THE ADDITION OF UREA TO RATIONS FOR CATTLE AND SHEEP

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BIOGRAPHY

James Smith Dinning, the son of James Starks Dinning and Blanche Smith Dinning, was born September 28, 1922, in Franklin, Kentucky. He was graduated from Middleton High School, Franklin, Kentucky, in 1939, and attended the University of Kentucky from 1939 to 1942. In 1942 he entered the Engineer's Corps of the Army and was transferred to A.S.T.P. in May of 1943. He studied at the University of Oklahoma from 1943 to 1945, and at the University of Tennessee, College of Medicine from 1945 to 1946.

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INTRODUCTION

Farm animals require adequate protein, not only for production but also for maintenance, and a deficiency of protein concentrates may be expected to result in serious economic losses to the livestock producer. A general shortage of high protein feeds has been indicated by the Feed Survey Committee of the American Feed Manufacturers Association, because in October, 1947, they estimated a requirement of 11,131,000 tons for the year 1947-48, while the estimated supply was 10,499,000 tons or a deficit of 632,000 tons. In past years this deficit of protein supplements has often been much greater and since livestock production is steadily increasing and there is little promise of an increase in supply, a shortage of protein concentrates may be expected to become progressively more acute. Evidence is available which indicates that ruminants may be able to utilize the nitrogen of urea and ammonium salts to supply a part of their protein needs. Since urea can be produced cheaply and in large quantities it would, if proved to be of value, help relieve the existing and impending protein shortage.

REVIEW OF PREVIOUS INVESTIGATIONS

Armsby (1911) was one of the first to review the literature concerning protein synthesis from non-protein sources. He concluded that there was evidence that microorganisms in the rumen of polygastric animals were able to synthesize protein from non-protein sources to a limited extent. Later Krebs (1937) summarized the literature pertaining to the feeding of urea, ammonium salts, and glycocoll in nitrogen balance experiments. He pointed out the need for long time growth experiments, and concluded that the values of urea nitrogen in replacing vegetable protein for growth and lactation were not well established. In a later review, Axelsson (1942) concluded that urea given alone has a toxic effect and that it is best given in such combinations as dried beet pulp, molasses, and urea. He estimated that about 1/3 of the nitrogen of normal rations of ruminants can be replaced by urea provided the energy supply is maintained.

Hart and co-workers (1939) worked with young dairy stock in a study of urea utilization. They fed a control group a basal ration of corn starch and timothy hay while another lot received the basal ration plus urea and a third group the basal ration plus casein. They concluded that urea was utilized, that a readily fermentable carbohydrate increased utilization, and that urea was more effective when fed at a level of 43 percent of the nitro-

gen ingested than at a level of 66 or 70 percent. Schmidt and Kliesch (1943) carried out one of the few long time growth experiments using urea. They used three lots of five calves each and fed them over a period of 252 days. One group received only the basal ration of clover hay and dried beet pulp, while a control group received the basal plus a concentrate thought adequate to cover their protein needs. For the third group urea nitrogen replaced 50 percent of the protein nitrogen of the control group. The growth curves of the control groups were far above those of the other two, while the group receiving urea grew at a rate only slightly above the basal group. The authors concluded that growing calves are not able to use the nitrogen of urea to any practical extent for growth. Bartlett and Cotton (1938) fed 21 young dairy heifers for 142 days on rations that contained normal protein, low protein, and low protein plus 0.127 pounds of urea daily. The urea fed group gained at a significantly higher rate than the low protein group, while there was no difference in the rate of gain between the urea and normal protein groups.

Wegner, Booth, Bohstedt and Hart (1941) used the rumen fistula technique to study urea utilization. They determined the total nitrogen, non-protein nitrogen, and NH_3 nitrogen of the rumen contents at various intervals following feeding and secured evidence on the conversion

of urea nitrogen to protein. They then studied the effect of protein level and urea level in the rumen on the rate of protein synthesis, by using the rate of NH_3 formation and disappearance as an index to the rate of protein synthesis. When the protein level of the rumen ingesta increased above 12 percent, the conversion of NH_3 nitrogen to protein began to decrease, and when no protein concentrate was present the urea was utilized up to a level of 4.5 percent of the total ration. Further work at Wisconsin by Wills, Booth, Hohstedt, and Hart (1942) using the rumen fistula technique demonstrated that corn starch greatly increased the utilization of urea nitrogen. Later work by Wills, Lardinois, Rupel, and Hart (1944) gave similar results. Rupel (1944) reports that the concentration of urea in a ration should not exceed 3 percent, and the protein equivalent of the concentrate should not exceed 18 percent.

Pearson and Smith (1943a) incubated urea with samples of rumen ingesta, in an effort to determine the mechanism of urea utilization. These workers (1943b) found that in the presence of rumen ingesta urea is rapidly hydrolyzed to ammonia. They also (1942a) determined total protein and non-protein nitrogen of the samples of rumen ingesta and urea, and from these values estimated the extent of protein synthesis. Synthesis and hydrolysis of protein were found to occur simultaneously, and while starch in the rumen ingesta favored protein synthesis, such sub-

stances as lactic acid and gelatin favored hydrolysis. Wegner et. al. (1941) also used the rumen fistula technique to study the effect of protein level in the rumen ingesta on the rate of conversion of urea nitrogen to protein nitrogen. They found that when the protein level of the rumen ingesta exceeded 12 percent, or when the protein in the concentrate being fed exceeded 18 percent, the rate of conversion of urea nitrogen to protein began to decrease.

Rupel, Bohstedt, and Hart (1943) compared urea and linseed meal as a source of supplemental nitrogen. In one ration urea supplied 46 percent of the nitrogen in the ration of dairy cows, while the linseed meal was used as the source of protein in the control ration. They reached the conclusions that there was no significant difference between the two for milk production and that urea should not be fed above a level of 1 percent of the dry matter of the ration or 3 percent of the concentrate. Willet et. al. (1946) found that urea could replace vegetable protein in the ration of dairy cows, but their production capacity was slightly reduced. Owen, Smith and Wright (1943) compared blood meal and urea as sources of dietary nitrogen for mature lactating dairy cows. In one ration urea supplied 25 percent of the total nitrogen intake, while blood meal furnished the supplement in the other ration. There was no significant difference between the two rations for milk production and weight gains.

About 25 percent more nitrogen appeared in the urine of animals fed the urea ration than in that of those fed the blood meal.

Bartlett and Blaxter (1947) conducted extensive feeding trials using 274 dairy cows on 12 farms in England. Low protein, low protein plus urea, normal protein, and normal protein plus urea rations were compared for milk production. The urea did not improve milk production when added to either the low or normal protein rations.

Harris, Work, and Henke (1943) conducted nitrogen balance experiments on steers, in which they compared urea with soybean oil meal when both were added to a basal ration containing 1.44 percent protein. The biological value of the protein of the urea ration was 34 and that of the soybean oil meal 60. They attributed the low biological value of urea to the high level at which it was fed. Loosli and McCay (1943) found two months old calves made satisfactory gains in weight and height when urea was added to raise the nitrogen level of a basal ration from 4.4 percent to 16.2 percent protein equivalent. The calves were in negative nitrogen balance on the basal ration, but stored from 28 to 36 percent of the nitrogen in the supplemental ration.

Briggs et. al. (1947) conducted investigations on the value of urea for nitrogen storage, fattening, and wintering of beef steers. Twenty-five percent and 50 percent of the nitrogen of cottonseed meal was replaced

by urea, and both cottonseed meal and the urea containing pellets were compared as ration supplements. They concluded that, from the standpoint of nitrogen retention, the 25 percent urea pellets were superior to the 50 percent pellets and steers utilized the 25 percent pellets as well as they utilized cottonseed meal. In the fattening study 30 calves with an average initial weight of about 455 pounds were divided into 3 lots. Lot 1 received cottonseed meal as the protein supplement, lot 2 received the pellet in which urea replaced 25 percent of nitrogen of cottonseed meal, and lot 3 received the pellet in which urea replaced 50 percent of the nitrogen of cottonseed meal. The rations were fed for 167 days and the average daily gains were 1.81 pounds for lot 1, 1.96 pounds for lot 2, and 1.98 pounds for lot 3.

Harris and Mitchell (1941a) used sheep to study the value of urea nitrogen for maintenance. They were able to keep sheep in nitrogen equilibrium for 100 days on rations in which urea supplied 90 percent of the nitrogen. Nitrogen equilibrium was maintained on 202 mg. of urea nitrogen per kilogram of body weight, while 161 mg. of casin nitrogen per kilo of body weight were required for nitrogen equilibrium. These same workers (1941b) were able to obtain normal growth in sheep on rations containing 11 percent protein in which urea supplied 50 percent of the nitrogen. Johnson and co-workers (1944) found that defaunated sheep utilized urea nitrogen as well as normal sheep indicating

that protozoa were not essential for urea utilization.

Hart and associates (1939) reported that kidney damage resulted from feeding urea at a level of 4.5 percent of the dry matter of the ration and that some damage occurred when urea was fed at a 2.8 percent level. Work, Hamre, Henke, and Harris (1943) fed two lots of cattle, one of which received urea at the rate of .88 percent of the dry matter consumed and the other at a 2.29 percent level. Histological studies of the livers and kidneys showed no pathological symptoms. These results indicate that the toxic level of urea lies between 2.29 percent and 2.8 percent. Briggs (1946) working at the Oklahoma Station fed steers that weighed approximately 450 pounds an intake of .4 pounds of urea per day for 14 days and observed no apparent ill effects. It was estimated that this was approximately 2.6 percent of the total dry matter intake.

EXPERIMENTAL OBJECTIVES

Experiments were designed to answer the following questions relative to the use and metabolism of urea:

1. The physiological effect of orally administered urea,
2. The toxicity of urea, and
3. The metabolism of urea nitrogen when added to maintenance and fattening rations.

THE PHYSIOLOGICAL EFFECTS OF ORALLY ADMINISTERED UREA

Many workers have suggested that bacteria in the rumen are responsible for the conversion of the urea nitrogen to a form which can be utilized by the host. If such a conversion takes place, the rate of absorption of urea should be a factor affecting the efficiency of its utilization, since that which is absorbed is no longer subject to the bacterial action. Studies have been made with sheep and cattle to determine the rate of absorption and possible toxicity of urea when administered orally in water solution and when mixed with concentrate feeds in a practical ration. Urea and ammonia were determined in both the portal and systemic blood of a sheep in one experiment and in the systemic blood of steers in all other experiments.

Experimental Procedure

The sheep used for the portal blood studies was a ram lamb weighing 90 pounds which had been on full feed of hay and grain. Twenty-four hours before the experiment all roughage was taken from the ration to reduce rumen and intestinal contents. The lamb was anesthetized with pentothal sodium injected intravenously, with supplements of ether given during the experiment. An incision was made in the right abdominal wall just posterior to the costal margin and the portal vein exposed by retraction of the

abdominal viscera. Samples of portal and systemic blood were drawn immediately. Forty grams of urea and 40 grams of sucrose dissolved in 500 ml. of water were then directed into the rumen by means of a stomach tube. Samples of portal blood were taken at 15-minute intervals thereafter for 2 hours and a sample of systemic blood from the jugular vein was taken at the time of the last portal sample. Urea and ammonia were determined by the method of Van Slyke and Cullen (1914), all determinations being completed within 4 hours after the first sample was drawn.

Four yearling steers weighing approximately 500 pounds each were used for the study of ammonia and urea levels in systemic blood following oral administration of water solutions of urea. Prior to the experiment the steers were on full feed of 8 pounds of prairie hay and 3 pounds of cottonseed meal daily. The morning on which urea was to be administered the steers were fed 4 pounds of concentrate containing 50 parts cottonseed meal, 32 parts hominy feed and 10 parts blackstrap molasses. When the animals had consumed their feed, blood samples were obtained by jugular stab to determine the initial blood urea and ammonia values. Urea, in varying amounts, was dissolved in a liter of water and given orally by means of a rubber tube 25 cm. in length which reached to about the midpoint of the esophagus. Steer numbers 1, 2, 3, and 4 received 57, 116, 272, and 490 grams of urea, respectively, in this manner. Urea and ammonia determinations were made on

jugular blood samples taken at frequent intervals until death or recovery of the animals. The results are presented graphically in Figures 1 and 2.

