Urea Utilization By Ruminant Animals

By Allan D. Tillman

The usage of urea in ruminant rations is increasing at an ever-increasing rate until it appears likely that over 200,000 tons of the feed-grade product will be used for this purpose by 1970. If this projection is real, urea will account for about 20 percent of the high-protein feeds being used at that time and will replace 667,000 tons of soybean or cottonseed meal. The purposes of this paper are to consider some of the factors affecting urea utilization by ruminants.

The Ruminant Animal

The ruminant animal is able to utilize urea and other non-protein nitrogen sources because of the anatomy of his stomach. The true stomach (Figure 1) is preceded by three compartments, the rumen, reticulum and omasum. The reticulo-ruminal area is large and is often called a "fermentation vat." Herein live billions of bacteria and protozoa, which are capable of converting cellulose to soluble products which can be utilized by the host, synthesizing of certain vitamins, and converting non-protein nitrogen compounds to protein.

Fortunately for the ruminant animal, the reticulo-ruminal compartment is located at the head of the digestive tract, giving the bacteria and protozoa prior access to dietary nutrients, thus any products which are

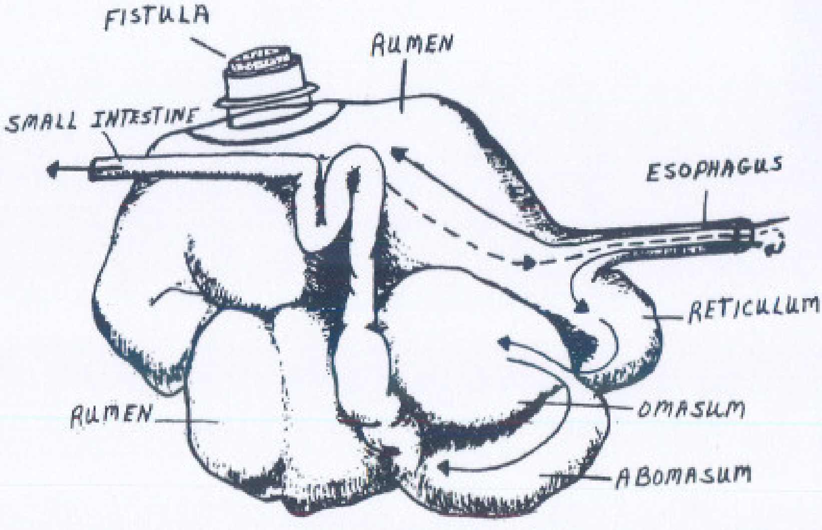

Figure 1. Schematic representation of the organs that comprise the stomach of the ruminant.

synthesized or partly catabolized here can be more completely absorbed than in non-ruminants which have their "fermentation vat" hooked onto the other end of their digestive tract.

How Ruminants Use Urea

All animals must have protein for maintenance, production and growth. Nathan Zuntz[1] in 1891 suggested that the micro-organisms in the rumen were important to the ruminant animal in its utilization of cellulose and nitrogen. Armsby[2] in 1911 reviewed the experimental evidence which concerned the utilization of urea and other non-protein compounds by ruminants and concluded that not enough of the non-protein compounds were converted to protein to be of significance in ruminant nutrition.

Research work on ruminant utilization of urea and other non-protein nitrogen compounds continued in Germany over the following 25 years

