Effect of source of energy and rate of growth on performance, carcass characteristics, ruminal fermentation, and serum glucose and insulin of early-weaned steers[1]

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ABSTRACT: Seventy-three crossbred steers (initial BW = 170.5 ± 5.5 kg) from The Ohio State University (Exp. 1) and 216 crossbred steers (initial BW 135.4 ± 4.4 kg) from the University of Illinois (Exp. 2) were used to determine the effect of source of energy and rate of growth on performance, carcass characteristics, and glucose and insulin profiles on early-weaned steers. Effects of the diets used in Exp. 1 and 2 on ruminal pH and VFA concentrations were quantified using ruminally fistulated steers (Exp. 3). Cattle were weaned at an average age of 119 d in all experiments and were allotted by age, BW, and breed to one of four diets: high-concentrate, fed ad libitum (ALCONC), high-concentrate fed to achieve a gain of either 1.2 kg/d (1.2CONC) or 0.8 kg/d (0.8CONC), or high-fiber, fed ad libitum (ALFIBER). At 218 d of age, all steers were placed on the ALCONC diet until slaughter. Steers were implanted with Compudose at the initiation of all experiments and with Revalor-S when they were estimated to be 100 d from slaughter. When steers in Exp. 1 averaged 181 and 279 d of age, serum samples were collected to determine glucose and insulin concentrations. Steers were slaughtered when a fat thickness of 1.27 cm was reached (Exp. 1) or after 273 d on feed (Exp. 2). In Exp. 1, days in the feedlot ($P < 0.01$) and age at slaughter ($P < 0.01$) were lowest for ALCONC and ALFIBER steers, and greatest for 0.8CONC steers. Overall, ADG was greatest for ALCONC and lowest for 0.8CONC steers; feed efficiency was lowest ($P < 0.01$) for ALFIBER steers. Final BW did not differ ($P > 0.57$) among treatments. At 181 and 218 d of age, serum insulin was increased ($P < 0.10$) and intramuscular fat percentage was greatest ($P < 0.07$), respectively, for ALCONC steers. In Exp. 2, overall ADG ($P < 0.06$) and final BW ($P < 0.04$) were greatest for ALCONC and lowest for 1.2CONC and 0.8CONC steers. Overall feed efficiency was greatest for 0.8CONC and lowest for ALFIBER ($P < 0.01$). Growing phase diet did not affect marbling score at 218 d of age or at slaughter ($P > 0.81$). In Exp. 3, differences in ruminal pH after feeding may have been a consequence of increasing acetate (ALFIBER), propionate (ALCONC), or a combination of VFA (0.8CONC and 1.2CONC), respectively (diet × time after feeding, $P < 0.10$). Controlling growth by limit-feeding a high-concentrate diet for only 100 d does not extend the growth curve of early-weaned steers or enhance intramuscular fat deposition at slaughter compared to ad libitum intake of a high-concentrate or high-fiber diet.

Key Words: Beef Cattle, Carcass Composition, Early Weaning, Feedlots, Insulin

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Introduction

The positive effects of marbling on palatability and a meat-grading system that penalizes carcasses with little marbling make it essential that cattle be produced with adequate amounts of intramuscular fat (Smith and Crouse, 1984). Accelerated finishing systems for early-weaned bulls and steers can result in carcasses with consistently high marbling scores (Myers et al., 1999b,c; Schoonmaker et al., 2002a,b). Smith and Crouse (1984) demonstrated that glucose provides 50 to 75% of the acetyl units for in vitro lipogenesis in the intramuscular fat depot. Therefore, starch fermentation, resulting in elevated blood glucose and insulin, may be a key component in triggering intramuscular adipocyte development in young calves (100 to

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200 d of age) fed a high-grain diet. However, feeding early-weaned calves a high-grain diet tends to hasten physiological maturity and can result in excessively fat or light-weight carcasses (Schoonmaker et al., 2001; 2002b).

Restricting intake increases carcass leanness, reduces rate of gain, and increases the time required for cattle to reach market weight and body condition (Plegge, 1987; Hicks et al., 1990; Murphy and Loerch, 1994). Controlling growth rate by limit-feeding grain-based diets may allow the growth curve of early-weaned calves to be extended while still achieving a starch fermentation that may result in enhanced intramuscular fat deposition. Controlling growth rate by feeding a fiber-based diet may similarly allow the growth curve of these calves to be extended, but the resultant fermentation may not positively affect intramuscular fat deposition. The effects of limit-feeding a grain-based diet or feeding a fiber-based diet to early-weaned calves on performance and eventual carcass characteristics are unknown. Thus, our objective was to determine the effects of source of energy and rate of gain of early-weaned steers on performance, carcass characteristics, ruminal volatile fatty acids, and serum glucose and insulin concentrations.