In the foregoing experiment the blood ammonia values increased rapidly and with fatal results. Therefore, it appeared desirable to continue the study by feeding urea mixed with a concentrate feed. The concentrate feed used was composed of cottonseed meal, hominy feed and molasses in the same proportions as given above plus 8 parts of urea. Four steers were fed 40, 48, 73, and 80 grams of urea in this manner and a fifth steer was given the same basal ration without urea. Attempts to induce the steers to eat large amounts of urea in a short period of time failed. Urea and ammonia determinations were made on jugular blood samples taken immediately after the steers had consumed their feed and at 30-minute intervals during the next 3 hours. The results are given in Figures 3 and 4.

Two additional experiments were then carried out. In one of these, the amount of urea fed in a mixed feed was gradually increased. In the other, a high urea ration was suspended in water and given as a drench.

RESULTS AND DISCUSSION

Table 1 presents values for urea and ammonia nitrogen in the portal and systemic blood of the sheep immediately preceding and following oral administration of urea in water solution. Portal urea-N values increased from 7.77

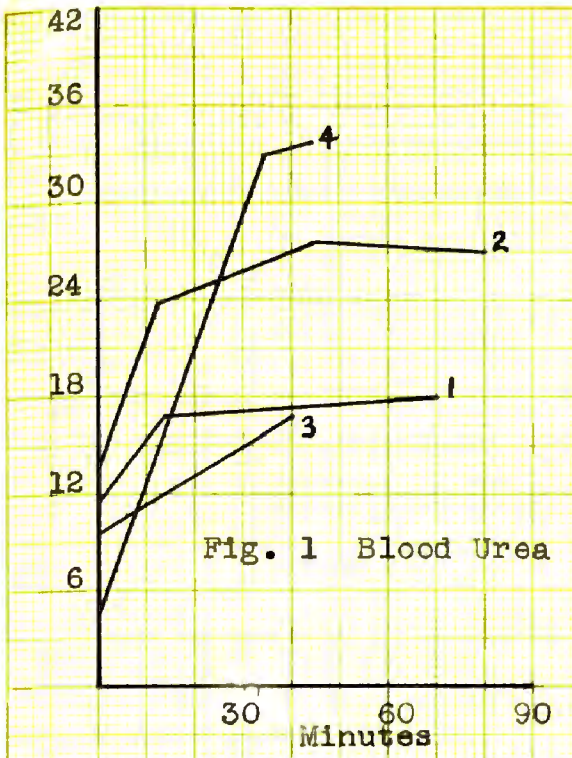

Fig. 1 Blood Urea

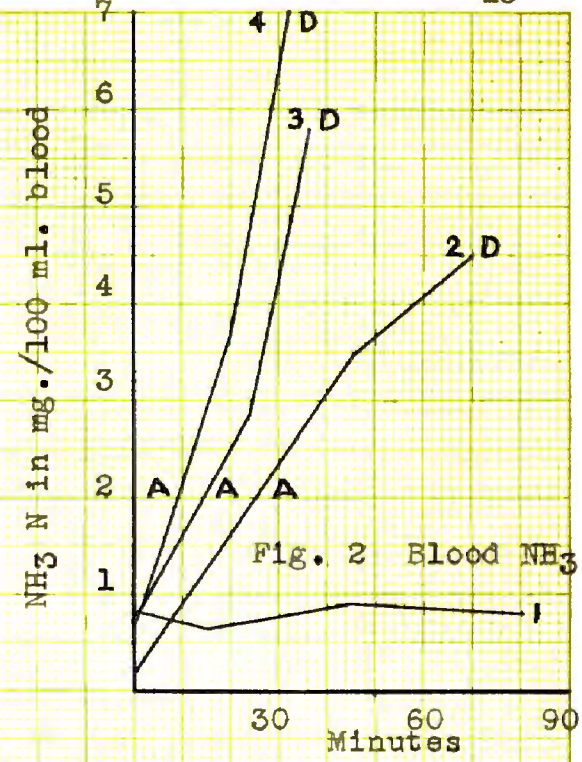

Fig. 2 Blood NH_3

Figures 1 and 2. Effect of administration of water solutions of urea on blood urea and NH_3 levels in cattle. Steers Nos. 1, 2, 3, and 4 received 57, 114, 272, and 490 gms. of urea, respectively. "A" represents the point at which ataxia was first observed; "D" represents death of the animal.

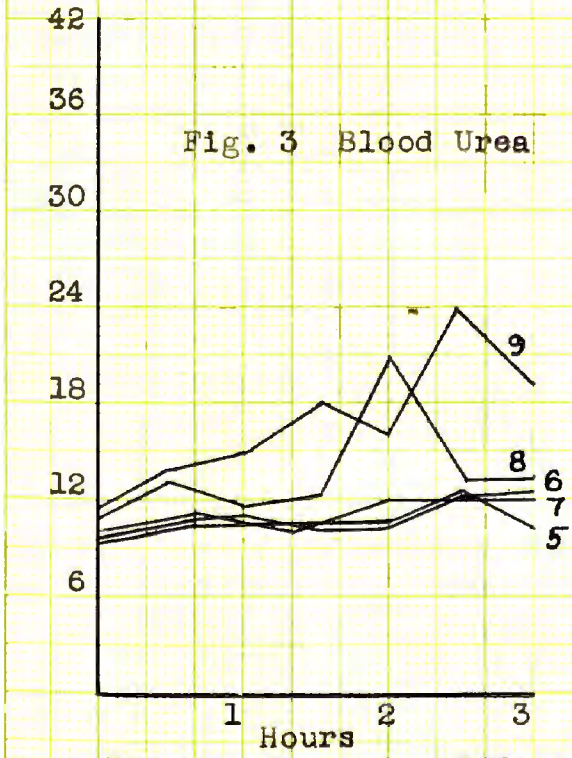

Fig. 3 Blood Urea

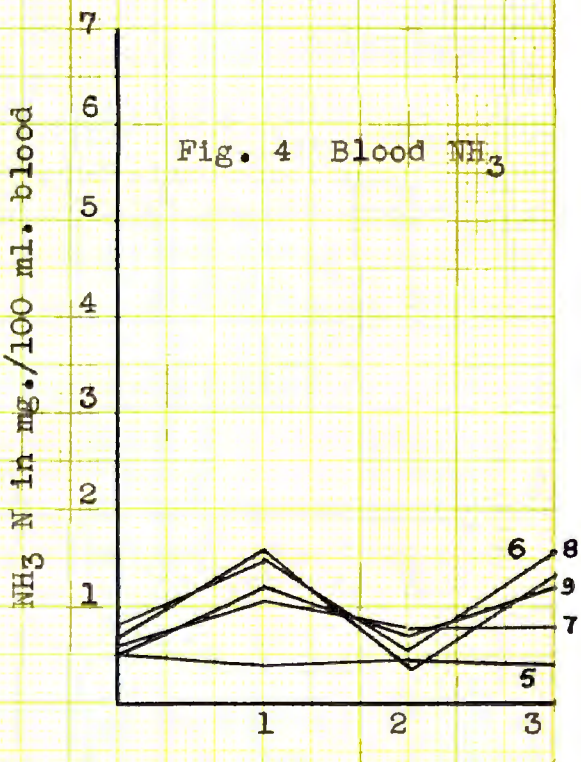

Fig. 4 Blood NH_3

Figures 3 and 4. Effect of urea eaten in mixed feed on blood urea and NH_3 levels in cattle. Steer No. 5 received the basal ration without urea. Steers Nos. 6, 7, 8, and 9 ate 40, 48, 73, and 80 gms. of urea, respectively.

mg. percent to 15.26 mg. percent within 15 minutes after the urea was given. During the same period portal NH_3-N values increased from 1.75 to 4.08 mg. Thereafter, the urea values remained fairly constant whereas the NH_3-N values continued to increase until at the end of 2 hours a value of 8.40 mg. was reached. Changes of similar magnitude were observed in the urea and NH_3-N value of the systemic blood at the end of 2 hours. The increase in NH_3-N of the portal blood indicates absorption of appreciable quantities of ammonia produced by the hydrolysis of urea in the gastro-intestinal tract.

Changes in blood urea and ammonia produced by oral administration of from 57 to 490 grams of urea to steers are shown in Figures 1 and 2. When 57 grams of urea were given to steer 1, urea-N values increased to about 18 mg. percent during the next 70 minutes while NH_3-N values varied only slightly from the initial value of 1 mg. percent. When 116, 262, and 490 grams of urea were given to steers 2, 3, and 4, respectively, there was a rapid rise in both urea and ammonia and death followed within a period of 70 minutes. At the time of death, NH_3-N values of steers, 2, 3, and 4 had reached 4.48, 5.74 and 7.14 mg. percent, respectively. Urea-N values, although high, at no time exceeded those which have been observed in other animals consuming high-urea rations without ill effects. The three steers exhibited almost identical symptoms preceding death. Ataxia, especially of the front legs,

TABLE I. UREA AND NH_3-N IN THE PORTAL AND SYSTEMIC BLOOD OF A SHEEP FOLLOWING ADMINISTRATION OF 40 GMS. OF UREA AND 40 GMS. OF SUCROSE (VALUES IN MG. N PER 100 ML. OF BLOOD)

Items compared	Time in minutes								
	0	15	30	45	60	75	90	105	120
NH_3-N in Portal blood	1.75	4.06	4.75	3.50	6.65	6.51	5.60	7.70	8.40
NH_3-N in Systemic blood	0.56								3.36
Urea-N in Portal blood	7.77	15.26	13.31	14.07	13.86	13.51	14.56	14.77	15.12
Urea-N in Systemic blood	8.40								16.10

occurred within 20 minutes after the urea was given. Ammonia-N values at that time had reached about 2 mg. percent. The steers became unable to stand and went into severe tetany. Respiration became slow and difficult with frequent gasping, and the animals exhibited excessive salivation with frothing. As blood ammonia values continued to rise the tetany became progressively worse. The highest NH_3-N value observed during the periods of survival was 3.74 mg. percent for steer No. 4 at the end of 24 minutes. The lowest value observed at the time of death was 4.48 mg. percent (steer No. 2). It is suggested, therefore, that the lethal level of NH_3-N in the blood is somewhat below these levels but above 2 mg. percent. Bang (1915-16) reports that for rabbits the lethal level is about 4 mg. percent.

In an attempt to alleviate the tetany of a steer which had been given 256 grams of urea by stomach tube, 75 gm. of a mixture of equal parts of calcium chloride, magnesium chloride and dextrose were given intravenously. The tetany completely disappeared within 15 minutes after the injection, but the steer died 1½ hours later.

Another steer was given 236 grams of urea in water by means of a stomach tube of such length that it could be palpated in the rumen. This longer tube was used to insure delivery of the urea into the rumen with little opportunity of its being shunted into other stomach compartments. In the following two hours urea-N of systemic blood increased

from an initial value of 18.40 mg. percent to 28.63 mg. percent; NH_3-N increased from 1.12 to 1.82 mg. percent. The steer showed none of the symptoms described for those given urea with a short tube, but died 7 hours later. Autopsy revealed severe inflammation of the wall of the rumen in the region in which the tube was palpated. The absence of the symptoms of alkalosis, relatively low NH_3-N values, and delayed death of this animal indicate a difference in the effect of urea when directed into the rumen and when directed into the esophagus from where it might bypass the rumen.

The effect of urea eaten in feed on the urea and ammonia concentration of the blood of steers is shown in Figures 3 and 4. When given in this manner 73 and 80 grams of urea eaten by steers 8 and 9, respectively, produced a slow rise in the urea-N blood level which reached its peak of about 24 mg. percent in from 2 to 2½ hours. The initial rise in urea-N was less rapid than that observed when comparable amounts of urea were given to steers No. 1 and 2 by stomach tube. Smaller amounts of urea consumed by steers 6 and 7 produced no significant change in blood urea. Ammonia-N levels for all steers remained below 2 mg. percent. Although the steers refused to eat urea in as large amounts as had been given some animals by stomach tube, it was possible by gradually increasing the percentage of urea in a mixed feed to induce one steer to eat 400 grams of urea daily for 70 days. Approximately 5 hours were required for the steer to eat the ration. Blood samples taken 2

hours after the steer had eaten contained 30.10 mg. percent of urea-N and 0.70 mg. percent of NH_3-N. At no time did this animal show symptoms of distress as a result of this high urea intake, although similar amounts and even smaller amounts of urea had proved fatal when given by stomach tube. In a feed lot test previously reported (Briggs, 1946) 8 steer calves gained weight and showed no symptoms of toxicity on rations which supplied 200 gms. of urea daily.

