied from 4 per cent to 84 per cent (Bentley et al., 1955; Hatfield et al., 1966 and Huber et al., 1968b); however, it is generally agreed that about 50 per cent of the urea applied remains as urea for silage in the dry matter range of 28 to 40 per cent.

Urea treated silage was found to have a slightly higher pH than untreated silage (Davis et al., 1944 and Cullison, 1944). Klosterman et al. (1963) reported that the buffering capacity of ammonia arising from urea hydrolysis produced a higher pH and increased levels of lactate and acetate in urea treated silage. Formation of ammonium salts resulting from the combination of ammonia and organic acids produced in the silage have been suggested by Bentley et al. (1955), Henderson et al. (1971a), Henderson and Geasler (1969), Henderson, Purser and Geasler (1970) and Johnson et al. (1967).

A comparative feeding trial with urea treated corn silage and untreated corn silage utilizing lambs indicated that apparent drymatter digestibility was similar and crude protein digestibility was improved (Bentley et al., 1955). Karr et al. (1965) reported that lambs retain more nitrogen when urea was added at time of ensiling and Hatfield et al. (1966) concluded that supplemental energy was more effectively utilized when urea was added at ensiling. Henderson and Purser (1968b) reported dry matter consumption of beef heifer calves was less when

urea was added to the silage at time of feeding when compared to adding urea at ensiling and control silage supplemented with soybean meal. The latter two were similar. Differences in gain were small for heifers receiving urea treated and urea supplemented silages and both urea groups gained slower than those fed control silage supplemented with soybean meal.

Early work with urea treated silage showed reduced ration acceptability but no reduction in milk production (Woodward and Sheppard, 1944 and Wise et al., 1944). Huber et al. (1968a) found no difference in average production of cows fed urea treated silage or untreated silage. They suggest that high heat of fermentation may render nitrogen unavailable since the persistence of lactation was lower for cows fed high dry matter (44-45 per cent) corn silage treated with urea.

When corn silage was treated with 0.5 per cent urea, a reduction in the natural protein in the concentrate from 18 to 13 per cent did not depress milk yield, but yields were decreased on the lower protein concentrate without the urea in the silage (Huber et al., 1967). Huber et al. (1967) also reported that it may be possible to increase the level of urea in silage to 0.85 per cent when urea is not present in the concentrate. Owens et al. (1968) reported that milk yields were depressed when the ration contained 0.5 per cent urea in the silage and a 1 per cent urea grain mixture.

Urea Utilization, Ammonia Absorption and Urea Toxicity

Helmer and Bartley (1971) cite many references that indicate that urea is rapidly hydrolyzed to ammonia and carbon dioxide in the rumen. However, Farlin et al. (1968a) questioned the theory that all urea is converted to ammonia before utilization. They observed that the carbon of urea did not equilibrate with the carbon dioxide pool, and suggested that urea is metabolized in the rumen without complete hydrolysis to carbon dioxide and ammonia, and that it need not be hydrolyzed for utilization of its nitrogen.

A major problem in efficient utilization of urea is rapid release of ammonia. Bloomfield et al. (1960) indicated that urea hydrolysis uccurred four times faster than uptake of liberated ammonia by the microorganisms. Ammonia absorption is one way nitrogen disappears from the rumen (McDonald, 1948) and this apparently depends on the concentration gradient of ammonia and the pH of the rumen (Hogan, 1961). Some ammonia may be utilized by the rumen mucosa in synthesizing l-glutamate (McLaren et al., 1961 and Hoshino et al., 1966).

It is well established that the consumption of large quantities of dietary urea in a short time can be toxic. Urea toxicity is more likely when urea is given as a drench (Dinning et al., 1948 and Word et al., 1969),

particularly if the diet is deficient in digestible carbohydrate (Dinning et al., 1948) or if the animals have been starved or fasted (Clark et al., 1951). Lewis (1960) noted a direct relationship among rumen ammonia concentration, blood ammonia concentration and rumen pH. Coombe et al. (1960) suggested that a high rumen ammonia concentration would not necessarily be toxic unless the pH rose above 7.3. This may be true with urea but not necessarily with other NPN compounds like ammonium acetate. Ammonium acetate has been reported to elevate rumen and blood ammonia concentration and produce toxicity without raising rumen pH (Webb and Bartley, as reported by Helmer and Bartley, 1971).

Most performance studies with animals fed urea have indicated that the utilization of urea nitrogen is inferior to that of conventional protein supplements (Helmer and Bartley, 1971) especially for growing type rations consisting primarily of roughages (Perry et al., 1967a) and for high urea rations for high producing dairy cows (Helmer and Bartley, 1971). In recent years, many NPN compounds other than urea have been explored in the hope of finding one that can safely, efficiently and economically meet a greater portion of the supplemental nitrogen requirements for ruminants than is feasible with urea as it is presently used.

Other Non-protein Nitrogen Compounds

Belasco (1954) compared various nitrogen compounds with urea, using artificial rumen techniques, cellulose digestion and ammonia concentration as criteria for evaluation. All 12 of the urea derivatives tested inhibited bacterial growth and were not extensively hydrolyzed. Amides of monocarboxylic acids (such as formamide, acetamide, etc.) were hydrolyzed to produce low levels of ammonia and good bacterial growth, but the resulting cellulose digestion was below that obtained with urea. The diamides tested were insoluble in water and, like the urea derivatives, were not hydrolyzable. Guanidine hydrochloride, guanidine acetate, and guanidine carbonate produce low levels of ammonia while supporting good bacterial growth and cellulose digestion. All of the other amidines tested resulted in inferior cellulose digestion and bacterial growth.

Brent et al. (1966) compared in vitro the microbial metabolism of urea, 1, 3-dimethyl-urea, biuret, biurea, guanidine hydrochloride, guanyl urea sulfate, and thiocarbanalide. Only urea appeared to be hydrolyzed to a useful degree. Accord et al. (1966) also used in vitro procedures to test the effectiveness of selected ammonium salts, amino acids, amides and amidines as nitrogen sources for starch digestion by rumen microorganisms. Aspartic acid was inferior to urea but significantly more effective

than the other amino acids tested. Acetamide, propionamide, butyramide, succinimide, malonamide, guanadine acetate, or amino guanadine bicarbonate did not affect starch digestion consistently. Simpson and Jones (1967) contradicted Belasco (1954) and Brent et al. (1966) when they indicated that urea derivatives can be hydrolyzed and will support in vitro cellulose digestion. Crystalline urea, methyl urea and glycourea promoted the greatest increase in cellulose digestion.

Repp et al. (1955b) determined the toxicity and comparative feeding value of several NPN compounds. The amides (propionamide, formamide and biuret) were nontoxic, while all ammonium salts of organic acids except ammonium succinate were toxic when administered orally in large doses. Repp et al. (1955a) reported that urea, formamide or propionamide appeared to support growth of lambs when they replaced 50 per cent of the protein nitrogen of the ration, but formamide was inferior. When less than 30 per cent of the protein nitrogen was replaced with propionamide or urea, the gains were equal to those obtained with natural protein. Growth data suggested that lambs require two to four weeks to become fully acclimated to the NPN compounds tested.

Of all the NPN compounds considered as substitutes for urea, biuret probably has received the most attention. But many early investigations were rather unproductive

because researchers were working with biuret that contained up to 50 per cent urea and most were unaware that biuret requires a long adaption period (Helmer and Bartley, 1971). Nitrogen balance studies as well as production studies have indicated that biuret is utilized somewhat better by sheep than by cattle. Hatfield et al. (1959) and Campbell et al. (1963) indicated that nitrogen retention for cattle was greater for urea than biuret, but Gaither et al. (1955) and Tomlin et al. (1967) reported greater nitrogen utilization for biuret than for urea for lambs. Growth studies with sheep (Meiske et al., 1955 and Hatfield et al., 1959) resulted in equal performance for biuret and urea while similar studies with cattle resulted in inferior performance with biuret when compared to urea (Campbell et al., 1963). Bucholtz and Henderson (1971) reported a greater average daily gain for biuret fed steers than for those fed urea or starea (starch coated urea compound).

Most researchers have confirmed that utilization of biuret by ruminants becomes more efficient with time. Apparently, efficient utilization of biuret requires a longer acclimation period than urea (Oltjen et al., 1969) and an animal adapted to urea is not necessarily adapted to biuret (Johnson and McClure, 1967; Farlin et al, 1968b and Oltjen et al., 1968). The length of time required

for adjustment to biuret is disputed and ranges from three to five weeks (Welch et al., 1957; Campbell et al., 1963; Tomlin et al., 1967 and Oltjen et al., 1969).

Another NPN compound which has been considered as a substitute for urea is diammonium phosphate (DAP). It is generally agreed that DAP is less likely to cause toxicity in ruminants than urea, but agreement is lacking on its relative value, as indicated by nitrogen retention and animal performance (Helmer and BArtley, 1971). Palatability seems to be a primary problem associated with DAP (Lassiter et al., 1962 and Oltjen et al., 1963).

Dicyanodiamide has been evaluated as a protein or urea substitute. There have been reports of loss of weight by lactating cows (Rust et al., 1956) or decreased milk production (Davis et al., 1956) or decreased palatability of the ration (Lassiter et al., 1955) from feeding this compound. However, Lassiter et al. (1955) and Rust et al. (1956) reported no significant differences in milk production between urea and dicyanodiamide supplemented cows. Magruder and Knodt (1954) obtained similar weight gains in dairy heifers fed a basal ration supplemented with either soybean meal, urea or dicyanodiamide.

Included in numerous NPN sources investigated are ammoniated cane molasses and ammoniated products of the milling industry. In vitro studies (Stallcup, 1954; Davis et al., 1955 and Hershberger et al., 1955) indicated that

only the free ammonia of ammoniated products was utilized by rumen microorganisms. Hughes et al. (1955) reported similar digestion coefficients for rations containing either soybean meal or ammoniated cane molasses, but other research reviewed indicated a marked depression in the digestibility of ammoniated cane molasses (Tillman et al., 1955; 1957b) as well as in ammoniated industrial products (Tillman and Swift, 1953 and Tillman et al., 1957a). Frye et al. (1954) and Parham et al. (1955) reported growth studies with dairy heifers in which similar gains were made by heifers receiving either cottonseed meal, urea or ammoniated molasses as the supplementary nitrogen source. In contrast, poor results were obtained when ammoniated molasses was used as a protein source in winter rations for beef calves (Richardson et al., 1954, as reported by Helmer and Bartley, 1971) or in fattening rations for cattle (Tillman et al. 1957a) or lambs (Tillman et al., 1957b).

Pro-Sil Addition to Corn Silage

A suspension of ammonia, minerals and molasses (Pro-Sil) has been developed by Michigan workers for addition to corn silage at ensiling time. Pro-Sil was formulated to make corn silage a balanced ration for feedlot cattle (Henderson et al., 1970b), non-lactating dairy cattle or cows producing below 30 pounds of milk (Huber and Hillman, mimeo D-236).

Henderson et al. (1971c) reported that corn silage treated with Pro-Sil significantly ($P < .01$) increased total nitrogen, water insoluble nitrogen, non-protein nitrogen, ammonia nitrogen, lactic acid and pH when compared to untreated corn silage. Acetic acid content in Pro-Sil treated silage decreased significantly ($P < .01$). This is in agreement with the other work (Beattie et al., 1971).

Beattie et al. (1971) reported that nitrogen fractionization of the Pro-Sil treated silage revealed 21 per cent of the increase in total crude protein was in the form of water insoluble protein, 58 per cent in the form of ammonium salts, and 21 per cent remained as unidentified nitrogen compounds. Approximately 95 per cent of the nitrogen added as Pro-Sil was accounted for by the increased crude protien content of the Pro-Sil treated silage.

Growth studies comparing Pro-Sil treated corn silage with urea treated corn silage and untreated corn silage supplemented with soybean meal have resulted in no significant difference in daily gains due to nitrogen sources (Beattie et al., 1971 and Henderson et al., 1971a, b, c, d). In addition, little difference in feed consumption was reported for the various protein sources and feed cost favored the NPN treated silages in all cases. Henderson et al. (1970a) reported that steers fed Pro-Sil treated

rye silage gained faster and more efficiently than steers receiving urea supplemented silage and feed costs were lower for the Pro-Sil fed steers.

Higher milk yields, less average change per day and greater milk persistencies have been noted for high producing cows fed Pro-Sil treated silage than those fed control silage or silage treated with urea or urea plus minerals (Huber and Thomas, 1971; Huber et al., 1971 and Huber and Hillman, mimeo D-236). Their data also indicate that Pro-Sil will maintain production even on silage of higher dry matter content (40 per cent) which is an advantage over urea treated corn silage.

Nitrogen balance studies with beef steers comparing silages treated with Pro-Sil, urea-minerals, or supplemented with soybean meal revealed no difference in dry matter digestibility, nitrogen digestibility or nitrogen retention (Beattie, 1970). Dry matter digestibility and nitrogen utilization were not different in Pro-Sil or urea treated corn silages fed both lambs (Henderson et al. 1970b) and lactating cows (Lichtenwaler et al., 1971).

Either urea or Pro-Sil addition to corn silage result in the formation of ammonium salts of the organic acids contained in the silage (Bentley et al., 1955; Henderson et al., 1969, 1970b, 1971a; Johnson et al., 1967; and Beattie et al., 1971). The literature cited indicates NPN treated silages will support performance similar to

soybean meal supplemented silages at a reduced cost. Therefore, interest in the utilization and production of ammonium salts has expanded in recent years.

Ammonium Salts

As noted previously, Belasco (1954) used *in vitro* techniques to compare various nitrogen compounds with urea. Each individual experiment had positive (urea) and negative (no nitrogen compound added) controls. The metabolic response of the various nitrogen compounds was expressed as a percent of the urea response.

The experiments with ammonium salts of various organic and inorganic acids illustrated a high availability of their nitrogen to the rumen microflora. In general, the main difference between the ammonium compounds and the amides and amidines was the high level of ammonium ion noted when introduced into the system. Belasco hypothesized that an excess of ammonium salts might not be as hazardous as a similar excess of urea because of the accompanying acid radical. The results of Belasco's work with ammonium salts are summarized in Tables 1 and 2.

Except for ammonium nitrate, all ammonium salts tested (Table 1) provided nitrogen for rumen bacterial growth and subsequent cellulose digestion. Nitrogen utilization, whatever a determination was analytically

possible, was comparable or superior to urea. Data could not be accurately obtained in systems containing ammonium sulfamate, nitrilotrisulfonate and triamidodiphosphate due to the instability of the materials when subject to analytical conditions. Ammonium nitrate proved toxic to the rumen microflora.

Nitrogen utilization was greater for ammonium formate, succinate, lactate, α-ketoglutarate and malate than for urea (Table 1). Belasco suggested that the organic fragments of these compounds might enter into some biosynthetic process that stimulated nitrogen fixation by rumen microflora. Salts of other acids associated with the citric acid cycle (citrate, fumrate and pyruvate) were comparable to urea.

Belasco further reported that ammonium succinate and lactate resulted in lower levels of free ammonia and a higher nitrogen utilization than urea at both 4 and 24 hours after introduction (Table 2). Ammonium formate showed the same trend, but to a lesser degree. The rapid utilization of ammonium succinate and lactate could not be duplicated by the addition of energy to urea as glucose in an amount equivalent to the lactate ion. Nor could this effect be fully duplicated by the addition of equivalent amounts of sodium succinate or succinic acid to urea. Belasco thought it was possible that the supplemental succinate or succinic acid was metabolized before

Table 1.--Metabolic response to ammonium salts.[1]

Compound	% of Urea Response: Nitrogen Utilization	% of Urea Response: Cellulose Digestion	Bacterial Growth
Urea	100	100	Excellent
NH_4 succinate	118	90	Excellent
NH_4 lactate	114	91	Excellent
NH_4 α-ketoglutarate	110	103	Excellent
NH_4 formate	107	104	Excellent
NH_4 malate	106	88	Excellent
NH_4 pyruvate	103	84	Excellent
NH_4 fumarate	102	100	Excellent
NH_4 citrate	100	94	Excellent
NH_4 adipate	97	91	Excellent
NH_4 acetate	95	97	Excellent
NH_4 sulfate	99	92	Excellent
NH_4 carbonate	91	97	Excellent
NH_4 sulfamate	---	78	Good
NH_4 nitrilotrisulfonate	---	87	Good
NH_4 triamidodiphosphate	---	67	Fair
NH_4 nitrate	0	-13[2]	None

[1]From Belasco (1954).

[2]A negative value indicates a cellulose digestion rate below the negative control.

Table 2. Comparison of selected ammonium salts.[1]

Compound[2]	Ammonia Level mg after: 4 hr	24 hr	Nitrogen Utilization % after: 4 hr	24 hr	Cellulose Digestion (%)
No nitrogen	22	9	0	0	25
Urea	225	106	25	77	79
NH_4 formate	215	102	32	82	81
NH_4 lactate	181	80	59	87	74
NH_4 succinate	191	78	51	90	77

[1]From Belasco (1954).

[2]187 mg nitrogen was used for all but the no nitrogen negative control.

all the ammonia was available from hydrolysis of urea and therefore could not affect the rate of nitrogen fixation. Wetterau and Holzchub (1960 and 1961, as reported by Coppock and Stone, 1968) reported that ammonia from ammonium salts is released more slowly than from urea in the rumen and this may facilitate rumen microbial growth.

Accord et al. (1966) also used in vitro procedures to test effectiveness of selected ammonium salts, amino acids, amides and amidines as nitrogen sources for starch digestion by rumen microorganisms. Ammonium salts of sulfate, chloride, acetate and phosphate were equivalent to urea at all levels tested. They associated increased

ammonia levels after 4 or 8 hours of fermentation with rapid starch digestion. These results are in general agreement with Belasco (1954).

Repp et al. (1955a, b) determined the toxicity and comparative feeding value of several NPN compounds for lambs. When administered orally in large doses, all ammonium salts of organic acids except ammonium succinate were toxic (Repp et al., 1955b). When urea, ammonium acetate, ammonium propionate and ammonium formate replaced as much as 50 per cent of the protein nitrogen in the ration, all NPN compounds appeared to support growth in lambs equally. At the 50 per cent level the NPN compounds promoted gains below those from protein sources. Moore and Anthony (1970) reported that ammonium acetate was more toxic and that ammonium lactate was less toxic than urea for sheep.

Varner and Woods (1971) reported two metabolic studies with ammonium salts of organic acids, urea and soybean meal. In their first metabolic study they compared urea and soybean meal with two mixtures of ammonium salts. The two mixtures were referred to as a high acetate supplement and a high propionate supplement. They consisted on 75 per cent ammonium acetate, 15 per cent ammonium propionate, 10 per cent ammonium butyrate and 30 per cent acetate, 40 per cent ammonium propionate and 30

per cent ammonium butyrate, respectively. In the second metabolic study urea was compared with ammonium acetate, ammonium propionate and ammonium butyrate.

There was no differences in digestibilities of dry matter, organic matter, cellulose or crude protein among the nitrogen supplements in either metabolic study. The total volatile fatty acid (VFA) concentrations of the rumen fluid samples was higher for the ammonium salts in both trials. Varner and Woods also reported that rumen pH was higher for urea in both trials and the change in rumen VFA for the ammonium salts reflected the individual ammonium salt or mixture fed.