Materials and Methods

Experiment 1. Seventy-three Angus × Simmental steers from The Ohio State University (OSU) beef herd were weaned at an average age of 119 d (June 29, 2000) and allotted by age, BW, and hide color to one of four treatments: 1) a high-concentrate diet fed ad libitum, 2) limit-fed to achieve a gain of 1.2 kg/d, 3) limit-fed to achieve 0.8 kg/d, or 4) fed a high-fiber diet ad libitum. Prior to early weaning, calves were grazed in southern Ohio on mixed pastures of orchardgrass, Kentucky bluegrass, clover, and tall fescue typical of the region. Steers were not creep fed. Five (initial) and two (booster) weeks prior to weaning, steers were vaccinated for protection against infectious bovine rhinotracheitis, bovine viral diarrhea, parainfluenza-3, bovine respiratory syncitial virus, *Haemophilus somnus, Pasteurella,* and *Clostridia* (Cattle Master-4, Bar Somnus 2P, Alpha-7, respectively; Pfizer, Exton, PA). Steers were revaccinated at 196 d of age, 2 wk prior to arrival of cattle in other, unrelated experiments. Upon arrival at the OSU Beef Center, steers were treated with Dectomax (Pfizer) for internal and external parasites. Health status of the cattle was recorded daily. Rectal temperatures were measured in animals with decreasing feed intakes and in those that were visibly anorexic or with severe nasal mucous drainage and rapid or labored breathing. Any animal with a rectal temperature >39.4°C prior to feeding in the morning was treated with antibiotics according to label instructions (Micotil, Elanco, Indianapolis, IN; Baytril, Bayer, Shawnee Mission, KS; Nuflor, Schering Plough, Union, NJ; Excenel, Pharmacia & Upjohn Co., Kalamazoo, MI). Antibiotic treatment continued until rectal temperature was below 39.4°C for all experiments. Research protocols regarding animal care followed guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Consortium, 1998).

Steers were fed individually in a totally enclosed feedlot barn (slatted concrete floor; metal gates). Pens were 2.6 × 1.5 m, giving each calf 3.9 m^2 of floor space. Phase 1 lasted for 100 d (119 to 218 d of age). Steers fed the grain-based diets (ad libitum or programmed to gain 0.8 or 1.2 kg/d) received a 7% chopped brome grass hay, 16% CP diet until 218 d of age (Table 1). The concentrate portion of the diet contained 71% dry whole shelled corn and 22% supplement. Steers fed the fiber-based diet received a 30% chopped brome grass hay, 16% CP diet until 213 d of age. The remaining portion of the diet contained 55% soy hulls and 15% supplement. To determine BW gain during the first phase, initial and final BW was calculated as an average of prefeeding BW on two consecutive days. In addition, all cattle were fed a common feedlot diet at 1.8% of BW for 5 d prior to the final weighing at the end of the first phase (218 d of age) to minimize gut fill effects. From 218 d of age until slaughter, all steers were given ad libitum access to a common diet (7% hay, 14% CP). Hay was purchased from a commercial hay broker in Indiana. Feed was delivered once daily at 0900, and feed refusals were recorded daily for each steer. Feed deliveries to limit-fed steers were determined based on BW and energy content of the diet (NRC, 1984). Steers were weighed every 14 d and intakes of limit-fed steers were adjusted to meet the increasing energy needs for maintenance as the steers grew (NRC, 1984). Feed samples were taken every 7 d throughout the trial and were composited for analysis of DM (AOAC, 1996), ADF, and NDF (Goering and Van Soest, 1970). Monthly composites of feed were analyzed for N content using a combustion-type N autoanalyzer (Leco 2000-FP, Leco Corp., St. Joseph, MI). Crude protein was calculated as N × 6.25.

Steers were implanted with Compudose (25.7 mg of estradiol, provided courtesy of VetLife, Overland Park, KS) at the initiation of the trial, and with Revalor-S (24 mg of estradiol, 120 mg of trenbolone acetate, provided courtesy of Intervet, Millsboro, DE) when steers within each treatment were estimated to be 100 d from slaughter (based on predicted rates of gain and subcutaneous fat accretion). Steers fed the high-grain diet ad libitum were implanted with Revalor-S at an average age of 230 d, steers fed the high-fiber diet ad libitum and steers programmed to gain 1.2 kg/d were implanted at an average age of 244 d, and steers programmed to gain 0.8 kg/d were implanted at an average age of 258 d.

