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Effects of repeated cycles of feed intake shifts on growth, feed efficiency and endocrine profiles of wether lambs

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ABSTRACT

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Fifteen wether lambs (average BW 28.8 ± 1.8 kg) were used in a 128-d trial to examine effects of cyclical feeding changes on growth, feed efficiency and endocrine profiles. Control lambs were fed a 40% concentrate diet (40C) at $1.5 \times NE_m$ requirement during period 1 (64 d). Another group ($1\times/2\times$) was fed 40C at 1 and $2 \times NE_m$ in 4-d intervals during period 1; a third group (70/10) was fed 70% and 10% concentrate diets in 4-d intervals during period 1. To achieve dry matter intake comparable to controls, 70/10 lambs were fed at 1.79 (70C) and 1.21 (10C) $\times NE_m$. All lambs were placed on the control diet during period 2 (32 d) and increased to $2\times$ maintenance during period 3 (32 d). During period 2, ADG and gain/feed of control lambs tended to be greater ($P<0.10$) than for lambs fed alternating treatments. Liver weight as a percentage of hot carcass weight was greater ($P<0.05$) for controls than for lambs fed alternating treatments. Hot carcass weight ($P=0.07$) and dressing percentage ($P=0.09$) tended to be greater for the 70/10 treatment than for controls. The $1\times/2\times$ treatment lowered ($P<0.05$) serum cholesterol compared with other groups on d 65, but not on d 0 or 129. Smaller liver weight per unit of hot carcass weight for lambs in the $1\times/2\times$ and 70/10 treatments suggests a possible reduction of maintenance requirements.

Key words: Growth; Lamb; Feed intake; Endocrine profile; Carcass weight

INTRODUCTION

Ferrell and Jenkins (1985) estimated that 70 to 75% of the yearly energy intake of a beef cow herd is used for maintenance requirements, and that only a small portion of variation in maintenance requirements results from differences in body composition. In contrast, Olthoff and Dickerson (1989) sug-

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gested that body composition affects maintenance requirements because of a positive relationship between lean body mass and fasting heat production. Maintenance expenditure varies with weight of metabolically active viscera, particularly the liver (Ferrell and Jenkins, 1985; Koong et al., 1985).

Little information exists on the effect of repeated, short-term cycles of alternating dry matter intake (DMI) or energy density on animal efficiency or size of their organs. Park et al. (1987) fed dairy heifers a control diet (0.45 kg gain/d) or one in which energy and protein density was 15% below or 40% above requirements for that amount of gain (two complete cycles of 5 months below and 2 months above requirements), and found that heifers fed an alternating dietary regimen gained faster and more efficiently than controls. Nir and Nitsan (1979) fasted chicks on alternate days followed by ad libitum repletion on alternate days. These workers reported lower liver weight per unit of BW for both control chicks and chicks on depletion days compared with liver weight from chicks on repletion days. Farrell and Williams (1989) suggested that with repeated cycles of food deprivation and realimentation, rats required less feed to attain the same BW loss or to regain that loss during subsequent cycles.

One objective of our study was to determine effects of cyclically varying DMI or dietary energy density on efficiency of growth, serum clinical chemistry and endocrine profiles of wether lambs. A second objective was to examine the effect of cyclical feeding followed by a period of constant feed intake on growth, serum clinical chemistry and endocrine profiles, organ weights and carcass characteristics of wether lambs. Our hypotheses were (1) alternating DMI or energy density of diets would improve average daily gain (ADG) and/or gain/feed ratio (GFR), and (2) any improvement in efficiency due to cyclical feeding would persist during a second phase of constant DM and energy intake.

MATERIALS AND METHODS

Fifteen fall-born wether lambs (Rambouillet and Rambouillet × Polypay; average BW 28.8 ± 1.8 kg) were randomly assigned to one of three treatment groups. The study consisted of a 64-d period and two 32-d periods with five lambs per treatment. Control lambs received a 40% concentrate diet (40C) fed at $1.5 \times NE_m$ requirement daily (NE_m requirement = 56 kcal/$BW^{0.75}$ daily; NRC, 1985) during period 1. Another group (1×/2×) received 40C at 1 and $2 \times NE_m$ cycled at 4-d intervals during period 1. Remaining lambs (70/10) were fed 70% and 10% concentrate (70C and 10C, respectively) diets cycled at 4-d intervals during period 1 at a daily DMI equal to that of control lambs. During period 2, all lambs were fed the 40C diet at 1.5× maintenance daily. All lambs were then increased to 2× maintenance (40C) during period 3. The three diets were pelleted (0.48 cm diameter) and contained ground corn, alfalfa meal and cottonseed meal in a ratio of 0:90:10 (10C), 30:60:10 (40C) and 60:30:10 (70C), respectively, on an as-fed basis. Pellet composition is presented in Table 1; components were averaged across periods for clarity.