In the first metabolic study, rumen ammonia levels were higher at one hour post-feeding for steers fed ammonium salt mixtures than for urea. Serum urea levels were highest for urea next for ammonium salts and lowest for soybean meal treatments. Steers fed soybean meal also had lower rumen ammonia levels at all sampling times.

In the second metabolic study, daily nitrogen retention was 6.6 g, 6.3 g, 3.8 g and 0.7 g for steers fed ammonium propionate, ammonium butyrate, ammonium acetate and urea, respectively. Steers fed ammonium acetate had the highest rumen ammonia levels. In contrast to the first study, serum urea levels were higher on ammonium acetate or ammonium butyrate than on ammonium propionate or urea.

Varner and Woods (1970) administered soybean flour, urea, ammonium acetate, ammonium propionate and ammonium butyrate at isonitrogenous levels through a stomach tube to portal cannulated lambs. The portal blood ammonia at one hour after feeding was 1055, 920, 650 and 425 micrograms/ml for lambs given urea, ammonium propionate, ammonium acetate, ammonium butyrate and soybean flour, respectively. Reductions in portal blood ammonia were noted when either ammonium acetate or urea plus acetic acid were compared with an isonitrogenous level of urea.

Varner et al. (1968) reported that a high propionate ammonium salt mixture was superior to urea and a high acetate ammonium salt mixture and almost equal to soybean meal in promoting gains in finishing trials for cattle. The high acetate mixture of ammonium salts was equivalent to urea. Varner and Woods (1969) reported that the gains of cattle fed ammonium salts of acetate, propionate or butyrate in a growing trial were significantly higher than for those fed urea.

Utilization of Volatile Fatty Acids

Virtually all the carbohydrate ingested by the ruminant is degraded by anaerobic microorganisms to volatile fatty acids (VFA) and ruminants are primarily dependent upon these acids (principally acetic, propionic and butyric) for their supply of energy (Johnson, 1955 and Carroll and

and Hungate, 1954). Carroll and Hungate (1954) estimated that the energy from VFA production in the rumen provided 70 per cent of the total energy required. Other workers (Balch, 1958 and Connolly et al., 1964) have estimated that VFA account for 36 to 42 per cent of the digested energy.

The gross kcal/g for VFA were reported as approximately 3.5, 5.0 and 6.0 for acetate, propionate and butyrate, respectively (Emery, 1965). However, the total energy furnished by these three acids were reported as approximately equal (Carroll and Hungate, 1954). In addition, Orskov et al. (1969) found no differences in utilization of the energy from acetate and propionate, but there were differences in the partition of energy into milk or body tissues. More of the acetate was secreted in milk of lactating cows and more of the propionate was retained in body tissue.

The VFA produced in the rumen are readily absorbed through the rumen wall (Barcroft et al., 1944). The rumen epithelium is active in the conversion of n-butyrate to beta-hydroxy butyrate (Seto and Umezu, 1959 and Ramsey and Davis, 1965). Acetate and butyrate that escapes oxidation by the rumen epithelium are converted to ketone bodies by the liver; the process is inhibited by propionate (Seto et al., 1959 and Johnson, 1955).

There is disagreement concerning the relative rates of absorption of VFA from the rumen (Gray and Pilgrin, 1951). Sutherland (1963) reported absorption rates for acetate, propionate and butyrate were 1.6, 1.9 and 2.0 meq./hour per meq./liter in the rumen, respectively. Tsuda (1956) reported that there was no difference in absorption rates of free fatty acids in the rumen. However, free fatty acids were absorbed faster from the rumen than the sodium salts of organic acid. The rate of absorption was greatest for sodium acetate and lowest for sodium propionate. Sodium butyrate was intermediate. Apparently, the absorption of free acetate is regulated by the concentration gradient between the blood and the rumen (Masson and Phillips, 1951 and Tsuda, 1956).

The efficiency of utilization of VFA for different physiological functions has been studied by several methods. Differences in the propotion of acetic, propionic and butyric acids in VFA mixtures continuously infused intra-ruminally had only a small effect on the efficiency of energy utilization in fasting lambs (Armstrong, Blaxter and Graham, 1957). For fattening, all acids were utilized less efficiently than for maintenance; this was particularly true for acetic acid (Armstrong et al., 1958). With salts of VFA, no difference could be found between acetate, propionate and butyrate in their ability to promote growth in lambs on an equal weight basis (Orskov and Allen, 1966a,

b, c and Orskov et al., 1966). Armstrong and Blaxter (1957) stated that acid administration did not interfere with the normal process of rumen fermentation or impose non-physiological conditions upon the animals.

Oxidation of the acids to provide the energy is not their only use by the animal. Studies with labelled acetic acid have shown that this acid is incorporated into many compounds. Lipogenesis in mammary tissure results in incorporation of acetic acid into milk fat (Folly and French, 1950 and Kleiber et al., 1952). Acetate can also act as a precursor of the milk constituents lactose and glyceral (Popjack et al., 1952) and the carbon moieties of non-essential amino acids in milk protein (Black et al., 1957). Acetic acid is also used in the synthesis of liver and body fat (Rittenberg and Bloch, 1945), the lipids of wool (Sjoberg, 1956) and cholesterol. Sheppard et al. (1959) reported that acetate was also used in the formation of propionic, butyric and higher acids in the rumen. They estimated that 12 per cent of acetate was converted to butyrate and 5 per cent to propionate.

Propionate is a major precursor of glucose in the body (Armstrong and Blaxter, 1957 and Leng and Annison, 1963). Increasing the proportion of concentrates and pelleting increases in the proportions of propionate and butyrate produced in the rumen (Bauman et al., 1971; Davis

1967 and Hawkins et al., 1963). Lactic acid administration also increases ruminal propionate or butyrate levels (Montgomery et al., 1963).

Butyrate is involved in the synthesis of lactose (Kleiber et al., 1954) and can provide the carbon moieties of amino acids in milk protein (Black et al., 1952). Ramsey and Davis (1965) reported studies with labelled butyrate that indicated that n-butyrate was metabolized via the citric acid cycle in the rumen.

The work of Elsden (1945), Phillipson (1952), Waldo and Schultz (1956) and Hueter et al. (1956) indicates that lactate is converted to other fatty acids, especially propionate. Other workers report that the primary VFA resulting from lactate metabolism in the rumen was acetate (Jayasuria and Hungate, 1959 and Bruno and Moore, 1962). Bruno and Moore (1962) used uniformly labelled lactate and reported that 35 per cent of lactate was converted to acetate, 9 per cent to propionate, 33 per cent in ether extracted aqueous residues and the remainder in other fatty acids and fermentation gases.

Hueter et al. (1956) reported the infusion of sodium lactate in the rumen resulted in a large increase in blood lactate which was followed by an increase in blood glucose. Annison et al. (1963) reported that lactate is the precursor for 15 per cent of the glucose pool and that lactate accounts for 7 per cent of the CO_2 production,

primarily via glucose. Salts of lactic acid (calcium, sodium and ammonium) were shown to alleviate ketosis (Seekles, 1951 and Shaw et al., 1955).

The Effect of Organic Acid Additions on Intake

Manning et al. (1959) suggested that blood acetate concentration in ruminants may be a chemostatic factor in controlling intake similar to glucose in non-ruminants. Acetic acid is the only fatty acid normally found in significant amounts in peripheral blood and its concentration changes with time after feeding (Balch and Campling, 1962).

Intravenous infusion of sodium acetate, acetic acid and propionic acid depressed intake in cattle (Dowden and Jacobson, 1960). Intravenous infusions of glucose, butyrate, valerate, hexanoic acid and lactate did not affect intake. Holder (1963) noted that intravenous infusions of either glucose or acetate did not affect intake in sheep.

Intraruminal infusions of acetate have been shown to decrease intake (Simpkins et al., 1965; Weston, 1966; Rook et al., 1963 and Baile and Pfander, 1965). Montgomery et al. (1963) observed a greater effect due to acetate than propionate or butyrate.

The regulation of intake by VFA appears to be in the rumen since no depression was noted after abomasal infusions of acetate (Baile and Mayer, 1967) or duodenal

infusions of propionate (Egan and Moir, 1965). Acetate receptors are more likely to be located on the lumen side of the reticulorumen than in an area where they respond to blood acetate since intraruminal infusions of acetate depress intake and intravenous infusions do not (Baile and Mayer, 1968). These authors suggested that the feed intake depression following an acetate infusion is related to satiety.

Many researchers have attempted to relate volatile fatty acids present in the silage to a reduction in consumption. Dinius et al. (1968) added acetic acid to green chop and corn silage and reported that added acetic acid reduced dry matter intake but did not effect caloric intake. Wilkins et al. (1971) reported a negative correlation between the acetic acid content of 70 grass and legume silages and consumption by sheep. Wilkins et al. also reported a positive correlation between voluntary intake of silage and silage lactic acid as a percentage of total acids.

Hutchinson et al. (1971) reported that free acetic acid infused into the rumen reduced silage intake, but addition of the same quantity of acid to silage did not effect intake over a 24-hour period.

Senel and Owen (1967) observed no reduction in voluntary intake when 2 per cent acetate, 1 per cent butyrate, or a combination of these acids were added to a

hay-concentrate ration. However, a mixture of 4 per cent acetate and 2 per cent butyrate appeared to cause nasal irritation and reduced intake.

Later work by Senel and Owen (1966) using sorghum silage showed increased dry matter intake when acetate was added at levels up to 2.8 per cent of the ration dry matter. Lactate addition to sorghum silage at a low level (5.90 per cent DM) decreased intake but at the high level (9.03 per cent DM) intake was greater than the control silage. Acetate and lactate improved feed efficiency, when compared to the control. They concluded that something other than acetate and lactate depressed silage consumption.

Emery et al. (1961) reported that lactic acid addition to corn silage reduced appetite in proportion to its concentration when fed to growing heifers. Feed efficiency increased in direct proportion to the lactic acid intake.

There are conflicting opinions regarding the effect of lactic acid content of grass silage on dry matter consumption. McLeod et al. (1970) reported reductions in dry matter intake were proportional to the amount of lactic acid added and the resulting decrease in pH. Other researchers; King, 1943; and McCarrisk et al., 1966) attribute the reduced intake of grass silages to the content of total organic acids.

The type of lactic acid used to study the effect of lactate on dry matter consumption must be evaluated. Dunlop and Hammond (1965) reported the L(+) isomer is more readily metabolized in the rumen and liver than the D(-) isomer. The lactic acid in corn silage consists of both the D and L forms; however, the D(-) isomer is more abundant (Schaadt and Johnson, 1968).

Summary

As knowledge of protein chemistry and nitrogen metabolism of the ruminant animal evolves there is a greater emphasis on using NPN to replace natural protein in the diet.

Extensive research with urea has established its advantages and limitations, but there is only limited information on other NPN sources. *In vitro* work with NPN compounds indicates that ammonium salts of organic acids are equal or superior to urea. Limited *in vivo* work indicates that ammonium salts may be utilized as a supplemental nitrogen source for ruminants. There have been no reports of comprehensive growth or metabolic studies with ammonium salts other than salts of acetate, propionate and butyrate.

Other research has demonstrated that the organic acid portion of ammonium salts can be utilized for energy

either by the rumen microorganisms or by animal tissues. However, the addition of organic acids, especially acetic acid, to the ration may cause a reduction in dry matter intake.

MATERIALS AND METHODS

The studies involved in this dissertation include two feeding trials comparing various ammonium salts with more conventional nitrogen supplements, two feeding trials to study the effect of added lactic or acetic acid and three metabolic studies. Materials and methods are presented under experimental headings.

Experiment I--Feeding Trial Comparing Ammonium Acetate, Ammonium Lactate, Urea and Soybean Meal

Design: Twenty-four cross bred yearling steers were randomly assigned by weight to one of the following treatments: soybean meal, urea, ammonium acetate or ammonium lactate.

Harvesting of Feed: High moisture shelled corn and corn silage were harvested from a stand of hybrid corn averaging approximately 35 metric tons of 35 per cent dry matter (DM) silage or 5 metric tons of 85 per cent DM shelled corn per hectare. The corn silage received no additives and was harvested between September 1 and September 23, 1970. After harvesting at an average 36.7 per cent DM, the silage was stored in a 9.1 x 18.3 m. silo. The high moisture shelled corn was harvested in October and placed in sealed storage.

Production of Ammonium Salts: Ammonium lactate and ammonium acetate were produced in 15 l. batches by neutralizing the respective acids with acqua ammonia until a pH of 6.5 was obtained. Technical grade 88 per cent lactic acid was used for the production of ammonium lactate and 8 l. glacial acetic acid was diluted with 7 l. of water for the production of ammonium acetate. This equalized the molar concentration of acid on the wet basis and provided for approximately 44.5 per cent crude protein solution (7.13 per cent N) for both ammonium salts. Each 15 l. batch was analyzed for nitrogen by the micro-Kjeldahl method to establish the amount of nitrogen fed. The average crude protein equivalent was 112 per cent and 81 per cent on a DM basis for ammonium acetate and ammonium lactate, respectively.

Feed Analysis: Silage and shelled corn samples were taken every Monday, Wednesday and Friday during the feeding trial. Dry matter was determined on each sample for intake estimates by oven-drying the samples at 105° C. for 24 hours. Composite samples of moist silage or shelled corn were analyzed for nitrogen and organic acid fractions and then expressed on a DM basis from analysis of a paired sample dried at 55° C. for 48 hours. Total nitrogen was obtained by macro-Kjeldahl procedures. Soluble extracts of silage and shelled corn were prepared by homogenizing 25 g. of fresh sample with 100 ml. of deionized, distilled

water for one minute. The pH of the solution was determined using a Corning Model 12 pH meter. The solution was strained through two layers of cheesecloth and total water soluble nitrogen was determined by micro-Kjeldahl.

A second sample of extract was deproteinized with 1 ml. of 50 per cent sulfosalicylic acid (SSA) per 9 ml. of extract, and a micro-Kjeldahl analysis of this fraction gave the water soluble non-protein nitrogen. The micro-diffusion method of Conway (1950) was used to determine the ammonia and urea fractions in the water soluble NPN fraction.

The remaining extract was deproteinized with 1 ml. of 50 per cent SSA per 9 ml. extract as before, and then centrifuged for 10 minutes at 18,000 r.p.m. Volatile fatty acid content of the samples was determined by injecting samples of this into a Packard gas chromatograph, and lactic acid content was determined by the colorimetric method of Barker and Summerson (1941). The average chemical analysis of corn silage and high moisture corn fed during the trial are shown in Table 3.

Feeding Trial: The yearling Hereford-Angus cross-bred steers utilized in this experiment originated in Texas and were purchased as fall calves on July 22, 1970, at an average weight of 253.8 kg. They were placed in outside lots and fed a full feed of corn silage until the smaller

Table 3.--Experiment I: Average chemical analysis of feeds fed.[1]

Observation	Corn Silage	High Moisture Sh. Corn
Percent DM	34.51	74.16
Crude Protein Fractions:		
Total crude protein	8.99	9.46
Organic protein	4.68	7.83
NPN protein	4.31	1.63
Ammonium salts	.65	.18
Urea	.02	.00
Unidentified	3.64	1.45
Organic Acid Fractions:		
Total organic acid	9.44	.33
Lactic acid	7.75	.32
Acetic acid	1.67	.01
Butyric acid	.02	.00
pH	3.89	5.46

[1]Each value is the mean of 18 different composite samples taken every two weeks during the feeding trial.

steers were placed on this experiment November 3, 1970, at an average weight of 294.9 kg.

The various nitrogen supplements were compared on a ration composed of 75 per cent concentrates (high moisture shelled corn, nitrogen supplement and mineral supplement) and 25 per cent untreated corn silage on a DM basis as shown in Table 4. The soybean meal and urea were fed as dry supplements combined with minerals and a dry mineral mix was formulated to be fed with the ammonium salts (Table 5). All ration ingredients were combined and mixed in a horizontal mixer prior to each feeding.

The steers were implanted initially with 24 mg. of diethylstilbesterol (DES) and injected with 2,000,000 I.U. of vitamin A. Four months later, all steers were re-implanted with 36 mg. of DES and re-injected with 2,000,000 units of vitamin A.

The steers were individually weighed on two successive days at the beginning and end of the trial. The average of the two successive weights was used as initial and final weights. Cattle were group weighed every 28 days during the experiment. The feeding trial was terminated after 170 days on feed.

The cattle were utilized in a metabolic study (to be discussed later) for nine days, then trucked 161 km., allowed to stand overnight, and slaughtered the next morning. After 48 hours in the cooler, carcasses were

Table 4.--Experiment I: Percent ration composition on a dry matter basis.

Ingredient	Lactate	Acetate	Soy	Urea
Corn silage	24.04	24.34	25.00	25.00
Shelled corn	65.74	66.54	68.36	68.36
Soy supp.[1]	-----	-----	6.64	-----
Urea supp.[1]	-----	-----	-----	6.64
Mineral supp.[1]	6.39	6.46	-----	-----
NH_4 acetate[2]	-----	2.66	-----	-----
NH_4 lactate[3]	3.83	-----	-----	-----
TOTAL	100.00	100.00	100.00	100.00

[1]See Table 5 for formulation.

[2]112 per cent crude protein (2.66 per cent of DM intake).

[3]81 per cent crude protein (3.83 per cent of DM intake).

ribbed, graded by a federal grader and fat and lean tracings were made of the 13th rib for determining cutability, fat thickness and ribeye area. The rib eye area was then determined by following the rib eye tracing with a planometer and the fat thickness perpendicular to the outside layer was measured three-fourths of the distance up the rib eye from the chine bone. The per cent kidney, heart and pelvic fat was estimated by the federal grader and the per cent boned, trimmed retail cuts was estimated using the USDA formula.

Table 5.--Experiment I: Formulation of supplements (percent of mix on a dry matter basis).

Ingredient	Soy-Mineral Supplement	Urea-Mineral Supplement	Mineral Supplement
Dicalcium phosphate (20%Ca-18.5%P)	3.45	3.37	3.89
Sodium sulfate (22.5%S)	3.07	3.00	3.46
Trace mineral salt (high Zn)	3.45	3.37	3.89
Soybean meal (50% prot.)	90.04	----	----
Feed grade urea (45%N)	----	13.12	----
Gr. shelled corn	----	77.08	88.77
TOTAL	100.00	100.00	100.00

Experiment II--Feeding Trial Comparing Various Ammonium Salts of Organic Acids with More Conventional Nitrogen Supplements

Design: An 8 x 2 factorial design was utilized to study the following treatments:

A. Two levels of concentrate
   (1) 40 per cent of the ration DM as shelled corn and 60 per cent as untreated corn silage.
   (2) 80 per cent of the ration DM as shelled corn and 20 per cent as untreated corn silage.

B. Eight protein sources.
   (1) Soybean meal
   (2) Urea
   (3) Urea + corn steep water (U-CSW - 50 per cent of N from urea and 50 per cent from natural protein)
   (4) Ammonium formate
   (5) Ammonium acetate
   (6) Ammonium propionate
   (7) Ammonium lactate
   (8) Ammonium butyrate

Harvesting of Feed: High moisture shelled corn and corn silage were harvested from a stand of hybrid corn averaging approximately 35 metric tons of 35 per cent DM silage or 5 metric tons of 85 per cent DM shelled corn per hectare. The corn silage received no additives and was

harvested during a three week period beginning September 2, 1971. It was stored in a 9.1 m. x 18.3 m. silo and averaged 33.4 per cent DM during harvest. The high moisture shelled corn was harvested in late September and early October, averaged 70.3 per cent DM at harvest and was placed in a sealed storage unit until feeding.

