

Influence of a Three-Day Feed and Water Deprivation Period on Gut Fill, Tissue Weights, and Tissue Composition in Mature Wethers^{1,2,3}

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ABSTRACT: Fourteen mature wethers (average BW $71.8 \pm .86$ kg) were used to study the effects of feed and water deprivation on the quantity and composition of gastrointestinal tract (GIT) contents and tissues. Sheep (seven/treatment) were randomly assigned to one of two treatments: 1) limit fed 1,400 g/d of a pelleted diet or 2) deprived of feed and water for 3 d. Before euthanasia, sheep were infused i.v. with Evans blue, sodium thiocyanate, and antipyrine to determine plasma, extracellular, and total body water, respectively. Blood samples were obtained for 4 h after the infusions. Sheep were killed by injection of a lethal dose of a general anesthetic and organs were immediately removed, weighed, and sampled. Compared with controls, unfed sheep lost 7.1 kg (9.9%; $P < .05$) of their BW during the 3-d deprivation period, of which

21.1% was from the stomach contents, 28.1% ($P < .05$) was from the GIT (stomach + intestine) contents, and 6.7% ($P < .02$) was from GIT tissues. The weight loss of the liver, lungs, heart, and kidneys each accounted for less than 1% of the total weight loss. Of the total weight loss, 80% ($P < .09$) was body water. Of total body water loss, 57% ($P < .20$) was from the intracellular compartment and 29% ($P < .06$) was from the GIT contents. Total Ca, Na, Mg, Cu, Fe, and Zn losses via fecal + urinary excretion were less or equal to losses from the GIT contents. In contrast, fecal + urinary losses of water, N, P, and K were greater than losses from the GIT contents, suggesting that appreciable losses of these nutrients occurred from the tissues.

Key Words: Sheep, Feed deprivation, Stress, Shrink

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Introduction

Feeder calves and lambs encounter periods of feed and water deprivation during movement from one production point to another. During deprivation, weight losses (shrinkage) may exceed 10% of the animals' BW. Much of this weight loss may be gastrointestinal tract (GIT: stomach + intestine) contents; however, more than 50% of the weight loss may occur from the tissues (Self and Gay, 1972; Phillips et al., 1985). Although a large portion of the weight loss may be water, the rumen does not seem to be a net reserve for water losses from the tissues (Cole and Hutcheson, 1985a,b, 1987). Appreciable

amounts of protein and minerals also may be lost during the deprivation period (Cole et al., 1986b, 1992; Cole, 1992).

Although the deprivation period encountered by feeder calves moving from auction markets to stocker or feeder operations usually does not exceed 36 h, the stressors of transport (Galyean et al., 1981; Phillips et al., 1985; Cole et al., 1986b, 1988) and infection (Cole et al., 1986a) can substantially increase weight and tissue losses. The weight and metabolic changes that occur during a 24-h transport period are similar to changes noted during a 48- to 72-h feed and water deprivation period (Phillips et al., 1985; Cole et al., 1986b, 1988).

This study was conducted using mature wethers as a model to determine the influence of a 3-d feed and water deprivation period on losses of weight, water, and minerals from tissues and the GIT.

Materials and Methods

All experimental protocols were reviewed and approved by the local animal care and use committee as outlined in the publication *Guide for the Care and*

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In this study, PWG was evaluated because it is used in the NSCE system and avoids the influence of WWT that is present in interpreting results for YWT. Phenotypically, there was some variation in the direction and amount of change per year in average PWG performance. Breeders in the North Central region did not make any significant phenotypic change in calves' PWG records. The regional phenotypic differences in PWG were largely due to differences in the average environment from year to year. The average PWG EBV increased in each region at least .55 kg/yr. The regional differences in average genetic merit were very slight. By comparing the genetic superiority of selected parents to their birth-year contemporaries, breeders selected for YWT performance through selection for preweaning and postweaning growth. The average level of PWG management did not change over time in the North Central and West regions. The average PWG environment declined over time for purebred calves in the South Central region.

Implications

Using the records supplied by Simmental breeders from 1978 to 1991, it was evident that across-herd selection of breeding stock based only on within-herd records can be significantly biased by the environment in which the record was made. Breeders need to understand that selection using Expected Progeny Differences will increase the likelihood of making the correct selection decision compared to using adjusted phenotypic records.

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Use of Agricultural Animals in Agriculture Research and Teaching (Consortium, 1988).

