2. FACTORS AFFECTING UREA UTILIZATION

The efficiency with which urea is utilized by ruminant animals and the amount of protein that can be replaced by urea have been found to depend on a number of factors. When the ration contains an ample amount of true protein, urea utilization is lower than on protein-low feeds. The kinds and amounts of carbohydrates in the ration have striking influences upon urea utilization. Various other factors such as levels of certain fatty acids and the levels of essential mineral elements may greatly affect urea utilization, and there may be differences in the response shown by different animal species.

Effect of level of protein

In 1940 Wagner et al. observed that, as the level of protein in a cultural medium was increased, the amount of urea converted to protein markedly decreased. Balance experiments with animals fed varying levels of true protein tended to confirm the in vitro experiments (Wagner et al., 1941).

Results differ with respect to the influence of amino acids or protein of different quality upon utilization of urea. Pearson and Smith (1943) found that certain amino acids promoted and others depressed synthesis of protein from urea by rumen micro-organisms. Loosli and Harris (1945) reported a marked improvement in nitrogen retention by lambs when methionine was added to a urea-containing ration. Burroughs et al. (1951) were unable to demonstrate that proteins of different amino-acid composition had any marked influence on urea nitrogen utilization. Gallup, Pope and Whitehair (1952) observed that there was no difference in nitrogen storage when urea supplemented cottonseed meal, soybean meal, or corn gluten meal, even though these proteins differed markedly in amino-acid makeup. McNaught and Smith (1947) pointed out that, when insoluble proteins were fed, the amount of ammonia formed from the protein might be small and this might favor a more efficient utilization of urea. McDonald (1952) demonstrated that when zein was fed there was very little increase in the ammonia content in the rumen ingesta, but when casein or gelatin was fed large amounts of ammonia were liberated.

Oltjen, Robbins and Davis (1964) tested the value of glutamic acid in high-urea diets in an effort to explain the much lower weight gains of lambs given urea as the sole nitrogen source compared to those given soybean protein (Oltjen, Sirny and Tillman, 1962). The soybean protein contained 19.5 percent of glutamic acid. In metabolism studies with steers, adding 3.0 percent of glutamic acid to a purified diet which contained 4.2 percent of urea did not significantly alter rumen ammonia levels or improve nitrogen retention. Rumen ingesta was lower in ammonia content and nitrogen retention was much higher when soybean protein was the only nitrogen source. Glutamic acid lowered the proportion of acetic acid and increased the butyric plus higher acids without changing the propionic acid in the rumen ingesta.

It seems clear that, on low-protein rations, urea can be utilized as a partial substitute for dietary protein in the ration of both cattle and sheep, but the urea will be wasted to the extent that the feed contains enough true protein to meet the needs of the animal.

Effect of carbohydrates

There is evidence that urea is less well utilized when it is fed with hay or other forage alone than when starch or cereal grains are included in the ration. Mills et al. (1942) observed an increased true protein content of rumen ingesta upon the addition of starch to a ration of only low-protein grass hay and urea. McDonald (1952) reported that adding starch to the rumen of sheep after they had been fed a casein-containing diet, when rumen ammonia content was high, effected a rapid reduction in the ammonia level, suggesting that the starch provided energy needed by the bacteria to utilize the ammonia.

Peirce (1951a) found that when Merino sheep were given a roughage ration with a crude protein content of 7 percent, a supplement of urea induced no increase in wool growth; the same experimental sheep showed a pronounced wool-growth response to a supplement of gluten. When, however, the urea supplemented a low-protein (5 percent) ration with a high starch content, wool growth showed a marked response which, nevertheless, was only about half the response to an equivalent supplement of gluten. In further long-term studies, Peirce (1951b) found that the amount of starch in 50 grams of dried potatoes was too small to give a wool-growth response with urea; with greater quantities of starch, the response to urea was proportional to the amount fed, up to 300 grams of potatoes per day. He demonstrated that the response to starch was not due to the energy supplied, as appropriate adjustments with oil in the ration did not influence the wool-growth response.