Production of Nitrogen Supplements: The compositions of the supplements used in this experiment are shown in Tables 6 and 7. All nitrogen supplements except soybean meal were added to rations as liquids.

The ammonium salts were produced by neutralizing solutions of the respective organic acids with anhydrous ammonia which was introduced through a sparger system. Preliminary preparations of salts were first made in the laboratory to determine the desirable level of ammonia with the various ammonium salts. An 8.4 per cent level of nitrogen was decided upon because the ammonium salts remained in solution for all organic acids utilized. In addition, this provided a supplement that would meet the supplemental nitrogen requirements when fed at 454 g. per head daily.

The ammonium salts were produced in bulk by using a 1893 l. tank equipped with a sparger system for anhydrous ammonia, an agitator, a pH probe and a water jacket for cooling. Anhydrous ammonia was introduced into the organic acid-water mixture until the pH reached 7.0. Before

Table 6.--Experiment II: Composition of supplements used in Experiment II.[1]

Supplement	% Acid	% Protein[2]	% DM
Soy	--	50.0	85.0
Urea	--	53.9	19.5
Urea-CSW	13.0	41.9	54.6
NH_4 formate	28.7	54.6	39.3
NH_4 acetate	38.1	55.6	48.9
NH_4 propionate	47.0	55.6	57.8
NH_4 lactate	53.9	52.5	64.1
NH_4 butyrate	54.3	54.1	64.8

[1]Calculated by using 1 mole acid + 1 mole NH_3 = 1 mole salt.

[2]Obtained by % nitrogen x 6.25.

Table 7.--Experiment II: Ingredient composition of urea - corn steep water supplement.[1]

Major Constituents	%	PPM[2]
Nitrogen	6.70	
Lactic acid	13.0	
Fat	0.2	
Ash	8.5	
Carbohydrates, as dextrose	1.3	
Potassium	2.25	
Magnesium	0.75	
Sodium	0.10	
Phosphorus	1.65	
Sulfur	0.35	
Calcium	0.03	
Chlorine	0.35	
Iron		150.0
Copper		50.0
Selenium		0.4
Manganese		25.0
Molybdenum		1.0

[1]Derived by taking 92.7 per cent of corn steep water analysis (wet basis).

[2]Parts per million or grams per kilogram.

removal from the tank, the solution was sampled and analyzed by micro-Kjeldahl to establish the nitrogen content which was then adjusted, if necessary, by the addition of water or anhydrous ammonia. A second sample was taken to establish the final nitrogen concentration and the supplement was stored in 208 l. barrels lined with polyethylene. The nitrogen and organic acid levels of the ammonium salts are shown in Table 6.

A liquid urea supplement was produced by dissolving crystalline urea in water. Micro-Kjeldahl analysis established that the corn steep water solution contained 3.61 per cent nitrogen. To produce a nitrogen supplement with one-half its nitrogen from natural protein (corn steep water) and one-half from urea, 119.9 kg. of urea were dissolved in 1523.6 kg. of corn steep water. Table 6 shows the DM, acid and nitrogen content of the urea-corn-steep-water (U-CSW) solution and Table 7 lists the other ingredients in the U-CSW supplement.

The grams of nitrogen supplement fed daily per steer were 508, 599, 463, 463, 454, 463, 481 and 463 on a wet basis for soy, U-CSW, urea, ammonium formate, ammonium acetate, ammonium propionate, ammonium lactate and ammonium butyrate treatments respectively.

Feed Analysis: Silage and shelled corn samples were taken weekly throughout the feeding trial. Composite samples of fresh silage or shelled corn were analyzed for

nitrogen and organic acid fractions and then expressed on a dry matter basis from analyses of paired samples dried at 55° C. for 48 hours. Aqueous extracts of feeds were prepared by homogenizing a 25 g. aliquot of the feed and 100 ml. of distilled water with a Sorvall Omni-Mixer for two minutes. A portion of the unstrained homogenate was used to determine total nitrogen by micro-Kjeldahl procedures.

The analyses for pH, water soluble NPN, ammonia, volatile fatty acid and lactic acid of the feeds were conducted using the procedures described in Experiment I. Chemical analysis of corn silage and high moisture corn fed during the trial are averaged in Table 8.

Feeding Trial: A total of 160 yearling Hereford steers purchased in Lusk, Wyoming from two consignors were utilized in this experiment. They arrived at the MSU Beef Cattle Research Center on October 8 and were fed free choice corn silage plus soybean meal for 28 days before being placed on the experiment at an average weight of 358.2 kg. Pre-experimental performance is shown in Appendix I.

All cattle were full fed twice daily a ration of either 60 per cent corn silage and 40 per cent concentrates or 20 per cent corn silage and 80 per cent concentrates on a dry matter basis, as outlined in Table 9. Steers receiving the urea supplement were fed an additional

Table 8.--Experiment II: Average chemical analysis of feeds fed.[1]

Observation	Corn Silage	High Moisture Sh. Corn
Percent Dry matter	35.60	70.89
Crude Protein Fractions:		
Total crude protein	7.44	10.74
Organic protein	6.25	8.44
NPN protein	1.19	2.30
Ammonium salts	.06	.21
Urea	.06	.00
Unidentified	1.07	2.09
Organic Acid Fractions:		
Total organic acid	7.57	1.86
Lactic acid	5.43	1.79
Acetic acid	2.14	.07
Butyric acid	.00	.00
pH	4.27	4.83

[1]Each value is the mean of analysis conducted each week during the feeding trial.

Table 9.--Experiment II: Ration composition on a DM basis.

Lot No.	Nitrogen Supplement[2]	Corn Silage	Shelled Corn	Protein Supplement	711 Mineral Supplement[1]
	40 Per cent Concentrate and 60 Per cent Corn Silage				
1	Soy	57.2	34.7	4.4	3.8
5	U-CSW[3]	58.2	35.3	2.8	3.6
3	Urea	58.8	36.4	1.0	3.8
7	NH_4 formate	58.9	35.7	1.8	3.6
10	NH_4 acetate	58.7	35.8	2.1	3.4
12	NH_4 propionate	58.2	35.3	2.5	3.9
14	NH_4 lactate	58.0	35.1	3.1	3.7
16	NH_4 butyrate	58.1	35.4	2.9	3.5
	80 Per cent Concentrate and 20 Per cent Corn Silage				
2	Soy	21.1	70.6	4.5	3.8
6	U-CSW[3]	21.5	71.8	3.0	3.8
4	Urea	21.9	73.3	1.0	3.8
9	NH_4 formate	21.3	73.2	1.8	3.7
11	NH_4 acetate	21.6	72.0	2.4	4.0
13	NH_4 propionate	21.4	72.4	2.4	3.8
15	NH_4 lactate	21.3	71.5	3.3	3.9
17	NH_4 butyrate	21.2	71.9	3.1	3.8

[1]See Table 10 for formulation.

[2]See Table 6 for composition.

[3]See Tables 6 and 7 for composition.

56.8 g. (fresh basis) daily of high moisture shelled corn to make the energy in the urea rations equivalent to that in the soy ration. The organic acid in all other supplements was assumed to furnish equal energy to that contained in the soy supplement. The steers were fed 18.6 mg. of diethylstilbestrol (DES) daily and vitamin A and D in the mineral supplement (Table 10) which was withhely during the final seven days of the experiment. The corn silage and shelled corn averaged 35.6 per cent and 70.9 per cent DM during the feeding trial, respectively. The shelled corn was rolled and all ration ingredients were combined and mixed in a horizontal mixer just prior to each feeding.

The experiment was initiated on November 2, 1971. Steers were randomly alloted by weight to the 16 treatment groups shown in Table 7. Final weights were taken on March 9, 1972 after 124 days on feed. All cattle were then trucked 161 km., allowed to stand overnight and slaughtered the next day. After 48 hr. in the cooler, carcasses were ribbed, graded by a federal grader and carcass measurements taken as described in Experiment I.

Experiment III--Acetic and Lactic Acid Additions to a High Concentrate Ration

Design: A 3 x 2 factorial design involving 36 Herford-Angus crossbred yearling steers was used to study the following treatments:

Table 10.--Experiment II: Formulation of mineral supplement.

Ingredient	%
Dicalcium phosphate (20% C - 18.5% P)	6.0
Calcium carbonate (38% Ca)	8.5
Sodium sulfate (22.5% S)	3.9
Trace mineral salt (High Zn)	11.0
Ground shelled corn	69.2
Stilbosol (2g/lb)	1.0
Vitamin A (30,000 IU/g)	0.2
Vitamin D (9,000 IU/g)	0.2
TOTAL	100.0

A. Two sources of supplemental nitrogen

(1) Soybean meal

(2) Urea

B. Both sources of supplemental nitrogen were compared with different acid additions to the ration.

(1) Control - no acid added

(2) Acetic acid addition

(3) Lactic acid addition

The soybean meal and urea supplemented controls (no acid addition) were the same lots that were used as controls in Experiment I.

Harvesting of Feed: The steers on this experiment were fed the same untreated corn silage and high moisture shelled corn described in Experiment I.

Feed Analysis: Feeds were sampled and analyzed as in Experiment I. The average chemical analysis of corn silage and high moisture corn fed during the trial are shown in Table 3.

Feeding Trial: Steers utilized in this experiment originated in Texas and were purchased as fall calves on July 22, 1970, at an average weight of 253.8 kg. They were placed in outside lots and fed a full of corn silage until they were placed on this experiment and Experiment I, November 3, 1970, at an average weight of 294.9 kg.

The various treatments were compared on a ration composed of 25 per cent untreated corn silage and 70 per cent concentrates on DM basis (Table 11). The soybean meal and urea were combined with minerals and fed as dry supplements (Table 5). The acids were fed at the same molar levels as the ammonium salts in Experiment I.

The steers were implanted initially with 24 mg. of diethylstilbestrol (DES) and injected with 2,000,000 I.U. of vitamin A. Four months later, all steers were reimplanted with 36 mg. of DES and re-injected with 2,000,000 units of vitamin A.

The steers were weighed as described in Experiment I. The feeding trial was terminated after 170 days on feed.

Table 11.--Experiment III: Per cent ration composition on a dry matter basis.

Nitrogen Supplement	Soybean Meal			Urea		
Acid Added	None	Acetic	Lactic	None	Acetic	Lactic
Corn silage	25.00	24.48	24.19	25.00	24.48	24.19
Shelled corn	68.36	66.93	66.14	68.36	66.93	66.14
Soy supp.[1]	6.64	6.50	6.43	-----	-----	-----
Urea supp.[1]	-----	-----	-----	6.64	6.50	6.43
Acetic acid[2]	-----	2.09	-----	-----	2.09	-----
Lactic acid[3]	-----	-----	3.24	-----	-----	3.24
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00

[1]See Table 5 for formulation.

[2]Molar level of acetic acid in NH_4 acetate in Experiment I.

[3]Molar level of lactic acid in NH_4 lactate in Experiment I.

The cattle were utilized in a metabolic study (to be discussed later) for nine days and then trucked 161 km., allowed to stand overnight, and slaughtered during the next morning. After 48 hr. in the cooler, carcasses were ribbed, graded by a federal grader and carcass measurements taken as described in Experiment I.

Experiment IV--Acetic and Lactic Acid Additions to All Silage Rations

Design: Two simultaenous feeding trials were conducted to study the effect of adding graded levels of acetic or lactic acid to corn silage rations supplemented with soybean meal. Acetic acid additions were 0, 1.5, 3.0, 4.5 and 6.0 per cent of silage DM; and lactic acid additions were 0, 2.5, 5.0, 7.5 and 10 per cent of silage DM. A single group acted as controls (no acid addition) for treatments with both acids.

Harvesting of Feed: Silage was the same that is described in Experiment II.

Feed Analysis: Feed samples were analyzed by the procedures discussed in Experiment II.

Feeding Trial: Ninety Hereford steer calves purchased at feeder calf sales in Virginia were utilized in this experiment. They arrived at the MSU Beef Cattle Research Center October 13-15, 1971, and were fed hay, corn silage to appetite plus 454 g. of 50 per cent crude protein

soybean meal daily. Hay feeding was discontinued on October 27, 1971 and the steers were placed on experiment November 10, 1971, at an average weight of 249 kg. Pre-experimental performance is shown in Appendix I.

All cattle were full fed twice daily the corn silage ration, their allotted quantity of acid and approximately 908 g. of a protein-mineral mixture (Table 12). This supplement was formulated to provide the supplemental mineral and vitamin requirements for the steers as well as diethylstilbestrol (DES).

The ration ingredients were combined and mixed in a horizontal mixer just prior to each feeding. The acids were considered 100 per cent DM and enough water was added with each increasing level of acid addition to maintain a ration DM equal to the control group. Ration composition on a DM basis is shown in Table 13.

The experiment was terminated after 124 days on feed and the cattle were then used in other experiments.

Experiment V--Study of Rumen and Blood Parameters Resulting from Addition of Ammonium Salts or Organic Acids to Cattle Rations

Design: Rumen and blood parameters were examined for steers on Experiment I and Experiment III.

Management: The cattle on Experiments I and III were held for nine days following the termination of the feeding trial for this study. The cattle were trained to

Table 12.--Experiment IV: Formulation of 714 supplement.

Ingredient	%
Ground Shelled Corn	15.17
Soybean Meal (49% CPE)	70.15
Ground Limestone (38% C)	1.35
Dicalcium Phosphate (20% C - 18.5% P)	6.15
Trace Mineral Salt (High Zn)	6.65
Stilbosol (2 g./lb.)	0.37
Vitamin A (30,000 I.U./g.)	0.08
Vitamin D (9,000 I.U./g.)	0.08
TOTAL	100.00

consume their ration within two hours on the first seven days by removing the feed two hours after it was offered. On the eighth day, rumen samples were obtained by stomach pumping and jugular blood was sampled before feeding (T_0) and 2.5 hours, 5 hours and 10 hours post-feeding. The cattle were shipped to slaughter on the ninth day.

Sample Collection: Rumen contents were sampled by using a one-quarter horsepower vacuum pump, a five-eighths inch stomach tube and a vacuum flask. A positive pressure was placed on the stomach tube while it was being

Table 13.--Experiment IV: Per cent ration composition on a dry matter basis.

	Control	Added Acetic Acid				Added Lactic Acid			
		1.5%	3.0%	4.5%	6.0%	2.5%	5.0%	7.5%	10.0%
Corn Silage	86.29	85.27	82.89	80.12	78.71	83.92	80.36	76.43	73.95
Soy-mineral supp.	13.71	13.21	13.99	15.21	14.90	13.50	14.58	15.30	15.56
Acetic Acid	-----	1.52	3.12	4.67	6.39	-----	-----	-----	-----
Lactic Acid	-----	-----	-----	-----	-----	2.58	5.06	8.27	10.49
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

passed down the esophagus to avoid collection of saliva. A strainer was placed on the hose and the rumen fluid was drawn into the vacuum flask.

Blood samples were collected from the jugular vein with a 10 cc. syringe and a 3.81 cm., 16 gauge needle. Collection time varied from three to five minutes per steer. After collection, the blood samples were placed in test tubes with heparin to prevent blood clotting.

Rumen samples were strained through two layers of cheesecloth and 1 ml. of mecuric chloride (saturated) was mixed with 19 ml. of the strained rumen fluid. Five ml. of the above mixture were then added to 1 ml. of metaphosphoric acid and centrifuged at 10,000 r.p.m. for 10 minutes. The supernatant was retained for volatile fatty acid analysis.

Laboratory Analysis: Rumen volatile fatty acid analyses were determined by injecting samples of the supernatant into a Packard gas chromatograph.

Blood was centrifuged at 6,000 r.p.m. for 10 minutes, and the plasma recovered with a Pasteur pipette. Urea content of the plasma and rumen ammonia were determined by the micro-diffusion method of Conway (1950).

Experiment VI--Nitrogen Balance Study with Ammonium Acetate, Ammonium Lactate, Urea and Soybean Meal

Design: A 4 x 4 latin square design was utilized in this study. Four 18-month old cannulated Hereford steers that had an average initial weight of 379.1 kg. were fed rations containing the nitrogen supplements shown in Table 14. Treatments were randomized by time and animal as shown in Table 15. Out of each 28 day period, 21 days were allowed for steers to adjust to new rations before being placed in the collection stalls. After an adjustment period of 14 hours (overnight) in the stalls, feed intake, fecal output and urine production were measured and sampled for chemical analysis over a period of six days. During the day following collection, jugular blood and rumen fluid samples were taken immediately before feeding and at two hour intervals thereafter up to 10 hours, post-feeding. The experiment was conducted concurrently with Experiment I. The study was initiated on January 31, 1971, and completed on May 5, 1971.

Feeding Regime: Steers in the collection stalls were fed twice daily at 8 a.m. and 5 p.m. The various nitrogen supplements were compared on a ration composed of 75 per cent concentrates (high moisture shelled corn, nitrogen supplement and mineral supplement) and 25 per cent untreated corn silage on a DM basis. The rations were mixed with the respective treatments in Experiment I and

Table 14.--Experiment VI: Metabolic study treatments utilized.

Ration	Nitrogen Supplement
A	Soybean Meal
B	Urea
C	Ammonium Acetate
D	Ammonium Lactate

Table 15.--Experiment VI: Design of experiment.

Period	870	897	888	981
	- - - - - - - - - - Ration - - - - - - - - - -			
1	B	A	D	C
2	A	C	B	D
3	C	D	A	B
4	D	E	C	A

collected from the mixer just prior to feeding. The ration composition is shown in Table 4 and the average chemical analysis of the feeds fed is shown in Table 3. The production and composition of the ammonium salts used are discussed in Experiment I. The compositions of the mineral supplement fed with the ammonium salts, the soybean meal supplement and the urea supplement are shown in Table 5.

Representative samples of all rations were taken just prior to feeding for chemical analysis and dry matter determination. Feed not consumed was weighed, sampled and discarded prior to the 8 a.m. feeding.

Sample Collection: Total feces were allowed to pass through a steel grid in the floor immediately behind each steer and were collected in large plastic containers in a pit below the collection stalls. Feces were removed every morning and total output was weighed. A 5 per cent aliquot was retained each day for nitrogen determination, a 100 g. sample was analyzed daily for dry matter content and the remaining feces were discarded. At the end of the six-day collection period, all samples from each steer were thoroughly mixed, composited and sampled for immediate total nitrogen determination.

Total urine was collected in a plastic carboy (in the pit below the collection stalls) which contained 200 ml. of 18 N sulfuric acid. The carboy was emptied daily

and urine volume was measured, then diluted to 12 liters with water and a 10 per cent aliquot was stored in a cooler. The remaining diluted urine was discarded. After the six-day collection period, all urine samples from each steer were mixed, composited and sampled for immediate total nitrogen determination.

Rumen contents were sampled through permanent rumen cannulas. Rumen samples were processed and analyzed as discussed in Experiment V.

Jugular vein samples (10 ml.) were taken with a 16 gauge needle. Plasma was kept for urea analysis as discussed in Experiment V.

Laboratory Analysis: Dry matter of feed and feces were determined daily by drying at 105° C. for 24 hours. Total nitrogen determination of feed, feces and urine were analyzed by macro-Kjeldahl procedures on fresh samples.