Fourteen mature Hampshire \times Suffolk wethers averaging $71.8 \pm .86$ kg of BW were assigned randomly to one of two treatments (seven sheep/treatment): 1) continuously fed 1,400 g/d (as-fed) of a 36% concentrate pelleted diet or 2) deprived of feed and water for 3 d. During an 8-wk preliminary period, sheep were housed in individual pens with slotted floors (2 m \times 1.5 m) and were fed 700 g (as-fed) of the pelleted diet at 0800 and 1600 daily. The diet, formulated to simulate a medium-quality forage and to meet the nutritional requirements for maintenance (NRC, 1985), contained 14% corn, 59% cottonseed hulls, 15% cottonseed meal, 5% alfalfa, 5% molasses, and 2% vitamin and mineral supplements (DM basis). Water was available for ad libitum consumption except during the deprivation period. Ambient temperature in the metabolism barn was maintained at 17 to 20°C and the relative humidity was maintained at 40 to 60%.

Seven days before the start of the deprivation period, the wethers were placed in digestion stalls. At the start of the deprivation period, wethers were weighed individually and one-half of the wethers were denied access to feed and water. The control wethers continued to receive their daily diet (1,400 g/d) and water for ad libitum intake. During the 3-d deprivation period, daily total outputs of feces and urine were collected, weighed, and stored at 4°C. At the end of the deprivation period (i.e., day of euthanasia), feces and urine collected from each wether was composited, and a subsample was frozen for later analysis.

On the day before euthanasia, catheters (Abbotath-T, 14 g \times 14 cm, Abbott Hospitals, North Chicago, IL) were placed in the jugular veins of each wether and flushed with a 3.5% (wt/vol) sodium citrate solution. On the day of euthanasia, an initial blood sample was taken from the right jugular vein, and wethers were then infused with solutions of antipyrine (10 mL of a 10% [wt/vol] solution in .9% saline), urea (30 mL of a 20% [wt/vol] solution in saline), sodium thiocyanate (SCN, 15 mL of a 10% [wt/vol] solution in saline), and Evans blue (5 mL of a 1% [wt/vol] solution in saline). Heparinized blood samples were obtained from the left jugular vein at 12, 30, 60, 90, 120, 180, and 240 min after infusion and immediately stored on ice.

After the final blood sample was collected, the wethers were anesthetized with an i.v. injection of xylazine hydrochloride (Rompun, Haver-Lockhart Labs, Shawnee, KS; .1 mg/kg BW) followed by an i.v. injection of sodium thiopental (15 mg/kg BW). When the wether was unconscious, death was ensured by exsanguination. The following tissues were removed immediately, placed in airtight plastic bags, weighed, and refrigerated: liver, spleen, kidneys, GIT (separated into reticulorumen, omasum, abomasum, small intestine, and large intestine), heart, and lungs with

trachea. Segments of the GIT were emptied into tared buckets, washed with deionized water, blotted dry, and weighed. Weight of the contents in each segment of the GIT was determined by the difference in full and empty weights of the GIT segment. Digesta, fecal, liver, kidney, and lung samples were dried to a constant weight in a forced-air oven at 60°C for determination of DM. Duplicate samples were frozen for later analysis. Urine samples were obtained by aspirating samples from the bladder using a 60-mL syringe equipped with an 18-gauge needle.

Laboratory Analyses. Packed cell volumes were determined on initial blood samples using microhematocrit tubes. Blood samples were centrifuged at $3,000 \times g$ for 30 min at 10°C, after which the plasma was decanted and frozen. Plasma concentrations of Evans blue, SCN, and antipyrine were determined by the colorimetric methods of Hix et al. (1959). Plasma and urine urea N concentrations were determined by the colorimetric method of Marsh et al. (1965). Plasma free fatty-acid concentrations were determined by the colorimetric procedure of Smith (1975) and plasma glucose concentrations were determined by the colorimetric method of Bittner and Manning (1966).

Total body water was calculated from plasma concentrations of antipyrine (Hix et al., 1959) and urea (Kock and Preston, 1979). Blood volume was calculated using plasma concentrations of Evans blue (Hix et al., 1959), and extracellular water was calculated using plasma concentrations of SCN (Hix et al., 1959). Antipyrine is known to enter the gut water (Panaretto and Reid, 1964), whereas SCN does not enter the rumen within the first 1.5 h after i.v. infusion (Panaretto, 1965). Therefore, antipyrine space was assumed to include gut water, whereas SCN space was assumed not to include gut water. Therefore, intracellular water was calculated as total body water minus [extracellular water + gut water].

Following digestion in a block digester, Na, K, Mg, Ca, Fe, Cu, and Zn content of tissues, digesta, feces, and urine were determined by atomic absorption spectroscopy. Concentrations of P were determined by automated colorimetric analysis (Technicon, 1977).