On d 63 (calves averaged 181 d of age) and d 161 (calves averaged 279 d of age) of the trial, blood samples were collected by jugular venipuncture at 0, 3, 6 and 9 h after feeding from 10 steers per treatment.

Table 1. Diet composition

Item	Growing phase		Finishing phase
	Concentrate	Fiber	Concentrate
Ingredient	Dry matter basis, %		
Shelled corn	70.790		76.590
Soy hulls		55.080	
Brome grass hay	7.280	30.400	7.360
Wheat middlings	3.151	1.963	2.306
Cottonseed meal	9.351	6.151	6.844
Soybean meal	5.384	3.646	3.940
Feather meal	1.645	1.089	1.204
Calcium carbonate	1.583	1.045	1.159
Monocalcium phosphate	0.039	0.030	0.028
Salt	0.445	0.367	0.326
Selenium, 200 mg/kg	0.007	0.007	0.005
Zinc oxide	0.003	0.002	0.002
Vitamin A, 650k	0.005	0.005	0.004
Vitamin D_3, 8 *M*	0.007	0.005	0.005
Vitamin E	0.004	0.005	0.003
Rumensin 80	0.017	0.017	0.012
Tylan 100	0.004	0.005	0.003
Trace mineral	0.061	0.041	0.045
Molasses	0.219	0.145	0.161
Nutrient composition[a]			
Crude protein, %	16.43	15.27	14.51
ADF, %	9.99	43.06	9.50
NDF, %	26.26	65.75	26.32
Calcium, %	0.78	0.98	0.59
Phosphorous, %	0.40	0.25	0.37
Potassium, %	0.69	1.49	0.63
NEm, Mcal/kg	2.07	1.64	2.11
NEg, Mcal/kg	1.38	1.03	1.40

[a]Crude protein, ADF, and NDF percentages were determined by analysis; remaining composition values were calculated using NRC (1996) values.

Steers were selected based on BW and age so that treatment responses would not be confounded by these variables. Samples were allowed to clot at room temperature and were centrifuged at 1,500 × *g* for 20 min. Serum was harvested, split into two aliquots and stored at −25°C until later analysis. Thawed serum was analyzed for glucose concentration by colorimetric determination by the glucose oxidase procedure (Sigma Diagnostics, St. Louis, MO.). Insulin concentrations were determined with a heterologous RIA using manufacturers specifications (Diagnostic Products Corp., Los Angeles, CA). Intra- and interassay coefficients of variation were 7.6 and 12.4%, respectively.

Steers were scanned (Classic Ultrasound Equipment, Classic Medical Supply, Tequesta, FL) at 118 and 218 d of age by a certified ultrasound technician for fat thickness and longissimus muscle area, and at 218 d of age for intramuscular fat percentage. Intramuscular fat percentage was determined at the Iowa State Centralized Ultrasound Processing (CUP) lab. Cattle were removed from the trial when a terminal fat thickness of 1.27 cm was reached (estimated by ultrasound). Hot carcass weight, fat thickness, percentage of kidney, pelvic and heart fat, longissimus muscle area, and USDA quality grades were determined by qualified OSU personnel 48 h after slaughter. Yield grade was calculated based on these measurements. Steaks dissected from the 13th rib were cooked to an average internal temperature of 71.7°C and peak Warner-Bratzler shear force was used as a measure of tenderness according to AMSA (1995) recommendations. The longissimus muscle from the 11th and 12th ribs was removed from the right side of each carcass, trimmed of external fat, ground three times and subsampled for determination of moisture, N, and ether-extractable lipid.

Performance and carcass data were analyzed using the GLM procedures of SAS (SAS Inst., Inc., Cary, NC) for a completely randomized design comparing four treatments. The model included effects due to diet. Residual mean square was the error term and animal was the experimental unit. For glucose and insulin concentrations, effects due to treatment, time, and treatment × time interactions were analyzed using the MIXED procedures of SAS.