Experiment VII--Nitrogen Balance Study Comparing Various Ammonium Salts of Organic Acids with Conventional Nitrogen Supplements

Design: Twenty-four Hereford steers were utilized in a nitrogen balance study to compare soybean meal, 1/2 liquid urea - 1/2 corn steep water (U-CSW), liquid urea, ammonium formate, ammonium acetate, ammonium propionate, ammonium lactate and ammonium butyrate as shown in Table 16. Each supplement was fed to three steers and steers

Table 16.--Experiment VII: Design of metabolic experiment comparing various nitrogen supplements.

Nitrogen Supplement	Period 1	Period 2	Period 3
Soybean meal	473	445	391
U-CSW	286	302	253
Urea	301	221	386
Ammonium formate	433	272	470
Ammonium acetate	285	202	247
Ammonium propionate	317	368	394
Ammonium lactate	250	332	465
Ammonium butyrate	432	395	335

were used only once. The steers were short yearlings that had been purchased the previous fall in Virginia feeder calf sales. They were full fed an all silage ration which was treated with urea-mineral at time of ensiling from October, 1971, until the experiment was initiated. All 24 steers were selected for uniformity in weight prior to initiation of the experiment. They were then divided according to weight into three groups to make the cattle within each group as uniform as possible. The average initial weight for each group was 404.6, 395.8 and 387.9 kg. for periods 1, 2 and 3, respectively.

The respective periods were initiated on April 12, April 20 and April 28, 1972. Each period consisted

of 14 days in which the steers were acclimated to their ration and seven days in the collection stalls. The steers were moved to the collection stalls the night before collections were to begin. Feed feces and urine were measured and sampled for chemical analysis over a period of six days. During the day following collection, rumen fluid and jugular blood samples were taken immediately before feeding and at two hour intervals thereafter up to 10 hours, post-feeding.

Feeding Regime: Steers in the collection stalls were fed twice daily at 7:30 a.m. and 5:30 p.m. They were watered three times daily from plastic buckets at 7 a.m., 12 noon and 5 p.m. The nitrogen supplements were compared on a 60 per cent untreated corn silage and 40 per cent concentrates (dry, shelled corn, nitrogen supplement and mineral supplement) on a DM basis. The corn silage was removed from the silo and mixed with rolled corn in a horizontal batch mixer once each day. The mineral and nitrogen supplement was thoroughly mixed with the silage-corn mixture by hand each afternoon before feeding. One-half of the daily ration for each steer was fed the same evening and the remainder was stored in a plastic bag until being fed the following morning. The steers were fed ad libitum during the first 10 days of the adjustment period and 90 per cent of their ad libitum consumption for the remainder of that period.

Mineral supplement (Table 10) was fed at 454 g. per head daily; and the nitrogen supplement at 508, 599, 463, 454, 463, 481 and 463 g. for steers on soy, U-CSW, urea, ammonium formate, ammonium acetate, ammonium propionate, ammonium lactate and ammonium butyrate, respectively. The production of the nitrogen supplements is discussed in Experiment II and their composition is shown in Tables 6 and 7.

Representative samples of all rations were taken just prior to feeding for laboratory analysis and dry matter determination. Feed not consumed was weighed, sampled and discarded prior to the 5:30 p.m. feeding.

Sample Collection: Collection of feces and urine was similar to that described for Experiment VI. A 10 per cent aliquot of the feces was retained each day for nitrogen determination and a 200 gram sample was analyzed daily for a dry matter determination.

Samples of rumen fluid were taken by stomach pumping and jugular blood samples were taken with a 10 ml. syringe. The procedures for obtaining, processing and analyzing these samples are discussed in Experiment V.

Laboratory Analysis: Dry matter of feed and feces were determined daily by drying in an over at 55° C. for 48 hours. Extracts of the feed and feces were prepared by homogenizing 25 g. of material and 100 ml. of distilled water with a Sorvall Omni-Mixer for two minutes. A

portion of the unstrained homogenate was used to determine total nitrogen by micro-Kjeldahl procedure. Micro-Kjeldahl procedures were also used to determine the total nitrogen of the diluted urine samples.

Statistical Analysis

All data reported in this dissertation were analyzed on a CDC 3600 computer at Michigan State University Computer Laboratory. Analysis of variance procedures were used in all experiments, and Duncan's New Multiple Range Test was used to test for significant differences between means.

RESULTS AND DISCUSSION

Experiment I--Feeding Trial Comparing Ammonium Acetate Ammonium Lactate, Urea and Soybean Meal

Cattle Performance: Complete results of this experiment are shown in Table 17. Average daily gain of the cattle receiving urea was depressed 5.9 per cent below the group receiving soybean meal (791 g. vs. 841 g.). Dry matter consumption and feed efficiency were slightly depressed for the urea supplemented group when compared to the soy-supplemented group. Although not significant ($P < .05$) these differences are in agreement with previous work (Newland et al., 1961 and Helmer and Bartley, 1971). Several workers have noted a lower level of performance on urea supplemented rations and have generally attributed this to a decreased palatability of such rations (Woodward and Sheppard, 1944; Wise et al., 1944 and Owens et al., 1968).

The cattle receiving ammonium acetate as a source of supplemental protein gained 5.4 per cent faster than cattle receiving soybean mean (886 g. vs. 841 g., daily) and 12.0 per cent faster than cattle receiving urea (886 g. vs. 791 g., daily). The difference in average daily

Table 17.--Experiment I: Ammonium salts as a source of crude protein for feedlot cattle (November 3, 1970 to April 22, 1971).

	Source of Supplemental Protein			
170 Day Test	Soybean Meal	Urea	NH_4 Acetate	NH_4 Lactate
Lot No.	19	20	17	16
No. of yearling steers	6	6	6	6
Av. initial wt., kg.	295.9	293.6	295.9	295.5
Av. Final wt., kg.	439.1	429.5	446.8	457.7
Av. daily gain, kg.	.841[ab]	.791[a]	.886[bc]	.955[c]
Daily Feed, kg. 85%DM:				
Corn silage	1.69	1.63	1.73	1.87
Gr. shelled corn	4.96	4.79	5.12	5.41
Nitrogen supplement	0.51	0.54	0.53	0.53
TOTAL	7.16	6.96	7.38	7.81
Feed Efficiency				
Feed per kg. gain, kg.	8.52	8.86	8.32	8.22
Feed and yardage cost per 100 kg. gain[1]	49.81	49.81	49.81	49.81
Relative value of supplements[1]	100.00	80.00	121.00	148.20

Table 17.--Continued

170 Day Test	Source of Supplemental Protein			
	Soybean Meal	Urea	NH_4 Acetate	NH_4 Lactate
Carcass Evaluation:				
Carcass grade[2]	13.34	13.51	13.17	13.50
Marbling score[3]	15.50	16.00	14.67	15.67
Fat thickness, cm.	1.73	1.35	1.68	1.78
Rib eye area cm^2	66.97	66.90	68.00	69.61
Per cent K. H. P. fat[4]	4.00	4.00	4.08	3.84
Per cent B. T. R. cuts[5]	47.61	48.64	47.78	47.77
Dressing per cent[6]	61.81[a]	60.30	60.84	60.97
Carcass price per 100 kg.	$113.30	$115.15	$115.15	$115.13

[1]Feed costs based on 35% DM corn silage $9.37/mt shelled corn $49.60/mt, yardage at 10¢/steer/day.

[2]Good=9, 10, 11; Choice=12, 13, 14.

[3]Small=10, 11, 12; Modest=13, 14, 15; Moderate=16, 17, 18.

[4]Per cent of carcass weight in kidney, heart and pelvic fat.

[5]Per cent of carcass weight in boneless, trimmed retail cuts.

[6]Cold carcass weight over off experiment weight.

Significance: Values having different superscript differ significantly; a, b, c ($P < .05$).

gain was significant ($P < .05$) between ammonium acetate and urea but not significant between soybean meal and ammonium acetate. Varner and Woods (1969) also noted a significant ($P < .05$) increase in average daily gain when ammonium acetate supplemented cattle were compared to cattle fed urea. Other work with lambs fed ammonium acetate (Repp et al., 1955a) and cattle fed a high-acetate ammonium salt mixture (Varner et al., 1968) have resulted in equal growth when compared to animals fed urea. Varner et al. (1968) also reported that the high-acetate ammonium salt mixture supported growth almost equal to soybean meal for finishing cattle.

The ammonium acetate fed cattle consumed 3.1 per cent more DM than the soybean meal supplemented steers and 6.0 per cent more than those fed urea. Feed efficiency was 2.3 per cent and 6.1 per cent greater, respectively for steers fed ammonium acetate than for those fed soybean meal or urea.

Ammonium lactate supplemented steers had significantly ($P < .05$) higher average daily gains than either the soybean meal or urea fed groups. The group receiving ammonium lactate as a source of supplemental nitrogen gained 13.5 per cent faster than the group supplemented with soybean meal (955 g. vs. 841 g., daily) and 20 per cent faster than the group receiving urea (955 g. vs. 791 g.). The ammonium lactate fed steers consumed 9.1 per cent

more DM than soybean meal fed animals and 12.2 per cent than the urea fed group. Similarly, feed efficiency was increased 3.5 per cent and 7.2 per cent with supplementation of ammonium lactate when compared to rations supplemented with soybean meal and urea, respectively.

Performance of the ammonium lactate and ammonium acetate groups was not significantly different ($P < .05$). However, average daily gain, daily DM consumption and feed efficiency for the ammonium lactate group were 7.8 per cent, 5.8 per cent and 1.2 per cent higher, respectively.

No feeding trials or growth studies have been reported in the literature that involved ammonium lactate.

However, the superiority of ammonium lactate over other NPN sources agrees with *in vitro* studies by Belasco (1954).

Relative Value of Supplements: The relative value of the four supplements is shown in Table 17 and was derived by equating for all treatments the total feed and yardage cost per kg. of gain and allowing supplemental nitrogen cost to vary. By assigning a relative value of 100 to soybean meal, the value of the other supplements is expressed relative to soy. This figure is an economic evaluation of the supplements based on average daily gain and feed efficiency.

Under the conditions of this experiment, urea had only 80 per cent of the value of soybean meal. Ammonium acetate and ammonium lactate were worth 21.0 per cent and 48.2 per cent more than soybean meal.

Carcass Evaluation: Differences in carcass desirability were small, and for the most part, non-significant. All groups of cattle graded average Choice, possessed a modest to moderate level of marbling and yielded approximately 48 per cent of their carcass weight in boneless, trimmed, retail cuts. The urea treatment group was trimmer and had highest yield of retail cuts. The soybean meal fed steers had the highest ($P < .05$) dressing percentage.

Experiment II--Feeding Trial Comparing Various Ammonium Salts of Organic Acids with Conventional Nitrogen Supplements

Cattle Performance: Table 18 shows the mean performance of the two concentrate levels for each nitrogen supplement. The differences in performance were not significant ($P < .05$). However, the average daily gain of the urea fed cattle was depressed by 5.3 per cent below the performance of the soybean meal group. This is consistent with the 5.9 per cent reduction in the average daily gain of the urea compared to the soybean meal group in Experiment I. The urea fed steers gained slower than all other groups on the low level of concentrate and slower than all but the ammonium acetate fed cattle on the high concentrate ration.

Table 18.--Experiment II: Ammonium salts as a source of crude protein for feedlot cattle (November 2, 1971 to March 9, 1972).

128 Day Test	Source of Supplemental Crude Protein							
	Soy	U-CSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Prope-nate	NH_4 Lactate	NH_4 Buty-rate
No. of yearling steers	20	20	20	20	20	20	20	20
Av. initial wt.	356.4	359.6	358.7	358.7	357.3	358.2	358.7	360.0
Av.	542.1	534.4	543.9	544.3	538.0	541.2	541.2	548.9
Av. daily gain, kg.	1.45	1.44	1.37	1.45	1.41	1.43	1.43	1.48
Daily Feed, kg. 85% DM:								
Corn silage	4.39	4.58	4.42	4.79	4.75	4.29	4.42	4.64
Gr. shell corn	5.86	6.03	5.97	6.04	5.96	5.88	5.82	6.08
Nitrogen supplement	0.50	0.33	0.10	0.21	0.25	0.27	0.35	0.35
Mineral supplement	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Total	11.17	11.36	10.91	11.46	11.38	10.86	11.01	11.49
Feed Efficiency:								
Feed per kg. gain, kg	7.71	7.90	7.96	7.92	8.06	7.59	7.73	7.79
Feed and yardage cost per 100 kg. gain[1]	$39.49	$39.49	$39.49	$39.49	$39.49	$39.49	$39.49	$39.49
Relative value of supplements[7]	100.00	66.95	35.54	73.10	55.59	111.84	89.86	96.53

Carcass Evaluation:

Carcass grade[2]	11.40^{ab}	11.50^{ab}	10.70^{b}	11.90^{a}	11.70^{ab}	11.65^{ab}	11.80^{ab}	11.40^{ab}
Marbling score[3]	9.95^{a}	10.80^{Aa}	8.65^{Bb}	11.75^{a}	11.05^{Aa}	11.25^{ab}	11.25^{Aa}	10.70^{a}
Fat thickness, cm.	1.70	1.88	1.32	1.78	1.80	1.60	1.88	1.78
Rib eye area, cm^2	76.84	74.59	75.23	73.10	77.36	76.84	76.07	75.68
Per cent K. H. P. fat[4]	2.78	2.75	2.70	3.03	3.00	2.80	3.03	2.73
Per cent B. T. R. cuts[5]	48.38^{ab}	47.75^{b}	49.26^{a}	47.67^{b}	48.18^{ab}	48.62^{ab}	47.79^{b}	47.93^{b}
Dressing per cent[6]	58.48	58.22	57.82	57.95	58.46	58.36	58.50	59.02
Carcass price per 100 kg.	$114.25	$114.58	$113.26	$115.24	$115.13	$114.91	$114.07	$114.29

[1]Feed cost based on 35% DM corn silage $9.37/mt., shelled corn $49.60/mt., mineral supplement $66.15/mt, yardage at 10¢/steer/day.

[2]Good=9, 10, 11; Choice=12,13,14.

[3]Small=10, 11, 12; Modest 13, 14, 15; Moderate=16, 17, 18.

[4]Per cent of carcass weight in kidney, heart and pelvic fat.

[5]Per cent of carcass weight in boneless, trimmed retail cuts.

[6]Cold carcass weight over off experiment weight.

[7]Based on relative average daily gain, relative feed efficience and feed cost.

Significance: values having different superscripts differ significantly: (A = (P < .01), a = (P < .05).

As in Experiment I, the daily DM consumption and feed efficiency of the urea supplemented cattle was slightly lower (2.3 per cent and 3.2 per cent, respectively) than for the soybean meal fed steers.

Gain of the groups fed the various ammonium salts was practically identical to that of the soybean meal and U-CSW groups when averaged over both concentrate levels (Table 18). However, performance on all the NPN supplemented diets except ammonium acetate increased at the higher level of concentrate (Table 19). Cattle fed ammonium acetate at the high concentrate level gained 3.8 per cent less than those on low concentrate. The increase in gain for high versus the low concentrate rations was 2.9 per cent, 5.4 per cent, 4.2 per cent, 10.0 per cent, 2.6 per cent and 4.4 per cent for the U-CSW, urea, ammonium formate ammonium propionate, ammonium lactate and ammonium butyrate fed groups, respectively.

On the high concentrate ration, all of the NPN fed steers except urea and ammonium acetate outperformed the soybean meal fed steers. In contrast, the soybean meal fed steers outgained all groups on the low level of concentrate. In addition, all of the NPN groups were more efficient than the soybean meal fed steers on the 80 per cent level of concentrate but less efficient than the soybean meal group on the low level of concentrate (Table 19).

Table 19.--Experiment II: Effect of various crude protein sources and concentrate levels (November 2, 1971 to March 9, 1972).

Nitrogen source	Soy		U-CSW		Urea		NH_4 Formate	
Percent concentration	40%	80%	40%	80%	40%	80%	40%	80%
Lot	1	2	5	6	3	4	7	9
No. of yearling steers	10	10	10	10	10	10	10	10
Av. initial wt., kg.	356.8	356.4	357.3	362.3	358.7	358.7	359.6	358.2
Av. final wt., kg.	544.8	539.4	538.9	548.9	529.4	538.9	541.2	548.0
Av. daily gain, kg.	1.47	1.43	1.42	1.46	1.33	1.41	1.42	1.48
Daily Feed, kg. 85% DM:								
Corn silage	6.44	2.34	6.79	2.37	6.46	2.38	6.78	2.43
Ground shell corn	3.90	7.82	4.12	7.94	4.00	7.96	4.11	8.34
Nitrogen supplement	0.49	0.49	0.33	0.33	0.10	0.10	0.21	0.20
Mineral supplement	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Total	11.25	11.07	11.66	11.06	10.98	10.86	11.52	11.39
Feed Efficiency:								
Feed kg. gain, kg.	7.67	7.75	8.23	7.59	8.23	7.72	8.11	7.70

Carcass Evaluation:

Carcass grade[1]	11.00	11.80	11.30	11.70	10.80	10.60	12.00	11.80
Marbling score[2]	8.80	11.10	10.40	11.20	9.30	8.00	12.30	11.20
Fat thickness, cm.	1.52	1.88	1.96	1.80	1.32	1.32	1.52	2.06
Rib eye area, cm.[2]	78.07	75.68	71.49	77.68	74.78	75.75	72.65	73.68
Per cent K. H. P. fat[3]	2.85	2.70	2.60	2.90	2.80	2.60	2.95	3.10
Per cent B. T. R. cuts[4]	48.86	47.89	47.38	48.12	49.27	49.25	48.52	46.83
Dressing per cent[5]	58.21	58.75	57.85	58.58	57.28	58.36	57.17	58.73
Carcass price per 100 kg.	$113.08	$115.39	$113.30	$115.83	$114.29	$112.20	$116.05	$114.40

[1]Good = 9, 10, 11; Choice = 12, 13, 14.

[2]Small = 10, 11, 12; Modest = 13, 14, 15; Moderate = 16, 17, 18.

[3]Per cent of carcass weight in kidney, heart and pelvic fat.

[4]Percent of carcass weight in boneless, trimmed retail cuts.

[5]Cold carcass weight over off experiment weight.

Table 19.--Continued

Nitrogen source	NH_4 Acetate		NH_4 Propinate		NH_4 Lactate		NH_4 Butyrate	
Percent concentrates	40%	80%	40%	80%	40%	80%	40%	80%
Lot	10	11	12	13	14	15	16	17
No. of yearling steers	10	10	10	10	10	10	10	10
Av. initial wt., kg.	355.5	358.7	358.7	357.8	357.3	360.0	360.0	360.0
Av. final wt., kg.	540.3	535.7	533.0	549.8	537.5	545.3	545.3	553.0
Av. daily gain, kg.	1.44	1.38	1.36	1.50	1.41	1.44	1.44	1.51
Daily Feed, kg. 85% DM:								
Corn silage	7.25	2.25	6.22	2.36	6.55	2.28	6.92	2.35
Ground shell corn	4.42	7.50	3.77	7.99	3.96	7.68	4.21	7.96
Nitrogen supplement	0.25	0.25	0.27	0.27	0.35	0.35	0.35	0.35
Mineral supplement	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Total	12.34	10.42	10.68	11.04	11.29	10.74	11.90	11.08
Feed Efficiency:								
Feed per kg. grain, kg.	8.58	7.52	7.84	7.37	8.02	7.44	8.24	7.35

Carcass Evaluation:

Carcass grade[1]	11.30	12.10	11.30	12.00	12.30	11.30	10.60	12.20
Marbling score[2]	9.60	12.50	10.60	11.90	12.50	10.00	9.30	12.10
Fat thickness, cm.	1.65	1.93	1.40	1.80	1.80	1.93	1.60	1.96
Rib eye area, cm^2	77.42	77.29	74.59	79.04	76.00	76.07	76.52	74.84
Per cent K. H. P. fat[3]	2.65	3.35	2.60	3.00	2.95	3.10	2.35	3.10
Per cent B. T. R. cuts[4]	48.70	47.65	49.11	48.14	48.06	47.52	48.72	47.15
Dressing per cent[5]	57.94	58.97	57.52	59.19	58.11	58.89	58.62	59.43
Carcass price per 100 kg.	$114.73	$115.50	$114.40	$115.39	$115.17	$112.97	$113.30	$115.28

[1]Good = 9, 10, 11; Choice = 12, 13, 14.