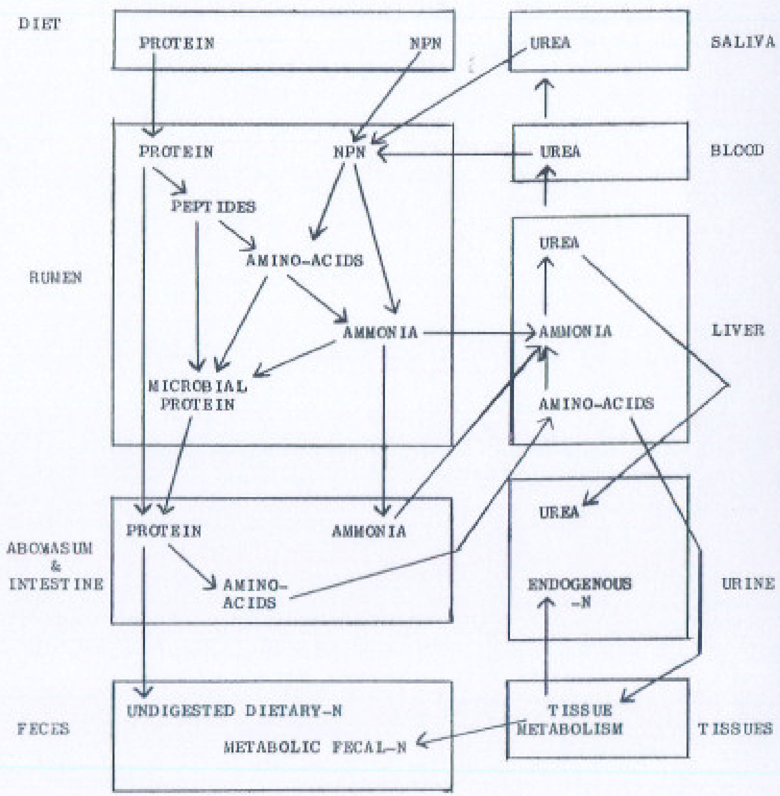

Figure 2. Nitrogen metabolism in the ruminant (Annison and Lewis[34])

and the review of Krebs[3] in 1937 was more optimistic than Armsby regarding the possibilities of using some urea in ruminant rations. Soon after Krebs' reviw several American laboratories began work on this problem. Wisconsin workers[4] found that when urea or ammonium bicarbonate was added to low-protein basal diets for calves that growth in these animals took place. Further research by the same group [5,6] was confirmatory as were results from Illinois [7,8,9], Massachusetts[10,11] and Cornell[12]. A review of the many feeding metabolism and toxicity reports, reveals the following findings:[13]

1. A low level of true protein and a high level of starch favors urea utilization[6].
2. Monosaccharides and disaccharides are inferior to starch for urea utilization[13].
3. Cellulose is hydrolyzed too slowly for effective urea utilization[13].
4. Highly soluble and easily hydrolyzable protein in the diet depresses urea utilization[13].
5. High levels of dietary protein reduce urea utilization. The more soluble proteins cause the greatest depression[6].
6. A deficiency of any minerals which are essential for rumen microorganisms, depresses urea utilization[14].
7. Urea should not replace over one-third of the natural protein in practical ruminant rations if optimum performance is to be obtained[13].
8. Frequent feedings stimulate urea utilization[15].
9. Under certain feeding conditions urea causes acute toxicity in ruminants[15].

Mechanism of Urea Utilization

As indicated earlier, the usage of urea in ruminant rations is increasing each year, yet basic microbiological changes involved in urea catalysis and subsequent synthesis of protein are obscure and but dimly perceived at the present time. Nontheless, the generally accepted sequence of events are as follows: (a) Microorganism urease in the rumen hydrolyzes urea to ammonia and carbon dioxide. (b) The ammonia nitrogen is combined with alpha-keto acids to synthesize amino acids, (c) amino acids are converted to microorganism protein, and (d) the microorganism protein is then digested to amino acids further down in the digestive tract and these are absorbed into the blood stream.

There is evidence[16] that the rate of urea hydrolysis (step a) exceeds synthesis of amino acids (step b) by a factor of about four. Under most conditions, there is enough buffering action in rumen fluid to convert the ammonia nitrogen to the ammonium ion. Ammonia has a pKa of 8.8 at 40°C[17] and the absorption across the rumen wall is slow if the pH is acid. As the pH of rumen fluid becomes alkaline more of the ammonium is converted to ammonia. The ammonia can penetrate the lipid layer of the ruminal wall in contrast to the impermeability of the charged ammonium ion. If excess urea is consumed, ammonia toxicity can result[15]. Levels of urea causing toxicity in fasted animals appear to be in the order of 20 grams per 100 pounds of liveweight but this can be modified by many factors which will be discussed later.