Statistical Analysis. Data were analyzed as a completely randomized design by analysis of covariance with initial BW as a covariate using the GLM procedure of SAS (1988). Effects of feed and water deprivation were tested via *F*-test comparing values for non-fed wethers to values for fed wethers. The model included effects of initial BW (the covariate), fed vs non-fed status (treatment), and animal within treatment (error term).

Results and Discussion

Weight Losses. Wethers lost an average of 7.1 kg (9.9% of predeprivation BW; $P < .05$) during the deprivation period (Table 1). Approximately 28.1% of

Table 1. Wet weights and weight of water in digesta and tissues of mature wethers continuously fed or deprived of feed and water for 3 days

Item	Fed	Unfed	Loss	SEM ^a	P < ^b
Body weight, kg					
Predeprivation	71.8	71.9	.1	3.2	.86
Postdeprivation	71.9	64.8	7.1	3.0	.01
Digesta wet wt, g					
Reticulorumen	7,657	6,298	1,359	421	.03
Stomach	8,048	6,549	1,499	436	.04
Small intestine	219	148	71	18	.08
Large intestine	1,228	803	425	86	.10
Total GIT	9,495	7,500	1,995	398	.04
Tissue wet wt, g					
Reticulorumen	1,381	1,159	222	69.8	.02
Small intestine	644	592	52	56.4	.49
Large intestine	955	814	141	68.6	.32
Total GIT	3,499	3,025	474	71.1	.02
Liver	658	590	68	22.7	.09
			Water content		
Total body, L	33.87	28.16	5.71	1.68	.09
Plasma, L	2.30	2.23	.07	.12	.32
Extracellular, L	14.04	13.22	.82	.90	.39
Intracellular, L	11.66	8.42	3.24	1.26	.20
Digesta, g					
Reticulorumen	6,741	5,628	1,113	415	.21
Stomach	7,049	5,816	1,233	424	.09
Small intestine	190	126	64	18	.04
Large intestine	932	577	355	66	.01
Total GIT	8,171	6,519	1,652	462	.06
Tissues, g					
Reticulorumen	1,149	946	203	61	.02
Small intestine	536	483	53	21	.40
Large intestine	794	663	131	57	.26
Total GIT	2,911	2,468	443	63	.04
Liver	419	374	45	16	.14

^aStandard error of the mean, n = 7.

^bObserved significance level for the comparison of fed vs unfed.

this loss was loss of GIT contents, 21.1% was loss of stomach contents, and 19.1% was loss of reticulorumen contents. Total fecal and urinary weight losses during the 3-d deprivation period were 580 ± 40 and $1,284 \pm 96$ g, respectively, or approximately 26% of total weight loss. These digesta losses are slightly lower than those reported for cattle by Self and Gay (1972) and Phillips et al. (1985), who noted that approximately one-half of total shrinkage in transported cattle was from loss of GIT contents.

Weight loss of GIT wet tissue accounted for approximately 6.7% of the total BW loss. Weight losses of liver, spleen, kidneys, heart, and lungs were small; each tissue accounted for less than 1% of the total BW loss. Hence, approximately 65% of the BW loss ($100 - [28 + 6.7\%]$) occurred in other tissues, presumably adipose and muscle.

The wethers deprived of feed and water lost approximately 16% ($P < .02$) of their reticuloruminal tissue weight, 8% ($P < .49$) of small intestinal tissue weight, 15% ($P < .32$) of large intestinal tissue weight, 13.5% ($P < .02$) of GIT tissue weight, and 10% ($P < .09$) of liver weight. These values are similar to

losses noted in cattle (Richmond et al., 1988) and sheep (Rompala and Hoagland, 1987) when they were switched from ad libitum to 50% ad libitum feed intakes.

Kabbali et al. (1992) noted that a decrease in live weight from 25 to 20 kg over a 10-d period was associated with a 17% loss in empty BW, a 30% loss of visceral organ weight, a 45% loss in liver weight, a 75% loss of internal fat, and a 19% loss in carcass weight. However, weight loss from 20 to 17 kg BW involved carcass to a greater extent than internal organs. The composition of BW loss consisted of 53% water, 28% fat, and 15% protein. When lambs were refed to their original BW, there was a rapid increase in internal organ weight and less fat regeneration. At the same BW, carcass and non-carcass components of realimented lambs were leaner than continuously fed lambs.