[2]Small = 10, 11, 12; Modest = 13, 14, 15; Moderate = 16, 17, 18.

[3]Per cent of carcass weight in kidney, heart and pelvic fat.

[4]Per cent of carcass weight in boneless, trimmed retail cuts.

[5]Cold carcass weight over off experiment weight.

These results do not support the theory that the increased energy availability of the ammonium salts is responsible for greater nitrogen utilization. A possible explanation for the increased level of performance on the high concentrate diet with the NPN supplements is an increased urea fermentation potential (UFP) of the ration as discussed by Burroughs et al. (1972).

Relative Value of Supplements: The relative values of the supplements are shown in Table 18, and the derivation of this figure is discussed in Experiment I. Under the conditions of this experiment, ammonium propionate had the greatest value (112 per cent of soy) and urea had the least value (36 per cent of soy). Therefore, a feeder could pay 3.1 times the cost of urea for the ammonium propionate supplement or 2.8 times the cost of urea for the soybean meal supplement and not affect his net return. Using this system of evaluation, the decreasing order of value for the supplements was ammonium propionate, soybean meal, ammonium butyrate, ammonium lactate, ammonium formate, U-CSW, ammonium acetate and urea. The relative value of the NPN supplements increased on rations of 80 per cent concentrate and decrease at 40 per cent concentrate.

Belasco (1954) did not test soybean meal, U-CSW, or ammonium salts of propionic and butyric acid. However, he did report the following decreasing order for nitrogen utilization, ammonium lactate, ammonium formate, urea and ammonium acetate. This is practically the same order in

which these supplements are listed for relative value. Belasco's rank on in vitro cellulose digestion does not follow this order and ammonium acetate fed steers outperformed those fed urea in Experiment I.

Carcass Evaluation: When averaged across both levels of concentrate (Table 18), the carcass grade for the urea supplemented cattle was average good and the average carcass grade for all other groups was high good. The urea fed steers graded significantly ($P < .05$) lower than the ammonium formate cattle and the difference in carcass grade approached significance when the urea cattle were compared to cattle fed ammonium salts of lactic, acetic and propionic acid.

The cattle on this experiment had an average final weight of 541.8 kg. and average fat thickness of 1.72 cm. However, only 50 per cent of the cattle graded Choice. In contrast, the cattle on Experiment I were lighter (443.3 kg.) at slaughter and had approximately the same fat thickness (1.64 cm.) but 96 per cent graded Choice or better. The low carcass grades on this experiment may have been of genetic origin. This hypothesis is supported by the fact that steers originated from only two herds (Appendix I).

Carcass grade, on the average, was significantly ($P < .05$) higher for the higher level of concentrate (Table 20). However, increased carcass grades on 80 per cent

concentrates were not observed for all of the nitrogen sources tested. Steers supplemented with urea, ammonium formate and ammonium lactate had lower carcass grades on the high concentrate ration. The interaction between nitrogen source and concentrate level for carcass grade was significant ($P < .01$). This same trend existed for marbling score, which is the primary determinant of carcass grade.

The urea fed steers not only yielded lower grading carcasses but also had less fat and lower carcass price than all other groups. Carcasses from the urea fed cattle were the trimmest in all fat measurements (external fat and internal fat), as well as in all carcass measurements that are correlated with the amount of carcass fat (marbling score, cutability and dressing per cent) as shown in Table 18. Difference in fat thickness was not significant ($P < .05$) between the urea and ammonium propionate fed cattle but it was significant ($P < .05$ or $P < .01$ as shown in Table 18) between the urea cattle and each of the other treatment groups.

The urea fed cattle had the lowest marbling score and this difference approached significance ($P = .062$). Carcasses from the urea fed cattle had significantly ($P < .05$) greater yields of boneless, trimmed retail cuts than carcasses from cattle fed U-CSW, ammonium formate, ammonium lactate and ammonium butyrate.

Carcasses from the urea fed cattle in Experiment I also had less external fat and a greater yield of boneless, trimmed retail cuts than those from other treatments, but the differences were not significant.

The differences in all other carcass traits when averaged across both concentrate levels (Table 18) among the steers fed ammonium salts, soybean meal or U-CSW were small and nonsignificant.

Concentrate Levels: Results of this comparison are shown in Table 20. The 40 per cent concentrates - 60 per cent corn silage and the 80 per cent concentrates - 20 per cent corn silage rations are approximately equal to 70 per cent and 90 per cent concentrate in the ration, respectively.

Although not significant ($P < .05$), the average daily gain was 2.9 per cent higher (1.45 vs. 1.41 kg.); and the feed required per unit of gain was 7 per cent lower (7.54 vs. 8.11) for the high concentrate diet. However, the lower concentrate ration resulted in more beef production per hectare (1,348 vs. 1,039 kg.), a higher gross return per hectare ($892 vs. $702) and a lower cost per 100 kg. of gain ($36.34 vs. $41.60).

Compared to cattle fed low concentrates, those on high concentrates had a significantly higher carcass grade ($P < .05$) and dressing per cent ($P < .01$). Moreover, carcasses were significantly fatter ($P < .01$) as

indicated by both external fat and per cent of the carcass weight as kidney, heart and pelvic fat. In addition, feeding the high concentrate ration resulted in carcasses that had significantly lower ($P < .01$) yields of boneless, trimmed retail cuts.

Experiment III--Acetic and Lactic Acid Additions to High Concentrate Rations

Cattle Performance: As shown in Table 21, adding acetic acid to an otherwise nutritionally balanced ration had no effect on average daily gain, but adding lactic acid stimulated gains 3.4 per cent (840 g. vs. 813 g.). The addition of acetic or lactic acid to the urea supplemented ration resulted in faster growth (Table 22), but only lactic acid addition was beneficial when added to soybean meal supplemented rations. The growth promoting effect of added organic acids, especially to urea supplemented rations, could be a result of increased energy for fermentation as reported by Arias et al. (1951) or it could be that the acid radical decreased the absorption of ammonia into the blood as suggested by Wetterau and Holzchub (1960 and 1961) and reported by Coppock and Stone (1968).

The addition of either acetic or lactic acid did not depress DM consumption as has been cited in the literature (Simpkins et al., 1965; Weston, 1966; Rook

Table 20.--Experiment II: 40 per cent shelled corn and 60 per cent corn silage vs. 80 per cent shelled corn and 20 per cent corn silage (November 2, 1971 to March 9, 1972).

128 Day Test	40% sh. corn 60% silage	80% sh. corn 20% silage
No. of yearling steers	80	80
Av. initial wt., kg.	358.2	359.1
Av. final wt., kg.	538.4	544.8
Av. daily gain, kg.	1.41	1.45
Daily Feed, kg. 85% DM:		
Corn silage	6.67	2.35
Ground shelled corn	4.06	7.90
Nitrogen supplement	0.30	0.30
Mineral supplement	0.42	0.42
Total	11.45	10.97
Feed Efficiency:		
Feed per kg. gain, kg.	8.11	7.54
Feed and yardage cost per 100 kg. gain[1]	$36.34	$41.60
Beef produced/hectare corn fed, kg.	13.48	10.39
Gross returns/hectare corn fed	$892	$702
Carcass Evaluation:		
Carcass grade[2]	11.33[a]	11.69
Marbling score[3]	10.35[A]	11.00
Fat thickness, cm.	1.60[A]	1.83
Rib eye area, cm.[2]	75.29[A]	76.13
Per cent K. H. A. fat[4]	2.72[A]	2.98
Per cent B. T. R. cuts[5]	48.58[A]	47.82
Dressing per cent[6]	57.84[A]	58.86
Carcass price per 100 kg.	$114.29	$114.62

[1]See Table 18 for feed cost.
[2]Good = 9, 10, 11; Choice = 12, 13, 14.
[3]Small = 10, 11, 12; Modest = 13, 14, 15; Moderate = 16, 17, 18.
[4]Per cent of carcass weight in kidney, heart and pelvic fat.
[5]Per cent of carcass weight in boneless, trimmed retain cuts.
[6]Cold carcass weight over off experiment weight.
[7]Based on corn yields of 35 mt. of 35% DM silage or 5 mt. of shell corn per hectare.
[8]Based on selling price of cattle.

Significance: Values having different superscripts differ significantly; A = (P < .01), a = (P < .05).

Table 21.--Experiment III: Effect of acetic acid and lactic acid addition (November 3, 1970 to April 22, 1971).

170 Day Test	Control	Acetic	Lactic
No. of yearling steers	12	11	11
Av. initial wt., kg.	299.2	302.4	296.9
Av. final wt., kg.	436.7	440.8	439.9
Av. daily gain, kg.	.813	.813	.840
Daily Feed, kg. 85% DM:			
Corn silage	1.66	1.72	1.68
Gr. shelled corn	4.88	5.08	4.91
Nitrogen supplement	0.53	0.53	0.53
Total	7.07	7.83	7.12
Feed Efficiency:			
Feed per kg. gain, kg.	8.69	9.01	8.46
Feed and yardage cost per 100 kg. gain[1]	49.81	49.81	49.81
Relative value of supplements[1]	90.00	73.40	101.10

Carcass Evaluation:			
Carcass grade[2]	13.42	13.30	12.19
Marbling score[3]	15.75	14.88	12.75
Fat thickness, cm.	1.52	1.52	1.37
Rib eye area, cm.[2]	66.97	71.87	69.22
Per cent K. H. P. fat[4]	4.00	3.94	3.46[a]
Per cent B. T. R. cuts[5]	48.12	48.63	48.87
Dressing per cent[6]	61.06	61.54	61.27
Carcass price per 100 kg.	$114.31	$114.51	$113.98

[1]Feed costs based on 35 per cent DM corn silage $9.37/mt shelled corn $49.60/mt, yardage at 10¢/steer/day.

[2]Good = 9, 10, 11; Choice = 12, 13, 14.

[3]Small = 10, 11, 12; Modest = 13, 14, 15; Moderate = 16, 17, 18.

[4]Per cent of carcass weight in kidney, heart and pelvic fat.

[5]Per cent of carcass weight in boneless, trimmed retail cuts.

[6]Cold carcass weight over off experiment weight

Significance: Values having different superscript differ significantly; a, b ($P < .05$).

Table 22.--Experiment III: Acetic acid and lactic acid addition to soy and urea supplemented rations (November 3, 1970 to April 22, 1971).

170 Day Test	Soy Supplement			Urea Supplement		
	Control	Acetic Acid	Lactic Acid	Control	Acetic Acid	Lactic Acid
Lot no.	19	22	18	20	21	15
No. of yearling steers	6	5	6	6	6	5
Av. initial wt., kg.	295.6	303.7	296.0	300.5	301.0	297.8
Av. final wt., kg.	438.6	443.1	443.6	434.5	438.6	436.7
Av. daily gain, kg.	.840	.822	.867	.790	.808	.817
Daily Feed, Kg. 85% DM:						
Corn silage	1.69	1.69	1.75	1.63	1.75	1.61
Gr. shelled corn	4.96	5.03	5.10	4.79	5.12	4.72
Nitrogen supplement	0.51	0.52	0.52	0.54	0.54	0.53
Total	7.16	7.24	7.37	6.96	7.41	6.86
Feed Efficiency:						
Feed per kg. gain, kg.	8.52	8.86	8.54	8.86	9.17	8.38
Feed and yardage cost per 100 kg. gain[1]	49.81	49.81	49.81	49.81	49.81	49.81
Relative value of supplements[1]	100.00	72.20	103.40	80.00	74.60	98.80

Carcass Evaluation:

Carcass grade[2]	13.33	13.27	12.83	13.50	13.33	11.53
Marbling score[3]	15.50	14.59	14.50	16.00	15.17	11.01
Fat thickness, cm.	1.70	1.65	1.60	1.35	1.40	1.17
Rib eye area, cm.[2]	66.90	72.06	70.64	66.90	71.68	67.74
Per cent K. H. P. fat[4]	4.00	3.89	3.42	4.00	4.00	3.51
Per cent B. T. R. cuts[5]	47.61	48.36	48.46	48.64	48.91	49.28
Dressing per cent[6]	61.82	61.51	62.13	60.30	61.57	60.41
Carcass price per 100 kg.	$113.48	$113.52	$114.22	$115.13	$115.50	$113.74

[1]Feed costs based on 35% DM corn silage $9.37/mt., shelled corn $49.60/mt., yardage at 10¢/steer/day.

[2]Good = 9, 10, 11; Choice = 12, 13, 14.

[3]Small = 10, 11, 12; Modest = 13, 14, 15; Moderate = 16, 17, 18.

[4]Per cent of carcass weight in kidney, heart and pelvic fat.

[5]Per cent of carcass weight in boneless, trimmed retail cuts.

[6]Cold carcass weight over off experiment weight.

et al., 1963; Montgomery et al., 1963 and Baile and Pfander, 1965).

Acetic acid depressed feed efficiency 3.7 per cent (9.01 vs. 8.69) but lactic acid increased feed efficiency 2.6 per cent (8.46 vs. 8.69). A decrease in feed efficiency on acetic and an increase on lactic acid were noted for both nitrogen supplements (Table 22). The increased feed efficiency with added lactic acid is in agreement with trends observed in other work at the Michigan Station in which feed efficiency has increased with the level of lactic acid in the silage (Henderson et al., 1971a; Cash, 1972; and Emery et al., 1961). In addition, the ammonium lactate ration was the most efficiently utilized in Experiment I and one of the more efficient rations in Experiment II.

Relative Value: The relative values of the acid additions to the two protein supplements are shown in Tables 21 and 22 and the derivation of this figure is discussed in Experiment I. Acetic acid additions reduced the value of the supplements but lactic acid additions had little effect on the value. Adding acetic acid and lactic acid to feedlot rations will probably never become an economic consideration, but these data do show that neither acetic nor lactic acid will reduce on consumption or impair feed efficiency when fed at the levels used in this experiment.

Carcass Evaluation: Lactic acid tended to slightly depress carcass grade in this trial. The group receiving lactic acid graded low Choice, whereas the control group and the group receiving acetic acid graded middle Choice. The groups receiving lactic acid had significantly ($P < .05$) less kidney, heart and pelvic fat than the other groups. Although the difference was not significant ($P < .05$), the group receiving lactic acid had only 1.37 cm. fat, whereas the control group and the group receiving acetic acid both had 1.52 cm. of fat over the rib eye.

Soybean Meal vs. Urea: Data have been pooled for each nitrogen supplement and are shown in Table 23. Compared to cattle on soybean meal, those on urea gained 4.3 per cent less (804 g. vs. 840 g.), ate 2.6 per cent less DM (7.08 vs. 7.26) and were 1.9 per cent less efficient (8.80 vs. 8.64).

Fat thickness of the group receiving urea was significantly less ($P < .05$) than for the soybean meal group (1.30 cm. vs. 1.65 cm.). Although differences in the remaining carcass traits were not significant, marbling scores and carcass grade values were slightly higher for the soy cattle.

Table 23.--Experiment III: Soybean meal vs. urea supplements (November 3, 1970 to April 22, 1971).

170 Day Test	Soybean Meal Supplement	Urea Supplement
No. of yearling steers	17	17
Av. initial wt., kg.	298.3	299.6
Av. final wt., kg.	441.7	436.7
Av. daily gain, kg.	.840	.804
Daily Feed, kg. 85% DM:		
Corn silage	1.71	1.66
Gr. shelled corn	5.03	4.88
Nitrogen supplement	0.52	0.54
Total	7.26	7.08
Feed Efficiency:		
Feed per kg. gain, kg.	8.64	8.80
Feed and yardage cost per 100 kg. gain[1]	49.81	49.81
Relative value of supplements[1]	91.86	84.46
Carcass Evaluation:		
Carcass grade[2]	13.15	12.79
Marbling score[3]	14.86	14.06
Fat thickness, cm.	1.65[a]	1.30
Rib eye area, cm.[2]	69.93	68.77
Per cent K. H. P. fat[4]	3.77	3.83
Per cent B. T. R. cuts[5]	48.14	48.94
Dressing per cent[6]	61.82	60.76
Carcass price per 100 kg.	$113.74	$114.80

[1]Feed costs based on 35% DM corn silage $9.37/mt., shelled corn $49.60/mt., yardage at 10¢/steer/day.

[2]Good = 9, 10, 11; Choice = 12, 13, 14.

[3]Small = 10, 11, 12; Modest = 13, 14, 15; Moderate = 16, 17, 18.

[4]Per cent of carcass weight in kidney, heart and pelvic fat.

[5]Per cent of carcass weight in boneless, trimmed retail cuts.

[6]Cold carcass weight over off experiment weight.

Significance: Values having different superscript differ significantly; a ($P < .05$).

Experiment IV--Acetic and Lactic Acid Additions to All Silage Rations

Acetic Acid Addition: The results of this trial are shown in Table 24. At all levels of addition, acetic acid depressed intake, gains and feed efficiency when compared to the control ration. However, none of these differences were significant ($P < .05$).

The depression in DM consumption was intermediate (3.2 per cent) at the 1.5 per cent level of acetic acid addition and maximized at 3 per cent which was 8.4 per cent below controls. Higher levels of acetic acid did not decrease daily consumption below that observed at 3 per cent. These findings contradict the results of Experiment III in which acetic acid had no effect on daily consumption of a high concentrate diet. But they support the numerous reports of depressed DM intake with rumen infusions of acetate (Simpkins et al., 1965; Weston, 1966; Rook et al., 1963; Baile and Pfander, 1965; and Montgomery et al., 1963) and with higher levels of acetate in the ration (Dinius et al., 1968 and Wilkins et al., 1971).

Gains were decreased by 10.3 per cent, 15.2 per cent, 11.7 per cent and 7.2 per cent below the control steers at the increasing levels of acetic acid addition. This response is also different from that obtained with

Table 24.--Experiment IV: Acetic acid addition to all silage rations (November 11, 1971 to March 13, 1972).