The basic problems of urea utilization may be presented if quantitative nutrient relationships are established. Feedgrade urea may contain 42 percent nitrogen*. Using the protein factor of 6.25, it can be seen that 100 grams of urea contains 42 grams of nitrogen and can supply 262 grams of protein if all of the nitrogen is converted to protein. Nitrogen makes 16 percent of the protein moiety, while carbon, hydrogen, oxygen and sulfur make up the remainder. If we consider the C, H and O to be in the same ratio as in carbohydrates, the main source of alpha keto acids, there would be 220 grams of this nutrient. This would mean that 2.2 gm. of carbohydrate must be added for each part of urea in the ration. As all dietary carbohydrates are not available for protein synthesis, there must be a much wider ratio than this. In purified diets, Oklahoma Workers [18,19,20] have used a ratio of 14 parts of starch plus dextrose to one part of urea and in the same ration of seven parts of cellulose to one part of urea. As cellulose is hydrolyzed too slowly to be of much value in supplying carbon fragments for animo acid synthesis[13], urea has not found wide usage in high roughage rations. The author and his graduate students have studies underway to determine the correct NFE: urea ratio when urea is fed in supplement for poor-quality roughage found in Oklahoma during the winter season.

Using Urea

The Association of America Feed Control Officials along with the American Feed Manufacturers Association have agreed on the following guide for the registration and subsequent labeling of urea-containing feeds found in the industry:

"Urea and ammonium salts of carbonic and phosphoric acids are acceptable ingredients in proprietary cattle, sheep and goat feeds only; these materials should be considered adulterants in proprietary feeds for other animals and birds; the maximum percentage of equivalent protein from nonprotein nitrogen must appear in the ingredient list.

"If feed contains more than 3 percent urea, or if the equivalent protein contributed by urea exceeds one-third of the total crude protein, the label shall bear: (1) a statement of proper usage; and (2) the following statement in type of such conspicuousness as to render it likely to be read and understood by ordinary individuals under customary conditions of purchase and use—WARNING: This feed should be used only in accordance with directions furnished on the label."

Feeders should follow very carefully these instructions. Failure to do so may result in loss of valuable cattle or sheep.

As Urea supplies only dietary nitrogen, which can be converted to microorganism protein if all other dietary factors are present in the

*Many feedgrade urea sources contain 45 percent N, but the principle of calculation is the same.

right quantities, it becomes of interest to compare ration conditions in which no urea utilization was obtained to those in which it was utilized. Such comparisons resulted in the recommendations already given. When urea is improperly used, toxicity may result. As Oklahoma[15], Florida[21], and English workers[22] have shown that 20 grams of urea/100 lb. body weight is toxic to cattle or sheep when consumed quickly or placed directly in the rumen, it is of interest to study conditions when the daily consumption of urea exceeds the above figure. Oklahoma workers[18,19,20] as well as Finnish workers[23] have fed purified diets to sheep and cattle. Urea supplied all of the dietary nitrogen in diets similar to that shown in Table 1. Sheep on this diet have gained at a rate up to 0.35[26] per day and while milk yields up to 9000 pounds per year have been obtained on several cows. Sheep, weighing 60 pounds, have consumed over five pounds per day of this ration, an intake of about 95 gm. of urea per day with no toxicity symptoms being observed. These animals consume their diets slowly and extend their feeding period over a large part of the day. Also, Oltjen (personal communication) of the United States Department of Agriculture, Beltsville, Maryland, using a diet similar to that shown in Table 1, has obtained normal reproduction in several cows. Such results indicate that urea may be used at higher levels than is recommended at this time. However, urea-containing rations require an adjustment period [24] before the ruminant can utilize it at the highest level of efficiency. There is no adequate explanation regarding the reason why such an adaptation period is necessary.

Beef Cattle Fattening Rations

Most beef cattle fattening-type rations in the United States now contain urea. Urea is usually incorporated into some premix, which contains a high level of protein, minerals, vitamins and other ration factors considered essential by the feeder. This is then mixed with other feeds

Table 1. Composition of the Oklahoma State University Purified Diet

Ingredient	Percent Level
Starch	29.38
Dextrose	29.38
Celulose (woodpulp)	30.00
Urea (46% N)	4.20
Corn oil	1.00
Polyethylene resin	1.00
Choline chloride	0.10
Minerals[1]	4.92
Vitamin A & D	0.02