Since dilution of urea with mixed feed appeared to favor its slow hydrolysis and absorption, a suspension of 5 pounds of the basal ration, previously described, plus 180 grams of urea in 4 gallons of water was directed into the rumen of a steer by means of a long stomach tube. Blood urea-N values determined an hour later increased from an initial value of 12.95 mg. percent to 21.77 mg. percent; NH_3-N at that time was 2.52 mg. percent. The steer exhibited the characteristic ataxia and tetany of animals with blood NH_3-N values above 2 mg. but appeared perfectly normal three hours later.

It appears from the combined results of all experiments that toxic levels of urea are reflected in the rapid rise of urea-N of the blood and an increase in blood NH_3-N to values over 2.5 mg. percent. The extent of these blood changes with accompanying symptoms of alkalosis which may result in death is conditioned by the manner of administration. Apparently steers are able to consume relatively

large quantities of urea in mixed feed, one steer receiving 400 grams daily for 70 days without ill effects. In contrast, a similar or even smaller amount of urea suddenly directed into the esophagus or rumen may prove fatal.

THE METABOLISM OF UREA NITROGEN

Three series of metabolism studies were conducted in which both lambs and steers were used in each series. In the first, urea was added to maintenance rations in amounts necessary to provide 25 percent of the concentrate nitrogen. In the second, urea was added to similar rations in amounts necessary to provide 50 percent of the concentrate nitrogen. Urea was added to fattening rations in the third metabolism study.

Experimental Proceedure

Steers. Two-year-old Hereford steers were placed in false bottom stalls for the metabolism studies. Four rations were fed in each study and the steers were rotated so that each steer was on each ration, with a 10-day preliminary period preceeding each 10-day collection period. Feces were dropped into gutter boxes and removed at frequent intervals and placed in covered containers. The feces were weighed daily, aliquoted, and the samples preserved with thymol and refrigeration. Nitrogen determinations were made on the wet samples, proximate analyses were made on the samples after drying. Urine was directed by means of a rubber funnel into glass collecting jars containing toluene, and sufficient H_2SO_4 to produce a pH of approximately 5.5. The urine was measured daily and an aliquot stored in the refrigerator. Total nitrogen,

urea nitrogen, ammonia nitrogen and creatinine were determined on the 10-day composite samples. Total nitrogen was determined by the Kjeldahl method, urea and ammonia by the method of Van Slyke and Cullen (1913), and creatinine by the method of Folin (1914). Preliminary work indicated that if the urine were kept acid during the 10-day collection period very little urea and creatinine were lost, while both urea and creatinine were rapidly hydrolyzed to ammonia in alkaline samples. Urea nitrogen determinations were made on blood samples taken at the end of each collection period, approximately 8 hours after the last feeding.

Lambs. Eight western range lambs weighing from 50 to 60 pounds each, were fed 4 rations in each of the metabolism studies. The lambs were placed in small pens and fed the test rations during 10-day preliminary periods after which they were transferred to metabolism cages for 10-day collection periods. The lambs were rotated so that each lamb received each of the four rations. The metabolism cages were so designed that feces were collected on a wire screen. The urine passed through the screen and was directed by means of a sloping pan into a glass collecting jar to which toluene and acid were added. The urine was measured daily and an aliquot for nitrogen determinations stored at 0°C. In the first 2 studies the feces were dried at 100°C for 24 hours, sampled, and nitrogen determinations and proximate analyses made on the dry samples.

The feces obtained during the study in which the fattening rations were fed contained much more water, and nitrogen determinations were made on the wet samples. Nitrogen was determined by the Kjeldahl method; the proximate analyses were conducted as described by the Association of Official Agricultural Chemists (1940), all determinations being made on 10-day composite samples.

Blood samples were taken at the end of each collection period, approximately 8 hours after the last feeding. Urea nitrogen was determined according to the method of Van Slyke and Cullen (1915).

Results of Maintenance Studies

The rations fed steers and lambs in the first metabolism study are given in tables 2 and 3 respectively. The ration constituents were fed in exactly the same proportions to both, with the lambs receiving 14 percent of the quantity given steers. The concentrate feeds in rations B and D are in the same proportions as they occur in the experimental pellet used at this station in which urea supplies 25 percent of the nitrogen. Rations A and C represent the constituents of this pellet without the urea; thus by comparison of ration A to B and of C to D the exact effect of the urea may be ascertained. Rations C and D supply 3 times the quantity of concentrates supplied by A and B, and comparison of the results from rations B and D will indicate the effect of protein level and energy intake on urea utilization.

TABLE 2. DAILY AMOUNTS AND CHEMICAL COMPOSITION OF THE FEEDS USED IN MAINTENANCE RATIONS GIVEN STEERS IN THE FIRST METABOLISM STUDY

Feed	Daily allowance in				Dry matter	Percentage composition of dry matter				
	Ration A	Ration B	Ration C	Ration D		Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	gm.	gm.	gm.	gm.	percent					
Prairie hay	4536	4536	4536	4536	92.38	4.95	2.27	32.83	51.55	91.60
Cottonseed meal	311	311	933	933	92.68	42.94	7.37	10.56	32.87	93.85
Hominy feed	50	50	150	150	90.44	12.81	6.91	5.15	71.39	96.25
Molasses	45	45	135	135	70.60	3.33	--	---	86.87	90.20
Urea[1]	--	18.6	--	56.0	100.00	262.50	--	---	---	---

[1] The urea fed in all the metabolism studies was a commercial preparation of urea with small amounts of conditioning agents added, the product carries the trade name of Du Pont "Two-Sixty-Two".

TABLE 3. DAILY AMOUNTS AND CHEMICAL COMPOSITION OF THE FEEDS USED IN MAINTENANCE RATIONS GIVEN LAMBS IN THE FIRST METABOLISM STUDY

Feed	Daily allowance in				Dry matter	Percentage composition of dry matter				
	Ration A	Ration B	Ration C	Ration D		Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	gms.	gms.	gms.	gms.	percent					
Prairie hay	636	636	636	636	92.09	4.63	2.45	30.43	53.54	91.06
Cottonseed meal	43.5	43.5	131	131	92.81	42.50	7.55	10.77	33.38	94.16
Hominy feed	7.0	7.0	21	21	90.89	12.52	7.44	5.04	71.39	96.39
Molasses	6.3	6.3	18.9	18.9	70.60	3.33	--	---	86.87	90.20
Urea	--	2.60	--	7.84	100.00	262.50	--	---	---	---

The chemical composition of the rations is given in table 4. Ration A supplied the steers 0.33 pounds of digestible protein daily, while ration C supplied 0.80 pounds. The reported maintenance requirements for digestable protein vary among different workers, much of which is due to different methods of determination. For cattle of comparable weight to those used in this study, Mitchell (1929) reports that 0.245 pounds of digestible protein daily are required for maintenance, Armsby (1917) 0.385 pounds, and Morrison (1946) recommends 0.76 to 0.83 pounds. The values of Mitchell and Armsby were calculated from data on endogenous nitrogen and nitrogen balance. Morrison's values were estimated from response in feed lot experiments under more practical conditions and are generally more widely used in feeding operations in this country. Ration A may be considered to contain adequate protein for a theortical maintenance, while ration C was a more practical maintenance ration.

Ration A supplied lambs 0.05 pounds of digestible protein daily while ration C supplied 0.11 pounds. Calculation from Brody's (1934) equation, in which maintenance protein requirement is related to the 0.734 power of the body weight, gives a maintenance requirement of digestible protein of 0.045 pounds for a 60 pound lamb. Thus as was the case with steers, ration A supplied lambs a theortical maintenance protein requirement, while ration C was a more practical maintenance ration.

TABLE 4. CHEMICAL COMPOSITION OF THE RATIONS GIVEN LAMBS AND STEERS IN THE FIRST METABOLISM STUDY

Ration	Percentage composition of dry matter				
	Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
A	7.39	2.65	30.63	51.04	91.72
B	8.45	2.64	30.56	50.94	91.53
C	11.30	3.21	27.64	49.76	92.02
D	13.94	3.17	27.35	49.23	91.05

In any study of protein utilisation, and especially when the nitrogen balance method is used, it is necessary to have adequate energy intake. When the dietary energy intake is insufficient to meet the maintenance requirements, body protein is catabolized and the nitrogen excreted. This would lead to lowered values for nitrogen retention and interfere with evaluation of dietary protein utilization. Kriss (1931) gave a value of 3.67 pounds of T.D.N. daily as the maintenance requirement for cattle weighing 700 pounds, the average body weight of steers used in the first study. Rations A and C supplied daily 5.44 and 6.97 pounds T.D.N. respectively. Thus the rations have adequate energy intake to supply the maintenance requirements. Lambs received 0.70 and 0.85 pounds of T.D.N. daily from rations A and C respectively, which is well above Brody's (1934) value of 0.28 pounds as the estimated

daily T.D.N. requirement for animals weighing 60 pounds.

The average daily nitrogen balance data for steers in the first metabolism study are given in table 5. The nitrogen intake as protein refers to the total nitrogen intake minus the amount in the added urea, and contains the small quantities of non-protein nitrogen known to be present in ordinary feed stuffs. The urea and NH_3 nitrogen were reported together because fresh urine samples were found to contain very little NH_3 nitrogen, and even under the best of conditions some urea was hydrolyzed.

Urea plus NH_3 nitrogen varied with total urinary nitrogen, and as might be expected comprised a greater percentage of the total urinary nitrogen at the higher levels of nitrogen intake. The dietary urea produced a marked increase in urinary urea plus NH_3 nitrogen. An addition of 23.5 grams of urea nitrogen to ration C to make ration D produced an increase in urinary urea plus NH_3 nitrogen of 16.7 grams, while an addition of 41.9 grams of protein nitrogen to ration A to make ration C produced an increase in urinary urea plus ammonia nitrogen of 18.9 grams. The dietary urea nitrogen had no effect on fecal nitrogen indicating complete absorption of the nitrogen of urea.

The addition of 7.8 grams of urea nitrogen to ration A increased nitrogen retention from 0.2 grams daily to 4.2 grams daily, a difference which was statistically significant when tested by the t-test, Snedecor (1946). This

TABLE 5. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR STEERS IN THE FIRST METABOLISM STUDY

Ration	N intake			N excretion			N retained	Urea N in blood	Creatinine in urine
				Urine		Feces			
	As protein	As urea	Total	As urea + NH_3	Total	Total			
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	mg. percent	gm.
A	53.8	--	53.8	11.6	23.4	30.2	0.2	9.6	9.1
B	53.8	7.8	61.6	13.3	27.8	29.6	4.2	11.8	8.5
C	95.7	--	95.7	25.0	42.3	37.8	15.6	12.6	9.9
D	95.7	23.5	119.2	41.7	59.4	37.8	22.3	18.2	10.6

TABLE 6. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR LAMBS IN THE FIRST METABOLISM STUDY

Ration	N intake			N excretion		N retained	Urea N in blood
	As protein	As urea	Total	Urine	Feces		
	gm.	gm.	gm.	gm.	gm.	gm.	mg. percent
A	7.2	-	7.2	2.8	3.9	0.5	7.8
B	7.2	1.1	8.3	3.5	3.9	0.9	8.6
C	13.0	-	13.0	5.2	5.0	2.8	12.2
D	13.0	3.3	16.3	6.7	5.1	4.5	17.0

increase in nitrogen retention represents 51.3 percent of the urea nitrogen added. The addition of 23.5 grams of urea nitrogen to ration C increased nitrogen retention 6.7 grams or 28.5 percent of the urea nitrogen added, a difference which was significant.

The dietary urea nitrogen produced significant increases in blood urea nitrogen at both levels of feeding. The addition of 23.5 grams of urea nitrogen to ration C increased blood urea nitrogen from 12.6 to 18.2 mg. percent. If it be assumed that urea nitrogen increased in all body tissues at the same rate as in the blood, the increase in body urea nitrogen between rations C and D would amount to 17.8 grams in a 700 pound steer. However since this increase is spread over the 10-day preliminary and 10-day collection periods, it would amount to only 0.89 grams of nitrogen daily. The dietary urea nitrogen improved nitorgen balance 6.7 grams daily between rations C and D and thus the increase in body urea nitrogen will account for only 13.3 percent of the increased nitrogen retention. The difference in nitrogen retention between rations C and D was significant after removal of the 0.89 grams which represented the assumed increase in body urea nitro en.

Urinary creatinine ranged from 8.5 grams daily in ration C to 10.6 grams in ration D and tended to be slightly higher on the high protein rations; however analysis of variance, Snedecor (1946), revealed no significant differences between rations. The average daily creatinine

nitrogen values for all rations was 3.64 grams; Brody (1933) gives a value of 3.388 grams for dairy cattle of the same weight.