It was shown by Clark and Quin (1951) that the digestibility of dry matter and cellulose by sheep was not changed by the addition of urea-molasses; however, the rate of digestion was increased, permitting greater feed intake and hence reduced loss of body weight on poor quality roughage. This important observation has been confirmed by later workers. Coombe and Tribe (1962) demonstrated that the digestibility of dry matter in straw by sheep was unchanged by urea, but the rate of digestion was increased. Later, Coombe and Tribe (1963) found that molasses reduced the digestibility of straw by sheep and that the further addition of urea abolished this effect. They noted that larger intakes of urea tended to reduce the feed intake and considered that this might be due to the elevation of rumen pH to a harmful level.

Campling, Freer and Balch (1962) fed cows a straw ration (3 percent crude protein) and infused a solution of urea into the rumen. This led to increased digestibility of crude fiber (cellulose was not measured) and nitrogen-free extract. Mean retention time of ingesta in the rumen was reduced, but there was little influence on the remainder of the gut. Like Clark and Quin, they concluded that voluntary feed intake was related to the rate of disappearance of food from the rumen. They also concluded that the effect was not mediated by increased rumination (indeed, there was less rumination per unit of feed eaten), metabolic rate, reticulum contraction rate or stimulation of the lower gut. Also palatability of the feed could not have been influenced, as the urea was given per rumen. Pieterse, Lesch and Van Schalkwyk (1963) confirmed that urea supplements increased the rate of passage of poor quality veld hay (2.8 percent crude protein) through the digestive tract of beef steers; the effect appeared to be confined to the rumen and reticulum. Lesch, Pieterse and Oosthuizen (1963), in the same experiment, found that urea increased intake and increased the digestibility of crude fiber and organic matter. This experiment also demonstrated (Pieterse and Lesch, 1963) that the urea supplement enabled the steers to pass from a negative nitrogen balance to nitrogen equilibrium.

Faichney (1965) found that the inclusion of sucrose in a urea-straw diet for sheep had no significant effect on dry matter intake or digestibility, crude fiber digestibility, rate of passage of ingesta, rate of cellulose digestion in the rumen, nitrogen balance, body weight, rumen pH or the concentration of volatile fatty acids or ammonia in the rumen; he concluded that the lack of readily available energy was not a limiting factor in the utilization of diets used.

Several groups of workers in the United States have reported that sugar in molasses does not favor as efficient a conversion of urea nitrogen to protein as does starch. Mills et al. (1944) measured the levels of true protein in the rumen contents at a uniform time after feeding rations equal in nitrogen and containing different sources of carbohydrates. The rumen dry matter ingesta contained 6.5 to 7.7 percent of true protein on a ration of grass hay and molasses, 9.3 percent when urea was added, and 11.0 percent when starch and urea were included. Growth responses of dairy heifers fed these rations were measured. The ration of grass hay, molasses and urea, having 11.3 percent crude protein, resulted in an average daily weight gain of 0.33 kilogram compared with 0.64 kilogram when 0.14 kilogram of starch replaced the molasses in the supplement.

In nitrogen balance experiments with steers (Bell, Gallup and Whitehair, 1951; Gallup, Pope and Whitehair, 1952), greater nitrogen retention occurred on a ration (11 percent crude protein) consisting of grass hay supplemented with urea and either ground maize, dehydrated sweet potatoes, milo or barley than with cane molasses. Davis et al. (1955a) found that steers retained more nitrogen on a combination of ground maize and molasses than on molasses as a carbohydrate supplement to grass hay and urea. Merrill et al. (1959) observed that cane molasses increased hay consumption by dairy heifers by 11 percent. Heifers fed molasses and soybean meal gained significantly more weight than those fed molasses and urea as a supplement to hay.

Glasscock et al. (1950) studied the effects on the growth of steers of daily urea intakes of 64 or 128 grams (equivalent to 0.45 and 0.90 kilogram of cottonseed meal) as supplements to citrus molasses and poor quality prairie hay. The controls consumed an average of 2.2 kilograms of prairie hay and lost 0.28 kilogram of body weight daily, while the steers that received urea consumed 5.0 kilograms of the hay and gained 0.34 kilogram of body weight daily.