[1] Each 100 lb. of diet contains the following mineral salts, in grams: Na_2B_407, 5.700; $CaHPO_4$, 0.893; $FeSO_4$, 19.300; KI, 0.031; K_2CO_3, 1005.400; $MnSO_4.H_2O$, 6.978; $Na_2MoO_4.2H_2O$, 0.227; $MgSO_4$, 54.500; $MgCO_3.Mg(OH)_2.3H_2O$, 121.000; Na_2SO_4, 113.400; Na_2SeO_4, 0.011; and $ZnSO_4.7H_2O$, 11.963. 601.000; CaF_2, 0.091; $CoCl_2.6H_2O$, 0.020; $Cr_2(SO_4)3$, 0.0181; NaCl, 283.500; $CuCo_3.Cu(OH)_2$,

in mobile mixing units while enroute to the animals. Examples of such premixes are the "Purdue 64"[25] and the "Iowa 80"[26] mixtures, composition of which are shown in Table 2. Such mixtures are usually fed at levels of one-half to one lb. per day per steer and urea consumption for each animal is from about 0.15 to 0.20 lb. per day, equivalent to 0.40 to .50 lb. of crude protein equivalent.

Urea has also found use in all concentrate rations for beef cattle. North Carolina Workers[27] have fed the diet shown in Table 3 and have results comparable to those when the oil meals are fed. (Also see McCartor and Tillman, p. 97)

The results attest that urea is an excellent substitute for the vegetable protein supplements in all ruminant rations containing high levels of grain.

High Roughage Ration

Still unanswered, however, are many problems regarding the use of urea in rations for mature cows being kept on low-protein forages during the winter season. The major deficiencies in such forages are minerals, especially phosphorus and certain trace elements, protein and energy. For many years the vegetable protein supplements have been used, and quite successfully so, to supplement such forages. As the world-wide shortage of protein has increased the demand for the oil meals in human nutrition, they are becoming expensive to feed to ruminants. Economics, therefore, dictate a wider usage of urea in such rations. Unfortunately, researchers have not been as successful in developing urea-containing supplements for ruminants kept under range conditions as in the case of fattening-type rations.

Nelson and Waller[28] summarized the results of 16 tests involving 879 cattle in which urea furnished one-third to one-half of nitrogen in supplements, which were isonitrogenous with cottonseed meal; cotton-

Table 2. Percentage Composition of Example Premixes for Beef Cattle Feeding. (Beeson et al.,[25] and Burroughs et al.,[26])

Rations	Purdue 64	Iowa 80
Dried molasses	---	33.0
Cane mola ses	14.0	---
Alfalfa meal	51.0	---
Bone meal	10.4	---
Iodized salt	3.5	---
$CaHPO_4$	---	20.0
$CaCO_3$	---	12.0
Trace minerals	---	1.0
Stilbestrol premix	---	2.0
Vitamin A mix	---	2.0
Urea	21.1	30.0
Total	100.0	100.0

Table 3. Percentage Composition of an All-Concentrate Diet for Beef Cattle (Wise et al[27])

Ingredient		Percent
Ground shelled corn		95.1
Urea		1.0
Cottonseed oil		2.0
NaCl		0.5
$CaCO_3$		0.7
Defluorinated phosphate		0.2
Trace minerals		0.4
Vitamin A & D		0.1
	Total	100.0

seed meal was replaced by urea and ground grain sorghum at about the ratio of one unit of urea plus six units of ground milo being equivalent to seven units of cottonseed meal. The urea-containing diets were greatly improved by the addition of trace minerals; however, animal performance was never as good as that in animals fed cottonseed meal. These results, along with the earlier results of Briggs *et al.*[20], indicate that the urea to NFE ratio in rations containing 40-45 percent crude protein is too narrow for good urea utilization and that supplements containing lower levels of crude protein and more starch or sugars are indicated. In this connection Beeson and Perry[30] modified the original Purdue Supplement A to include urea and the composition of these diets are shown in Table 4. When fed in diets containing corn cobs as the roughage, the urea-containing diet gave results as good as soybean meal. When corn cobs were the roughage source, daily gains of 1.28, 1.25, 1.14 and 1.17 lb., respectively, were obtained on rations 1, 2, 3 and 4. These differences were not significant. However more feed was required in the meal containing diets. Other workers[31] have obtained similar results when either corn cobs or corn stalks was the roughage source.