Weights of the GIT and liver are considered to be related to maintenance energy requirements in rats (Canas et al., 1982) and sheep (Koong et al., 1985; Ferrell et al., 1986; Burrin et al., 1990). Burrin et al. (1989) noted that in vivo oxygen consumption by the

portal-drained viscera was 37% less and in liver was 63% less in lambs on a maintenance diet than in lambs fed for ad libitum consumption. The relative contributions of the portal-drained viscera and liver to whole-body metabolism also decreased in lambs fed at maintenance. Similarly, Eisemann and Nienaber (1990) noted that during a 78- to 84-h feed deprivation period, oxygen consumption attributable to the portal-drained viscera decreased 50%, that attributable to the hindquarter decreased 31%, and that attributable to the liver decreased 18%. In rats, Burrin et al. (1988) noted that a 48-h feed deprivation period caused a decrease in the weights and RNA mass of the liver and small intestine. When expressed per gram of tissue, feed deprivation did not affect in vitro hepatic oxygen consumption; however, total hepatic oxygen consumption was decreased in feed-deprived rats because of decreased liver size. Thus, the decreases in visceral organ weight noted in the present study could result in a decreased maintenance energy requirement in ruminants deprived of feed and water for short periods of time.

Water Losses and Movements. The urea dilution technique (using the single 12-min blood sample) produced total body water estimates that ranged from approximately 10% to 85% of BW. Values determined using the antipyrine dilution technique were much more consistent; therefore, these values are reported. The reason for the poor results obtained using the urea dilution technique are not apparent; however, Bartle et al. (1988) noted that timing of infusions and sampling were very critical for the urea dilution technique to work in sheep. In addition, Poland et al. (1991) suggested that urea space did not predict carcass water with enough precision to warrant its use in lambs. Possibly, the i.v. infusion of several solutions at one time may have caused water and/or urea movements that resulted in the poor estimates of total body water using the urea dilution technique.

In the present study, total body water composed approximately 47% of BW in fed wethers and 43% of BW in unfed wethers ($P < .01$; Table 1). These values are within expected ranges (Bensadoun et al., 1963). Hix et al. (1959) reported a similar decrease in total body water in sheep severely dehydrated by feeding a diet high in potassium bicarbonate (56 vs 49% of total BW). Extracellular water, as a percentage of BW, was not affected by feed and water deprivation (19.5% in fed and 20.4% in unfed wethers). These values are similar to previous reports (MacFarlane and Howard, 1969; Gad and Preston, 1990; Ross et al., 1992).

Extracellular water composed 41% of total body water in fed wethers and 47% of total body water in unfed wethers. Similar values were reported by Degen and Young (1980) and by Gad and Preston (1990). In contrast, Hix et al. (1959) reported that extracellular water constituted only 22 to 30% of total body water. The lower values reported by Hix et al. (1959) are probably due to the fact that water in the GIT

contents was considered a portion of intracellular water in their calculations. Gut water composed approximately 24% of total body water in both fed and unfed wethers in the present study. Bensadoun et al. (1963) noted that gut water composed 16.7 to 30.9% of total body water and that the percentage was greater in sheep fed a chopped hay diet than in sheep fed a corn-hay pelleted diet.

Of the total BW loss in deprived sheep, approximately 80% was body water (5.71 L; $P < .09$) and 20% (1.39 kg) was body solids (Table 1). Similarly, in sheep exposed to cold, Degen and Young (1980) noted that 66% of BW loss was body water and 34% was body solids.

Approximately 57% of total body water loss occurred from intracellular fluids, approximately 29% occurred from the GIT digesta, and 14% occurred from the extracellular fluids. The loss of intracellular water was approximately four times the loss of extracellular fluid volume during the 3-d feed and water deprivation period. Similarly, Shell et al. (1991) noted that diet and shade affected the total body water of heifers primarily by affecting the intracellular water space, with little effect on the extracellular water space. MacFarlane and Howard (1969) noted that a decrease in water supply led to a decrease in DMI, followed by a decrease in plasma and intracellular water volume. In contrast, Hix et al. (1959) reported that the decrease in total body water in sheep dehydrated by feeding a diet high in potassium bicarbonate resulted from a decrease in the extracellular water space; the intracellular water space was not affected. Degen and Young (1980) noted that body water loss in sheep exposed to cold (0°C) occurred primarily from the ruminal fluid (78%) and extracellular pool (29%); intracellular volume was unaffected.

These variable results relating to the source of body water loss during stress might be expected for several reasons. The water pools in the ruminant are highly dynamic. Extracellular and plasma volume can decrease 10 to 20% during a meal (Scott, 1975) as a result of movement of water to and from the lumen of the GIT. This same movement of water between the gut lumen and tissues leads to inherent inaccuracies in determining body water and extracellular water spaces, especially in ruminants. These variable results could also result from the length or severity of the stress used in the individual experiments. During "normal" dehydration in nonruminants, extracellular fluid volume initially decreases. This decrease may be followed by an increase in plasma osmolality and a subsequent decrease in intracellular fluid volume (Greenleaf and Fregly, 1982). Thus, these variable results might also suggest that the severity of nutritional and/or environmental stressors may affect the mechanisms involved in regulating water balance during stress. Although water and electrolyte losses from the body are controlled primarily by the kidneys, the gut may play a role in controlling the

distribution of water within the intracellular and extracellular compartments.