While urea-molasses mixtures have been widely used in the United States, they have attracted less attention elsewhere. Clark and Barrie (1954) reported that young cattle, on poor quality grass hay for five months, benefited from access to a urea-molasses mixture. Beames (1960b) noted that the intake of molasses ad libitum by grazing cattle was very variable and conferred no improvement in body weight while the cattle were on poor pasture. His tests with cattle in yards suggested that the ratio of molasses to urea could be reduced from the usual 8:1 to 2:1 and still obtain the same ad libitum intake of urea, and the same response to intake of low quality hay.

Urea-molasses mixtures have been self-fed in troughs with some degree of success. When molasses is diluted with water to reduce its viscosity, cattle will consume much more. Cattle sometimes consume so much of the mixture and reduce their intakes of grazed or hand-fed forage as to make the practice uneconomical. In spite of the somewhat unfavorable results sometimes obtained when combinations of urea and molasses have been fed, this is a convenient and safe method of feeding urea and the liquid feed can be handled in bulk with little labor.

Several authors have reported increased intake of roughage when a supplement of urea and molasses has been provided: Clark and Quin, 1951; Morris, 1958a, 1958b, 1958c; Coombe, 1959; Williams et al., 1959; Beames, 1959, 1963; Coombe and Tribe, 1960, 1963; Smith, 1962; Greef, van der Merwe and Swart, 1963. In these experiments, no animals were given urea without molasses, but often molasses alone was used and in general was found to have no effect on voluntary feed intake. In other experiments, it has been clearly demonstrated that intake of low quality roughage was increased by urea alone (Morris, 1958a; Coombe and Tribe, 1962; Campling, Freer and Balch, 1962; Freer, Campling and Balch, 1962; Hemsley and Moir, 1963; Leach, Pieterse and Oosthuizen, 1963). It is curious that there are few data to suggest that molasses alone has any important role to play in stimulating increase in feed intake. The experiments of Faichney (1965), Campling, Freer and Balch (1962) and Hemsley and Moir (1963) all indicate that when urea is used to supplement straw diets, addition of sucrose has no beneficial effect. It may well be that the principal effect of molasses is to attract the animals' interest — this is probably especially so in the case of sprayed pastures.

In studies in Texas (Riggs, 1958) beef cows fed limited amounts of cottonseed hulls or Johnson grass hay in dry lot consumed more than 5.5 kilograms of a liquid molasses-urea supplement without unfavorable effects. The supplement consisted of cane molasses, urea to equal 30 percent crude protein, phosphoric acid to provide 0.75 percent phosphorus with vitamin A and trace mineral elements. The liquid mixture was considered to be a satisfactory feed.

Effect of alcohol in liquid supplements

Liquid supplements consisting of molasses, ethyl alcohol, phosphoric acid, urea and certain trace minerals are available in a number of countries. There remains some question as to whether the addition of ethyl alcohol improves the value of molasses-urea mixtures.

Richardson et al. (1958) were not able to demonstrate an improvement in rate of gain of beef cattle or feed utilization when alcohol was added to a molasses-urea mixture; there were no differences in carcass composition or grade. Drori and Loosli (1959) compared the effects of ethyl alcohol and starch on urea utilization on high and low molasses diets. Apparent digestibility of nitrogen was highest on the basal diet of hay, molasses and urea, but nitrogen retention was lowest. Both starch and alcohol improved nitrogen retention and the highest values were observed when urea replaced only part of the protein from soybean meal. The results confirmed earlier studies (Bell, Gallup and Whitehair, 1951) in showing relatively poor utilization of urea nitrogen on diets of only roughage and molasses compared to higher values when grains were also fed (Bohman et al., 1945; Davis et al., 1955a). Bates et al. (1958) reported that the addition of alcohol to a liquid supplement of molasses, urea, phosphoric acid and minerals did not increase the weight gain of dairy heifers. It should be noted that pure ethyl alcohol has a combustible energy value of 7.12 kilocalories (kcal) per gram as against 4.18 kcal for starch. Alcohol also has the advantage that it can more easily be added to molasses than can starch or grains.