The average daily nitrogen balance data for lambs in the first metabolism study are given in table 6. Here again the urea nitrogen was apparently completely absorbed, as judged by the similar fecal nitrogen values in rations A and B and C and D. The addition of 1.1 grams of urea nitrogen increased nitrogen retention 0.4 grams, a difference which did not prove significant. When 3.3 grams of urea nitrogen were added, nitrogen retention was increased 1.3 grams, and the increase was significant. The increase in nitrogen retention in ration D over ration C amounted to 51.5 percent of the urea nitrogen added. Since only 1.1 grams of urea nitrogen were added in ration B, the increased nitrogen retention was not significant because of the relatively large experimental error always encountered in metabolism studies. Blood urea levels were similar to these in steers on the same rations, ranging from 7.8 mg. percent on ration A to 17.0 on ration D.

Table 7 gives the apparent digestion coefficients of nutrients in the rations fed steers in the first metabolism study. There were significant differences only in the digestibility of protein and fat. Addition of urea to a ration would be expected to increase the digestibility of crude protein, since the nitrogen of urea was found to be completely absorbed. The increase in protein nitrogen

TABLE 7. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED STEERS IN THE FIRST METABOLISM STUDY

Ration	Apparent digestibility of nutrients in ration				
	Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	percent	percent	percent	percent	percent
A	43.7	50.5	62.0	58.8	58.5
B	52.6	49.6	66.4	63.1	62.5
C	60.5	65.8	66.5	64.5	64.7
D	68.4	65.4	64.5	62.2	61.3

TABLE 8. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED LAMBS IN THE FIRST METABOLISM STUDY

Ration	Apparent digestibility of nutrients in ration				
	Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	percent	percent	percent	percent	percent
A	46.1	53.7	58.0	58.3	57.2
B	52.9	54.4	58.2	59.0	57.6
C	61.3	67.9	57.8	60.5	60.4
D	68.6	67.1	57.8	60.9	60.2

between rations A and C resulted in a significant increase in protein digestibility, the values being 43.7 percent for ration A and 60.5 percent for ration C. Neither the increased protein intake in rations C and D nor the urea in rations B and D affected the digestibility of crude fiber or N-free extract.

The apparent digestion coefficients for lambs given in table 8 follow the same pattern as did those of the steers, with significant differences obtained only in digestibility of protein and fat. Comparison of digestion coefficients between lambs and steers reveals that lambs were slightly more efficient in digestion of fat and protein, while steers were more efficient in the digestion of crude fiber and N-free extract.

The rations offered steers in the second metabolism study are given in table 9. The concentrate feeds in rations F and H are in the same proportions as they occur in the experimental pellet in which urea has furnished 50 percent of the nitrogen. Rations E and G have all the pellet constituents except urea. Ration H proved completely unpalatable; none of the 6 steers in the study completely consumed the ration. Ration G was completely consumed by all the steers, and since ration H differs only in urea addition, its unpalatibility must be attributed to its high urea content. No data are presented for rations G and H since feed refusuals make a comparison impossible. The rations fed lambs in the second metabolism study are given

TABLE 9. DAILY AMOUNTS AND CHEMICAL COMPOSITION OF THE FEEDS USED IN MAINTENANCE RATIONS OFFERED STEERS IN THE SECOND METABOLISM STUDY

Feed	Daily allowance in				Dry matter	Percentage composition of dry matter				
	Ration E	Ration F	Ration G	Ration H		Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	gm.	gm.	gm.	gm.	percent					
Prairie hay	3629	3629	3629	3629	93.02	5.13	2.41	32.49	53.06	93.10
Cottonseed meal	227	227	681	681	93.11	44.68	7.14	9.53	32.15	93.51
Hominy feed	145	145	435	435	91.35	12.64	6.19	5.52	71.69	96.05
Molasses	45	45	136	136	70.60	3.33	--	---	86.87	90.20
Urea	--	37.2	--	111.6	100.00	262.5	--	---	---	---

TABLE 10. DAILY AMOUNTS AND CHEMICAL COMPOSITION OF THE FEEDS USED IN MAINTENANCE RATIONS GIVEN LAMBS IN THE SECOND METABOLISM STUDY

Feed	Daily allowance in				Dry matter	Percentage composition of dry matter				
	Ration E	Ration F	Ration G	Ration H		Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	gm.	gm.	gm.	gm.	percent					
Prairie hay	508	508	508	508	92.71	5.58	2.45	31.49	53.38	92.90
Cottonseed meal	31.8	31.8	95.4	95.4	92.82	44.55	7.09	8.42	33.58	93.64
Hominy feed	20.3	20.3	60.9	60.9	91.39	12.67	6.38	5.61	71.45	96.10
Molasses	6.3	6.3	18.9	18.9	70.60	3.33	--	---	86.87	90.20
Urea	--	5.21	--	15.6	100.00	262.50	--	---	---	---

in table 10. The ration constituents were fed in the same proportions as offered steers, the lambs again receiving 14 percent of the quantity given steers. The lambs completely consumed all rations. The rations fed lambs and steers in the second metabolism study were similar to those used in the first except that urea supplied 50 percent of the concentrate nitrogen instead of 25, and the same type of comparisons may be made.

The chemical composition of the rations fed steers and lambs in the second metabolism study are given in table 11. Ration E supplied steers 0.31 pounds of digestible protein daily which is quite similar to the quantity supplied by ration A and meets the theoretical maintenance requirements of Mitchell (1929). Ration E supplied lambs with 0.04 pounds of digestible protein daily while ration G furnished 0.10. Steers received 5.03 pounds of T.D.N. daily from ration E, lambs received 0.70 pounds and 0.85 pounds daily from rations E and G respectively. The T.D.N. intake for both steers and lambs was adequate to cover their maintenance requirements as estimated by Grody (1934).

TABLE 11. CHEMICAL COMPOSITION OF THE RATIONS OFFERED LAMBS AND STEERS IN THE SECOND METABOLISM STUDY

Ration	Percentage composition of dry matter				
	Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
E	7.65	2.79	29.70	52.80	93.16
F	8.52	2.76	29.41	52.28	92.24
G	11.85	3.40	25.29	52.91	93.09
H	17.92	3.31	24.67	51.63	90.83

The average daily nitrogen balance data for steers in the second metabolism study are given in table 12. The addition of 15.6 grams of urea nitrogen in ration F increased urea plus NH_3 nitrogen excretion 13.3 grams, a difference which accounts for most of the increase in total urinary nitrogen. The addition of urea to the ration did not increase fecal nitrogen values, a result observed in both steers and lambs in the first metabolism study. The dietary urea nitrogen did not materially alter nitrogen retention for steers in this study, as four of the six steers used stored more nitrogen on ration E than on F. The slight increase in average nitrogen retention in ration F is due to steer No. 5 having a negative nitrogen balance of 7.4 grams when fed ration E. The dietary urea produced a significant increase in blood urea nitrogen at the level fed with the 15.6 grams of dietary urea nitrogen fed daily increasing blood urea nitrogen 4.5 mg. percent. No significant differences in urinary creatinine were obtained, the values being 8.7 grams for ration E and 8.9 for ration F. These values are slightly lower than those obtained in the first study. This difference may be attributed to the lower body weight of steers used in the second study as the values per unit of body weight were quite similar.

The average daily nitrogen balance data for lambs in the second metabolism study are given in table 13. An idea of the effect of dietary urea on urinary nitrogen

TABLE 12. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR STEERS IN THE SECOND METABOLISM STUDY

Ration	N intake			N excretion			N retained	Urea N in blood	Creatinine in urine
	As protein	As urea	Total	Urine		Feces			
				As urea+NH3	Total	Total			
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	mg. percent	gm.
E	45.9	-	45.9	10.2	21.6	21.9	2.4	7.0	8.7
F	45.9	15.6	61.5	23.5	36.0	21.5	4.0	12.5	8.9

TABLE 13. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR LAMBS IN THE SECOND METABOLISM STUDY

Ration	N intake			N excretion		N retained	Urea N in blood
	As protein	As urea	Total	Urine	Feces		
	gm.	gm.	gm.	gm.	gm.	gm.	mg. percent
E	6.8	-	6.8	2.1	3.4	1.3	4.7
F	6.8	2.2	9.0	3.8	3.4	1.8	7.9
G	11.9	-	11.9	3.8	4.5	3.6	9.9
H	11.9	6.6	18.5	8.5	4.4	5.6	13.7

may be obtained by comparison of rations F and G. In ration F, 9.0 grams of total nitrogen, in which urea contributed 2.2 grams, produced the same quantity of urinary nitrogen as the 11.9 grams of protein nitrogen in ration G. The dietary urea again did not appreciably increase fecal nitrogen. The difference in nitrogen retention between rations G and H proved significant statistically, while that between H and F did not. The addition of 6.6 grams of urea nitrogen in ration H increased nitrogen retention 2.0 grams or 30.3 percent of the added urea nitrogen. This seems to indicate a species difference between steers and lambs in urea utilization, since steers did not utilize the urea nitrogen when it supplied 50 percent of the concentrate nitrogen. The blood urea nitrogen values for lambs in the second metabolism study were quite similar to those obtained in previous trials, ranging from an average of 4.7 mg. percent on ration E to 13.7 on ration H.

Table 14 presents the apparent digestion coefficients for steers in the second metabolism study. The only significant difference was the increased protein digestibility of ration F. The digestion coefficients for lambs in this study are given in table 15. Again addition of urea affected only the apparent digestibility of crude protein. The increased protein nitrogen between rations F and G also significantly increased apparent digestibility of crude protein.

TABLE 14. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED STEERS IN THE SECOND METABOLISM STUDY

Ration	Apparent digestibility of nutrients in ration				
	Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	percent	percent	percent	percent	percent
E	52.3	57.2	70.2	66.5	66.3
F	65.0	57.6	71.8	67.3	67.4

TABLE 15. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED LAMBS IN THE SECOND METABOLISM STUDY

Ration	Apparent digestibility of nutrients in ration				
	Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	percent	percent	percent	percent	percent
E	49.0	58.6	62.9	61.2	60.0
F	61.8	58.3	65.3	61.8	61.8
G	61.6	71.8	60.4	63.2	63.2
H	75.7	72.6	62.3	66.0	64.8

If it is assumed that the increased nitrogen retention observed when urea was added to a ration is due to the urea nitrogen being converted to protein and stored in the body, a coefficient may be calculated that will compare urea utilization between lambs and steers and between different rations. Such coefficient may be calculated by dividing the increased nitrogen retention observed when urea was added to the ration by the amount of urea nitrogen added. If the quotient is multiplied by 100 it should represent the percentage utilization of urea nitrogen. Comparisons should be made only in such instances that the increased nitrogen retention resulting from urea addition were significant.

The coefficients of urea utilization of steers fed rations B and D were 51.3 and 28.5 percent respectively, and the value for lambs on ration D was 51.5. These values indicate that lambs and steers utilize urea with similar efficiency when it is fed to supply 25 percent of the concentrate nitrogen. Lambs fed ration B utilized only 30.3 percent of the dietary urea nitrogen, a value which indicates that lambs utilize urea more efficiently when it supplies only 25 percent of the concentrate nitrogen. Since steers did not utilize the urea nitrogen at all at the 50 percent level, lambs may be considered more efficient in utilization of urea nitrogen at high levels of feeding.

Discussion. The data presented confirm previous

work, Briggs et al. (1947), Owen et al. (1943), Loosli and McCay (1943), Harris and Mitchell (1941a, 1941b), that additions of urea improves nitrogen balance in cattle and lambs. The increased retention of nitrogen cannot all be due to increases in concentration of urea nitrogen in body tissues, as shown by calculation using changes in blood urea nitrogen as in index to changes in total body urea nitrogen. The validity of this assumption was proved by determination of the urea content of muscle and liver tissue from steers which had received dietary urea and others which had not. The differences obtained almost exactly paralleled differences in blood urea nitrogen concentration. It becomes evident that the addition of urea resulted in increased retention of protein or amino acid nitrogen. This increased nitrogen retention may have been due to urea exerting a stimulatory effect on the utilization of the dietary protein nitrogen, or the nitrogen of the urea may have been used in synthesis of amino acids.

The fecal nitrogen values obtained in these maintenance studies suggest bacterial action in the rumen cannot be solely responsible for the utilization of urea under these conditions. The addition of urea did not increase fecal nitrogen values at any time. This means that if bacteria in the rumen used the urea nitrogen for protein synthesis this protein was completely digested and absorbed by the host.