124 Day Test	Added acetic acid, % of silage DM				
	Control	1.5	3.0	4.5	6.0
No. of steer calves	10	10	10	10	10
Av. initial wt., kg.	248.8	250.2	248.3	249.7	247.9
Av. final wt., kg.	374.6	362.7	354.6	360.5	356.4
Av. daily gain, kg.	1.01	0.91	0.86	0.89	0.94
Dry Matter Consumption, kg.:					
Corn silage	5.60	5.36	4.95	4.83	4.75
Soy-mineral supplement	0.89	0.83	0.84	0.92	0.90
Total	6.49	6.19	5.79	5.75	5.65
Acetic acid	none	0.10	0.19	0.28	0.39
Total	6.49	6.29	5.98	6.03	6.04
Per cent of body wt.	2.08	2.05	1.98	1.99	2.00
DM consumed per kg. gain, kg.	6.41	6.93	6.92	6.74	6.42
Daily Intake of Acetic Acid, kg.:					
Added acetic acid	none	0.10	0.19	0.28	0.39
Acetic acid in silage	0.12	0.11	0.10	0.10	0.10
Total	0.12	0.21	0.29	0.38	0.49
Per cent of DM consumption	1.82	3.32	4.87	6.40	8.05

the high concentrate ration and is probably a result of the decreased drymatter consumption.

As in Experiment III, adding acetic acid to the ration decreased feed efficiency. Feed efficiency was decreased 8.6 per cent, 8.5 per cent, 5.6 per cent and 0.6 per cent by the increasing increments of added acetic acid.

Lactic Acid Addition: Gains were not affected by adding lactic acid to the ration. There was also no difference in feed efficiency or DM consumption among the various levels of added lactic acid.

The addition of lactic acid did result in a decreased consumption of the basal ration (silage and protein), but this decrease was offset by the lactic acid consumption. Similarly, Emery et al. (1961) reported that lactic acid addition reduced appetite in proportion to its concentration when fed to growing heifers.

These results differ from Experiment III in which lactic addition resulted in both an increased average daily gain and feed efficiency. Emery et al. (1961) reported that feed efficiency increased in proportion to lactic acid intake.

Table 25.--Experiment IV: Lactic acid addition to all silage rations (November 11, 1971 to March 13, 1972).

124 Day Test	Added lactic acid, % of silage DM				
	Control	2.5	5.0	7.5	10.0
No. of steer calves	10	10	10	10	10
Av. initial wt., kg.	248.8	247.7	249.9	248.8	249.2
Av. final wt., kg.	374.6	369.7	376.6	367.3	376.4
Av. daily gain, kg.	1.01	0.97	1.06	1.01	1.02
Dry Matter Consumption, kg.:					
Corn silage	5.60	5.45	5.33	4.99	4.90
Soy-mineral supplement	0.89	0.88	0.97	1.00	1.03
Total	6.49	6.33	6.30	5.99	5.93
Lactic acid	none	0.17	0.34	0.54	0.69
Total	6.49	6.50	6.64	6.53	6.62
Per cent of body wt.	2.08	2.10	2.10	2.10	2.12
DM consumed per kg. gain, kg.	6.41	6.71	6.27	6.45	6.51
Daily Intake of Lactic Acid, kg.:					
Added lactic acid	none	0.17	0.34	0.54	0.69
Lactic acid in silage	0.30	0.30	0.29	0.27	0.27
Total	0.30	0.47	0.63	0.81	0.96
Per cent of DM consumption	4.69	7.13	9.45	12.45	15.60

Experiment V--Study of Rumen and Blood Parameters Associated with the Addition of Ammonium Salts or Organic Acids to Cattle Rations

Rumen Ammonia and Blood Urea Concentrations for Nitrogen Sources: Mean values for rumen ammonia and blood urea for the various nitrogen sources are shown in Table 26. The rumen ammonia concentration was highest at $T_{2.5}$ (2.5 hours post feeding) for urea, ammonium acetate and ammonium lactate supplemented steers. The soybean meal fed steers had a maximum rumen ammonia concentration at T_0 (immediately before being fed). Rumen ammonia was significantly higher $P < .01$) for the cattle fed ammonium salts at $T_{2.5}$ than for the urea or soybean meal fed cattle. Cattle fed ammonium lactate also had the highest ($P < .05$) rumen ammonia levels at T_5 and T_{10}.

The blood urea levels were higher than urea or soy fed cattle at all sampling times for the cattle fed ammonium salts, but the differences were not significant ($P < .05$) at T_0 and $T_{2.5}$. At T_5, blood urea levels were significantly greater for cattle fed ammonium lactate ($P < .01$) or ammonium acetate ($P < .05$) than for cattle fed urea or soybean meal. None of the differences in blood urea between ammonium acetate and lactate fed cattle or between urea and soybean meal fed cattle were significant (Table 26).

Table 26.--Experiment V: Mean[1] rumen ammonia and blood urea values for steers fed ammonium salts (mg/100 ml).

Time	Nitrogen source				
	Soy	Urea	NH_4 Acetate	NH_4 Lactate	SE[2]
Rumen Ammonia					
T_0	4.27	2.18	2.72	2.63	0.90
$T_{2.5}$	4.05^{A}	4.50^{A}	10.73^{B}	10.67^{B}	1.43
T_5	0.77^{Ba}	0.95^{a}	1.17^{a}	1.73^{Ab}	0.19
T_{10}	1.46^{a}	1.26^{a}	1.13^{Ba}	2.70^{Ab}	0.36
Blood Urea					
T_0	6.92	6.88	8.62	9.28	0.88
$T_{2.5}$	9.43	9.87	11.42	11.25	0.61
T_5	8.67^{ACa}	8.43^{ACa}	10.86^{Cb}	12.12^{Bb}	0.54
T_{10}	8.20^{ac}	7.77^{Aa}	9.82^{bcd}	11.03^{Bd}	0.60

[1]Six observations per mean.

[2]SE = Standard error of means.

Values having different superscripts differ significantly: a,b, ($P < .05$); A, B ($P < .01$).

Rumen VFA Concentrations for Nitrogen Sources:

Rumen acetate, propionate and butyrate levels for cattle supplemented with nitrogen from various sources are shown in Table 27. Rumen acetate concentration was higher at all determinations for cattle fed ammonium lactate than those fed ammonium acetate or urea. The difference was highly significant ($P < .01$) between ammonium lactate and urea at T_0 and significant ($P < .05$) between ammonium lactate and soybean meal or ammonium acetate at T_0. Cattle fed both ammonium acetate and ammonium lactate had higher rumen acetate levels at $T_{2.5}$ than soybean meal.

Differences in rumen propionate levels were not significant ($P < .05$) at T_0, $T_{2.5}$, or T_{10}. However, ammonium lactate and soybean meal supplemented cattle tended to have higher rumen propionate concentrations at all post feeding determinations. Rumen propionate concentrations were significantly higher ($P < .01$) at $T_{2.5}$ for the ammonium lactate cattle than for any other group. Urea fed cattle had the lowest ($P < .05$) rumen propionate level at $T_{2.5}$.

Rumen butyrate was not detectable in rumen fluid samples of the ammonium lactate fed steers at any sampling time. The cattle fed urea had significantly lower ($P < .05$) rumen butyrate levels at T_0 and $T_{2.5}$ than cattle receiving soybean meal or ammonium acetate at T_{10}.

Table 27.--Experiment V: Mean[1] rumen VFA concentrations for steers fed ammonium salts.

Time	Nitrogen source				
	Soy	Urea	NH_4 Acetate	NH_4 Lactate	SE[2]
Rumen Acetate					
T_0	210^{Dcd}	178^{BCc}	223^{CDad}	270^{ADb}	12.36
$T_{2.5}$	285^{bc}	253^{c}	357^{cd}	434^{ad}	43.89
T_5	257	267	267	302	32.57
T_{10}	237	195	197	227	24.79
Rumen Propionate					
T_0	78	42	67	67	10.97
$T_{2.5}$	115^{ACb}	73^{Ca}	110^{Cb}	167^{B}	11.70
T_5	97	77	83	110	15.38
T_{10}	83	65	55	68	14.12
Rumen Butyrate					
T_0	33^{Aa}	22^{Ab}	43^{Ba}	0^{C}	3.59
$T_{2.5}$	60^{Aa}	43^{Ab}	60^{Aa}	0^{B}	5.43
T_5	58^{A}	47^{A}	63^{A}	0^{B}	6.42
T_{10}	58^{Aa}	45^{Ab}	42^{Bb}	0^{C}	3.56

[1]Six observations per mean.

[2]SE = Standard error of means.

Values having different superscripts differ significantly: a,b, ($P < .05$); A, B ($P < .01$).

Rumen butyrate levels were significantly higher ($P < .05$) for cattle fed soybean meal than for those receiving either ammonium acetate or urea.

Rumen Ammonia and Blood Urea Concentrations of Acid Fed Cattle: The differences in rumen ammonia levels (Table 28) were not significant at T_0 or $T_{2.5}$. However, rumen ammonia was higher at $T_{2.5}$ for the cattle fed lactic acid ration. At T_5, the lactic acid fed cattle had greater ($P < .05$) levels of rumen ammonia than the control cattle. The rumen ammonia concentration for the lactic acid fed cattle was significantly higher at T_{10} than for cattle on control ($P < .01$) or acetic acid ($P < .05$) rations.

Blood urea levels were highest at all sampling times for lactic acid fed cattle, especially at T_5 when blood urea was significantly higher than for cattle receiving the control ($P < .05$) or the acetic acid ration ($P < .01$). The blood urea levels for the cattle on the acetate ration were significantly lower ($P < .05$) than the lactic acid fed cattle at all post feeding sampling times.

Rumen VFA Concentrations for Acid Fed Cattle: Rumen acetate concentrations were higher ($P < .01$) at T_0 for the lactic acid fed cattle. All other differences in rumen acetate concentrations were not significant, but the acetic fed cattle had the highest concentrations

Table 28.--Experiment V. Mean[1] rumen ammonium and blood urea values for acid fed steers (mg./100 ml.).[3]

Time	Acid supplemented			
	Control	Acetic acid	Lactic acid	SE[2]
Rumen Ammoniam:				
T_0	3.23	2.29	2.69	0.53
$T_{2.5}$	4.28	3.73	6.56	0.90
T_5	0.86^{a}	1.68^{ab}	2.41^{b}	0.35
T_{10}	1.37^{Aa}	2.04^{ACa}	3.75^{BCb}	0.51
Blood Urea:				
T_0	6.90	7.04	8.58	0.57
$T_{2.5}$	9.65^{ab}	8.26^{a}	10.37^{b}	0.52
T_5	8.55^{ABa}	7.80^{Aa}	9.85^{Bb}	0.40
T_{10}	7.98^{ABab}	6.83^{Aa}	9.36^{BCb}	0.49

[1]Twelve observations per mean.

[2]SE = Standard error of means.

[3]Means for the individual protein-acid groups are in Appendix II.

Values having different superscripts differ significantly: a,b ($P < .05$); A,B ($P < .01$).

at $T_{2.5}$ and the lactic acid cattle had the highest concentration at T_5 and T_{10} (Table 29).

Rumen propionate concentration at $T_{2.5}$ was significantly higher ($P < .01$) for cattle fed lactic acid than either the control or acetate fed groups and higher ($P < .01$) for cattle fed lactic acid than for those fed acetic acid at T_5. The acetic acid fed cattle had the lowest rumen propionate concentration at all sampling times, and they were significantly lower ($P < .05$) than the control group at T_5.

The control group had a significantly higher rumen butyrate level than the lactic acid fed steers at $T_{2.5}$ ($P < .05$) and higher than the control or lactic acid group ($P < .01$) at T_5 and T_{10}. Rumen butyrate was not detectable for steers fed urea in combination with lactic acid, but when soy was fed in combination with lactic acid the rumen butyrate levels were higher than any other protein-acid combination at T_0, $T_{2.5}$ and T_5. The means of the individual protein-acid groups are presented in Appendix II.

Rumen Ammonia and Blood Urea Concentrations on Soybean Meal and Urea Rations: The results of this study are presented in Table 30. Rumen ammonia concentration was significantly higher at T_0 for cattle fed soybean than for those fed urea. Rumen ammonia concentration was maximized at $T_{2.5}$ and was slightly higher

Table 29.--Experiment V:[3] Mean rumen VFA concentrations for acid fed steers (mg./100 ml.).

Time	Acid supplemented			
	Control	Acetic acid	Lactic acid	SE[2]
Rumen Acetate				
T_0	194^{A}	226^{A}	302^{B}	13.43
$T_{2.5}$	269	320	312	17.85
T_5	262	231	281	18.70
T_{10}	216	191	252	19.40
Rumen Propionate				
T_0	60	61	73	7.20
$T_{2.5}$	94^{A}	86^{A}	153^{B}	9.68
T_5	87^{ABa}	61^{Ab}	95^{Ba}	6.87
T_{10}	74	55	67	7.21
Rumen Butyrate				
T_0	28	30	26	3.82
$T_{2.5}$	52^{a}	51^{a}	38^{b}	3.71
T_5	53^{A}	31^{B}	33^{B}	4.47
T_{10}	52^{A}	33^{B}	28^{B}	4.48

[1]Twelve observations per mean.

[2]SE = Standard error of means.

[3]Means for the individual protein-acid groups are in Appendix II. Values having different superscripts differ significantly: a,b ($P < .05$); A,B ($P < .01$).

Table 30.--Experiment V: Mean[1] blood and rumen values for urea and soybean meal supplemented animals (mg/100 ml.).[3]

Time	Soy	Urea	SE[2]
Rumen Ammonia			
T_0	3.54[a]	1.93	0.43
$T_{2.5}$	4.54	5.17	0.74
T_5	1.78	1.52	0.29
T_{10}	2.65	2.12	0.42
Blood Urea			
T_0	7.01	8.01	0.46
$T_{2.5}$	8.64[a]	10.21	0.43
T_5	8.13[a]	9.33	0.33
T_{10}	7.58	8.54	0.40
Rumen Acetate			
T_0	240	242	10.97
$T_{2.5}$	302	299	14.58
T_5	246	270	15.27
T_{10}	216	224	15.84
Rumen Propionate			
T_0	73[a]	56	5.88
$T_{2.5}$	122	100	7.90
T_5	83	79	5.61
T_{10}	70	61	5.89
Rumen Butyrate			
T_0	39[A]	17	3.12
$T_{2.5}$	63[A]	31	3.03
T_5	49[A]	28	3.65
T_{10}	49[A]	26	3.66

[1]Eighteen observations per mean.

[2]SE = Standard error of mean.

[3]Means for the individual protein-acid groups are in Appendix II.

Values having different superscripts differ significantly: a ($P < .05$); A ($P < .01$).

for the urea cattle than the soybean meal cattle at this time.

Blood urea levels were significantly higher ($P < .05$) at $T_{2.5}$ and T_5 for the urea fed cattle. Blood urea was maximized at $T_{2.5}$ for cattle on both supplements.

Rumen VFA Concentrations on Soybean Meal and Urea Rations: There was practically no difference in rumen levels of acetic acid between cattle receiving the urea or soybean supplemented rations. Rumen acetate levels were highest at $T_{2.5}$ for both nitrogen sources.

Propionic acid levels in the rumen were highest at all determinations for the soy fed cattle, and the difference was significant at T_0. The differences at all other sampling times were not significant.

Rumen butyrate levels were significantly higher ($P < .01$) at all sampling times for the soybean meal fed steers.

Experiment VI--Nitrogen Balance Study with Ammonium Acetate, Ammonium Lactate, Urea and Soybean Meal

Rumen Ammonia and Blood Urea Concentrations: Comparison of rumen ammonia and blood urea levels are shown in Table 31. None of the differences in these parameters were significant.

Rumen ammonia levels were maximized at T_2 for all rations. In contrast to Experiment V, the rumen ammonia

Table 31.--Experiment VI: Mean[1] rumen ammonia and blood urea values (mg./100 ml.).

Time	Nitrogen supplement				
	Soy	Urea	NH_4 Acetate	NH_4 Lactate	SE[2]
Rumen Ammonia					
T_0	3.28	7.50	4.95	4.90	1.13
T_2	4.95	8.93	5.65	6.30	2.34
T_4	6.95	14.88	9.95	10.05	3.93
T_6	3.68	9.93	2.60	4.95	3.49
T_8	0.55	9.63	1.00	3.28	2.61
T_{10}	9.75	5.70	6.20	3.68	3.64
Blood Urea					
T_0	7.93	9.13	7.83	7.05	0.89
T_2	8.43	10.38	8.25	7.28	0.95
T_4	9.30	12.78	9.15	8.60	1.15
T_6	9.33	12.33	9.25	9.53	1.68
T_8	8.83	12.98	8.68	8.83	1.62
T_{10}	8.90	13.35	7.95	8.35	1.76

[1]Least squares means of four observations.

[2]SE = Standard error of mean.

No significant differences between means.

level for the urea fed cattle was higher than for cattle fed ammonium salts at all sampling times except T_{10}. The blood urea levels of the urea fed cattle were also higher than for cattle fed the ammonium salt or soybean meal supplemented rations.

Varner and Woods (1971) reported that rumen ammonia levels were higher at one hour post feeding for cattle fed ammonium salts than for urea. Serum urea levels were highest for urea fed steers, intermediate for steers fed ammonium salts and lowest for soybean meal fed animals. In a second study, reported in the same paper, they found that serum urea levels were higher for the ammonium salt supplemented steers than for urea fed steers.

Rumen VFA Concentrations: Table 32 shows mean values for acetate, propionate and butyrate concentrations expressed as mg. of VFA for 100 ml. of rumen fluid.

Rumen acetate concentrations were highest for the ammonium lactate fed cattle at T_0 and T_2. Although these differences were not significant, they do agree with the results in experiment V. Rumen acetate levels reflected the addition of ammonium acetate to the ration. The probable explanation for increased rumen acetate levels when lactic acid and ammonium lactate are fed is the catabolism of lactic acid to acetic acid. Jayasuria and Hungate (1959) and Bruno and Moore (1962) reported

Table 32.--Experiment VI: Mean[1] rumen VFA concentrations (mg./100 ml.).

Time	Nitrogen source				
	Soy	Urea	NH_4 Acetate	NH_4 Lactate	SE[2]
Rumen Acetate					
T_0	303	322	341	439	61.86
T_2	288	312	325	331	67.35
T_4	355	300	392	394	63.64
T_6	360	317	412	399	50.44
T_8	389	347	351	370	64.08
T_{10}	387	322	362	381	30.97
Rumen Propionate					
T_0	159	234	130	198	36.43
T_2	141	142	120	189	33.41
T_4	116	205	141	205	43.58
T_6	166	156	146	212	44.40
T_8	172	236	133	205	46.73
T_{10}	202	152	187	202	30.74
Rumen Butyrate					
T_0	39	78	141	145	51.17
T_2	42	119	118	150	43.67
T_4	63	56	105	159	23.14
T_6	56	60	140	125	29.23
T_8	57	64	116	126	30.42
T_{10}	61	90	91	117	34.85

[1]Least squares means of four observations.

[2]SE = Standard error of mean.

No significant differences between means.

that acetate was the major conversion product of lactic acid in the rumen.

Rumen propionate levels were also increased by supplementing the ration with ammonium lactate. Ammonium acetate fed steers had the lowest rumen propionate concentration at all sampling times except T_4. At T_4, the rumen propionate level of acetate fed steers was lower than for steers fed urea or ammonium lactate but higher than on soybean meal.

Rumen butyrate concentrations were higher for steers fed ammonium salts than for steers fed urea or soybean meal. The urea fed steers did have levels of rumen butyrate at T_2 and T_{10} that were comparable to the concentrations found in ammonium acetate fed steers at the same time.