Richardson et al. (1956–57) fed beef heifer calves a basal ration of sorghum silage free choice and the control lot received a supplement of 0.45 kilogram of soybean meal plus 0.9 kilogram milo grain in comparison to several mixtures of molasses, phosphoric acid and alcohol fed free choice. Either 3 or 6 percent of ethyl alcohol tended to increase feed intake and rate of gain above the control mixture. Results were satisfactory with mixtures containing cane molasses and urea or ammoniated cane molasses but they were not equal to soybean meal. The large intakes of molasses caused a mild degree of scouring.

Thompson (1961) compared 0.9 kilogram of soybean meal and free choice feeding of a liquid supplement for wintering beef calves and during the subsequent fattening period. Maize silage served as the roughage. Feeding 0.9 kilogram of soybean meal per head daily produced more gain than 2.8 kilograms of the liquid supplement on equal silage intakes during wintering. For the fattening period the steers fed 0.68 kilogram of soybean meal gained 0.9 kilogram per head daily compared to 0.86 kilogram for steers that consumed 0.54 kilogram of the liquid supplement. The steers fed soybean meal required 120 kilograms less ear maize (grain and cob) per 100 kilograms of gain.

Morris and Horton (1959) compared a liquid protein supplement (consisting of 10 percent urea, 80 percent molasses, 6 percent ethyl alcohol, 4 percent phosphoric acid and trace minerals) with other supplements for dairy heifers fed cottonseed hulls as roughage. On a ration of pasture clippings plus 0.9 kilogram of maize, heifers gained 0.56 kilogram per day, compared to 0.40 kilogram per day on cottonseed hulls plus 0.45 kilogram of maize and 1.36 kilograms of the alcohol-molasses-urea mixture, and 0.35 kilogram per day on cottonseed hulls plus 0.9 kilogram of cottonseed meal and 0.45 kilogram of maize. While the liquid supplement gave good results, it did not supplement the poor roughage to equal the pasture clippings. When lactating cows were given 1.0 kilogram daily of the same molasses-urea-alcohol liquid supplement studied by Morris and Horton (Loosli and Nicholson, 1960) they produced about the same amount of milk as they did on 1.0 kilogram of cane molasses or dried citrus pulp. Andersen (1961) in Denmark reported that cows produced 18.6 kilograms of milk daily on vegetable oil meals compared with 14.9 kilograms when additional nitrogen was supplied by a liquid supplement of urea, molasses and alcohol similar to the one used in the studies cited above.

Balch and Campling (1961) fed milking cows rations adequate in energy but low in protein.

When 90 percent of the recommended crude protein allowance was supplied by a mixture of molasses, 9 to 10 percent of urea, 2 percent of phosphoric acid and 7 percent of ethyl alcohol, urea nitrogen utilization was poor. At a level of 40 percent of the recommended allowance of nitrogen, urea was as well utilized as groundnut meal. Ethyl alcohol was of no benefit in these studies. The research of Head (1957) and Williams et al. (1959) also showed no benefit from ethyl alcohol, while the addition of sulfate or B vitamins had no effect.

In studies with growing-finishing lambs, a liquid supplement consisting of molasses, urea, phosphoric acid, ethyl alcohol and trace minerals was compared with cottonseed meal and sorghum silage (Pratt and England, 1962). All lambs were fed the basal ration of milo, alfalfa hay and minerals. Sorghum silage as the only supplement gave fastest gains, and sorghum silage plus cottonseed meal the slowest. Lambs fed the liquid supplement and those on the basal ration alone were intermediate in rate of gain. There were no differences in carcass grades. There were no deaths from urinary calculi among lambs fed phosphoric acid.

Chalupa, Evans and Stillions (1964), using in vitro rumen fermentation techniques, observed that adding small amounts of ethyl alcohol to a basal medium increased cellulose digestion and that equal caloric amounts of starch, acetic acid and other sources of energy had a similar influence. Alcohol supplements did not significantly improve nitrogen retention in growing cattle. There were slightly higher ruminal ammonia levels 2 to 3 hours after feeding; this suggested decreased utilization of ammonia for protein synthesis owing to an inhibitory action of alcohol on microbial activity.