Experiment 2. Two hundred sixteen Angus × Simmental crossbred steers from the University of Illinois beef herd were weaned at an average of 120 d of age and allotted by age and BW to the four treatments described in Exp. 1. Prior to early weaning, calves were grazed in Illinois on mixed pastures of tall fescue and clover, which are typical of the region. Steers were

Table 2. Effect of growing phase source of energy and rate of gain on performance in Exp. 1 (The Ohio State University)[a]

	Treatment[b]					
Item	ALCONC	ALFIBER	1.2CONC	0.8CONC	SE	$P <$
No. of animals	20	19	17	17	—	—
Age at early weaning time	119	120	119	118	4.1	0.99
Age at normal weaning time	218	219	218	217	4.1	0.99
Age at slaughter, d	313[x]	326[x]	341[y]	357[z]	5.1	0.01
Days on feed	194[x]	205[x]	222[y]	238[z]	5.1	0.01
Final implant to slaughter, d	82.1[x]	79.3[x]	96.2[y]	98.3[y]	5.1	0.02
Body weight, kg						
d 119	170.5	173.2	168.4	169.8	5.5	0.93
d 218	321.9[x]	286.8[y]	281.8[y]	255.7[z]	6.8	0.01
Slaughter	498.5	495.3	511.1	515.5	12.1	0.57
ADG, kg/d						
d 119 to 217	1.54[x]	1.16[y]	1.16[y]	0.88[z]	0.03	0.01
d 218 to slaughter	1.85	1.95	1.87	1.88	0.06	0.61
d 119 to slaughter	1.69[x]	1.57[y]	1.54[y]	1.45[z]	0.04	0.01
Daily DMI, kg/d						
d 119 to 217	6.5[x]	6.3[x]	4.6[y]	3.5[z]	0.1	0.01
d 218 to slaughter	9.0	9.4	8.9	8.8	0.3	0.46
d 119 to slaughter	7.7[x]	7.8[x]	6.9[y]	6.6[y]	0.2	0.01
Cumulative DMI, kg						
d 119 to 217	640.3[x]	613.8[x]	448.3[y]	347.0[z]	14.4	0.01
d 218 to slaughter	857.3[x]	992.9[y]	1,105.3[y]	1,244.3[z]	57.4	0.01
d 119 to slaughter	1,497.6	1,606.8	1,553.6	1,591.4	63.1	0.57
Gain:feed, g:kg						
d 119 to 217	237[x]	186[y]	254[z]	248[xz]	5.3	0.01
d 218 to slaughter	207	209	212	213	4.7	0.75
d 119 to slaughter	220[x]	201[y]	224[x]	220[x]	4.3	0.01
Hip height, cm						
d 119	101.6	101.9	100.8	101.9	1.0	0.92
d 218	113.8	112.3	113.0	112.3	1.0	0.59
Slaughter	125.5	125.7	127.0	127.3	1.3	0.55

[a]Steers were implanted with Compudose (25.7 mg of estradiol; provided courtesy of VetLife, Overland Park, KS) at 119 d of age and with Revalor-S (24 mg of estradiol, 120 mg of trenbolone acetate; provided courtesy of Intervet, Millsboro, DE) at 230, 244, 244, and 258 d of age for ALCONC, ALFIBER, 1.2CONC, and 0.8CONC, respectively.

[b]ALCONC = High-concentrate diet fed ad libitum; ALFIBER = High-forage diet fed ad libitum; 1.2CONC = High-concentrate diet limit fed to gain 1.2 kg/d; 0.8CONC = High-concentrate diet limit fed to gain 0.8 kg/d.

[x,y,z]Within a row, means that do not have a common superscript differ ($P < 0.10$).

not creep fed. Three to four weeks prior to weaning, and upon feedlot arrival, steers were vaccinated for protection against infectious bovine rhinotracheitis, bovine viral diarrhea, parainfluenza-3, bovine respiratory syncitial virus, *Haemophilus somnus, Pasteurella,* and *Clostridia* (Vira-shield-5, Grand Laboratories, Larchwood, IA; Pulmo-guard PH-M and Bar Vac-7, Boehringer Ingelheim, St. Joseph, MO). Steers were revaccinated at 205 d of age. Upon arrival at the feedlot, steers were treated for internal and external parasites with Ivomec pour-on (Merck, Rahway, NJ). Steers were fed in an outdoor feedlot. Diets (Table 1), diet analysis, and intake restriction were as in Exp. 1; however, intake of steers programmed to gain 0.8 kg/d were adjusted as needed to match the ADG of steers fed the high-fiber diet ad libitum. Hay was purchased at the same time from the same commercial hay broker as in Exp. 1. Health status was monitored as in Exp. 1, and cattle were treated with antibiotics according to label instructions (Baytril, Bayer; Nuflor, Schering Plough).

Steers were implanted with Compudose at the initiation of the trial (d 0), and with Revalor-S at 260 d of age (d 140 of the trial). Steers were scanned by ultrasound (Aloka 500V, Corometrics Medical Systems, Wallingford, CT) at 218 d of age as described in Exp. 1. Cattle were removed from the trial after 273 d on feed. Carcass characteristics were measured by trained University of Illinois personnel, and USDA quality and yield grades were determined by a USDA grader.