Daily DMI required to provide the various target multiples of NE_m was calculated for each lamb on d 1 and every 16 d thereafter based on individual BW (NRC, 1985). Diets were formulated such that the average of 10C and 70C would be equivalent to 40C in composition and nutrient concentration. To achieve DMI comparable to controls for the 70/10 treatment during period 1, 10C and 70C diets were fed at 1.21 and 1.79×maintenance, respectively. The alternating intake treatment (1×/2×) provided DMI fluctuations above and below controls (but constant energy density) in 4-d intervals during period 1 using the same pelleted diet as fed to controls. Diets were formulated such that they met nutrient requirements over an 8-d cycle, rather than within the 4-d interval (NRC, 1985). Both 1×/2× and 70/10 treatments had comparable DMI and energy density to controls in each 8-d cycle, with the only difference being pattern of consumption. This scheme provided a treatment with a cyclical pattern of energy intake and a constant DMI (70/10), as well as one with a cyclical pattern of DMI and a constant energy density (1×/2×). Four-day cycles were chosen in an attempt to achieve the maximum number of cycles within a period, while allowing time for a given shift to have an effect at the tissue level. The assumption was made that 4-d cycles would be short enough that readaptation to each shift would not be necessary.

Before the study began, lambs were adapted incrementally to the 40C pel-

TABLE 1

Chemical composition of diets

Item	Diet[a,b]		
	10C	40C	70C
DM (%)	92.6 (0.4)	92.4 (0.2)	91.4 (0.3)
	....	% of DM	....
Ash	13.4 (0.1)	10.1 (0.5)	7.0 (0.2)
CP	20.5 (0.2)	18.2 (0.2)	17.1 (0.1)
NDF	50.5 (0.5)	40.4 (0.6)	30.2 (0.3)
ADF	37.7 (0.4)	28.0 (0.2)	18.6 (0.5)
ADL	10.6 (0.09)	8.0 (0.15)	6.0 (0.23)
Ca	1.58 (0.02)	1.01 (0.07)	0.8 (0.01)
P	0.42 (0.01)	0.38 (0.01)	0.42 (0.00)

[a]Pelleted ground corn, alfalfa meal and cottonseed meal in a ratio of 0:90:10 (10C), 30:60:10 (40C) and 60:30:10 (70C).
[b]Values are means (SE), n=4, 8 and 4 for 10C, 40C and 70C, respectively.

leted diet as a group for 7 d, with alfalfa hay and whole milo grain as the remainder of the diet. Lambs were fed only the pelleted diet (40C diet at $1.5 \times NE_m$) by d 6. Lambs were then adapted to individual outdoor pens (1.2×3.1 m) for 5 d at the $1.5 \times NE_m$ intake level. Lambs were fed once daily at 08:00, and orts were recorded when necessary. Water and trace mineral salt (96–99% NaCl, ≥0.2% Mn, ≥0.1% Fe, ≥0.1% Mg, ≥0.05% S, ≥0.025% Cu, ≥0.01% Co, ≥0.008% Zn and ≥0.007% I) were available free choice. Lambs had been injected with a Se (1 mg/ml)-vitamin E complex (BOSE, Schering Corp., Kenilworth, NJ) and vaccinated for *Clostridium perfringens* type C and D (Convac®CD, Affilitated Industries, Bristol, TN) at weaning (approx. 2 months of age). Lambs were revaccinated for *Clostridium* at the beginning of the trial and treated for internal parasites (Levisol®, Pitman-Moore, Washington Crossing, NJ) on d 17 of the trial.

Daily samples of each feed were composited by period, ground to pass a 2-mm screen in a Wiley mill, and analyzed for DM, ash, P (molybdovanadate method) and CP (AOAC, 1990) and NDF (Robertson and Van Soest, 1981), ADF and ADL (non-sequential; Goering and Van Soest, 1970). Calcium content of feeds was determined by solubilizing ash residues in boiling HCl (3.1 M), and measuring Ca concentration with atomic absorption spectrophotometry using an air/acetylene flame and lanthanum oxide to prevent interferences (Instrumentation Laboratory, Model 551, Wilmington, MA).

Lambs were weighed on d 1 of the trial and every 16 d thereafter at 08:00, before feeding. Water was removed from each pen at 17:00 the day before weighing to reduce variation in BW associated with water intake. Weigh periods always followed a 4-d interval when lambs on cyclical intake treatments received $2 \times NE_m$ or 10C during period 1. Gain/feed ratio and ADG were calculated for each period.