In the vast majority of the experiments cited, the addition of alcohol to a mixture of molasses and urea has not improved the performance of animals in comparison with a similar mixture without alcohol. In addition, the alcohol usually increases the cost of the feed, which raises serious doubts about its use in ruminant feeds. The possibility remains, however, that the ethyl alcohol may increase nitrogen utilization of a molasses-urea mixture for grazing ruminants not receiving supplements of starch-containing feeds. Further studies are needed.

Effects on digestibility and feed intakes

Williams et al. (1959) found that urea-molasses did not increase the digestibility of dry matter or crude fiber in oat straw although the daily intake was increased. Although urea increased feed intake, there was a gradual decline in intake of sheep in both control and supplemented groups.

Hemsley and Moir (1963) found that urea increased the intake of milled oaten hay by sheep; this increase was associated with increased rate of cellulose digestion, rate of passage of ingesta and increased concentration of volatile fatty acids in the rumen. The further addition of molasses did not improve these effects. Greef, van der Merwe and Swart (1963) also found that urea enhanced the digestibility of gross energy and crude fiber in a straw-molasses diet, and converted the nitrogen balance from negative to positive.

Several authors have used the cotton thread technique to obtain information on the rate of digestion of cellulose in the rumen (Coombe and Tribe, 1960, 1963; Campling, Freer and Balch, 1962; Hemsley and Moir, 1963). In all cases, the results were in conformity with expectation from the rate of digestion of dry matter or crude fiber of the feed.

Coombe and Tribe (1962) found no beneficial effect on digestibility from the addition of phosphate to a urea supplement. Later, Hemsley (1964) reported that when oat hulls (with low nitrogen and high lignin contents) provided the basal ration, urea alone had no effect on dry matter intake; addition of molasses to the urea supplement produced a marked response which, however, could be obtained by replacing the molasses with a complete mineral mixture.

Buziassy and Tribe (1960a, b) noted that in the rumen of sheep given diets of urea-starch-sugar-straw or urea-straw, normal levels of thiamine, riboflavin and nicotinic acid are maintained as a result of microbial synthesis. There appears to be no experimental evidence of the importance of vitamin synthesis in the role of urea as a supplement to poor quality diets.

Freer, Campling and Balch (1962) reported a study of the factors affecting voluntary intake of roughages by cows. They compared rations of hay, oat straw, and straw with urea, and concluded that the limit to the amount of each roughage eaten was set by the time required for the breakdown of food particles by chewing and microbial digestion to a size suitable for transfer to the omasum. Regardless of the roughage type, there was a linear relation between total intake of food and the amount of organic matter transferred to the omasum with each primary contraction of the reticulum. As feed intake increased, the total chewing time (eating and ruminating) also increased— thus a greater number of small particles was produced and this allowed an increased output of organic matter to the omasum with each reticulum contraction. They reasoned therefore that the limiting factor on voluntary intake was not output per contraction but the time required to reduce feed particles to a small enough size. The probable importance of rate of microbial digestion of feed was shown in the observation that the time spent chewing was higher, per unit of feed, on a straw ration than on hay; when urea was given with the straw, intake greatly increased and the time spent chewing, per unit of feed, was reduced.

French (1957) has shown that the apparent digestibility of crude protein in rations containing urea conforms with that in ordinary rations. This is rather surprising in view of the ease with which urea is converted to ammonia in the rumen and the ammonia absorbed from the rumen. If French's findings are confirmed, it would suggest that absorbed ammonia contributes to the nitrogen of digesta, by recycling to a greater extent than previously envisaged, or that dietary nitrogen has a very high true digestibility.

It is clear that present knowledge cannot adequately account for the observed effects of urea nor permit prediction with untested rations. With some roughages urea alone will increase the intake, while with others further supplements are required. The full role of the molasses is not clear, but there are indications that its effect may sometimes be due to its mineral content (Hemsley, 1964), rather than to the need for a supply of easily fermented carbohydrate (Faichney, 1965). Further, Hemsley (1964) has shown that sheep can attain positive nitrogen balances and satisfactory dry matter intakes when urea supplies the only nitrogen source in a diet containing as much as 74 percent of purified cellulose. Since low quality roughages vary widely in their contents of cellulose, lignin, protein and inorganic substances, it seems probable that the effects of urea on the intake and utilization of roughage must be influenced not only by the chemical composition but also by the physical structure of the plant material. It seems at present that the critical factor is the rate of decomposition of plant cell walls in the rumen, and that supplements to low quality roughage will be useful only when they rectify deficiencies in nutrients for fiber-digesting organisms in the rumen.