Data were analyzed using the GLM procedures of SAS for a completely randomized experiment comparing four treatments. The model included effects due to diet. Residual mean square was the error term and pen was the experimental unit.

Experiment 3. Five ruminally fistulated steers were used in a 4 × 4 Latin square trial at Ohio State University to determine ruminal pH and VFA concentrations at 0, 3, 6, and 9 h after feeding. Steers were fistulated approximately 1 mo prior to the initiation of the experiment. Experimental diets were those described for the growing phase of Exp. 1 and were fed for 3 wk in each of four periods. On the last day of each period, rumen fluid was collected, strained, and analyzed for pH immediately and 8 mL of strained ruminal fluid was acidified with 2 mL of fresh 25% metaphosphoric acid. Acidifed ruminal fluid samples were centrifuged at 12,000 × g for 20 min and the supernatant was saved and stored frozen at −25°C. Volatile fatty acid analysis of ruminal fluid was accomplished by gas chromatography using 2-ethyl butyric acid as an internal standard (Supelco, 1975).

For ruminal pH and VFA concentrations, effects due to treatment, time, and treatment × time interactions were analyzed using the MIXED procedures of SAS. Residual mean square was the error term.

Results and Discussion

Experiment 1. Calves on all treatments averaged less than 1 yr of age at slaughter. Cattle fed diets ad libitum during the growing phase (either high forage or high grain) spent the least amount of time in the feedlot and were the youngest at slaughter ($P < 0.01$), followed by steers programmed to gain 1.2 kg/d during the growing phase. Steers programmed to gain 0.8 kg/d during the growing phase spent the most time in the feedlot and were the oldest at slaughter (Table 2). By contrast, Knoblich et al. (1997), Loerch and Fluharty (1998), and Rossi et al. (2001) all demonstrated that, for cattle weaned at 205 d of age and programmed to achieve stepwise increases in gain, no difference existed for days on feed when steers were slaughtered at a constant BW. Limit-fed cattle are leaner when fed to a constant BW (Knoblich et al., 1997; Loerch and Fluharty, 1998; Rossi et al., 2001); thus, it may have taken more days for limit-fed cattle in these trials to achieve a constant fat thickness. Steers in this trial whose growth rates were controlled had approximately 16 more days from last implant to slaughter ($P < 0.02$) compared to cattle fed ad libitum.

Final weight was low (approximately 504 kg), but did not differ ($P > 0.57$) among treatments. Target gains were achieved during the growing phase; thus, gains were highest for steers fed the high-grain diet ad libitum, intermediate for steers fed the high-forage diet ad libitum and for steers programmed to gain 1.2 kg/d, and lowest for steers programmed to gain 0.8 kg/d ($P < 0.01$). Diet fed during the growing phase did not affect ($P > 0.61$) gains during the finishing period. This is in agreement with studies by Hicks et al. (1990) and Loerch (1990), where diets high in forage fed ad libitum were compared to high-concentrate diets limit fed during the growing phase. However, our results are in contrast to many studies that have demonstrated a compensatory growth response when cattle were fed ad libitum following limit-feeding (Knoblich et al., 1997; Loerch and Fluharty, 1998; Rossi et al., 2001). Steers in those trials were weaned at 205 d of age, compared with 119 d of age in the present trial. Age of the animal at the time of growth restriction may play an important role in a compensatory growth response. Tudor and O'Rourke (1980), who weaned steers at 4 d of age and restricted their energy intake until 200 d of age, observed no compensatory growth upon realimentation at 200 d of age. Morgan (1972) studied age effects of intake restriction on subsequent growth by restricting calves from birth to 16 wk or from 16 to 32 wk of age. Calves were not weaned. Calves restricted from birth to 16 wk of age had rates of gain similar to ad libitum-fed control calves upon realimentation and underwent no compensatory growth. However, calves restricted from 16 to 32 wk of age had increased rates of gain and exhibited compensatory growth upon diet realimentation. Steers in this trial, at 17 wk of age, could fall into either of these two categories. Average daily gains from 119 d of age until slaughter in the current study were greatest for steers fed the high-grain diet ad libitum during the growing phase, intermediate for steers fed the high-forage diet ad libitum and steers programmed to gain 1.2 kg/d during the growing phase, and lowest for steers programmed to gain 0.8 kg/d during the growing phase ($P < 0.01$).