When urea supplied 25 percent of the concentrate

nitrogen, lambs were about equally efficient in its utilization at both levels of concentrate feeding, while steers were more efficient when the concentrate was fed at the lower level. The response of steers and lambs to the constituents of the 50 percent urea pellet indicates a species difference in palatability of urea containing feeds, when the constituents of this pellet were offered at the high level of intake they were unpalatable to steers but were completely consumed by all the lambs. Steers ate the constituents of the 50 percent pellet at the low level of intake, but urea did not significantly improve nitrogen retention.

Results of Fattening Studies

The rations fed to steers and lambs in the third metabolism study are given in tables 16 and 17, respectively. The ration constituents were fed in the same proportions to both with the lambs receiving 12 percent of the quantity given the steers. The cottonseed meal, hominy feed, molasses, and urea in ration J were fed in the same proportions as they were present in experimental urea pellet No. 1 fed at this station; in this pellet urea had supplied approximately 25 percent of the nitrogen. Ration I was the same except that no urea was added. The constituents of the experimental urea pellet No. 2 used at this station, in which urea supplied 50 percent of the nitrogen, were added to the corn and prairie hay in ration L. Ration K was comprised of the same constitu-

TABLE 16. DAILY AMOUNTS AND CHEMICAL COMPOSITION OF THE FEEDS USED IN FATTENING RATIONS GIVEN STEERS IN THE THIRD METABOLISM STUDY

Feed	Daily allowance in				Dry matter	Percentage composition of dry matter				
	Ration I	Ration J	Ration K	Ration L		Protein (Nx6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
	gm.	gm.	gm.	gm.	Percent					
Prairie Hay	1815	1815	1815	1815	90.69	4.80	2.17	33.84	52.24	92.75
Corn	3100	3100	3100	3100	87.75	9.97	4.90	1.81	81.79	98.47
Cottonseed meal	390	390	284	284	91.04	44.88	7.04	11.39	31.25	93.96
Hominy feed	63	63	182	182	89.67	10.00	5.82	5.91	76.92	98.05
Molasses	57	57	57	57	70.60	3.33	--	---	86.87	90.20
Urea	--	23.3	---	46.6	100.0	262.50	---	---	---	97.35

TABLE 17. DAILY AMOUNTS AND CHEMICAL COMPOSITION OF THE FEEDS USED IN FATTENING RATIONS GIVEN LAMBS IN THE THIRD METABOLISM STUDY

Feed	Daily allowance in				Dry matter	Percentage composition of dry matter				
	Ration I	Ration J	Ration K	Ration L		Protein (Nx6.25	Ether extract	Crude fiber	N-free extract	Organic matter
	gm.	gm.	gm.	gm.	Percent					
Prairie Hay	218	218	218	218	92.80	4.48	2.31	34.43	51.82	93.04
Corn	372	372	372	372	88.21	10.30	4.92	2.06	81.23	98.53
Cottonseed meal	46.8	46.8	34.1	34.1	91.20	44.07	6.69	11.51	31.54	93.81
Hominy feed	7.6	7.6	21.8	21.8	89.73	10.13	5.13	6.06	76.97	98.29
Molasses	6.8	6.8	6.8	6.8	70.00	3.33	--	---	86.87	90.20
Urea	---	2.8	---	5.6	100.00	262.50	---	---	---	97.35

ents except no urea was fed. The four rations proved very palatable to both steers and lambs.

The chemical composition of the rations is given in table 18. The steers digested 0.65 pounds of protein daily from ration I, while they digested 0.56 pounds of protein daily from ration K. Mitchell (1929) states that the minimum protein requirement for fattening cattle is 0.75 to 1.5 pounds of digestible protein daily per 1000 pounds live weight. The steers in the third metabolism study had an average weight of 600 pounds so that their minimum protein requirement, according to Mitchell, should have been from 0.45 to 0.90 pounds of digestible protein daily. Morrison (1946), however, recommends 1.20 to 1.41 pounds of digestible protein daily for fattening cattle weighing 600 pounds, and the National Research Council (1945) recommended 1.3 pounds. According to Morrison's and the National Research Council recommendations both fattening rations contained inadequate protein.

Ration I supplied lambs with 0.081 pounds of digestable protein daily while ration K supplied 0.076. The National Research Council (1945) recommended 0.18 pounds of digestible protein daily for fattening lambs of the size used in this study, and Morrison (1946) recommended 0.20 to 0.23 pounds. According to these standards the lamb rations contained inadequate digestible protein.

TABLE 18. CHEMICAL COMPOSITION OF RATIONS GIVEN LAMBS AT SPELL IN THE THIRD METABOLISM STUDY

Ration	Percentage composition of dry matter				
	Protein (N x 6.25)	Ether extract	Crude fiber	N-free extract	Organic matter
I	10.68	4.09	13.39	67.96	96.11
J	11.90	4.07	13.32	67.64	95.66
K	9.99	4.05	13.26	68.89	96.20
L	12.41	4.01	13.13	68.22	95.27

The average daily nitrogen balance data for steers in the third metabolism study are given in table 19. The addition of 9.8 grams of urea nitrogen to ration I increased urinary nitrogen 9.2 grams; this increase was entirely accounted for by the increased excretion of urea plus ammonia. The addition of 19.6 grams of urea nitrogen to ration K increased total urinary nitrogen excretion 11.8 grams, and urinary urea plus ammonia was increased 12.2 grams.

The addition of 9.8 grams of urea nitrogen to ration I increased nitrogen retention in steers 1.4 grams, a difference which was not significant. The addition of 19.6 grams of urea nitrogen to ration K increased nitrogen retention 9.4 grams, and the increase was significant.

The blood urea nitrogen levels for steers receiving rations I, J, K, and L were 6.5, 7.5, 6.8, and 3.6 mg.

TABLE 19. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR STEERS IN THE THIRD METABOLISM STUDY

Ration	N intake			N excretion			N retained	Urea N in blood	Creatinine in urine
	As protein	As urea	Total	Urine		Feces			
				As urea+NH3	Total	Total			
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	mg. percent	gm.
I	82.7	-	82.7	10.7	25.6	36.7	22.4	6.3	10.7
J	82.7	9.8	92.5	19.9	32.8	35.9	23.8	7.5	10.9
K	77.4	-	77.4	8.8	20.9	37.1	19.4	6.8	10.0
L	77.4	19.6	97.1	21.0	32.7	35.6	28.8	8.6	10.0

TABLE 20. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR LAMBS IN THE THIRD METABOLISM STUDY

Ration	N intake			N excretion		N retained	Urea N in blood
	As protein	As urea	Total	Urine	Feces		
	gm.	gm.	gm.	gm.	gm.	gm.	mg. percent
I	9.9	-	9.9	2.4	4.3	3.2	5.6
J	9.9	1.2	11.1	2.7	4.5	3.9	7.6
K	9.3	-	9.3	2.3	4.3	2.7	4.0
L	9.3	2.4	11.7	3.2	4.3	4.2	6.5

percent respectively. These values are lower than those of lambs receiving the same intake of nitrogen in maintenance rations.

Urinary creatinine values ranged from 10.0 to 10.9 grams daily, and there were no significant differences in excretions of steers on the different rations.

The average daily nitrogen balance data for lambs in the third metabolism study are given in table 20. The addition of 1.2 grams of urea nitrogen to ration I increased urinary nitrogen excretion 0.3 grams and the addition of 2.4 grams of urea nitrogen to ration A increased urinary nitrogen 0.9 grams. Fecal nitrogen was not significantly increased by the urea additions.

The addition of 1.2 grams of urea nitrogen to ration I increased nitrogen retention 0.7 grams, a difference which was not significant. The addition of 2.4 grams of urea nitrogen to ration K increased nitrogen retention 1.5 grams, a significant increase.

Blood urea nitrogen values for lambs on the fattening rations were lower than those for lambs on maintenance rations, and ranged from 4.0 mg. percent on ration K to 7.6 on ration J. The additions of urea to the rations did not significantly increase blood urea nitrogen for lambs in the fattening studies.

Discussion

Both steers and lambs stored a greater percentage of nitrogen in fattening rations than in maintenance rations.

Table 21 summarizes the results of the metabolism studies in which rations A through H can be designated as maintenance rations and those from I through K as fattening rations. These values for percent nitrogen retained emphasize the well known protein sparing action of dietary carbohydrates.

Urea improved nitrogen balance in lambs when added to both maintenance and fattening rations at both levels of feeding. Nitrogen balance in steers was improved when urea was added to fattening rations and when it was added to maintenance rations at a level to supply 25 percent of the concentrate nitrogen, but not at a level to supply 50 percent of the concentrate nitrogen. It has been demonstrated by Harris and Mitchell (1941a) that sheep receiving dietary urea do not excrete urea through the skin and unpublished data from the Oklahoma Experiment Station has shown that steers eating rations containing urea do not expire ammonia. Also it has been pointed out that increases in tissue urea plus ammonia content could account for only a small part of the increased nitrogen retention resulting from additions of urea to rations for cattle and sheep. Hence the increased nitrogen retention resulting from additions of urea to the rations should be attributed to an increase in body protein of the animals. Thus the nitrogen balance method should be an accurate measure of the value of dietary urea as a precursor of protein for cattle and sheep.

TABLE 21. SUMMARY OF THE NITROGEN BALANCE DATA FOR THE METABOLISM STUDIES

Ration	N Intake				N Retained		Coefficient of urea utilization	
	Steers		Lambs		Steers	Lambs	Steers	Lambs
	Total	As urea	Total	As urea				
	gm.	gm.	gm.	gm.	percent	percent	percent	percent
A	53.8	--	7.2	--	0.04	6.94	---	---
B	61.6	7.8	8.3	1.1	6.81	10.84	81.28*	33.36
C	95.7	--	13.0	--	16.30	21.54	---	---
D	119.2	23.5	16.3	3.3	18.71	27.61	28.51*	51.51*
E	45.9	--	6.8	--	5.23	19.11	---	---
F	61.5	15.6	9.0	2.2	6.50	20.00	10.26	22.73
G	--	--	11.9	--	--	30.25	---	---
H	--	--	18.6	6.6	--	30.27	---	30.30*
I	82.7	--	9.9	--	27.09	32.32	---	---
J	82.7	9.8	9.9	1.2	28.72	35.14	14.29	58.33
K	77.4	--	9.3	--	25.08	29.03	---	---
L	77.4	19.6	9.3	2.4	29.66	35.90	47.06*	62.50*

The calculation of the coefficient of urea utilization was explained earlier and may be considered the percent of dietary urea nitrogen which was retained. It is difficult to relate the coefficients of urea utilization with the level of urea fed, the protein content of the basal ration, or the carbohydrate content of the basal ration. Steers were more efficient in the utilization of urea at the low level of feeding than at the high level in maintenance rations, while the reverse was true when urea was added to fattening rations. The utilization of urea by steers did not be related to the protein or carbohydrate content of the basal ration.

Lambs were slightly more efficient in the utilization at the high level of feeding than at the low level in both maintenance and fattening rations, and again no relation could be found between the protein content of the basal ration and the efficiency of urea utilization. The lambs were more efficient in the utilization of urea in fattening rations than in maintenance rations, indicating that dietary carbohydrate may enhance urea utilization in these animals. Wegner et. al. (1941) found that bacterial synthesis of protein, using the nitrogen of urea, decreased as the protein level of the rumen ingesta increased, and Wegner et. al. (1942), found that a readily fermentable carbohydrate increased urea utilization. From these observations it would be expected that urea would be more efficiently utilized when added to low protein rations

and also when added to fattening rations. This was not in general, true in our metabolism studies. Explanation of these discrepancies may involve a reconsideration of possible mechanisms for urea utilization.

Knowledge of the mechanism of urea utilization is of great practical and theoretical importance. If the exact mechanism were known rations could be designed to produce maximum utilization of urea nitrogen. From the results of the metabolism studies, the effects of orally administered urea, and the literature reports of other workers, it appears that there exist at least three possible mechanisms by which the ruminant can utilize urea nitrogen.

The rumen fistula work of Wegner et. al. (1941) and Mills et. al. (1942) and the in vitro studies of Pearson and Smith (1943a, 1943b, 1943c) indicate that rumen bacteria are able to use the nitrogen of urea for protein synthesis. However, some of this bacterial protein should escape digestion and appear in the feces. In no instance in the six metabolism studies of this station, which have involved 17 steers and 24 lambs, did additions of urea significantly increase fecal nitrogen. It would appear that, in addition to rumen synthesis of protein, other mechanisms of urea utilization should be considered.