Table 4. Composition of Some Urea-Containing Supplements Fed with Poor Quality Forages (Beeson and Perry,[30])

Rations	1[1]	2[2]	3[3]	4[4]
Ingredients		Pounds per Days		
Soybean meal	2.25	1.06	0.46	---
Molasses feed (45% mol)[6]	1.00	2.85	3.75	4.46
Bone meal	0.18	0.18	0.18	0.18
Salt	0.06	0.06	0.06	0.06
Vitamin A & D	0.01	0.01	0.01	0.01
Urea	---	0.14	0.21	0.26
Total	3.50	4.30	4.67	4.97

[1] Original Purdue Supplement A.
[2] One-third of nitrogen from urea.
[3] One-half of nitrogen from urea.
[4] Two-thirds of nitrogen from urea.
[5] The percentages of urea in rations 2, 3 and 4, respectively, were 3.3, 4.5, and 5.2.
[6] 45 percent molasses dried on oat hulls and screenings.

Berry, *et al.*[32] fed cattle a diet composed of urea, molasses, phosphoric acid, trace minerals and vitamins and poor quality roughage free choice. The level of phosphoric acid can be varied in such mixtures to control intake when the liquid is fed free choice. Many of the commercial mixtures now available contain four percent phosphoric acid and these appear to be effective in limiting appetite of cattle on the dry ranges. As phosphoric acid is corrosive to metals and more diffecult to handle than other sources of phosphorus, there is interest in mechanical control of intake of urea-molasses mixture. The effectiveness of those devices available in commerce is not known by the author. The use of these supplements, of course, depends upon the price of molasses. When the price of molasses is that of milo or corn, these supplements become too expensive.

Toxicity

The major difficulty concerning the use of urea-containing protein supplements when poor-quality roughages are fed concerns the rapid hydrolysis of urea and the danger of toxicity if an animal consumes too much of the feed within a short time. Oklahoma workers[15] have studied in some detail toxicity symptoms when animals consume too much urea and these were as follows:

1. From 30 to 60 minutes after ingesting of urea, their steers showed uneasiness, staggering and kicking at the flanks.
2. These symptoms were followed by more serious incoordination, tetany and finally prostration.
3. These animals were down within 30 to 60 minutes after dosing. While prostrate, the most pronounced symptoms of distress were severe convulsions, slobbering at the mouth and bloating.
4. Ammonia levels of rumen contents were high which were quickly followed by high ammonia levels in peripheral blood.
5. There was a definite odor of ammonia on the breath of the animals.
6. Blood urea levels were high but cannot be taken as an indicator of severity of toxicity. When tetany begins, blood urea levels begin to drop.
7. Bloating was always present and the rumen contents had pH readings consistently above 8.0.
8. The amount of urea necessary to produce toxicity was about 20 grams per 100 lb. body weight.
9. All animals were dead within one to three hours after dosing.

Oklahoma workers[33] conducted further research on unusual feeding conditions which might cause urea toxicity and their results indicate that there are predisposing factors which increase the susceptibility of cattle and sheep to urea toxicity. These are as follows:

1. Animals which have never consumed urea appear to be the most susceptible.
2. Animals which have previously been consuming only low-

nitrogen roughages and are in a semi-starved condition will consume urea-containing feed rapidly.

3. Individual animals within the herd which are aggressive and consume their feed rapidly are most susceptible. In many cases where urea toxicity in the field has occurred, the rancher reports that his best animals were the victims.
4. Animals which have had previous access to urea-containing feeds will consume the diet slowly and will not consume enough urea to cause toxicity. In Oklahoma studies, sheep weighing 75 lb. have consumed over 80 grams of urea per day but consumption was slow; the animals simply nibble the feed and spend much more time at the feed trough. Also cattle weighing 500 lb. consumed in a similar manner over 400 grams of urea with no toxicity symptoms becoming apparent.

Prospects for Further Urea Usage

The results obtained by the Oklahoma and Finnish workers, in which ruminants were able to consume purified diets, containing urea as the sole nitrogen source, at levels necessary to maintain their body integrity, and then to put the surplus protein into body tissues and/or milk have opened up many possibilities of practical importance: Such tests must now be expanded to find other carbohydrate sources. For example, many countries have plenty of forests, thus the possibilities that certain wood products such as cellulose and hemi-cellulose, extracted in liquid form by the use of steam under pressure, might be combined with urea, minerals and vitamins to produce meat and milk products for feeding a protein-hungry world must be explored.