Nutrient Losses and Movements. Approximately 43% ($P < .04$) of the N within the GIT digesta was lost during the 3-d deprivation period; most of the losses occurred from the ruminal ($P < .03$) and large intestinal ($P < .01$) contents (Table 2).

It has been noted in several studies that during realimentation, following a feed and water deprivation period, ruminants are more efficient at retaining dietary N (Cole and Hutcheson, 1988; Cole, 1992). Repletion of N in GIT contents does not account for all of the improved efficiency. Other factors, such as the reduced gut and liver mass noted previously, or a rapid proliferative activity in the gastric and intestinal mucosa (Stangassinger and Giesecke, 1986) also might be involved.

Calcium losses from the digesta approached 12 g (Table 2; $P < .01$), and most of the losses occurred from the ruminal (55%; $P < .02$) and large intestinal (40%; $P < .01$) contents. Approximately 40% of the Ca within the GIT was lost ($P < .01$) during the deprivation period. With the exception of the large intestine ($P < .05$), the Ca content of sampled tissues was not affected by feed and water deprivation.

Sklan and Hurwitz (1985) and Wylie et al. (1985) noted there is no net secretion of Ca into the ruminal

contents of sheep, that the major site of disappearance of Ca is the small intestine, and that there is little apparent absorption of Ca from the large intestine. In the present study fecal Ca losses were greater than losses from the large intestinal digesta (8.27 vs 4.76 g, respectively). Thus, these findings suggest that the losses of Ca from the stomach digesta were primarily a result of passage of digesta to the small intestine, and losses from the large intestine digesta were a result of excretion in the feces.

Total P content of ruminal digesta was not significantly affected by deprivation (Table 2). In contrast, there was a net loss of P in large intestine contents ($P < .07$) and from the ruminal tissues ($P < .06$). Less than 3% of the P in the digesta was lost ($P < .59$) during deprivation.

Several studies (Sklan and Hurwitz, 1985; Wylie et al., 1985; Yano et al., 1991) have noted a net secretion of P into the ruminal contents of fed sheep, primarily via the saliva. The non-significant increase in ruminal P content in the present study suggests that this net secretion can continue even during a 3-d feed and water deprivation period. Because the major site of disappearance of P is the small intestine, and there is little apparent absorption of P from the large intestine (Sklan and Hurwitz, 1985; Wylie et al., 1985), the apparent loss of P from the large intestinal digesta was probably a result of excretion in the feces.

Table 2. Nitrogen, Ca, and P content of digesta and tissues in fed or unfed mature wethers

Item	Fed	Unfed	Loss	SEM ^a	$P <^b$
Digesta N, g					
Reticulorumen	25.5	14.4	11.3	2.55	.03
Stomach	27.7	15.4	12.3	2.36	.04
Small intestine	1.4	.9	.5	.14	.12
Large intestine	8.9	5.4	3.5	.83	.01
Total GIT	38.0	21.7	16.3	2.68	.04
Digesta Ca, g					
Reticulorumen	16.33	9.77	6.56	1.91	.02
Stomach	17.17	10.21	6.96	1.94	.02
Small intestine	.55	.41	.24	.06	.69
Large intestine	11.43	6.67	4.76	1.22	.01
Total GIT	29.15	17.29	11.78	2.01	.01
Tissue Ca, g					
Reticulorumen	1.33	1.34	-.01	.25	.98
Small intestine	.42	.49	-.07	.13	.81
Large intestine	1.53	.84	.69	.09	.05
Liver	.07	.07	.00	.01	.82
Digesta P, g					
Reticulorumen	16.34	17.84	-1.50	1.26	.54
Stomach	17.14	18.37	-1.23	1.37	.44
Small intestine	.29	.25	.04	.03	.61
Large intestine	4.12	2.31	1.81	.76	.07
Total GIT	21.55	20.93	.62	.54	.59
Tissue P, g					
Reticulorumen	7.91	5.77	2.14	.82	.06
Small intestine	6.11	4.97	1.14	.58	.28
Large intestine	2.92	3.15	-.23	.11	.56
Liver	3.92	4.11	-.19	.17	.52

^aStandard error of the mean, $n = 7$.

^bObserved significance level for the comparison of fed vs unfed.

In P-depleted sheep, Preston and Pfander (1964) and Young et al. (1966) noted that the rate of excretion of metabolic fecal P was markedly increased when the sheep were provided diets that were adequate in P, which was seemingly a result of decreased reabsorption of intestinally secreted P, rather than an increased secretion of P into the intestine. It has been noted in sheep and cattle deprived of feed and water that P retention is substantially decreased for 7 to 14 d after the reintroduction of feed and water (Cole and Hutcheson, 1988; Cole, 1992). It is possible that during feed and water deprivation, mechanisms for P absorption in the small intestine are altered and that several days are required for the mechanisms to return to normal.