Blood samples were obtained by jugular venipuncture from each lamb on d 0 (last day of adaptation, while on same diet), 65 (first day of period 2) and 129 (last day of period 3). Sampling dates were selected to eliminate the confounding effect of diet and intake level with blood variables. All sampling was conducted while lambs were fed the same diet (40C), but level of intake varied ($1.5 \times NE_m$ on d 0 and 65; $2 \times NE_m$ on d 129). On each sampling day, blood samples were obtained at 06:00, 07:00, 08:00, 09:00, 10:00, 11:00 and 12:00. Lambs were fed immediately after the 08:00 blood sample was taken. Blood samples were allowed to clot at room temperature for 30 min, centrifuged at $2300 \times g$ for 15 min at 4°C, and serum was decanted and frozen at −20°C. Serum clinical chemistry profiles (Southwest Medical Diagnostic Laboratory, Las Cruces, NM) were obtained for serum samples collected at 08:00 on each sampling day. All serum samples were analyzed for growth hormone (GH; Hoefler and Hallford, 1987) and insulin (Sanson and Hallford, 1984).

Concentrations of triiodothyronine (T3) and thyroxine (T4) were also measured in all serum samples by RIA. The T3 and T4 assays were conducted using rabbit antisera (ICN Biomedicals, Costa Mesa, CA; anti-T3 No. 65-851-1 and anti-T4 No. 65-850-1), radioiodinated (Du Pont New England Nuclear, Boston, MA) T3 and T4, and purified T3 and T4 (Sigma Chemical Co., St. Louis, MO) as standard preparations. Both assays were developed as direct serum, double-antibody radioimmunoassays using buffer systems described by Hoefler and Hallford (1987) for determination of GH.

Standard or serum was added to 12×75 mm plastic culture tubes that were then normalized to 400 μl using 0.01 M phosphate-buffered saline containing 1% (w/v) bovine serum albumin (PBS+1% BSA, pH 7). Thyroxine and T3 were dissociated from their binding proteins by addition of 100 μl of 8-anilino-1-naphthalene sulfonic acid-sodium salt (Du Pont New England Nuclear, Boston, MA; 2 mg/ml in PBS+1% BSA). Subsequently, 200 μl of an appropriate dilution of either anti-T3 (1:6000) or anti-T4 (1:1000) were added to each tube, followed by addition of 100 μl PBS+1% BSA containing either [^{125}I]T3 or [^{125}I]T4. Tubes were then vortexed and incubated overnight at 4°C, after which bound fractions were precipitated using a second antibody (sheep antirabbit γ-globulin). Tubes were incubated overnight at 4°C with the precipitating antibody, after which they were centrifuged (2300×*g*, 4°C), the supernatant fluid decanted and the bound fraction counted.

Total binding for T3 and T4 assays were 40 and 36%, respectively. Addition of 0.1 ng of T3 and 1 ng of T4 displaced 11 and 41% of the radioactivity from the antisera, respectively. When 1 ng of T3 was added to wether serum containing 3.1 ng of T3/ml, 3.9±0.06 ng/ml were recovered (95%). Likewise, when 20 ng of T4 were added to wether serum containing 74 ng of T4/ml, 96±5 ng/ml were recovered (102%). All serum samples were quantified in a single assay resulting in within assay coefficients of variation ($n=10$) of 9 and 10% for T3 and T4, respectively.

Lambs were slaughtered at the New Mexico State University Meats Laboratory within 48 h of the last sampling day. Feed was withheld 24 h before slaughter. Hot carcass weight (HCW) and liver weight (including gall bladder) were measured at slaughter. Carcasses were chilled (24 h at 2°C) before routine carcass measurements were obtained (National Livestock and Meat Board, 1977). Kidney weight was recorded after chilling. The 9th to 11th rib section was removed, and tissue was separated from bone and stored at −20°C. Tissue was thawed and ground with a food processor (Cuisinart, Model DLC-7M, Norwich, CT) for approx. 1 min, and analyzed for DM, ash, CP and ether extract (AOAC, 1990).

One lamb on the 1×/2× treatment developed respiratory problems during period 1 and was removed from the study. Analysis of variance was conducted using GLM procedures of SAS (1985). Gain/feed and ADG were analyzed using a split-plot design with treatment in the main plot and period in the subplot. Because period × treatment interactions ($P<0.05$) were detected, variables were analyzed within period. Carcass and organ weight data were analyzed as a completely random design. Nonparametric carcass data were analyzed using Chi-square procedures (Everitt, 1977).

Serum constituents and hormones were analyzed using a split-plot analysis of variance for repeated measures (Gill and Hafs, 1971). When a single sample was collected on each day (serum constituents), treatments were included in the main plot and tested using variation associated with animal within treatment. Day and day × treatment interactions were included in the subplot. Because hormone data were collected repetitively on 3 days, treatment effects were analyzed in the main plot, day in the subplot and hour in the subsubplot. When interactions were detected for serum constituents or hormones with day and/or hour in the model, these variables were reanalyzed by day or hour within day. Means were separated using predicted difference (SAS, 1985) when significant F values ($P<0.05$) were detected.