A second possible mechanism of urea utilization can be postulated from the results of oral administration of urea to sheep and cattle. Ammonia was produced and absorbed when water solutions of urea were given. This

indicated that the feeding of urea to ruminants may be quite similar to the feeding of ammonium salts. Taylor and Ringer (1913) fed ammonium carbonate to dogs, and the dogs retained as high as 50 percent of the nitrogen. These workers suggested that the high concentration of ammonia reversed the process of deaminization of amino acids, thus resulting in increased nitrogen retention. This mechanism may be involved in the utilization of urea by ruminants and may explain the lack of change in fecal nitrogen values when urea was added.

Evidence of a third possible mechanism of urea utilization may be obtained by comparison of the literature reports of other workers with the results of our metabolism studies. Harris et. al. (1943) fed a basal ration to steers which supplied only 5.31 grams of nitrogen daily and to this added urea to increase the daily nitrogen intake to 59.40 grams daily. The average daily fecal nitrogen values were 9.50 grams for the basal ration and 15.60 grams for the urea ration. Since urea and ammonia are readily absorbed, it is unlikely that this increased fecal nitrogen was due to unabsorbed urea or ammonia; more likely it resulted from the undigested bacterial protein. The addition of urea to rations supplying from 45.9 to 95.7 grams of protein nitrogen to steers did not increase fecal nitrogen in our metabolism studies.

Harris and Mitchell (1941a) added 4.63 grams of urea nitrogen to a basal ration which supplied 0.62 grams of

nitrogen to sheep and fecal nitro en was increased 1.14 grams daily. In ration 4 fed to sheep in our second metabolism study, the addition of 6.6 grams of urea nitrogen to a ration containing 11.9 grams of protein nitrogen did not increase fecal nitro en. Since our rations contained more protein nitrogen and since an addition of urea did not increase the fecal nitrogen, it is possible that urea acts to increase the utilization of preformed dietary protein. Thus the fecal nitrogen from undigested bacterial protein containing the urea nitrogen would tend to be counterbalanced by the decreased fecal nitrogen from preformed dietary protein. Swift et. al. (1947) actually decreased fecal nitrogen excretion by additions of urea to the rations of sheep.

It seems logical that all three of these mechanisms may function when urea is fed under practical conditions, the predominating mechanism being contingent upon the composition of the ration to which urea is added and possibly also on the species of animals used. The work of Wegner et. al. (1941) has shown that high protein rations depress the bacterial synthesis of protein from urea. It was also shown that a readily fermentable carbohydrate was necessary for bacterial utilization of urea nitrogen. Hence in high protein rations or low carbohydrate rations, bacterial synthesis could be expected to be a minor factor in urea utilization. However, high protein rations could be influenced by urea additions through a stimulatory

effect on the utilization of preformed dietary protein. This mechanism might account for a large part of the utilization of urea when added to high protein rations.

The extent of the utilization of urea by the absorption of ammonia and consequent depression of deaminization of amino acids would depend on the rate of formation and absorption of ammonia. There is no evidence available as to factors which affect the rate of ammonia absorption. Since ammonia is definitely formed in the rumen when urea is fed, it seems logical to conclude that there is competition between bacterial synthesis of protein and absorption of the ammonia. If this assumption is correct, the factors which decrease the rate of bacterial synthesis of protein could be expected to increase the utilization of urea by absorption of ammonia and consequent depression of deaminization of amino acids.

EXCRETION OF CREATININE AND CREATINE BY BEEF STEERS

In the classical theory of protein metabolism proposed by Folin (1905) two types of protein metabolism are recognized, one a constant or endogenous metabolism, and the other a variable or exogenous metabolism. According to this theory the endogenous metabolism is represented by the excretion of creatinine at a relatively constant rate which is independent of protein intake. More recently the independence of creatinine excretion to protein intake has been questioned and as pointed out by Friedemann and associates (1948), there has been increased emphasis on the variation rather than on the uniformity of creatinine excretion. Most of the research relating to this problem has been conducted with human subjects and laboratory animals.

The creatinine and creatine excretion of dairy cattle on standard dairy rations was studied by Ashworth and Brody (1933); however, no data were presented to show the effect of protein intake on the excretion of these two urinary constituents. Carpenter (1927) determined the creatinine and creatine excretion of beef steers on pasture and on maintenance rations. The protein intake of the animals was not calculated. Although similar values for creatinine excretion were obtained in these two investigations, slightly higher creatine values were

reported for the dairy cows than for the steers. In a comparison of the results, Ashworth and Brody (1933) suggest that creatine excretion in cattle is influenced by the level of protein intake.

The present study was undertaken to determine the creatinine and creatine excretion of beef steers on rations containing different amounts of protein and different amounts of dietary urea added as a protein substitute.

Experimental Procedure

Two-year-old Hereford steers in metabolism stalls were fed rations of constant composition during 20-day periods. During the last 10 days of each period urine was quantitatively collected by means of rubber funnels which led to glass collection jars beneath the floor of the stalls. Toluene was used as a preservative and sufficient sulfuric acid was added to the collection jars to maintain the pH of the urine below 6. Preliminary work showed that at pH values below 6 both creatinine and creatine are stable. Urine was collected and measured daily. Creatinine and creatine were determined by Folin's method as outlined Hawk, et. al. (1947).

In the first series of experiments the nitrogen intake of all of the steers was approximately the same, the rations being composed of prairie hay supplemented with either cottonseed meal or a pelleted feed containing 75 percent cottonseed meal, 4 percent urea, 10 percent

molasses and 11 percent hominy feed. Creatinine and creatine were determined on daily samples of urine. The results are presented in table 22.

In the second series of experiments, the nitrogen intake of the steers was progressively increased from about 54 grams daily to 124 grams daily. The rations were composed of prairie hay supplemented with different amounts of the pelleted feed constituents used in the first experiments. Creatinine and creatine were determined on 10-day composited samples of urine which had been preserved as described above and stored at 0°C during the collection period. The combined results representing data secured from fifty-five animals are presented in table 23.

Results and Discussion

The results in table 22 show that the excretion of total nitrogen and creatinine nitrogen of individual steers on a uniform nitrogen intake is relatively constant from day to day as compared to variations between individuals. There are, however, some apparent exceptions. The greatest variations were observed with steers 3 and 6 on the 9th and 10th days of collection. Such variations as were observed in the daily creatinine excretion of individual animals were for the most part unrelated to the daily total nitrogen excretion. Creatine excretion varied markedly from day to day.

Differences between animals in excretion of total nitrogen over the 10-day periods were related to small

OF COTTONSEED MEAL AND UREA-CONTAINING PELLETS.

Steer No.	1			2			3			4			5			6			7		
Supplement	Urea-containing Pellets[2]			Cottonseed Meal			Urea-containing Pellets[2]			Cottonseed Meal			Urea-containing Pellets[2]			Urea-containing Pellets[2]			Cottonseed Meal		
Av. Body Wt. (Kgm.)	348.8			371.5			332.9			353.6			307.5			290.8			296.9		
N Intake (Gm.)	124.0			117.5			124.2			117.8			124.0			124.2			117.8		
Day	Tot. Urinary N Gm.	Creatinine N Gm.	Creatine N Gm.	Tot. Urinary N Gm.	Creatinine N Gm.	Creatine N Gm.	Tot. Urinary N Gm.	Creatinine N Gm.	Creatine N Gm.	Tot. Urinary N Gm.	Creatinine N Gm.	Creatine N Gm.	Tot. Urinary N Gm.	Creatinine N Gm.	Creatine N Gm.	Tot. Urinary N Gm.	Creatinine N Gm.	Creatine N Gm.	Tot. Urinary N Gm.	Creatinine N Gm.	Creatine N Gm.
1	53.9	2.62	1.26	51.3	3.62	0.00	57.5	2.29	0.47	45.3	3.58	0.84	58.5	3.54	1.01	66.0	1.60	1.23	58.6	2.29	0.49
2	60.0	3.39	1.11	57.7	3.62	1.71	57.0	2.15	0.94	54.7	3.29	1.26	68.6	4.02	0.85	43.7	1.65	1.90	62.6	2.91	0.61
3	59.1	3.28	0.73	51.9	4.09	0.41	62.4	2.51	1.93	53.4	3.36	1.31	66.6	3.92	0.37	45.4	2.39	0.60	53.0	2.57	1.48
4	67.8	5.53	1.30	57.7	4.36	0.43	82.4	3.35	1.37	56.2	4.59	0.45	69.5	5.12	0.44	62.2	2.37	0.65	59.5	3.59	0.92
5	62.0	3.72	1.00	57.9	3.83	0.48	63.2	3.23	0.60	50.8	3.51	1.32	68.6	3.85	0.72	48.1	2.29	0.26	55.4	2.96	1.32
6	54.3	4.74	0.93	57.3	5.47	0.13	76.2	3.82	1.06	56.0	3.65	0.88	64.8	3.99	1.62	46.9	1.08	0.46	58.7	2.66	0.74
7	56.3	4.96	1.40	54.0	4.99	0.75	68.9	3.44	0.77	46.5	3.52	1.67	50.2	2.27	0.82	44.5	2.12	1.08	54.4	3.11	1.03
8	60.9	3.64	0.79	51.3	3.06	1.36	66.5	2.79	1.29	47.1	2.96	1.45	76.4	3.71	1.19	61.3	2.00	0.84	58.5	2.94	0.52
9	62.4	3.69	2.30	53.5	4.64	0.66	37.5	1.95	0.12	49.0	3.77	0.39	73.3	4.02	0.49	37.7	1.82	0.48	57.3	3.41	0.78
10	63.6	3.63	0.95	60.0	4.48	0.10	30.8	1.78	0.38	59.7	4.02	1.43	76.1	3.92	1.79	38.6	5.39	0.20	65.5	2.88	0.57
Av.	60.0	3.92	1.15	55.3	4.33	0.61	66.2	2.74	0.89	51.9	3.62	1.07	67.3	3.84	0.93	54.4	2.27	0.77	58.4	2.93	0.68
Creatinine[3] Coefficient	11.24			11.63			8.36			10.25			12.48			7.80			9.88		

1. All steers received 10 lbs. of prairie hay and 3 lbs. of supplement daily.
2. The urea pellets contained 75% cottonseed meal, 4% urea, 10% molasses, and 11% hominy feed.
3. Mgm. of creatinine N per Kgm. of body weight.

differences in the amount, and particularly in the form of nitrogen ingested. As might be expected total nitrogen excretion of steers that received urea was generally high. There were also marked differences between animals in creatinine excretion. The differences were unrelated to the amount and form of nitrogen ingested. Although creatinine excretion is generally related to body weight, in these experiments the steers with low creatinine excretion values had correspondingly low creatinine coefficients.

Average creatinine and creatine coefficients for steers ingesting from 53.8 gm. to 124.0 gm. of nitrogen daily are given in table 23. The nitrogen balance status of these animals varied from nitrogen equilibrium to a positive nitrogen balance of 22.3 grams daily. It is obvious from the results that changes in nitrogen intake over the range studied and the addition of urea to the rations were without effect on the creatinine coefficients. The weighted mean creatinine coefficient was 11.18. This value is higher than the value of 9.5 reported by Ashworth and Grady (1933) for dairy cows. Differences in breed, age and sex of the animals might contribute to this difference. Carpenter (1927) reported creatinine coefficients between 8 and 9 for steers, however, destruction of creatinine during storage and shipping of the urines as described in his paper might easily account

TABLE 23. THE AVERAGE CREATININE AND CREATINE EXCRETION BY BEEF STEERS ON RATIONS CONTAINING DIFFERENT AMOUNTS OF PROTEIN AND UREA NITROGEN

Daily N intake[1]		No. of Animals	Ave. body weight	Daily Creatinine N excreted	Daily Creatine N excreted	Average Creatinine coefficient	Average Creatine coefficient
Total	As urea						
gm.	gm.		kgm.	gm.	gm.		
53.8	—	4	332.8	3.39	0.32	10.19	0.96
61.6	7.8	4	326.0	3.16	1.11	9.69	3.40
95.7	—	4	336.2	3.68	0.54	10.95	1.61
96.0	24.0	24	318.5	3.72	0.97	11.68	3.06
100.0	—	8	317.5	3.67	0.89	11.56	2.80
117.7	—	3	340.7	3.63	0.84	10.65	2.47
119.2	23.5	4	336.3	3.94	0.45	11.72	1.34
124.0	23.5	4	320.0	3.20	0.95	10.00	2.97

[1] All steers received 10 lbs. of prairie hay supplemented with varying amounts of cottonseed meal, urea, molasses, and hominy feed daily.

for these lower values.