Dry Matter Intake and Digestibility: As shown in Table 33, the ammonium acetate fed cattle consumed less dry matter daily than any other treatment group. The reduction in dry matter consumption for the ammonium acetate fed steers was 12.0 per cent, 10.9 per cent and 17.2 per cent when compared to the soybean meal, urea and ammonium lactate fed steers, respectively. These differences were not significant.

The ammonium lactate supplemented rations had the greatest dry matter digestibility (72.6 per cent) and was followed by ammonium acetate (69.7 per cent),

Table 33.--Experiment VI: Effects of nitrogen sources on digestion parameters.[1]

	Nitrogen source				
	Soy	Urea	NH_4 Acetate	NH_4 Lactate	SE[2]
No. of steers	4	4	4	4	--
DM intake, g/day	6475	6397	5697	6880	619.5
DM digested, g/day	4469	4210	4018	5056	511.8
Per cent DM digested, %	67.9	64.6	69.7	72.6	2.87
Nitrogen intake, g./day	110.1	105.3	136.1	146.3	13.80
Fecal nitrogen, g./day	60.1	55.6	52.7	51.7	8.08
Nitrogen digested, g./day	50.0	49.8	83.5	94.6	13.33
Per cent nitrogen digested, %	45.8	43.7	57.8	62.8	6.87
Urinary nitrogen, g./day	87.2	79.7	76.0	77.8	8.89
Nitrogen retained, g./day	-37.2^{A}	-29.9^{A}	7.5^{B}	16.9^{B}	7.87
N. retained as % of N intake	-39.6^{A}	-35.1^{A}	4.3^{B}	7.9^{B}	7.65

[1]Least square means.

[2]SE = Standard error of means.

Values having different superscripts differ significantly: A,B ($P < .01$).

soybean meal (67.9 per cent) and urea supplemented rations (64.6 per cent). The digestibility of the urea supplemented ration was decreased by 4.9 per cent, 7.3 per cent and 11.0 per cent when compared to soybean meal, ammonium acetate and ammonium lactate supplemented rations, respectively.

Nitrogen Balance: The mean values for all nitrogen balance parameters are shown in Table 33. The differences in nitrogen intake, fecal nitrogen, urinary nitrogen and nitrogen digestibility were not statistically significant ($P < .05$).

Steers fed ammonium salts had greater nitrogen intakes but did not lose any more nitrogen in the feces or urine than the soybean meal and urea fed steers. This resulted in an increased quantity of nitrogen digested and an increased nitrogen retention. The urea and soybean meal supplemented steers were in a negative nitrogen balance and retained significantly ($P < .01$) less nitrogen than ammonium acetate or ammonium lactate fed steers.

Experiment VII--Nitrogen Balance Study Comparing Various Ammonium Salts of Organic Acids with Conventional Nitrogen Supplements

Rumen Ammonia Concentrations: Tables 34 and 35 show the data from the study of rumen ammonia and blood urea levels in this experiment.

Table 34.--Experiment VII: Mean[1] rumen ammonia concentrations (mg./100 ml.).

Time	Nitrogen source								
	Soy	U-CSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Propionate	NH_4 Lactate	NH_4 Butyrate	SE[2]
T_0	7.0	5.7	5.3	6.0	8.7	4.3	7.3	3.3	1.36
T_2	12.0^{c}	14.3^{bc}	13.7^{bc}	17.0^{abc}	22.3^{ab}	14.3^{bc}	23.3^{a}	12.3^{c}	2.64
T_4	8.3	3.0	4.7	6.0	4.0	3.3	4.0	3.7	1.11
T_6	5.7	2.7	5.3	4.7	4.7	2.3	4.0	3.0	0.77
T_8	8.7	3.7	4.0	5.0	5.3	3.0	3.0	3.0	1.54
T_{10}	7.7	7.0	5.7	5.0	5.7	3.3	3.0	3.3	1.09

[1]Three observations per mean.

[2]SE = Standard error of means.

Values having different superscripts differ significantly; a,b,c ($P < .05$).

Table 35.--Experiment VII: Mean[1] blood urea concentrations (mg./100 ml.).

Time	Nitrogen source								
	Soy	U-CSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Propionate	NH_4 Lactate	NH_4 Butyrate	SE[2]
T_0	9.9	8.7	7.4	9.6	9.9	8.7	8.8	8.7	0.76
T_2	11.2	11.9	10.1	13.2	13.5	11.0	11.5	10.9	1.08
T_4	10.9	10.9	9.3	12.4	12.6	11.0	9.6	11.3	1.26
T_6	10.7	10.2	9.6	12.0	11.8	10.1	9.1	10.3	1.09
T_8	9.7	8.7	8.7	10.2	10.6	9.2	9.2	9.5	0.98
T_{10}	9.7	8.9	8.0	10.3	8.9	8.6	9.3	9.2	1.09

[1]Least square mean of three observations.

[2]SE = Standard Error of mean.

No significant differences between means.

As in experiments V and VI, rumen ammonia values were maximized at T_2. The ammonium lactate fed steers had significantly ($P < .05$) higher rumen ammonia values at T_2 than steers fed ammonium propionate, U-CSW, Urea, ammonium butyrate or soybean meal supplemented rations. Cattle fed ammonium acetate had significantly ($P < .05$) higher rumen ammonia levels than those fed ammonium butyrate or soybean meal. All other differences in rumen ammonia levels were not significant.

The relative rumen ammonia levels for ammonium acetate, ammonium lactate, urea and soybean meal fed steers paralleled the results of experiment V but do not agree with the results of experiment VI. The results of experiments V and VII agree with previously published work (Varner and Woods, 1971).

There was virtually no difference in rumen ammonia concentration, among the various nitrogen sources, other than the difference at T_2.

Blood Urea Concentrations: There was no significant difference in blood urea levels among the cattle fed the various nitrogen sources tested (Table 35). Maximum blood urea levels occurred between T_2 and T_6 for all treatments. Steers fed ammonium acetate and ammonium formate had the highest blood urea levels. The relative blood urea level of the urea fed steers was lower than expected.

Blood analysis in experiment VI showed a higher urea level for the urea fed steers than for soybean meal or ammonium salt fed steers, but the same analysis in experiment V showed higher blood urea levels for the ammonium salts. Varner and Woods (1971) reported higher blood urea levels for urea fed steers when compared to ammonium salt fed steers in one trial and higher blood urea levels for ammonium salt fed steers in another trial.

Rumen Acetate Concentrations: Rumen acetate concentrations (Table 36) were highest for ammonium acetate fed steers at T_2 but significantly ($P < .05$) lower for the ammonium acetate fed steers than for steers supplemented with soybean meal at T_4. This same trend was observed in experiments V and VI and for the addition of both ammonium acetate and acetic acid to the ration.

The rumen acetate levels were elevated in steers fed rations supplemented with soybean meal or ammonium lactate. These same trends existed in experiments V and VI.

Soy fed cattle had significantly ($P < .05$) higher rumen acetate concentrations than cattle fed rations supplemented with urea, ammonium acetate or ammonium propionate at T_4. U-CSW fed cattle had significantly ($P < .05$) higher levels of rumen acetate than urea or ammonium propionate fed cattle. All other differences in rumen acetate levels were not significant ($P < .05$).

Table 36.--Experiment VII: Mean[1] rumen acetate concentrations (mg./100 ml.).

Time	Nitrogen sources								
	Soy	UCSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Propionate	NH_4 Lactate	NH_4 Butyrate	SE[2]
T_0	310	348	433	297	357	291	456	320	62.56
T_2	462	373	435	380	497	357	483	290	62.73
T_4	543^{a}	483^{ab}	320^{c}	420^{abc}	343^{bc}	314^{c}	442^{abc}	401^{abc}	45.40
T_6	391	373	387	357	393	285	355	398	36.35
T_8	488	377	351	350	377	300	397	271	49.03
T_{10}	406	425	346	370	337	319	423	332	38.13

[1]Three observations per mean.

[2]SE = Standard error of means.

Values having different superscripts differ significantly; a,b,c ($P < .05$).

Rumen Propionate Concentrations: The rumen propionate levels of steers fed various nitrogen sources are shown in Table 37. Supplementing the ration with soybean meal or ammonium lactate resulted in elevated rumen propionate levels. The rumen propionate concentration was higher for ammonium propionate supplemented steers at T_2 than for steers receiving other supplements except ammonium lactate.

The difference in rumen propionate concentration between ammonium lactate and ammonium propionate was not significant at T_2. Steers fed ammonium salts of lactic or propionic acids had higher ($P < .05$) rumen propionate levels at T_2 than steers fed rations supplemented with ammonium formate or ammonium butyrate. The ammonium lactate fed cattle also had significantly ($P < .05$) higher rumen propionate levels than cattle fed soybeam meal, urea, U-CSW and ammonium acetate.

At T_4, rumen propionate levels were significantly higher ($P < .01$) than urea or ammonium acetate fed cattle and higher ($P < .05$) than for cattle fed ammonium butyrate or ammonium propionate. Soybean meal fed cattle had higher ($P < .05$) rumen propionate levels than steers receiving urea, ammonium butyrate or ammonium acetate. The difference between the U-CSW fed cattle in rumen propionate at T_4 and cattle fed urea or ammonium acetate was also significant.

Table 37.--Experiment VII: Mean[1] rumen propionate concentrations (mg./100 ml.).

Time	Nitrogen sources								
	Soy	UCSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Propionate	NH_4 Lactate	NH_4 Butyrate	SE[2]
T_0	86	89	107	93	97	71	132	80	20.01
T_2	161^{Abc}	149^{Abc}	147^{Abc}	130^{Ac}	140^{Abc}	228^{ABab}	260^{Aa}	114^{Bc}	28.70
T_4	168^{BAab}	152^{ABabc}	97^{BCd}	127^{BAabed}	90^{Bd}	119^{BAbcd}	173^{Aa}	108^{BACcd}	15.91
T_6	146	69	107	100	107	84	113	103	17.60
T_8	160	95	62	87	103	79	118	62	24.62
T_{10}	112	118	109	97	83	71	119	73	17.10

[1]Three observations per mean.

[2]SE = Standard error of means.

Values having different superscripts differ significantly; a,b,c ($P < .05$), A,B,C ($P < .01$).

The data from this experiment combined with results from experiments V and VI suggest that a major intermediate in lactic acid metabolism in the rumen is propionic acid. This agrees with conclusions of other workers (Elsden, 1945; Philipson, 1952; Waldo and Schultz, 1956; Montgomery et al., 1963).

Supplementing rations with soybean meal resulted in higher rumen propionate levels than feeding the other nitrogen sources except for ammonium propionate at T_2 and ammonium lactate at all sampling times. This may have been a result of a stimulation of propionic acid fermentation or a decrease in the inhibition of propionic fermenters as compared to the other sources of nitrogen.

Rumen Butyrate Concentrations: Rumen butyrate was highest at T_2, T_4 and T_6 on the ammonium butyrate supplemented ration (Table 38). When acetate or propionate was added to the diet, the rumen concentration of the respective acid appears to be maximized at T_2 and decreases rapidly thereafter (Experiment V, VI and VII). This may be a result of an increased rate of acetate or propionic metabolism as absorption when these acids are added to the diet.

Rumen butyrate at T_4 was higher ($P < .05$) for ammonium butyrate fed cattle than for those fed other rations and higher ($P < .05$) for cattle fed ammonium butyrate, soybean meal and ammonium lactate than for

Table 38.--Experiment VII. Mean[1] rumen butyrate concentrations (mg./100 ml.).

Time	Nitrogen sources								
	Soy	UCSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Propionate	NH_4 Lactate	NH_4 Butyrate	SE[2]
T_0	87	93	143	107	107	73	152	97	30.96
T_2	178^{ABb}	105^{bc}	116^{bc}	113^{bc}	130^{bc}	99^{Bc}	173^{Abc}	263^{Aa}	23.34
T_4	203^{Aa}	166^{Bab}	77^{Bd}	150^{Babc}	100^{Bbcd}	91^{Bcd}	176^{Ba}	218^{Aa}	22.43
T_6	162	78	103	130	130	88	103	174	22.89
T_8	191	97	64	120	117	105	140	97	28.53
T_{10}	131	118	78	123	93	89	144	104	20.35

[1]Three observations per mean.

[2]SE = Standard error of means.

Values having different superscripts differ significantly; a,b,c ($P < .05$); A,B,C ($P < .01$).

those fed urea or ammonium salts of acetic or propionic acid. Urea fed cattle had the lowest ($P < .05$) rumen butyrate level at T_4. The increased level of rumen butyrate with lactate supplementation is in agreement with work by Montgomery et al. (1963) who reported increased rumen butyrate concentration with lactic acid administration. However, these results disagree with those in Experiment V in which a combination of lactic acid and NPN resulted in an unexplained absence of rumen butyrate.

Rumen pH: Differences in rumen pH were small and insignificant at all times of sampling except T_4 (Table 39). Rumen pH was lowest on the soybean meal supplemented ration except T_0, and rumen pH was significantly ($P < .05$) lower on soybean than other rations at T_4.

Rumen pH at T_4 was higher ($P < .05$) for the ammonium propionate ration than for the U-CSW, ammonium lactate or soybean meal ration.

Dry Matter Intake and Digestibility: None of the differences in dry matter intake or digestibility were significant (Table 40). Soybean meal fed steers had the lowest dry matter consumption and the least dry matter digested.

Nitrogen Balance: There were no significant differences ($P < .05$) in any of the nitrogen paramers (Table 40).

Table 39.--Experiment VII. Mean[1] rumen pH values.

Time	Nitrogen source								
	Soy	U-CSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Propionate	NH_4 Lactate	NH_4 Butyrate	SE[2]
T_0	6.65	6.67	6.71	6.72	6.63	6.78	6.54	6.78	0.076
T_2	6.48	6.67	6.61	6.67	6.34	6.64	6.47	6.56	0.164
T_4	6.50^{BCc}	6.61^{ACbc}	6.72^{Cab}	6.67^{Cabc}	6.73^{Cab}	6.83^{Aa}	6.60^{ACbc}	6.78^{Cab}	0.063
T_6	6.84	6.95	6.72	6.80	6.77	6.79	6.72	6.70	0.128
T_8	6.57	6.78	6.91	6.84	6.84	7.07	6.82	6.86	0.112
T_{10}	6.67	6.95	6.82	6.70	6.94	6.93	6.71	6.83	0.114

[1]Three observations per mean.

[2]SE = Standard error of means.

Values having different superscripts differ significantly: a,b,c ($P < .05$), A,B,C ($P < .01$).

Table 40.--Experiment VII: Effect of nitrogen sources on digestion parameters.[1]

	Nitrogen source								
	Soy	U-CSW	Urea	NH_4 Fermate	NH_4 Acetate	NH_4 Propionate	NH_4 Lactate	NH_4 Butyrate	SE[2]
No. of steers	3	3	3	3	3	3	3	3	--
DM intake g./day	4821	5927	5214	4912	4990	5337	5693	4975	479.7
DM digested, g./day	3626	4527	3919	3783	3936	4124	4265	3877	354.4
Per cent DM digested, %	75.1	76.4	75.4	77.5	79.4	77.1	74.9	78.0	1.82
Nitrogen intake, g./day	86.1	126.0	114.9	106.2	100.8	113.6	112.7	102.8	12.20
Fecal nitrogen, g./day	34.3	36.5	38.4	31.9	31.5	32.6	40.7	29.9	5.20
Nitrogen digested, g./day	51.8	89.5	76.5	74.3	69.3	81.1	72.1	72.9	10.13
Per cent nitrogen digested, %	60.7	70.3	66.9	70.9	69.8	70.4	63.8	70.5	3.75
Urinary nitrogen, g./day	54.8	59.8	64.1	59.3	61.5	66.2	60.0	57.0	2.95
Nitrogen retained, g./day	-3.0	29.8	12.4	15.0	7.8	14.9	12.0	15.9	8.47
N retained as % of N intake	-3.6	21.7	10.9	13.7	7.5	10.2	9.9	12.7	6.14

[1]Least square means.

[2]SE = Standard error of means.

No significant ($P < .05$) differences between means.

All nitrogen sources except soybean meal promoted positive nitrogen balances.

Daily nitrogen intake was highest for the U-CSW fed steers, lowest for the soybean meal fed steers and intermediate for cattle fed urea or ammonium salts. As in Experiment VI, urine and fecal nitrogen losses were relatively constant and the decreased nitrogen intake on the soy ration was probably the major cause of the negative balance.

Daily nitrogen retention was 29.8 g, 15.9 g, 15.0 g, 14.9 g, 12.4 g, 12.0 g, 7.8 g and -3.0 g for the U-CSW, ammonium butyrate, ammonium formate, ammonium propionate, urea, ammonium lactate, ammonium acetate and soybean meal fed cattle respectively. As in the comparative feeding trial (Experiment II) ammonium acetate was the poorest ammonium salt tested.

GENERAL DISCUSSION

Growth studies with cattle in this dissertation and in other work (Varner and Woods, 1968; 1969) have consistently resulted in gains that were greater for cattle fed ammonium salts than those fed urea. In fact, gains of ammonium salt fed cattle are frequently equal to or superior to those of cattle fed soybean meal.

Feeding ammonium salts did not affect DM consumption in these experiments. The relative commercial value of the ammonium salts was 2 to 3 times greater than for urea and comparable to soybean meal.

Nitrogen balance and metabolic studies were conducted in an attempt to determine why ammonium salts were superior to urea. Digestibility of rations supplemented with ammonium salts was slightly higher than for those supplemented with soybean meal or urea. In addition, the nitrogen retention for steers fed ammonium salts was greater than or comparable to those fed soybean meal or urea.

Both ammonium lactate and ammonium acetate fed steers had significantly ($P < .05$) greater nitrogen retentions in Experiment VI but none of the differences

were significant in Experiment VII. Soy fed steers were in negative nitrogen balance in both experiments.

The variability in nitrogen retention is primarily a result of differences in nitrogen intake and not of nitrogen excretion. Steers in collection stalls were fed 90 per cent of their consumption during the acclimation period but many of the steers still went off feed during the collection period. Since there is a digestive lag between consumption and excretion, the collection of excreta compares to consumption only when the consumption is uniform from two to three days prior to collection until the collection period is completed. The consistency of results should be improved if steers were acclimated to the collection stalls prior to collection.

Rumen ammonia and blood urea were measured in experiments V, VI and VII. Feeding ammonium salts resulted in higher rumen ammonia levels than feeding urea or soybean meal at the first post-feeding sample when consumption was limited to the first two hours of feeding. Ammonium salts result in an immediate increase in rumen ammonia because the ammonia is immediately available, but the urea must be hydrolized before its ammonia is available.

The results of Experiment VI are different from other data because steers consumed their diet throughout the day as usually occurs when steers are full fed in a feedlot. However, this makes comparison of metabolic

parameters more difficult with a small number of steers because of differences in consumption patterns. For this reason, the feed was removed from the steers two hours after feeding in all other metabolic studies.

The highest concentrations of blood urea occurred at the same sampling time as the maximum rumen ammonia concentrations. If samples had been collected at shorter intervals after feeding, rumen ammonia should have peaked prior to blood urea.

Blood urea was higher for ammonium salt fed steers than for those fed urea or soybean meal. By our current interpretation of this data, we would predict ammonium salts to be inferior to urea. But ammonium salts have consistently promoted greater and more efficient gains than urea.