In an experiment at Ottawa (Minson and Pigden, 1961) urea was given by aqueous solution through a rumen fistula (cattle), by drenching every 90 minutes (sheep), or by incorporation into a pelleted ration (sheep) along with wheat straw. The urea did not improve consumption or digestibility of the wheat straw as the work of Campling, Freer and Balch (1962) indicated.

When urea is added to a good quality roughage no benefit accrues. Peirce (1951a) fed sheep an all roughage ration ad libitum (about 11 percent crude protein [CP] with and without urea; the urea had virtually no effect, over a period of 2 months, on intake, body weight or wool growth; the basal ration provided 13 grams of nitrogen per day and maintained body weight. Williams et al. (1959) gave sheep grassclover hay, with 11.2 percent CP, and found no response from a supplement of urea and molasses.

Coombe and Tribe (1963) summarized the position by saying that a small supplement of urea improves the intake of poor quality roughage and thus supplies more digestible energy to the animal, and improves the nitrogen status which consequently reduces weight loss. However, they noted that low quality roughage plus urea and molasses did not “provide conditions suitable for the retention of high amounts of nitrogen.”

Influence of sulfur

When lambs were fed a purified diet containing urea as the only source of nitrogen, and without added sulfur, they lost body weight and were in negative balance for both nitrogen and sulfur. The same diet supplemented with sulfates supported positive balances and weight gains (Thomas et al., 1950). Such a response would be expected since sulfur is needed for synthesis by rumen bacteria of methionine and cystine as well as thiamine and biotin.

In an experiment at Lethbridge (Slen and Whiting, 1955) urea, with and without the addition of inorganic sulfur, was compared with a number of other nitrogen sources (linseed meal, soybean meal, field peas, alfalfa meal, meat meal and lactalbumen) in meeting the protein requirements of pregnant and lactating ewes. During early pregnancy the various sources of nitrogen supplied approximately 40 percent of the total nitrogen, and during late pregnancy and lactation about 70 percent of the total nitrogen. As measured by wool growth, body gains of the ewes, and growth rate of the lambs, urea was inferior to the other sources of nitrogen. The addition of inorganic sulfur to the urea had no beneficial effects.

Davis, Williams and Loosli (1954) studied the total sulfur content of feeds commonly used in rations for dairy cattle in the United States. None of the feeds contained a wider ratio of sulfur to nitrogen than 1:15, the ratio found in average proteins of body tissues. The hay and silage analyzed contained 1 part of sulfur to each 5 parts of nitrogen. In a study with lactating cows these workers did not observe any beneficial response from the addition of sulfates to a ration in which urea supplied all of the supplemental nitrogen to the grains. On rations low in sulfur and high in urea content the addition of sulfate may be desirable.

Influence of other factors

Bentley et al. (1954) reported that cobalt stimulated urea utilization and cellulose digestion and the growth rate of cattle fed nonlegume hay. Various mineral elements including phosphorus are needed for optimal microbial growth in the rumen and efficient use of urea (Burroughs, Gerlaugh and Bethke, 1950). The ash of natural feeds such as alfalfa and soybean meal has been shown to stimulate digestibility and growth of animals when urea is fed (Swift et al., 1951).

It can be generalized that any nutrient deficiency which decreases the activity of the microflora of the rumen or lowers dry matter digestibility will be likely to depress urea utilization. Hemsley and Moir (1963) observed that a mixture of volatile fatty acids (isobutyric, n-valeric and isovaleric acids) enhanced the effect of the urea on the intake of a low quality roughage (4.4 percent protien). As these acids provided only negligible amounts of energy, it was concluded that they provided specific microbial nutrients which stimulated growth. Virtanen (1963) found it necessary to add a small quantity of oil to purified rations to get satisfactory performance of dairy cows when urea and ammonium salts were the only nitrogen sources. It seems likely that future research will yet uncover other shortages or imbalances which limit the synthetic powers of the rumen microflora, or find new substances to effect a stimulation.