RESULTS AND DISCUSSION

During period 2, differences ($P<0.10$) were noted among treatments for ADG or GFR (Table 2). Control lambs had greater ADG and GFR than either alternating treatment during this period. However, during period 1, a trend was noted for greater ADG ($P=0.15$) and GFR ($P=0.12$) in 1×/2× lambs than control lambs. When lambs on alternated diets were weighed on d 65, they had received 10C (70/10 treatment) or 2× maintenance (1×/2× treatment) diets on the previous day; thus, fill could have contributed to the increased BW noted at this time. However, lambs generally consumed

TABLE 2

Average daily gain and gain to feed ratio (G/F) of wether lambs fed in three patterns

	Treatment											
	period 1[a]				period 2[b]				period 3[c]			
	CON	1×/2×	70/10	SE[d]	CON	1×/2×	70/10	SE[d]	CON	1×/2×	70/10	SE[d]
ADG (g/d)	40	66	48	9.2	94[e]	71[f]	62[f]	8.7	159	188	150	13.3
G/F (g/kg)	51	84	59	11.1	111[e]	83[f]	72[f]	10.9	133	153	122	10.8

[a]Wethers were fed 40% concentrate at 1.5× maintenance (CON), 40% concentrate at maintenance and 2× maintenance alternated at 4-d intervals (1×/2×) or 70 and 10% concentrate (1.8 and 1.2× maintenance) alternated at 4-d intervals (70/10).
[b]All wethers were fed 40% concentrate at 1.5× maintenance.
[c]All wethers were fed 40% concentrate at 2× maintenance.
[d]SE of least squares means, $n=5$, 4 and 5 for CON, 1×/2× and 70/10, respectively.
[e,f]Within period, row means with different superscripts differ ($P<0.10$).

their feed within 30 min, thus it is unlikely that fill made a substantial contribution to differences in BW after 24 h at this level of intake.

Gains for all groups were below maximal production levels for growing lambs. Nutrient intake levels were below those typically offered in practice, but were selected to allow several cycles of intake fluctuations. Predicted gains (approx. 180 g/d; NRC, 1985) were greater than actual gains during periods 1 and 2. During period 3 (after intake was increased), gains and GFR were more in line with desired values. Because diets were pelleted, increased particulate passage rate through the gastrointestinal tract and subsequent reduced digestibility could explain the divergence of predicted and actual gains. Alternatively, the nutrient supply of the feeds used was atypical, or literature values for gains from these feeds are not accurate for lambs used and conditions imposed in our experiment. Orts rarely occurred and were usually related to occurrence of wet feed rather than to obvious digestive disturbances. More problems would likely have been encountered if the average intake had been greater than $1.5\times NE_m$, of if shifts above and below maintenance had been wider than 1 and 2 × maintenance.

Ruminants are usually fed in a consistent manner and modifications of intake or concentrate level are made gradually. Consequently, little data are available with which to compare our results. Existing data, however, indicate that previous nutritional level can affect maintenance requirements and/or efficiency of growth during subsequent periods (Ferrell et al., 1986; Park et al., 1987; Hicks et al., 1990). Farrell and Williams (1989) reported that for rats in successive cycles of BW loss and gain, number of days to reach target BW decreased, as did ME intake needed to reach target BW in both gain and loss phases.

Although trends existed for improved ADG and GFR in period 1, this study provided no conclusive evidence to support the hypothesis that cyclical feeding patterns affect efficiency of feed use by lambs. Although no data are available for direct comparison from ruminants receiving several short cycles of intake, it is conceivable that fewer cycles of greater length may have produced different results. The data do not support the hypothesis of a persistence of effects of previous shifts in subsequent periods with a constant level of intake. A rapid reversal of any effect might be expected considering the adaptive capacity of the liver (McBride and Kelly, 1990) and its ability to change mass quickly in response to a change in intake (Rompala and Hoagland, 1987); assuming that liver weight and/or activity and maintenance requirements are related.

Liver and kidney weights did not differ among treatment groups (Table 3). When expressed per unit of $BW^{0.75}$ (MBW), kidney weight of 70/10 lambs tended ($P=0.09$) to be greater than 1×/2× lambs. When scaled to a HCW basis, liver weight was greater ($P<0.05$) for controls than either 1×/2× or

TABLE 3

Organ weights of wether lambs fed in three different patterns

Item	Treatment[a]			
	CON	1×/2×	70/10	SE[b]
Liver (g)	621	616	633	20.5
Liver (g/kg HCW[c])	32.1[e]	30.1[f]	30.2[f]	0.43
Liver (g/kg MBW[d])	39.9	38.2	39.8	0.78
Kidney (g)	103	102	109	3.0
Kidney (g/kg HCW)	5.3	5.0	5.2	0.14
Kidney (g/kg MBW)	6.6	6.3	6.8	0.17