Changes in Na content of digesta were small except for the large intestinal contents ($P < .01$; Table 3). Approximately 6% of Na in the digesta was lost ($P < .07$) during deprivation. Changes in Na content of sampled tissues tended to be small and were not statistically significant.

Several studies (Sklan and Hurwitz, 1985; Wylie et al., 1985; Gabel and Martens, 1991) indicate that

there is a net secretion of Na into the ruminal contents and that approximately 50% of Na secreted into the rumen is reabsorbed from the rumen. The present results suggest that the net secretion of Na into the rumen continues even during a 3-d feed and water deprivation period. The major site of disappearance of Na is the small intestine, although there also is considerable absorption of Na in the large intestine (Sklan and Hurwitz, 1985; Wylie et al., 1985; Argenzio, 1988). Sodium losses from the large intestinal contents (1.69 g) were considerably greater than losses in the feces (.17 g). Thus, the losses of Na from the large intestinal digesta were primarily a result of absorption rather than excretion in the feces.

Changes in K content of digesta in individual segments of the GIT tended to be the reverse of changes in Na content (Table 3), with net losses of K from the stomach digesta ($P < .07$) and net gains in the large intestinal digesta ($P < .02$). However, the total net loss of K from digesta was similar to the net losses of Na. Approximately 12% of K in the digesta was lost ($P < .06$) during deprivation. Appreciable quantities of K were lost from the ruminal tissues (P

Table 3. Sodium, K, and Mg content of digesta and tissues in fed or unfed mature wethers

Item	Fed	Unfed	Loss	SEM ^a	$P <^b$
Digesta Na, g					
Reticulorumen	16.60	17.03	-.43	1.18	.88
Stomach	17.20	17.57	-.37	1.14	.87
Small intestine	.52	.55	-.03	.03	.73
Large intestine	3.74	2.05	1.69	.34	.01
Total GIT	21.46	20.17	1.33	.46	.07
Tissue Na, g					
Reticulorumen	6.36	5.25	1.11	.36	.12
Small intestine	3.63	3.59	.04	.54	.97
Large intestine	3.68	2.86	.82	.28	.14
Liver	1.18	1.15	.03	.06	.80
Digesta K, g					
Reticulorumen	13.52	10.78	2.74	.80	.09
Stomach	14.05	11.06	2.99	.78	.07
Small intestine	.33	.31	.02	.03	.94
Large intestine	1.39	2.56	-1.17	.32	.02
Total GIT	15.79	13.93	1.84	.48	.06
Tissue K, g					
Reticulorumen	10.18	8.12	2.06	.66	.02
Small intestine	4.46	4.15	.31	.46	.75
Large intestine	3.22	4.06	-.84	.21	.09
Liver	2.60	2.79	-.19	.20	.66
Digesta Mg, g					
Reticulorumen	1.94	1.06	.88	.20	.02
Stomach	2.03	1.11	.92	.21	.02
Small intestine	.07	.05	.02	.01	.74
Large intestine	1.58	1.00	.58	.16	.02
Total GIT	3.68	2.16	1.52	.29	.03
Tissue Mg, g					
Reticulorumen	.84	.51	.33	.15	.23
Small intestine	.35	.27	.08	.04	.33
Large intestine	.53	.41	.12	.03	.06
Liver	.17	.19	-.02	.01	.47

^aStandard error of the mean, $n = 7$.

^bObserved significance level for the comparison of fed vs unfed.

< .02), whereas appreciable quantities were retained by the tissues of the large intestine ($P < .09$).

Sklan and Hurwitz (1985) and Wylie et al. (1985) noted that there was no net secretion of K into the ruminal contents and that the major absorption site of K was the small intestine; there was little apparent absorption of K from the large intestine. Argenzio (1988) noted that there was a net secretion of K into the colon at least partly resulting from active transport of Na from the lumen. Thus, the net gain of K in the large intestinal digesta was probably the result of secretion of K into the lumen, rather than the passage of K from the small intestine.

Over 41% of the Mg in the digesta was lost ($P < .03$) during deprivation (Table 3). Magnesium losses from sampled tissues tended to be small, although 39% ($P < .23$) of ruminal tissue Mg and 23% ($P < .06$) of large intestinal tissue Mg was lost.