Daily DMI from 218 d of age until slaughter was not affected ($P > 0.46$) by the previous growing phase diet. However, due to intake restriction, daily DMI during the growing phase and from 119 d of age until slaughter was greatest ($P < 0.01$) for cattle fed ad libitum compared to cattle with controlled growth rates during the growing phase. As expected, cumulative DMI in the growing phase was highest for cattle fed ad libitum, lowest for cattle programmed to gain 0.8 kg/d, and intermediate for cattle programmed to gain 1.2 kg/d. Cumulative DMI in the finishing phase was inversely related to cumulative DMI in the growing phase. Steers programmed to gain 0.8 kg/d in the growing phase consumed the most DM in the finishing phase, steers programmed to gain 1.2 kg/d and steers fed a high-forage diet in the growing phase consumed an intermediate amount of DM in the finishing phase, and steers fed a high-concentrate diet ad libitum in the growing phase consumed the least amount of DM in the finishing phase. Because it took 17 to 44 d more for cattle limit fed during the growing phase to achieve the target fat thickness of 1.27 cm, cumulative DMI was not different ($P > 0.57$) among treatments when measured from 119 d of age until slaughter. Cattle whose growth rates were controlled were 5.9% more efficient during the growing phase compared with steers fed a high-grain diet ad libitum, and were 34.9% more efficient in the growing phase compared with steers fed a high-forage diet ad libitum ($P < 0.01$). Steers fed the high-grain diet ad libitum were 27% more efficient than steers fed the high-forage diet ad

Table 3. Effect of growing phase source of energy and rate of gain on carcass characteristics in Exp. 1 (The Ohio State University)[a]

	Treatment[b]					
Item	ALCONC	ALFIBER	1.2CONC	0.8CONC	SE	$P <$
Fat thickness, cm						
d 119[c]	0.15	0.15	0.15	0.15	0.03	0.99
d 218[c]	0.64[w]	0.38[x]	0.46[y]	0.28[z]	0.03	0.01
Slaughter	1.24	1.30	1.24	1.27	0.05	0.83
Longissimus muscle area, cm^2						
d 119[c]	23.6	23.6	23.6	23.6	0.5	0.99
d 218[c]	58.1[w]	48.4[x]	50.3[x]	45.2[y]	0.5	0.01
Slaughter	72.3	68.4	71.6	70.3	0.8	0.46
Hot carcass weight, kg	298.9	296.3	313.4	311.9	8.1	0.30
Dressing, %	60.0[w]	59.7[w]	61.3[x]	60.4[w]	0.4	0.02
Kidney, pelvic, and heart fat, %	3.1	3.4	3.2	3.3	0.1	0.34
Yield grade	3.3	3.6	3.4	3.5	0.1	0.17
Yield grade distribution						
Yield grade 1, %	0.0	0.0	0.0	0.0	0.0	1.00
Yield grade 2, %	40.0[w]	5.3[x]	17.6[x]	5.9[x]	8.8	0.02
Yield grade 3, %	60.0	84.2	70.6	88.2	10.4	0.18
Yield grade 4, %	0.0	10.5	11.8	5.9	6.2	0.49
Intramuscular fat at d 218, %[cd]	3.6[w]	3.2[x]	3.1[x]	3.2[x]	0.1	0.07
Marbling score[e]	310.0	296.3	310.0	343.5	19.8	0.37
Quality grade						
Select, %	60.0	63.2	47.1	41.2	12.2	0.51
Low choice, %	30.0	21.1	41.2	23.5	11.1	0.57
Average choice, %	0.0[w]	15.8[wx]	11.8[wx]	29.4[x]	8.1	0.08
High choice, %	10.0	0.0	0.0	5.9	4.8	0.34
Longissimus dorsi composition[f]						
Protein, %	18.4[w]	19.0[x]	18.4[w]	18.3[w]	0.2	0.08
Moisture, %	73.9	73.8	73.6	73.2	0.2	0.17
Fat, %	3.2	3.3	3.6	3.9	0.3	0.34
Ash, %	4.5[w]	3.9[x]	4.4[w]	4.6[w]	0.2	0.01
Shear force, kg	5.3	5.3	5.0	5.9	0.4	0.40