[a]Wethers were fed 40% concentrate at 1.5× maintenance (CON), 40% concentrate at maintenance and 2× maintenance alternated at 4-d intervals (1×/2×) or 70 and 10% concentrate (1.8 and 1.2× maintenance) in 4-d intervals (70/10) for 64 d. All wethers were then fed 40% concentrate at 1.5× maintenance for 32 d, followed by 40% concentrate at 2× maintenance for 32 d.
[b]SE of least squares means, $n=5$, 4 and 5 for CON, 1×/2× and 70/10, respectively.
[c]Hot carcass weight.
[d]Metabolic body weight, $BW^{0.75}$.
[e,f]Row means with different superscript differ ($P<0.05$).

70/10 lambs. Organ weights were expressed on a HCW as well as a MBW basis to reduce variability associated with BW measurement and gut fill.

Organ weights (particularly liver and gut, as well as heart and kidney in some cases) have been positively related to maintenance requirements of ruminants (Koong et al., 1985; Ferrell et al., 1986; DiCostanzo et al., 1990), but the liver responds quickly to a change in feeding level (Rompala and Hoagland, 1987). Possibly, the liver may also adapt as quickly to a change in feeding pattern; hence, differences might have been more pronounced if cyclical feeding patterns had been continued throughout our study. Whether the trend for improved GFR and ADG with the 1×/2× treatment in period 1 could be attributed to an effect on maintenance requirements is unknown. Yet, lower liver weight per unit of HCW with the 1×/2× and 70/10 treatment suggests a possible reduction of maintenance requirements compared with control lambs. Nir and Nitsan (1979) and Pinchasov et al. (1985) reported decreased liver weight per unit of BW for both chicks that had been fasted and control chicks compared with chicks that had been repleted. Ferrell et al. (1986) indicated that effect of previous plane of nutrition on energy expenditure of lambs was related to variation in weight of metabolically active organs, whereas other research with ruminants has shown no change in liver and/or other organ weights resulting from previous nutritional level (Varga and Tyrell, 1989; Hicks et al., 1990). We are not aware of other organ mass data with energy density alternated cyclically for comparative purposes, although varied forage intake at a constant ME intake had little effect on liver or gut weight (Johnson et al., 1990).

Hot carcass weight ($P=0.07$) and dressing percentage ($P=0.09$) tended to be greater for 70/10 lambs than controls (Table 4). No differences ($P>0.10$) were noted for loin eye area, fat thickness, kidney and pelvic fat, yield grade, composition of the 9th to 11th rib section (Table 4) or quality grade (data not shown).

Differences in GFR and ADG did not appear to be related to body composition (based on composition of the 9th to 11th rib section). With similar body composition, differences in GFR should translate to differences in energy use for maintenance, rather than differences in efficiency of deposition of lean and fat. Body composition of lambs did not appear to be affected by previous plane of nutrition (Ferrell et al., 1986), leading these researchers to suggest that body composition was not responsible for the effect of previous nutrition on subsequent differences in maintenance requirements.

Because of day×treatment and day×hour×treatment interactions ($P<0.05$), respectively, T3 and T4 were reported by day, and GH and insulin were reported by hour within day. On d 0, differences in serum GH concentration among treatments were not detected ($P>0.10$) at any of the sampling times (Fig. 1). Serum insulin concentration at 2 h before feeding on d 0 (Fig. 2) tended to be greater ($P<0.10$) for the 70/10 lambs than for lambs

TABLE 4

Carcass characteristics of wether lambs fed in three patterns

Item	Treatment[a]			
	CON	1×/2×	70/10	SE[b]
Hot carcass weight (kg)	19.4	20.5	21.0	0.50
Dressing percentage	49.7	50.3	52.3	0.88
Loin eye area[c] (cm^2)	11.9	13.4	12.4	0.65
Fat thickness[c] (cm)	0.33	0.38	0.36	0.08
Kidney and pelvic fat (%)	3.1	3.0	2.7	0.30
Yield grade	2.75	2.88	2.71	0.21
Rib[d] DM (%)	51.9	51.7	49.2	2.0
	....	% of DM	....	
Rib[d] ash	1.4	1.5	1.5	0.12
Rib[d] CP	28.0	26.8	31.1	2.32
Rib[d] ether extract	65.8	64.7	67.6	5.64

[a]Wethers were fed 40% concentrate at 1.5× maintenance (CON), 40% concentrate at maintenance and 2× maintenance alternated at 4-d intervals (1×/2×) or 70 and 10% concentrate (1.8 and 1.2× maintenance) in 4-d intervals (70/10) for 64 d. All wethers were then fed 40% concentrate at 1.5× maintenance for 32 d, followed by 40% concentrate at 2× maintenance for 32 d.
[b]SE of least-squares means, $n=5$, 4 and 5 for CON, 1×/2× and 70/10, respectively.
[c]12th rib.
[d]Tissue from the 9th to 11th rib section.