References

1. Zuntz, N. 1891. *Pfuger's Archiv. fur die gesamte physiologie* 49:477.
2. Armsby, H. P. 1911. U.S.D.A. Bureau of Animal Industries Bull. 139:49.
3. Krebs, Kurt. 1937. Biedermanns Zentr. B. Tierernahrung 9:394.
4. Hart, E. B., G. Bohstedt, H. J. Deobold, and M. I. Wegner. 1938. Proc. Am. Soc. Animal Prod. 31:333.
5. Hart, E. B., G. Bohstedt, H. J. Deobold, and M. I. Wegner. 1939 J. Dairy Sci. 22:785.
6. Wegner, M. I., A. N. Booth, G. Bohstedt and E. B. Hart. 1941 J. Dairy Sci. 24:835.
7. Harris, L. E. and H. H. Mitchell. 1941. J. Nutr. 22:167.
8. Harris, L. E. and H. H. Mitchell. 1941. J. Nutr. 22:183.
9. Johnson, B. C., T. S. Hamilton, H. H. Mitchell and W. B. Robinson. 1942. J. Animal Sci. 1:236.
10. Archibald, J. G. 1941. Mass Agr. Exp. Sta. Bull. 378.
11. Archibald, J. G. 1943. Mass Agr Exp. Sta. Bull. 406.
12. Loosli, J. K., C. M. McKay and L. A. Maynard. 1942. J. Dairy Sci. 25:680.
13. Reid, J. T. 1953. J. Dairy Sci. 36:955.

14. Burroughs, Wise, M. Latona, P. DePaul, P. Gerlaugh and R. M. Bethke. 1951. J. Animal Sci. 10:693.
15. Gallup, W. D., L. S. Pope and C. K. Whitehair. 1953. Okla. Agr. Exp. Sta. Bull. B-409.
16. Bloomfield, R. A., G. B. Garner and M. E. Muhrer. 1960. J. Animal Sci. 19:1248.
17. Bloomfield, R. A., E. O. Kearley, D. O. Creach and M. E. Muhrer. 1963. J. Animal Sci. 22:883.
18. Oltjen, R. R., R. J. Sirny and A. D. Tillman. 1962. J. Animal Sci. 21:277.
19. Oltjen, R. R., R. J. Sirny and A. D. Tillman. 1962. J. Animal Sci. 21:302.
20. Oltjen, R. R., R. J. Sirny and A. D. Tillman. 1962. J. Nutr. 77:269.
21. Davis, George K. and Harry F. Roberts, 1959. Fla. Agr. Exp. Sta. Bull. 611.
22. Lewis, D. 1960. J. Agric. Sci. 55:41.
23. Virtanen, Artturi I. 1966. Science 153(3744):1603.
24. McLaren, G. A., C. C. Anderson, J. A. Welch, C. D. Campbell, and G. S. Smith. 1959. J. Animal Sci. 18:1319.
25. Beeson, W. M., W. H. Mohler and T. W. Perry. 1964. Indiana Agric. Exp. Sta. Cattle Feeders Day, Purdue Univ., Lafayette, Ind.
26. Burroughs, Wise, C. Ludwig, A. Mukhter and A. Trenkle. 1965. Iowa Agr. Exp. Sta. A. S. Leaflet R. 69.
27. Wise, M. B., T. N. Blumer, G. Matrone and E. R. Barrick. 1961. J. Animal Sci. 20:561.
28 Nelson, A. B. and G. R. Waller. 1962. J. Animal Sci. 21:387.
29. Briggs, H. M., W. D. Gallup, A E. Darlow, D. F. Stephens and C. Kinney. 1947. J. Animal Sci. 6:445.
30. Beeson, W. M. and T. W. Perry. 1952. J. Animal Sci. 11:501.
31. Burroughs, Wise, C. C. Culbertson, Roger Yoerger and W. E. Hammond. 1953. Iowa Agr. Exp. Sta. A. H. Leaflet 186.
32. Berry, Jr., W. T., H. O. Kunkel and J. K. Riggs. 1957. Texas Agr. Exp. Sta. Progress Rept. 1966.
33. Whitehair, C. K., J. P. Fontenot, C. C. Pearson and W. D. Gallup. 1955. Okla. Agr. Exp. Sta. Misc. Publ. 43, p. 92.
34. Annison, E. F. and D. Lewis, 1959. Metabolism in the Rumen. John Wiley and Sons, New York.