[a]Steers were implanted with Compudose (25.7 mg of estradiol; provided courtesy of VetLife, Overland Park, KS) at 119 d of age and with Revalor-S (24 mg of estradiol, 120 mg of trenbolone acetate; provided courtesy of Intervet, Millsboro, DE) at 230, 244, 244, and 258 d of age for ALCONC, ALFIBER, 1.2CONC, and 0.8CONC, respectively.
[b]ALCONC = High-concentrate diet fed ad libitum; ALFIBER = High-forage diet fed ad libitum; 1.2CONC = High-concentrate diet limit fed to gain 1.2 kg/d; 0.8CONC = High-concentrate diet limit fed to gain 0.8 kg/d.
[c]Measured via ultrasound.
[d]<3.40 = Standard, 3.40 to 4.99 = Select, 5.00 to 6.49 = Choice, >6.50 = Choice°; Illinois State University CUP lab.
[e]Practically devoid = 100 to 199, slight = 200 to 299, small = 300 to 399, modest = 400 to 499, moderate = 500 to 599.
[f]As-is basis.
[w,x,y,z]Within a row, means that do not have a common superscript differ ($P < 0.10$).

libitum during the growing phase ($P < 0.01$). No difference due to growing phase diet existed ($P > 0.75$) during the finishing phase for gain:feed, which is in contrast to the results of Hicks et al. (1990), Knoblich et al. (1997), and Rossi et al. (2001), where feed efficiency was improved after periods of restriction in limit-fed cattle. Improvements in efficiency after realimentation have been attributed to a reduced visceral organ mass and a resultant lowering of maintenance energy requirements (Fluharty and McClure, 1997). However, Schoonmaker et al. (2001) observed that reduced visceral organ mass may not have significant influences on feed efficiency in early-weaned cattle on a high plane of nutrition. From 119 d of age until slaughter, gain:feed was greatest ($P < 0.01$) for steers fed high-grain diets (ad libitum or programmed to gain 0.8 or 1.2 kg/d) during the growing phase compared to steers fed the high-forage diet during the growing phase.

Differences in body composition can result from restricting feed intake and are affected by the severity and duration of the feed restriction period as well as age of the animal at restriction. Butterfield (1966), Mader et al. (1989), and Carstens et al. (1991) demonstrated that restricting feed intake for a portion of the feeding period in cattle that were 6 mo of age or older has been shown to decrease fat and increase lean deposition at the end of the finishing period. When growth was restricted in cattle less than 2 mo of age (while calves were still with their dams), increased fat deposition occurred upon realimentation (Stuedemann et al., 1968; Tudor et al., 1980). Because steers were slaughtered at a common fat thickness in the present trial, fat thickness did not differ ($P > 0.83$) at slaughter (Table 3). However, at 218 d of age, steers fed the high-grain diet ad libitum during the growing phase were the fattest ($P < 0.01$), steers fed the high-forage diet ad libitum were intermediate, followed by steers programmed to gain 1.2 kg/d; steers programmed to gain 0.8 kg/d were the leanest. No difference in slaughter weight, at a common fat thickness, indicates that increased fat deposition occurred upon realimentation of limit-fed cattle in this trial. Longissimus muscle area was not different at early weaning ($P > 0.99$) or at slaughter ($P > 0.46$). At 218 d of age, steers fed the high-grain diet ad libitum during the growing phase had the largest longissimus muscle area, steers fed the high-forage diet and steers programmed to gain 1.2 kg/d during the growing phase were intermediate, and steers programmed to gain 0.8 kg/d had the smallest longissimus muscle area. No differences existed for hot carcass weight ($P > 0.30$), kidney, pelvic, and heart fat percentage ($P > 0.34$), yield grade ($P > 0.17$), or shear force ($P > 0.40$) among treatments. However, the percentage of cattle grading yield grade 2 was greatest ($P < 0.02$) for steers fed a high-grain diet ad libitum in the growing phase, indicating that yield grade distribution in these steers tended to be leaner. No differences existed ($P > 0.18$) for cattle grading yield grade 1, 3, or 4. Steers programmed to gain 0.8 kg/d during the growing phase produced the highest ($P < 0.08$) percentage of carcasses grading average choice, indicating that there may be a favorable economic impact if they were priced on a grid. Despite a difference in quality grade distribution at slaughter, the diet fed during the growing phase did not affect ($P > 0.37$) average marbling score; however, at 218 d of age, cattle fed the high-grain diet ad libitum had a higher ($P < 0.07$) percentage of intramuscular fat compared to cattle on the other diets, despite having the largest longissimus muscle. Days on a high-grain diet may be particularly important for increasing marbling score. Thus a difference at 218 d of age did not translate into a difference at slaughter because steers fed the high-grain diet ad libitum during the growing phase only had 95 d to slaughter, whereas steers fed the high-forage diet ad libitum and those programmed to gain 1.2, and 0.8 kg/d had 107, 123, and 140 d to deposit more intramuscular fat before slaughter, respectively. Feeding high-concentrate diets ad libitum causes appreciable amounts of energy to be partitioned to subcutaneous fat, thus accelerating physiological maturity. Longissimus protein percentage was increased ($P < 0.08$) and longissimus ash percentage was decreased ($P < 0.01$) for steers fed a high-forage diet ad libitium in the growing period compared to cattle fed the high-concentrate diets in the growing period.