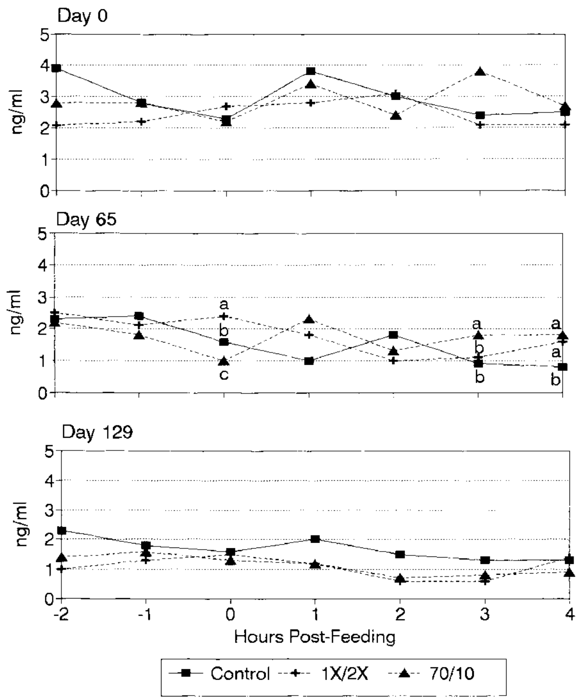

Fig. 1. Serum growth hormone concentrations of wethers receiving diets in three different patterns (SE range = 0.15 to 1.07). Wethers were fed 40% concentrate at 1.5× maintenance (CON), 40% concentrate at maintenance and 2× maintenance alternated at 4-d intervals (1×/2×) or 70 and 10% concentrate (1.8 and 1.2× maintenance) in 4-d intervals (70/10) for 64 d. All wethers were then fed 40% concentrate at 1.5× maintenance for 32 d, followed by 40% concentrate at 2× maintenance for 32 d. Means within hour with different letters differ ($P<0.10$).

in the other two treatments. Serum T3 and T4 (Table 5) did not differ among treatments on d 0 ($P>0.10$).

Differences in serum GH were detected on d 65 at 0, 3 and 4 h after feeding ($P<0.10$; Fig. 1). At 0 h postfeeding, GH concentration of 1×/2× lambs was greater than that of control lambs, which in turn was greater than that of 70/10 lambs. Serum GH of 70/10 lambs was greater than that of the other two groups at 3 h postfeeding, whereas control lambs had lower serum GH 4 h after feeding. Serum insulin tended to be greater on d 65 at 2 h after feeding in control lambs than in the other two groups, and lower 4 h after feeding in 1×/2× lambs than in the other two groups ($P<0.10$; Fig. 2).

Serum T3 (Table 5) was less for 70/10 lambs than for controls on d 65 ($P<0.05$), whereas T4 did not differ among treatments on d 65 ($P>0.10$). Differences in GH and insulin concentrations among treatments were not de-

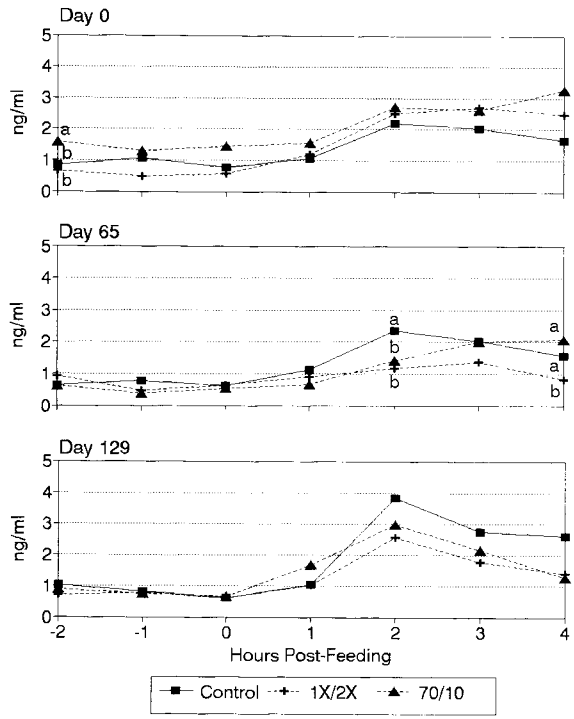

Fig. 2. Serum insulin concentrations of wethers receiving diets in three different patterns (SE range = 0.07 to 0.78). Wethers were fed 40% concentrate at 1.5× maintenance (CON), 40% concentrate at maintenance and 2× maintenance alternated at 4-d intervals (1×/2×) or 70 and 10% concentrate (1.8 and 1.2× maintenance) in 4-d intervals (70/10) for 64 d. All wethers were then fed 40% concentrate at 1.5× maintenance for 32 d, followed by 40% concentrate at 2× maintenance for 32 d. Means within hour with different letters differ ($P<0.10$).

tected ($P>0.10$) on d 129 for any of the sampling times (Figs. 1 and 2). Serum T3 and T4 (Table 5) did not differ among treatments on d 129 ($P>0.10$). Serum GH/insulin ratios (data not shown) differed ($P<0.05$) at only one sampling time (d 65, 0 h); at this sampling time, the 1×/2× treatment resulted in a greater GH/insulin ratio than the other two treatments. In general, GH/insulin ratios were highly variable.