The creatine coefficients shown in table 23 varied from 0.96 to 3.40 and could not be correlated with total nitrogen intake. The weighted mean creatine coefficient was 2.62, a value similar to that reported by Carpenter (1927) but considerably lower than the value of 7.6 reported by Ashworth and Brody (1933) for dairy cows.

SUMMARY

Studies were conducted to determine the physiological effect of orally administered urea, the metabolism of urea nitrogen when added to maintenance and fattening rations for steers and lambs, and the effect of dietary urea and protein level on the excretion of creatinine and creatine by beef steers.

Oral administration of 40 grams of urea in water solution to a sheep under light anesthesia produced a rapid rise in urea and ammonia of the portal blood. Portal blood-ammonia values, which continued to increase during the 2-hour observation period and reached 8.4 mg. percent, indicated hydrolysis of urea in the rumen and absorption of large quantities of ammonia. When administered as a drench to steers, urea in amounts exceeding 100 grams produced a rapid rise in the levels of both urea and ammonia of the systemic blood. Ataxia appeared in steers when ammonia nitrogen of the systemic blood reached a level of approximately 2.5 mg. percent, and symptoms of alkalosis followed by death occurred at a level of about 4 mg. percent. When given as feed, mixed with other concentrates, urea in amounts up to 400 grams daily produced no ill effects in steers.

Steers were able to utilize the nitrogen of urea when it supplied 25 percent of the concentrate nitrogen in maintenance rations. However, when it supplied 50 percent of

the concentrate nitrogen, it was not utilized by steers and proved unpalatable when fed to supply 36 percent of the total nitrogen intake. Lambs utilized the nitrogen of urea very efficiently in maintenance rations, with nitrogen retention being significantly increased by additions of urea to supply 25 and 50 percent of the concentrate nitrogen. Urea significantly increased the apparent digestibility of crude protein for both steers and lambs, but failed to affect the digestibility of other ration nutrients.

Urea significantly increased nitrogen retention in both steers and lambs when added to supply 20 percent of the total nitrogen in fattening rations. Urea was about equally utilized when added to fattening and maintenance rations of lambs. However, a species difference was observed between steers and lambs, with the latter being more efficient in the utilization of high levels of urea in maintenance rations.

Neither the level of dietary protein nor additions of urea affected the excretion of creatinine or creatine by beef steers. Creatinine excretion was found to be quite constant in relation to body weight, and the average creatinine nitrogen coefficient was 11.18. The excretion of creatine was found to be more variable than the excretion of creatinine with an average mean creatine nitrogen coefficient of 2.62.

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APPENDIX

Complete Data for Metabolism Studies

TABLE 24. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR STEERS IN THE FIRST METABOLISM STUDY

Ration No.	Steers No.	N intake			N excretion			N retained	Urea N in blood	Creatinine in urine
		As protein	As urea	Total	Urine		Feces			
					Urea N	Total	Total			
		Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Mg. percent	Gm.
A	1	54.5		54.5	10.4	36.1	27.0	1.4	9.5	8.2
	2	53.4		53.4	8.0	21.8	38.2	- 5.6	10.6	9.8
	3	54.9		54.9	11.7	24.8	28.3	1.8	11.4	8.2
	4	52.4		52.4	16.4	20.9	30.4	1.1	6.8	10.1
	Av.	53.8		53.8	11.6	23.4	30.5	0.2	9.6	9.1
B	1	52.4	7.8	60.2	14.5	23.0	27.9	4.3	10.3	7.1
	2	54.5	7.8	62.3	14.2	28.4	29.7	4.2	8.8	8.9
	3	53.4	7.8	61.2	9.5	23.8	32.9	4.5	15.7	9.7
	4	54.9	7.8	62.7	15.2	31.2	28.0	3.5	14.4	8.4
	Av.	53.8	7.8	61.6	13.3	27.8	29.6	4.2	11.8	8.5
C	1	96.8		96.8	29.7	45.5	37.5	13.8	14.2	7.2
	2	95.2		95.2	22.5	36.1	36.8	18.3	10.2	11.0
	3	95.9		95.9	21.9	40.2	35.0	20.7	11.8	11.3
	4	94.8		94.8	26.8	45.3	39.8	9.7	14.4	10.1
	Av.	95.7		95.7	25.0	42.3	37.8	15.6	12.6	9.9
D	1	94.8	23.5	118.3	45.4	84.3	80.4	18.6	20.4	11.9
	2	93.8	23.5	120.3	36.5	54.0	37.1	29.2	15.6	9.5
	3	95.2	23.5	118.7	39.7	55.5	39.7	23.5	14.6	9.3
	4	95.9	23.5	119.4	45.1	63.8	38.0	17.6	19.3	11.7
	Av.	95.7	23.5	119.2	41.7	59.4	37.5	22.3	18.2	10.6

TABLE 25. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR LAMBS IN THE FIRST METABOLISM STUDY

Ration No.	Lamb No.	N intake			N excretion		N retained	Urea in blood
		As protein	As urea	Total	Urine total	Feces total		
		Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Mg. percent
A	1	7.2		7.2	2.5	4.2	0.5	6.4
	2	7.4		7.4	2.6	3.9	0.9	7.5
	3	7.6		7.6	3.4	4.0	0.2	12.8
	4	7.2		7.2	2.5	3.9	0.8	7.1
	5	6.9		6.9	2.3	3.6	1.0	5.0
	6	7.2		7.2	3.6	3.5	0.1	10.2
	7	7.2		7.2	2.1	4.1	1.0	10.4
	8	7.2		7.2	3.2	3.9	0.1	4.8
	Av.	7.2		7.2	2.8	3.9	0.5	7.8
B	1	7.2	1.1	8.3	2.7	3.7	1.9	3.4
	2	7.2	1.1	8.3	2.7	4.1	1.5	6.7
	3	7.4	1.1	8.5	4.6	4.4	- 0.5	11.7
	4	7.6	1.1	8.7	3.7	4.1	0.9	11.4
	5	7.2	1.1	8.3	3.2	3.9	1.2	10.6
	6	6.9	1.1	8.0	3.6	3.5	0.9	3.0
	7	7.2	1.1	8.3	4.0	3.6	0.7	15.5
	8	7.2	1.1	8.3	3.4	4.1	0.8	8.1
	Av.	7.2	1.1	8.3	3.5	3.9	0.9	8.8
C	1	13.4		13.4	4.9	5.4	3.1	17.2
	2	13.0		13.0	4.0	4.9	4.1	11.1
	3	13.0		13.0	5.7	5.5	1.8	11.2
	4	13.2		13.2	5.2	4.3	3.7	12.7
	5	13.0		13.0	4.6	5.0	3.4	12.8
	6	13.0		13.0	5.9	4.9	2.2	14.0
	7	12.7		12.7	4.4	5.2	3.1	7.8
	8	13.0		13.0	6.7	5.2	1.1	10.9
	Av.	13.0		13.0	5.2	5.0	2.8	12.2
D	1	13.2	3.3	16.5	7.5	5.1	3.9	18.0
	2	13.4	3.3	16.7	5.3	5.4	6.0	14.9
	3	13.0	3.3	16.3	7.0	5.3	4.0	18.0
	4	13.0	3.3	16.3	6.8	5.2	4.3	13.5
	5	13.0	3.3	16.3	8.0	5.0	3.3	19.9
	6	13.0	3.3	16.3	5.9	4.8	5.6	15.3
	7	13.0	3.3	16.3	7.1	5.1	4.1	19.4
	8	12.7	3.3	16.0	6.3	5.1	4.6	16.7
	Av.	13.0	3.3	16.0	6.7	5.1	4.5	17.0

TABLE 26. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED TO STEERS IN THE FIRST METABOLISM STUDY

Ration	Steer	Apparent digestibility (percent) of:				
		Crude protein	Ether extract	Crude fiber	N.F.E.	Organic matter
A	1	50.4	57.7	62.4	60.5	60.4
	2	34.0	44.3	56.6	50.7	51.1
	3	48.3	55.0	63.9	63.2	62.0
	4	41.9	45.1	65.3	60.9	60.5
	Av.	43.7	50.5	62.0	58.8	58.5
B	1	54.4	48.2	67.1	62.6	62.6
	2	54.5	58.1	65.7	63.8	63.0
	3	46.2	36.1	62.5	60.5	59.7
	4	55.3	56.1	70.2	65.6	65.6
	Av.	52.6	49.6	66.4	63.1	62.5
C	1	61.3	67.2	67.0	63.5	64.5
	2	59.1	60.4	64.3	61.6	62.1
	3	63.6	72.4	70.1	68.3	68.4
	4	58.0	63.3	64.7	64.8	63.9
	Av.	60.5	65.3	66.5	64.5	64.7
D	1	70.1	69.0	66.6	63.8	64.6
	2	69.2	67.3	65.1	63.4	67.6
	3	66.3	59.6	61.4	59.0	59.6
	4	68.2	65.9	65.0	62.8	63.3
	Av.	68.4	65.4	64.5	62.2	61.3

TABLE 27. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED TO LAMBS IN THE FIRST METABOLISM STUDY

Ration	Lamb	Apparent digestibility (percent) of:				
		Crude protein	Ether extract	Crude fiber	N.F.E.	Organic matter
A	1	42.1	50.0	49.7	51.9	50.4
	2	47.1	58.9	58.3	59.8	58.5
	3	46.7	49.7	55.6	55.2	54.5
	4	45.8	56.4	64.2	61.4	60.9
	5	47.7	55.3	60.5	60.6	59.4
	6	51.4	51.4	58.5	60.6	59.0
	7	42.8	53.3	54.8	56.8	55.0
	8	45.1	55.4	62.6	60.4	60.0
	Av.	46.1	53.7	58.0	58.3	57.2
B	1	55.6	58.7	58.8	61.2	59.5
	2	50.9	56.8	54.5	57.4	55.4
	3	48.4	58.9	57.1	57.5	56.1
	4	52.1	48.6	58.8	55.7	55.7
	5	52.3	55.4	62.2	60.4	59.6
	6	56.8	55.3	63.4	63.2	62.0
	7	57.0	52.6	56.4	58.5	57.0
	8	49.9	49.7	54.8	58.0	55.5
	Av.	52.9	54.4	58.2	59.0	57.6
C	1	59.9	65.6	56.5	58.9	58.6
	2	62.0	66.9	60.7	64.7	63.3
	3	57.9	67.6	51.6	56.5	55.7
	4	67.4	69.1	60.2	58.7	63.0
	5	61.8	71.5	59.2	61.4	61.2
	6	62.3	63.8	58.4	61.9	61.0
	7	59.1	67.1	56.9	60.2	59.4
	8	60.4	71.3	59.1	62.1	61.4
	Av.	61.3	67.9	57.8	60.5	60.4
	1	69.1	69.9	55.6	60.9	59.9
	2	67.8	63.6	57.0	58.2	58.3
	3	67.2	67.7	58.8	61.2	60.5
	4	67.8	67.6	55.1	58.2	57.9
	5	69.3	67.6	60.2	63.3	62.3
	6	70.2	64.7	55.9	61.9	60.4
	7	68.9	68.1	58.8	61.9	61.1
	8	68.3	67.6	60.7	61.5	61.5
	Av.	68.6	67.1	57.8	60.9	60.2

TABLE 23. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR STEERS IN THE SECOND METABOLISM STUDY

Ration No.	Steer No.	N intake			N excretion			N retained	Urea N in blood	Creatinine in urine
		As protein	As urea	Total	Urine		Feces			
					As urea+NH_3	Total	Total			
		gm.	gm.	gm.	gm.	gm.	gm.	gm.	mg. percent	gm.
E	2	46.3		46.8	7.6	21.0	21.8	4.0	7.0	8.0
	3	46.0		46.0	5.5	19.0	21.5	5.2	4.2	9.2
	5	45.5		45.5	19.9	30.7	23.2	- 7.4	13.3	9.9
	6	46.8		46.8	12.9	22.2	20.2	4.4	8.9	8.7
	7	46.0		46.0	4.3	17.3	22.5	6.4	4.5	8.1
	8	44.4		44.4	10.9	19.6	23.0	1.8	4.4	8.5
	Av.	45.9		45.9	10.2	21.6	21.9	2.4	7.0	8.7
F	2	46.4	15.6	61.1	18.8	30.3	21.1	9.7	14.7	8.2
	3	46.8	15.6	62.4	24.4	38.4	20.8	3.2	10.1	9.2
	5	44.4	15.6	60.0	22.1	34.8	22.4	2.8	6.5	9.7
	6	45.5	15.6	61.1	29.1	39.4	21.2	0.5	19.6	8.3
	7	46.8	15.6	62.4	21.1	36.3	20.2	5.9	11.6	9.0
	8	46.0	15.6	61.6	25.7	37.1	23.5	1.2	12.2	8.9
	Av.	45.9	15.6	61.5	23.5	36.0	21.5	4.0	12.5	8.9