Another source of urea nitrogen in peripheral blood is nitrogen obtained from catabolism of body tissue and absorbed amino acids. If the steer was absorbing greater quantities of amino acids from the small intestine (as suggested by increased growth and nitrogen balance), the catabolic contribution to blood urea should be greater.

To outline the metabolism of ammonium salts, more sophisticated measures are indicated. Analysis of digesta passing into the abomasum or small intestine would provide information concerning the synthesis of natural protein

and the loss of ammonia from the rumen via this pathway. Analysis of portal blood would be a more sensitive test for the absorbtion of ammonia from the gastrointestinal tract and would also provide information concerning amino acid absorption. Connulation of the rumen vein should be the most accurate method of determining the absorption of ammonia from the rumen into the blood.

Rumen VFA concentration reflected the ammonium salt fed. Feeding ammonium salts of acetic propionic or butyric acids resulted in an increased rumen concentration at T_2 for the respective acid. Rumen butyrate levels were higher for steers fed ammonium butyrate through T_6, but feeding ammonium acetate or ammonium propionate resulted in an increased disappearance of the respective acids from the rumen. By T_4, the concentration of these acids in the rumen was lower when they were fed than for the other nitrogen sources tested.

Feeding ammonium lactate resulted in elevated rumen levels of acetic and propionic acids. These results agree with other work reporting the catabolism of lactic acid to acetic (Jayasuria and Hungate, 1959; Bruno and Moore, 1962) and lactic propionic acid (Elsden, 1954; Phillipson, 1952; Waldo and Schultz, 1956; Montgomery et al., 1963).

The rumen VFA data indicates the acid portion of ammonium salts is utilized and contributes to the energy available to the rumen microorganisms and the animal

However, it is not possible, at this time, to assess their mode of action or whether they are responsible for the greater utilization of ammonium salts than urea. Studies correlating rumen and rumen vein levels of the various VFA and ammonia with protein passing into the abomasum should be useful in determining their effect on ammonia utilization.

SUMMARY

The feeding value, metabolism and utilization of supplemented organic acids or ammonium salts of organic acids were studied in four feeding trials and three metabolic studies. The effect of high versus moderate levels of concentrate on the utilization of ammonium salts was also studied.

Extensive research with urea has established its advantages and limitations, but there is only limited information available concerning other NPN sources. In vitro studies have consistently demonstrated that ammonium salts of organic acids are equal or superior to urea as nitrogen supplements. Cattle fed ammonium salts have outperformed urea supplemented animals in the two trials that have been published (Varner et al., 1968 and Varner and Woods, 1969).

In Experiment I, ammonium acetate, ammonium lactate, soybean meal and urea were compared in a growth study on a ration composed of 75 per cent concentrates and 25 per cent corn silage. Cattle supplemented with ammonium acetate gained 5.4 per cent faster than cattle receiving soybean meal and 12 per cent faster than urea fed steers. The difference in average daily gain was

significant ($P < .05$) between the ammonium acetate and urea fed steers. Ammonium lactate fed steers gained significantly ($P < .05$) faster than soybean meal (13.5 per cent) and the urea (20 per cent) fed groups.

Cattle fed ammonium acetate consumed 3.1 per cent and 6.0 per cent more DM and showed 2.3 per cent and 6.1 per cent higher feed efficiency compared to the soybean meal and urea fed steers, respectively. Dry matter consumption was increased 9.1 per cent and 12.2 per cent for the ammonium lactate steers when compared to the soybean meal and urea fed steers, respectively. Similarly, feed efficiency was increased 3.5 per cent and 7.2 per cent. Although the difference was not significant, ammonium lactate fed steers were more efficient and had higher DM consumption and gains than ammonium acetate fed steers. Differences in carcass desirability were small and, for the most part, non-significant.

In Experiment II, ammonium salts of formic, acetic, propionic lactic and butyric acids were compared to soybean meal, urea and a supplement that derived one-half of its protein equivalent from urea and one-half from corn steep water (U-CSW). The nitrogen supplements were added to either a ration of 40 per cent concentrates and 60 per cent corn silage or a ration of 80 per cent concentrates and 20 per cent corn silage. None of the differences in

gains were significant. However, the urea fed cattle had the lowest average daily gain, feed efficiency and DM consumption.

The average daily gain of the groups fed the various ammonium salts was practically identical to the daily gain of the soybean meal and U-CSW supplemented groups when averaged over both concentrate levels (Table 18). However, the performance of all the NPN supplemented diets except ammonium acetate increased with a higher level of concentrate in the ration. The ammonium acetate fed cattle on the high concentrate ration gained 3.8 per cent less than those on the lower concentrate diet. The increased gains on the high concentrate rations compared to the rations low in concentrate were 2.9 per cent, 5.4 per cent, 4.2 per cent, 10.0 per cent, 2.6 per cent and 4.4 per cent for the U-CSW, urea, ammonium formate, ammonium propionate, ammonium lactate and ammonium butyrate fed groups, respectively.

On the high concentrate ration, all of the NPN fed steers except urea and ammonium acetate outperformed the soybean meal fed steers. In contrast, the soybean meal fed steers outgained all other groups on the low level of concentrate. In addition, all of the NPN fed groups were more efficient than the soybean meal fed steers on the 80 per cent level of concentrate but less efficient than the soybean meal group on the low level concentrate.

The decreasing order of value of the nitrogen supplements, under the conditions of this experiment, was ammonium propionate, soybean meal, ammonium butyrate, ammonium lactate, ammonium formate, U-CSW, ammonium acetate and urea.

The urea fed steers had the lowest carcass grade and were the trimest in all fat measurements as well as in all carcass measurements that are correlated with the amount of carcass fat. The differences in all other carcass traits among the various nitrogen supplements, were small and non-significant.

The average daily gain of cattle on high concentrate diets was 2.9 per cent higher and the feed required per unit of gain was 7 per cent lower than on low concentrate diets. However, the lower concentrate ration resulted in more beef production per hectare, a higher gross return per hectare and a lower cost of gain. Cattle fed the high concentrate diet had a significantly higher carcass grade ($P < .05$) and dressing per cent ($P < .01$). In addition they were significantly ($P < .01$) fatter and had carcasses with significantly ($P < .01$) lower yields of boneless, trimmed retail cuts than those fed the low concentrate diet.

Experiment III was designed to study the effect of the addition of lactic or acetic acid in equalmolar concentrations as contained in the ammonium salts fed in

Experiment I. The acid additions were compared in both urea and soybean meal supplemented rations. Adding acetic acid decreased feed efficiency 3.7 per cent but adding lactic acid increased feed efficiency 2.6 per cent. The addition of lactic tended to reduce the amount of carcass fat.

Urea fed cattle had a decrease of 4.3 per cent, 2.6 per cent and 1.9 per cent in gain, consumption and feed efficiency, respectively, when compared to soybean meal fed steers. Fat thickness of the urea supplemented steers was significnatly ($P < .05$) lower than for steers fed soybean meal.

In Experiment IV, the addition of acetic or lactic acids in increasing increments to all silage rations was studied. The addition of acetic acid to the ration depressed gain and feed efficiency for all levels of acetic acid addition compared to the control. However, none of these differences were significant ($P < .05$). Average daily gain was not affected by adding lactic acid to the ration. There was also no difference in feed efficiency or consumption for the various levels of added lactic acid. The addition of lactic acid did result in a decreased consumption of the basal ration (silage and protein), but this decrease was offset by the lactic acid intake.

Experiment V involved stomach pumping and bleeding cattle that had previously been on Experiments I and III.

The rumen ammonia concentrations were highest at $T_{2.5}$ (2.5 hours post feeding) for urea, ammonium acetate and ammonium lactate. The ammonium lactate cattle also had higher ($P < .05$) rumen ammonia levels at T_5 and T_{10}. The blood urea levels were higher at all determinations for the cattle fed ammonium salts. At T_5, blood urea levels were significantly greater for cattle fed ammonium lactate ($P < .01$) or ammonium acetate ($P < .05$) than for cattle fed urea or soybean meal.

Rumen acetate concentration was higher at all determinations for cattle fed ammonium lactate than for cattle receiving ammonium acetate or urea. Rumen acetate levels were higher for steers fed ammonium salts at T_2 than for those fed soybean meal or urea. Rumen propionate levels tended to be higher for the steers fed soybean meal and ammonium lactate at all sampling times and were significantly higher ($P < .01$) at $T_{2.5}$ for the ammonium lactate fed cattle than for any other group. Rumen butyrate was not detected in rumen fluid samples of the ammonium lactate fed steers. Rumen butyrate levels were significantly higher ($P < .05$) for cattle fed soybean meal than for those fed ammonium acetate or urea.

When lactic acid was added to the ration, the rumen ammonia level as well as the blood urea level, was higher at all sampling times. Cattle receiving acetic acid in the diet had the highest rumen acetate level at

$T_{2.5}$. Lactic acid fed steers had the highest rumen acetate (except $T_{2.5}$) as well as the highest rumen propionate levels at all sampling times. Rumen butyrate levels were highest for the control groups and was not detectable when urea was fed in combination with lactic acid.

In Experiment VI, nitrogen balance and metabolic studies were conducted with fistulated steers fed the same rations as Experiment I. In contrast to Experiment V, the rumen ammonia and blood urea level of the urea fed steers was higher at all sampling times except T_{10} than for the soybean meal or ammonium salt fed cattle. As in Experiment V, supplementation with ammonium lactate increased the levels of rumen acetate and propionate. Rumen butyrate levels were higher for steers fed ammonium salts than for steers fed urea or soybean meal.

The ammonium acetate fed cattle had the lowest DM consumption. The ammonium lactate fed steers had the highest DM digestibility (72.6 per cent). They were followed by ammonium acetate (69.7 per cent), soybean meal (67.9 per cent and urea supplemented rations (64.6 per cent). The steers fed ammonium salts had a greater nitrogen intake but did not lose any more nitrogen in the feces or urine than the soybean meal and urea fed steers. This resulted in an increased quantity of nitrogen digested and a significantly ($P < .01$) higher nitrogen balance for the steers fed ammonium salts.

Experiment VII was a nitrogen balance and metabolic study of the nitrogen supplements in Experiment II on the 40 per cent concentrate - 60 per cent corn silage ration. Rumen ammonia concentrations were maximized at T_2 and were highest for ammonium lactate and ammonium acetate fed steers. Steers fed natural protein (soybean meal) had the highest rumen ammonia values at T_8 and T_{10}. There was no significant difference among the various nitrogen sources tested for blood urea levels.

Rumen acetate concentrations were higher for ammonium acetate fed steers at T_2 but lower than soybean meal, ammonium lactate, U-CSW, ammonium formate and ammonium butyrate at T_4. Supplementing the diets with soybean meal or ammonium lactate resulted in higher rumen propionate levels. Rumen propionate concentration was higher for ammonium propionate fed steers at T_2 than for steers receiving other supplements except ammonium lactate. Rumen butyrate was higher at T_2, T_4 and T_6 for the ammonium butyrate fed steers. Ammonium lactate and soybean meal fed steers also had elevated rumen butyrate levels at T_4.

Differences in rumen pH were small and insignificant except that rumen pH was significantly lower at T_4 for soybean meal fed steers.

None of the differences in DM intake or digestibility were significant. Soybean meal fed steers had the lowest dry matter digested. There were no significant

differences in any of the nitrogen parameters studied. All nitrogen sources except soybean meal promoted positive nitrogen balances. Daily nitrogen intake was highest for the U-CSW fed steers, lowest for the soybean meal steers and intermediate for cattle fed urea or ammonium salts. As in Experiment VI, urine and fecal nitrogen losses were relatively constant and the decreased nitrogen intake on the soy ration was probably the major cause of the negative balance.

The results of these experiments indicate that ammonium salts of organic acids are superior to urea and in many cases equal or superior to soybean meal in promoting efficient beef gains and positive nitrogen balance. Ammonium acetate was the poorest ammonium salt tested.

The acid portion of ammonium salts is an efficient energy source and does not, with the exception of ammonium acetate, effect DM consumption.

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APPENDIX I

PRE-EXPERIMENT PERFORMANCE

Yearling Steers

A total of 166 Hereford yearling steers were purchased at a yearling sale in Lusk, Wyoming on October 5, 1971. Each consignors cattle was sorted at the sale yards into three groups based on size. A total of 71 head of the heavyweight cut were purchased from the Johnson Sisters; 95 head of the middleweight cut were purchased from the Kaan Corporation. The steers had almost identical weights, but cattle from the Johnson Sisters were larger framed and thinner than the Kaan cattle.

The cattle were held at the Lusk Livestock Exchange with water and hay from sale time until they were picked up by truckers at 9 p.m. on October 6th. Three trucks hauled the cattle for approximately 28 hr. (1200 mi.). The trucking rate was 75¢ per loaded mile or $2.34 per cwt. Thus the laid-in cost was $37.81 per cwt. The cattle were weighed immediately upon arrival and the total weight off the truck was 115,670 lb. Thus shrink amounted to 7,840 lb. or 6.3%.

The cattle arrived at the Beef Cattle Research Center (BCRC) at 1 a.m. on October 8, 1971. After group weighing, they were placed in outside lots and fed free choice hay, corn silage and one pound of soybean meal per head daily. By October 14, 1971, they were consuming 38.6 lb. of corn silage per head daily and hay feeding was discontinued.

All cattle were individually weighed, ear-tagged and placed on a vaccination experiment 12 hr. after arrival at the BCRC. The ranch of origin was identified by reading brands and recorded. Only two steers were treated for shipping fever and no death losses were encountered.

All cattle were individually weighed and assigned to experimental lots on November 2, 1971. Pre-experimental performance was computed for the 28-day period (Table 2).

Appendix I - Table 1.--Purchase price and weight of yearling cattle.

No. of Head	Consignor	Total Wt.	Av. Wt.	Price Per Cwt.	Price Per Head
71	Johnson Sisters	52,800	743.7	$36.30	$269.95
95	Kaan Corp.	70,710	744.3	$34.80	$259.39
166	All Jusk Steers	123,510	744.0	$35.47	$263.91

Appendix I - Table 2.--Pre-experiment performance and feed consumption for yearling steers.

	Johnson	Kaan	Combined
No. of steers	71	95	166
Av. purchase wt., lb.	743.7	744.3	744.0
Av. final wt., lb.	796.6	787.2	791.2
Av. gain, lb.	52.9	42.9	47.2
Days on test	28	28	28
Av. daily gain, lb.	1.89	1.53	1.69
Daily Feed, lb. 85% DM:			
Corn silage			14.3
Hay			3.0
50% soybean meal			.8
Total			18.1

Steer Calves

A total of 262 Hereford steer calves were purchased at four different feeder calf sales in Virginia from October 12 to 15, 1971. At each sale cattle were sorted into groups based on weight and grade. Therefore, each purchase represents cattle from several farms. Purchase data are shown in Table 3.

The calves were delivered to the BCRC on three trucks arriving at 7:00 p.m. on October 13, and 2:00 a.m. and 9:00 p.m. on October 15, 1971. The trucking rate was $1.25 per cwt., thus the delivered price averaged $41.61 per cwt. The total purchase weight was 130,055 lb. All loads were weighed immediately and the total off-truck weight was 119,960 lb. Thus, shrink was 7.8%.

At the BCRC, cattle were placed in outside lots and full fed hay, corn silage and one pound of 50% soybean meal daily. By October 27, calves were consuming 15.5 lb. of 35% dry matter corn silage per head daily and hay feeding was discontinued.

All cattle were weighed, ear-tagged and placed on a vaccination experiment the day after arrival. Twenty-six per cent of the calves (69 head) were treated for shipping fever. Each animal treated received treatment for four consecutive days. No death losses were encountered. Pre-experimental performance was computed for the 28-day period (Table 4).

Appendix I - Table 3.--Purchase price and weight of Virginia calves.

No. of Head	Sale	Date	Grade	Av. Wt.	Price Per Cwt.	Price Per Head
64	Abingdon	10/12/71	Choice	478.9	$41.00	$196.35
34	Abingdon	10/12/71	Choice	528.2	$39.00	$206.01
17	Narrows	10/13/71	Choice	509.1	$39.00	$198.56
11	Narrows	10/13/71	Good	504.5	$38.75	$195.51
82	Dublin	10/14/71	Choice	501.1	$41.50	$207.96
44	Galax	10/15/71	Choice	474.5	$39.75	$188.63
10	Galax	10/15/71	Choice	527.0	$38.75	$204.21
262	Combined			496.4	$40.36	$200.35

Appendix I - Table 4.--Pre-experiment performance and feed consumption for steer calves.

No. of steers	262
Av. purchase wt., lb.	496.4
Av. final wt., lb.	510.5
Av. gain, lb.	14.1
Av. no. days on test	27.6
Av. daily gain, lb.	.51
Daily Feed, lb. 85% DM:	
Corn silage	12.6
Hay[1]	3.3
50 per cent soybean meal, lb.	1.0
Total	16.9

[1]Hay was fed on the ground in open lots and a large share was wasted.

APPENDIX II

EXPERIMENT V: MEANS OF INDIVIDUAL PROTEIN-ACID TREATMENT GROUPS

Appendix II - Table 1.--Rumen ammonia and blood urea levels of individual acid-protein treatment groups in Experiment V (mg./100 ml.).

Time	Control		Acetic Acid		Lactic Acid		SE[1]	P[2]
	Soy	Urea	Soy	Urea	Soy	Urea		
Rumen Ammonia								
T_0	4.27	2.18	3.03	1.55	3.33	2.05	0.74	.855
$T_{2.5}$	4.05	4.50	2.85	4.60	6.72	6.40	1.27	.717
T_5	0.77	0.95	2.57	0.80	2.00	2.82	0.50	.038
T_{10}	1.47	1.27	3.23	0.85	3.25	4.25	0.73	.078
Blood Urea								
T_0	6.92	6.88	6.95	7.13	7.17	10.00	0.80	.156
$T_{2.5}$	9.43	9.87	7.78	8.73	8.72	12.02	0.74	.135
T_5	8.67	8.43	7.47	8.13	8.27	11.43	0.56	.015
T_{10}	8.20	7.77	6.17	7.50	8.37	10.35	0.70	.219

[1]SE = Standard error of means.

[2]P = Approximate probability of F statistic for interaction (AB).

Appendix II - Table 2.--Rumen VFA concentrations of individual acid-protein treatment groups in Experiment V (mg./100 ml.).

Time	Control		Acetic Acid		Lactic Acid		SE[1]	P[2]
	Soy	Urea	Soy	Urea	Soy	Urea		
Rumen Acetate								
T_0	210	178	242	210	268	337	18.99	.018
$T^{2.5}_0$	285	253	310	330	310	313	25.25	.586
$T^5_{2.5}$	257	267	225	237	255	307	26.44	.671
T_{10}	237	195	198	183	212	293	27.43	.079
Rumen Propionate								
T_0	78	42	65	57	77	70	10.18	.271
$T^{2.5}_0$	115	73	83	88	167	139	13.69	.231
$T^5_{2.5}$	97	77	57	65	95	96	9.71	.334
T_{10}	83	65	57	53	70	64	10.20	.741
Rumen Butyrate								
T_0	33	22	32	28	52	0	5.41	<.0005
$T^{2.5}_0$	60	43	52	50	77	0	5.24	<.0005
$T^5_{2.5}$	58	47	23	38	65	0	6.32	<.0005
T_{10}	58	45	33	33	57	0	6.34	<.0005

[1]SE = Standard error of means.

[2]P = Approximate probability of F statistic for interaction (AB).

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