The three sampling times before feeding were selected to monitor baseline hormone concentrations, whereas postfeeding samples were collected to assess acute responses to feed intake. Figs. 1 and 2 illustrate that any differences resulting from treatment seldom occurred at prefeeding sample times because serum GH and insulin were quite uniform and stable at these times on all 3 days. Differences among treatments in serum hormone profiles appeared to occur in response to feeding and these differences nearly all occurred on d 65. This sampling time coincided with the end of period 1 when alternating diet shifts were terminated.

TABLE 5

Serum triiodothyronine (T3) and thyroxine (T4) of wether lambs fed in three different patterns

Item	Treatment			
	CON[a]	1×/2×[a]	70/10[a]	SE[b]
	(nmol/liter)			
Day 0				
T3	4.0	3.6	3.6	0.39
T4	134.4	123.5	138	13.6
Day 65				
T3	4.0[c]	3.6[c,d]	3.0[d]	0.39
T4	135	126	131	8.7
Day 129				
T3	4.2	3.4	3.9	0.33
T4	140	121	143	9.6

[a]Wethers were fed 40% concentrate at 1.5× maintenance (CON), 40% concentrate at maintenance and 2× maintenance alternated at 4-d intervals (1×/2×) or 70 and 10% concentrate (1.8 and 1.2× maintenance) in 4-d intervals (70/10) for 64 d. All wethers were then fed 40% concentrate at 1.5× maintenance for 32 d, followed by 40% concentrate at 2× maintenance for 32 d.
[b]SE of least-squares means, $n=35$, 28 and 35 for CON, 1×/2× and 70/10, respectively.
[c,d]Row means with different superscripts differ ($P<0.05$).

As stated previously, a trend for improved ADG and GFR was noted at this time for the 1×/2× treatment. Differences in endocrine profiles may be related to differences in growth rate, as well as to differences in organ weight (and subsequently, organ activity) detected on d 129. Because thyroid hormones are related to O_2 consumption, respiration and metabolic rate (McDonald, 1976), treatments that result in decreased maintenance requirements might be expected to reduce T3 and/or T4 concentrations. The 70/10 treatment resulted in a lower T3 concentration than in controls on d 65; however, no differences were detected between 1×/2× lambs and controls for either T3 or T4. Intermittent feeding (fed and fasted on alternate days) of chicks (Nir et al., 1983) resulted in greater plasma GH on depletion days, and to a lesser extent, on repletion days than observed for controls. In our study, GH for 1×/2× lambs was greater than for controls at 0 and 4 h after feeding on d 65, suggesting a possible response of GH to alternating intake pattern. Variable effects of treatment on GH and insulin concentrations, however, obviate simplistic interpretation of results. Perhaps hourly blood sampling was inadequate to assess hormone profiles.

Serum constituents and metabolites (0 h, prefeeding) are presented in Table 6. Only cholesterol exhibited a day × treatment interaction ($P<0.05$); thus, variables were reported across the 3 sampling days. Although not anticipated, the day × treatment interaction for cholesterol may be important. On

TABLE 6

Serum clinical profiles of wether lambs fed in three different patterns

Item	Treatment			
	control[a]	1×/2×[a]	70/10[a]	SE[b]
Glucose (mg/dl)	71	69	72	2.1
Cholesterol[c] (mg/dl)	43	38	42	2.5
Triglycerides (mg/dl)	17	18	15	1.7
Urea nitrogen (mg/dl)	20[d]	21[d]	24[e]	0.9
Creatinine (mg/dl)	0.9	0.9	1.0	0.05
Urea nitrogen/creatinine	21	23	23	1.0
Uric acid (mg/dl)	0.11[f]	0.08[g]	0.08[g]	0.008
Albumin (g/dl)	4.0	3.7	4.0	0.08
Globulin (g/dl)	2.3	2.1	2.3	0.12
Total protein (g/dl)	6.3[f]	5.8[g]	6.3[f]	0.14
Albumin/globulin	1.8	1.8	1.8	0.11
Total bilirubin (mg/dl)	0.11	0.11	0.13	0.013
Alkaline phosphatase (U/liter)	332	284	308	23.2
Lactate dehydrogenase (U/liter)	347	339	352	10.7
Aspartate aminotransferase (SGOT) (U/liter)	67	65	65	3.6
Alanine aminotransferase (SGPT) (U/liter)	8	10	11	1.0
SGOT/SGPT	9	7	6	1.3
Sodium (mEq/liter)	144[f]	138[g]	143[f]	1.3
Chloride (mEq/liter)	108	105	107	1.1
Potassium (mEq/liter)	4.8	4.8	5.0	0.14
Bicarbonate/ CO_2	18	18	19	0.6
Anion gap (mEq/liter)	17	15	17	0.7
Calcium (mg/dl)	9.9	9.5	10.0	0.16
Inorganic phosphorus (mg/dl)	8.2	7.4	7.6	0.61
Osmolality (mOSM/liter)	288[f]	277[g]	287[f]	2.4