Sklan and Hurwitz (1985) reported that the major absorption site of Mg was the small intestine, with little apparent absorption of Mg from the large intestine. However, other studies (Wylie et al., 1985; Gabel and Martens, 1991; Yano et al., 1991) sug-

gested that the rumen was the major absorption site for Mg. Thus, losses of Mg from the ruminal contents could be the result of both absorption and passage, whereas losses of Mg from the large intestinal digesta were probably a result of excretion in the feces.

Approximately 30% of Fe in the ruminal contents ($P < .05$), 28% of Fe in the large intestinal contents ($P < .07$), and 24% of Fe in the total GIT contents ($P < .05$) was lost during deprivation (Table 4). Abomasal digesta had a very high concentration of Fe compared with other segments of the GIT; however, little Fe was lost (30.7 mg of 448.6 mg) from the abomasal digesta during deprivation. Very little Fe (< 5 mg) was excreted in the urine of the deprived wethers; hence, most of the Fe loss from the GIT digesta was via excretion in the feces.

Of Fe in the ruminal tissues, approximately 26% was lost during deprivation, but this was not statistically significant ($P < .19$). There was no change in the Fe content of the liver or intestine during deprivation. In contrast, Richards et al. (1987) noted increases in hepatic, pancreatic, and renal Fe content and a decrease in duodenal mucosa Fe content during feed deprivation in turkey poults.

Table 4. Iron, Cu, and Zn content of digesta and tissues in fed or unfed mature wethers

Item	Fed	Unfed	Loss	SEM ^a	$P <^b$
Digesta Fe, mg					
Reticulorumen	917.5	638.8	278.7	94.9	.05
Stomach	1,402.1	1,079.3	322.8	88.9	.09
Small intestine	37.0	44.1	-7.1	4.8	.98
Large intestine	698.6	505.2	193.4	82.3	.07
Total GIT	2,137.7	1,628.6	509.1	105.6	.05
Tissue Fe, mg					
Reticulorumen	379.1	278.6	100.5	48.0	.19
Small intestine	72.0	68.6	3.4	9.2	.83
Large intestine	76.6	62.5	14.1	4.8	.25
Liver	113.1	113.3	-2	10.7	.99
Digesta Cu, mg					
Reticulorumen	211.9	175.6	36.3	22.6	.24
Stomach	214.8	177.5	37.3	18.9	.29
Small intestine	9.5	12.1	-2.6	1.6	.63
Large intestine	193.5	118.2	75.3	28.6	.03
Total GIT	417.8	307.8	110.0	55.5	.18
Tissue Cu, mg					
Reticulorumen	8.31	8.07	.24	.60	.83
Small intestine	2.50	2.52	-.02	.32	.95
Large intestine	3.48	3.30	.18	.08	.65
Liver	1,316.0	1,195.0	121.0	282.8	.82
Digesta Zn, mg					
Reticulorumen	156.8	138.3	18.5	19.4	.46
Stomach	174.2	147.0	27.2	14.8	.35
Small intestine	8.4	10.8	-2.4	1.4	.99
Large intestine	141.6	88.6	53.0	18.6	.04
Total GIT	324.2	246.4	77.8	50.2	.12
Tissue Zn, mg					
Reticulorumen	125.2	100.7	24.5	6.5	.06
Small intestine	40.5	36.3	4.2	3.9	.56
Large intestine	44.8	45.8	-1.0	.7	.85
Liver	50.8	55.4	-4.6	6.6	.74

^aStandard error of the mean, $n = 7$.

^bObserved significance level for the comparison of fed vs unfed.

Approximately 26% of the Cu in the GIT digesta was lost during deprivation; 68% of the loss occurred from the large intestinal contents ($P < .03$; Table 4). Copper losses from the large intestine (75 mg) of deprived sheep were appreciably greater than losses in the feces (10.6 mg), suggesting that there was considerable absorption of Cu from the large intestine.

Copper losses from the liver and other sampled tissues were small and not statistically significant. The liver is a primary storage site for Cu. During stress, especially infection, Cu stores in the liver are mobilized in the production of the acute-phase protein, ceruloplasmin, resulting in an increase in plasma Cu concentrations and subsequent decrease in liver Cu concentrations (Chandra and Dayton, 1982). However, Richards et al. (1987) noted an increase in the quantity of Cu in the liver, pancreas, duodenal mucosa, and kidney of turkey poults during feed deprivation. Because feed and water deprivation do not seem to affect serum Cu concentrations in sheep (Cole et al., 1994), it might be expected that deprivation would not affect tissue Cu quantities.

As with Cu losses, approximately 68% of Zn losses from GIT contents occurred in the large intestine ($P < .04$; Table 4). In contrast to Cu, Zn losses from the large intestine (53 mg) were similar to losses in the feces (50 mg), suggesting there was little net absorption of Zn from the large intestine.