TABLE 29. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR LAMBS IN THE SECOND METABOLISM STUDY

Ration No.	Lamb No.	N Intake			N Excretion		N retained	Urea N in blood
		As protein	As urea	Total	Urine	Feces		
		Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Mg. percent
E	1	6.8		6.8	2.1	4.0	0.4	3.7
	2	6.5		6.5	1.5	3.3	1.7	4.2
	3	6.8		6.8	1.4	3.4	2.0	3.7
	4	7.0		7.0	2.5	3.1	1.4	4.8
	5	6.4		6.4	2.0	3.8	0.6	3.2
	6	6.9		6.9	2.5	3.1	1.3	7.2
	7	7.1		7.1	2.9	3.2	1.0	6.3
	8	7.0		7.0	1.8	3.4	1.8	5.1
	Av.	6.8		6.8	2.1	3.4	1.3	4.7
F	1	7.0	2.2	9.2	3.8	3.3	2.1	5.2
	2	6.5	2.2	8.7	3.8	3.6	1.3	7.7
	3	6.5	2.2	8.7	2.6	3.3	2.8	10.0
	4	6.8	2.2	9.0	3.7	3.2	2.1	4.2
	5	7.0	2.2	9.2	4.7	3.4	1.1	8.5
	6	6.4	2.2	8.6	4.3	3.3	1.0	6.7
	7	6.9	2.2	9.1	3.0	3.5	2.6	11.2
	8	7.1	2.2	9.3	4.3	3.5	1.5	9.4
	Av.	6.8	2.2	9.0	3.8	3.4	1.8	7.9
G	1	12.2		12.2	4.0	4.8	3.4	7.0
	2	12.3		12.3	2.7	4.3	5.3	11.9
	3	11.5		11.5	3.6	4.7	3.2	8.7
	4	11.8		11.8	3.9	4.3	3.6	11.1
	5	12.5		12.5	3.6	4.0	4.9	8.0
	6	12.3		12.3	5.7	4.7	1.9	10.4
	7	11.2		11.2	3.5	4.6	3.1	11.1
	8	11.6		11.6	3.7	4.4	3.5	11.1
	Av.	11.9		11.9	3.8	4.5	3.6	9.9
H	1	11.8	6.6	18.4	9.0	4.1	5.3	14.7
	2	12.1	6.6	18.7	4.6	4.6	9.5	14.3
	3	12.2	6.6	18.8	8.3	4.4	6.1	14.7
	4	11.4	6.6	18.0	10.3	4.5	3.2	11.5
	5	11.6	6.6	18.2	8.4	4.8	5.0	13.2
	6	12.4	6.6	19.0	10.2	4.0	4.8	12.6
	7	12.2	6.6	18.8	9.1	4.0	5.7	13.4
	8	11.1	6.6	17.7	8.2	4.9	4.6	15.3
	Av.	11.9	6.6	18.5	8.5	4.4	5.6	13.7

TABLE 30. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED TO STEERS IN THE SECOND METABOLISM STUDY

Ration	Steer	Apparent digestibility (percent) of:				
		Crude protein	Ether extract	Crude fiber	N.F.E.	Organic matter
E	2	53.5	67.5	70.7	68.1	67.7
	3	52.5	46.3	70.0	66.9	66.1
	5	51.1	62.6	73.1	66.3	67.2
	6	56.9	71.1	73.1	68.6	69.1
	7	51.4	45.7	62.9	63.5	61.9
	8	48.3	52.0	71.7	65.8	65.9
	Av.	52.3	57.2	70.2	66.5	66.3
F	2	65.4	59.3	72.1	67.4	67.6
	3	66.8	64.7	71.7	68.0	68.0
	5	62.6	56.3	72.1	66.4	66.6
	6	65.4	64.5	75.3	67.9	69.1
	7	67.7	71.8	70.7	67.3	67.6
	8	62.2	28.9	68.7	67.0	65.8
	Av.	65.0	57.8	71.8	67.3	67.4

TABLE 31. THE AVERAGE APPARENT DIGESTION COEFFICIENTS OF NUTRIENTS IN EACH RATION FED TO LAMBS IN THE SECOND METABOLISM STUDY

Ration	Lamb	Apparent digestibility (percent) of:				
		Crude protein	Ether extract	Crude fiber	N.-f.-e.	Organic matter
E	1	39.4	55.9	60.9	55.6	56.1
	2	48.9	62.1	63.5	62.9	61.9
	3	49.8	64.0	57.8	60.2	58.7
	4	56.9	58.2	63.2	61.9	61.7
	5	40.5	55.6	63.4	61.3	60.1
	6	51.6	70.8	64.6	64.1	63.4
	7	54.6	46.7	61.6	64.7	56.8
	8	51.0	55.6	67.9	59.1	61.0
	Av.	49.0	58.6	62.9	61.2	60.0
F	1	64.2	66.0	65.5	62.9	62.9
	2	58.6	62.1	64.4	58.6	59.5
	3	61.9	64.-	62.0	62.5	61.3
	4	64.2	64.0	62.3	62.0	61.3
	5	62.4	56.2	68.5	60.8	62.2
	6	61.4	50.8	64.9	62.3	61.7
	7	59.6	55.2	58.7	62.1	59.5
	8	62.2	47.5	60.5	63.4	61.0
	Av..	61.8	58.3	63.3	61.8	61.2
G	1	60.2	70.0	52.0	59.2	57.9
	2	64.9	74.9	61.5	65.1	64.4
	3	58.8	81.5	58.2	50.4	59.3
	4	64.1	76.3	62.9	66.7	65.7
	5	57.7	69.4	61.7	70.7	67.9
	6	61.9	69.9	65.9	63.1	64.0
	7	59.0	65.3	62.9	64.9	63.6
	8	56.3	67.0	58.2	65.5	62.6
	Av..	61.6	71.8	60.4	63.2	63.2
H	1	77.6	77.2	64.5	67.2	66.6
	2	75.3	74.8	59.0	64.6	63.2
	3	76.5	74.9	58.5	63.3	62.5
	4	75.4	79.1	63.0	63.1	63.4
	5	70.8	69.3	59.3	66.3	65.0
	6	78.8	69.4	61.8	70.9	68.1
	7	78.9	73.1	72.7	67.6	69.2
	8	72.1	63.2	59.8	65.3	62.6
	Av.	75.7	72.6	62.3	66.0	64.8

TABLE 32. THE AVERAGE NITROGEN BALANCE DATA FOR STEERS IN THE THIRD METABOLISM STUDY

Ration No.	Steer No.	N intake			N excretion			N retained	Urea N in blood	Creatinine in urine
		As protein	As urea	Total	Urine		Feces			
					Urea N	Total	Total			
		Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Mg. percent	Gm.
I	1	83.6		83.6	4.8	16.6	38.6	39.6	4.7	8.9
	2	83.1		83.1	8.0	20.5	37.8	24.8	7.3	9.4
	3	82.2		82.2	11.3	28.0	38.0	13.2	5.9	12.2
	4	81.9		81.9	13.7	38.5	37.5	16.1	6.4	13.7
	5	83.6		83.6	11.8	21.1	33.6	26.6	4.2	8.2
	6	82.2		82.2	14.6	30.0	34.6	17.6	9.4	11.8
	Av	82.7		82.7	10.7	33.6	38.7	22.4	6.3	10.7
J	1	81.9	9.8	91.7	19.4	31.8	37.5	22.4	8.0	11.3
	2	83.5	9.8	93.3	15.1	24.0	38.0	31.3	4.9	9.6
	3	83.1	9.8	92.9	13.8	30.5	34.8	27.6	8.0	10.3
	4	82.2	9.8	92.0	19.0	34.7	39.2	18.1	9.8	11.6
	5	81.9	9.8	91.7	17.4	31.0	31.8	29.2	7.8	9.8
	6	83.5	9.8	93.3	38.1	44.9	34.5	13.9	6.6	13.1
	Av.	82.7	9.8	92.5	19.9	38.8	35.9	23.8	7.3	10.9
K	1	77.0		77.0	8.0	21.7	33.9	21.4	10.5	11.8
	2	76.7		76.7	7.9	22.1	37.7	16.9	6.2	11.8
	3	78.3		78.3	9.8	17.8	36.1	24.7	4.2	7.3
	4	77.9		77.9	9.6	19.5	42.1	16.8	7.0	8.6
	5	77.9		77.9	7.2	20.8	36.9	20.5	5.2	9.4
	6	76.7		76.7	10.5	24.2	36.1	15.4	6.8	11.4
	Av.	77.4		77.4	8.8	20.9	37.1	19.4	6.8	10.0
L	1	77.9	19.6	97.5	17.6	30.1	33.6	33.2	8.4	8.8
	2	77.0	19.6	96.6	20.4	34.6	35.9	26.1	8.0	10.8
	3	76.7	19.6	96.3	19.2	30.6	34.1	31.7	8.7	12.8
	4	78.3	19.6	97.9	20.9	33.6	38.4	35.9	8.3	8.0
	5	77.0	19.6	96.6	23.4	36.1	36.1	24.4	12.2	8.8
	6	77.9	19.6	97.5	25.6	40.8	35.8	20.9	8.0	11.0
	Av	77.4	19.6	97.1	21.0	32.7	35.6	28.8	8.6	10.0

TABLE 33. THE AVERAGE DAILY NITROGEN BALANCE DATA FOR SHEEP IN THE THIRD METABOLISM STUDY

Ration No.	Sheep No.	N intake			N excretion		N retained	Urea N in blood
		As protein	As urea	Total	Urine	Feces		
		Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Mg. percent
I	1	10.3		10.3	2.1	4.5	3.7	4.5
	2	9.8		9.8	2.7	5.0	2.1	3.8
	3	9.8		9.8	2.3	4.2	3.3	4.5
	4	9.8		9.8	2.5	3.9	3.4	1.7
	5	10.4		10.4	2.4	3.8	4.2	9.8
	6	9.8		9.8	2.3	4.5	3.0	8.3
	7	9.8		9.8	1.9	4.7	3.2	6.3
	8	9.8		9.8	3.3	4.2	2.3	5.9
	Av.	9.9		9.9	2.4	4.3	3.2	5.6
J	1	9.8	1.2	11.0	2.8	4.0	4.5	9.4
	2	10.3	1.2	11.5	2.7	4.7	4.1	8.8
	3	9.8	1.2	11.0	2.1	4.6	4.3	10.5
	4	9.8	1.3	11.0	2.7	5.1	3.2	8.2
	5	9.8	1.2	11.0	2.1	3.9	5.0	7.5
	6	10.4	1.2	11.6	2.8	4.2	4.8	9.1
	7	9.8	1.3	11.0	3.5	5.1	2.4	5.9
	8	9.8	1.2	11.0	3.3	4.4	3.3	6.4
	Av.	9.9	1.2	11.1	2.7	4.5	3.9	7.8
K	1	9.2		9.2	3.0	3.4	2.8	5.2
	2	9.2		9.2	2.2	4.7	2.3	2.4
	3	9.7		9.7	1.3	4.1	3.8	2.4
	4	9.2		9.2	2.1	4.8	2.3	3.8
	5	9.2		9.2	2.4	4.0	2.8	5.9
	6	9.2		9.2	1.6	4.4	3.2	4.0
	7	9.8		9.8	2.3	4.9	2.6	4.1
	8	9.2		9.2	3.1	4.0	2.1	4.2
	Av.	9.3		9.3	2.3	4.3	2.7	4.0
L	1	9.2	2.4	11.6	3.9	4.6	3.1	10.8
	2	9.2	2.4	11.6	4.9	4.2	2.5	4.7
	3	9.2	2.4	11.6	2.2	3.3	6.1	4.9
	4	9.7	2.4	12.1	2.3	4.9	4.9	3.5
	5	9.2	2.4	11.6	3.8	4.5	3.3	8.7
	6	9.2	2.4	11.6	3.6	5.2	2.8	5.6
	7	9.2	2.4	11.6	2.5	3.8	5.3	6.5
	8	9.8	2.4	12.2	2.8	4.3	5.4	7.3
	Av.	9.3	2.4	11.7	3.2	4.3	4.2	6.5