[a]Wethers were fed 40% concentrate at 1.5× maintenance (CON), 40% concentrate at maintenance and 2× maintenance alternated at 4-d intervals (1×/2×) or 70 and 10% concentrate (1.8 and 1.2× maintenance) in 4-d intervals (70/10) for 64 d. All wethers were then fed 40% concentrate at 1.5× maintenance for 32 d, followed by 40% concentrate at 2× maintenance for 32 d.
[b]SE of least-squares means, $n=15$, 12 and 15 for CON, 1×/2× and 70/10, respectively.
[c]Treatment × day interaction ($P<0.05$).
[d,e]Row means with different superscripts differ ($P<0.10$); [f,g]($P<0.05$).

d 65, 1×/2× lambs had lower ($P<0.05$) serum cholesterol than lambs in the other two groups (46, 32 and 46 mg/dl for controls, 1×/2× and 70/10, respectively), whereas no differences were detected among groups on d 0 or 129. Considering that cholesterol is primarily synthesized and metabolized in the liver (Bartley, 1989), and if liver size was decreased with the 1×/2× treatment (which theoretically should have been more pronounced on d 65 than at slaughter), cholesterol concentrations might logically be lowered.

No differences ($P>0.10$) were detected for serum glucose or triglycerides (Table 6), suggesting no effects of treatment on prefeeding concentrations of these constituents. Serum urea nitrogen (N) was greater in 70/10 lambs than in lambs in the other two groups ($P<0.10$). Serum urea N values were at the high end of the normal range (Kaneko, 1989a), suggesting adequate protein intake. Uric acid was greater in control lambs ($P<0.05$) than in lambs in the other two groups, whereas total serum protein was less in the 1×/2× treatment ($P<0.05$) than in lambs in the other two groups. Serum proteins are synthesized in the liver (Kaneko, 1989b); thus, a difference in total protein indicates that liver function in 1×/2× lambs was different than in the other groups. However, serum albumin, globulin and creatinine concentrations, and urea N/creatinine and albumin/globulin ratios did not differ ($P>0.10$) among treatments.

Protein status of the lambs may have been affected by alternating feeding patterns. Possibly, a ruminal effect was encountered with cyclical feeding; it is conceivable that dietary protein escaping the rumen was altered with cyclical feeding. Differences were not detected ($P>0.10$) for bilirubin or any enzymes or enzyme ratios, suggesting no impairment of liver function resulted from the imposed treatments. No differences were noted ($P>0.10$) for any of the serum minerals measured except Na, which was less ($P<0.05$) in 1×/2× lambs than in the other two groups. Serum osmolality was also lower ($P<0.05$) for 1×/2× lambs than for lambs in the other two groups, which was probably a result of decreased serum Na and total protein in this treatment. Bicarbonate/CO_2 ratio and anion gap did not differ ($P>0.10$) among treatments, suggesting serum acid-base balance was similar for all three groups (Carlson, 1989).

CONCLUSIONS

Cyclical feeding tended to improve ADG and GFR during period 1 when shifts occurred and reduced ADG and GFR in period 2 after shifts were terminated. Liver weight (HCW basis), hot carcass weight and dressing percentage also were altered. Hormonal and serum clinical chemistry profile responses to cyclical feeding were also evident, especially on d 65. Whether these responses are related to maintenance requirements cannot be determined from our results. Effects of intake and concentrate level at the tissue level and ruminal effects on passage rate, digestibility and fermentation are difficult to separate. Passage rate should have fluctuated with the 1×/2× treatment and could have affected digestibility, microbial protein production, ruminal escape protein, microbial species and fermentation patterns. These factors should be studied in greater detail, particularly given the apparent effect of cyclical feeding on protein status as evidenced by several nitrogenous serum constituents. Further exploration is also warranted concerning effects of number and length of individual cycles, level of intake and gain, degree of intake and energy density shifts (without problems associated with acidosis) and continued cycling throughout the finishing phase.

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