Zinc losses in the sampled tissues were generally small, although 20% ($P < .06$) of reticulorumen Zn was lost. Hepatic Zn content was not significantly affected by the deprivation period. In contrast to Cu, during infection plasma concentrations of Zn normally decrease, apparently due to a movement of Zn to the liver for storage (Chandra and Dayton, 1982). However, a 3-d feed and water deprivation period did not affect serum Zn concentrations (Cole et al., 1994). In turkey poults, Richards et al. (1987) noted an increase in the Zn content of liver, pancreas, duodenal mucosa, and kidney during feed deprivation. They suggested that metallothionein, a Zn transport protein, served as a storage mechanism for the conservation of body Zn stores.

Blood and Urine Composition. As would be expected, plasma urea N (19.2 vs 14.6 mg/100 mL) and free fatty acid (1,542 vs 514 μ mol/L) concentrations were greater ($P < .02$) in deprived than in fed wethers. Plasma glucose concentrations were greater ($P < .03$) in fed than in deprived wethers (58.5 vs 49.1 mg/100 mL).

Urine samples (aspirated from the bladder after euthanasia) of deprived wethers had higher concentrations of N (2.09 vs 1.70%; $P < .08$), P (.31 vs .03%; $P < .09$), and urea N (18.0 vs 12.5 mg/mL; $P < .07$) than samples from fed wethers.

Fecal and Urine Losses. Losses of weight, water, DM, Ca, Na, Fe, Cu, and Zn from the GIT digesta tended to be equal to or slightly greater than losses in the feces and urine (Table 5). Copper losses from the GIT

digesta were substantially greater ($P < .05$) than losses in the feces and urine. In contrast, N, P, and K losses from the GIT digesta were less ($P < .05$) than losses in the feces and urine. Magnesium losses in the digesta, although numerically greater than losses in the feces + urine, were not statistically different ($P > .15$). These findings suggest that during the 3-d deprivation period, quantities of Ca, Na, Fe, Cu, and Zn absorbed from the gut were adequate to replenish nutrient losses from the tissues. In contrast, it seems that N, P, K, and possibly Mg, were depleted from the tissues and not entirely replenished from the GIT digesta during the feed and water deprivation period. It is not clear from these results whether the losses of these nutrients are interrelated and(or) a function of protein loss.

It has been shown that increasing the feed intake of feeder calves before a 72-h feed and water deprivation period resulted in greater feed intakes and weight gains after deprivation (Cole and Hutcheson, 1985a). It was suggested that a greater predeprivation store of nutrients within the GIT allowed the calf to better withstand the stress of feed and water deprivation and to recover more rapidly from the stress. Results of the current study further suggest the importance of the nutrient composition of GIT contents on animal response to a stress period such as feed and water deprivation.

Implications

Results of this study indicate that appreciable quantities of nutrients can be lost from tissues during a 3-d feed and water deprivation period in ruminants.

Table 5. Nutrient losses in the digesta compared to losses in the feces and urine during a 3-day feed and water deprivation period

Item	Feces+urine		Difference ^c
	loss ^a	Digesta loss ^b	
Weight, kg	1.81	2.00 (9.50)	.19
DM, kg	.33	.37 (1.33)	.04
Water, kg	1.48	1.65 (8.17)	.17
N, g	24.1	16.3 (38.0)	-7.80*
Ca, g	8.55	11.86 (29.2)	3.31
P, g	3.04	.62 (21.6)	-2.42*
Na, g	.62	1.33 (21.5)	.71
K, g	7.58	1.84 (15.8)	-5.74*
Mg, g	1.93	1.52 (3.7)	-.41
Cu, mg	11.1	110.0 (418)	98.9*
Fe, mg	456	509 (2,137)	53
Zn, mg	54	78 (324)	24

^aFecal and urine losses of lambs during the 3-d feed and water deprivation period.

^bDigesta content in fed sheep minus digesta content in unfed sheep. Values in parentheses are quantity of nutrient present in the GIT digesta of fed sheep.

^cDigesta loss minus loss in feces and urine.

*Digesta losses different from feces + urine losses ($P < .05$).

Approximately 57% of total body water losses occurred from the intracellular compartment. Supplies of Ca, Na, Cu, Fe, and Zn within the gastrointestinal tract were adequate to compensate for tissue losses during the deprivation period. However, appreciable tissue N, P, K, and possibly Mg, supplies were used during the deprivation period. These results suggest that studies on the prestress feeding of marketing/transport-stressed feeder calves should probably concentrate on preventing the losses of intracellular water and tissue N, P, K, and Mg. This knowledge will potentially lead to development of feeder calf prestress diets that will decrease these tissue losses and subsequently decrease morbidity and improve performance.

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