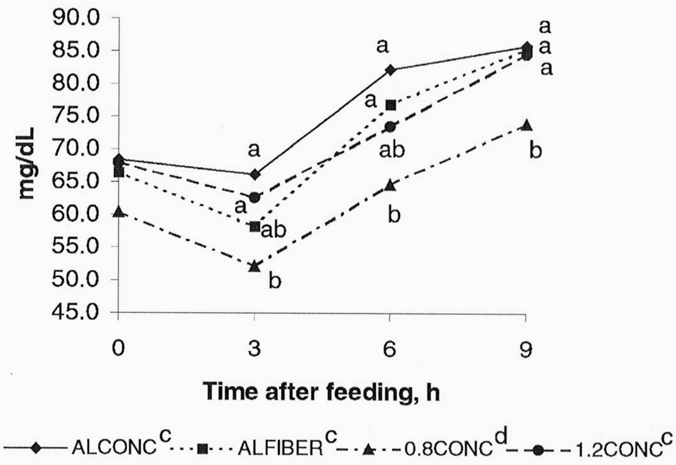

Figure 1. Effect of growing phase source of energy and rate of gain on serum glucose concentration (mg/dL) at 181 d of age (n = 10 steers per treatment). ALCONC = high-concentrate diet fed ad libitum; ALFIBER = high-fiber diet fed ad libitum; 0.8CONC = high-concentrate diet limit fed to gain 0.8 kg/d; 1.2CONC = high-concentrate diet limit fed to gain 1.2 kg/d. [a,b]Within a timepoint, means that do not have a common superscript differ ($P < 0.10$). [c,d]Diet means differ ($P < 0.10$).

Serum glucose at 181 d of age (Figure 1) was lower ($P < 0.10$) in steers programmed to gain 0.8 kg/d compared to other steers, as was serum insulin (Figure 2). Even though serum glucose was not greater in

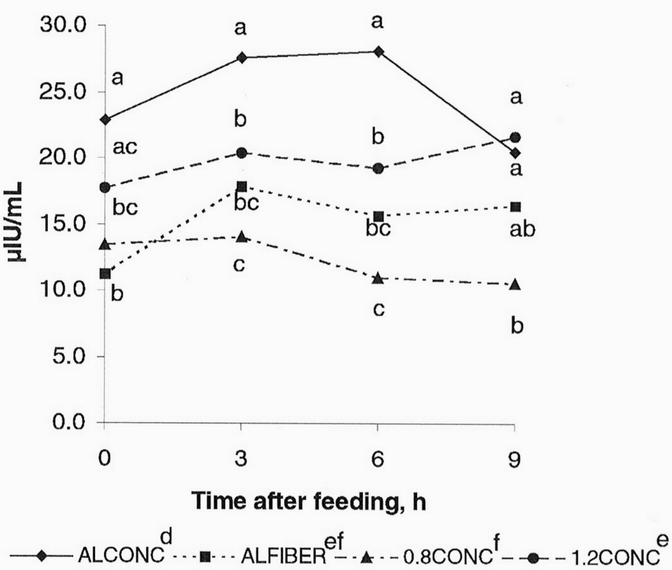

Figure 2. Effect of growing phase source of energy and rate of gain on serum insulin concentration (µIU/mL) at 181 d of age (n = 10 steers per treatment). ALCONC = high-concentrate diet fed ad libitum; ALFIBER = high-fiber diet fed ad libitum; 0.8CONC = high-concentrate diet limit fed to gain 0.8 kg/d; 1.2CONC = high-concentrate diet limit fed to gain 1.2 kg/d. [a,b,c]Within a timepoint, means that do not have a common superscript differ ($P < 0.10$). [d,e,f]Diet means differ ($P < 0.10$).

steers fed a high-grain diet ad libitum at 181 d of age, insulin, which regulates blood glucose, was elevated ($P < 0.10$). Murphy et al. (1994) similarly reported no difference in serum glucose, but observed a lower insulin concentration throughout the feeding period for ad libitum-fed steers compared with steers whose intake was restricted 30%. Evans et al. (1975) and Jenny and Polan (1975) observed elevated plasma glucose and insulin in cows fed a high-concentrate diet compared with sheep and cows fed a low-concentrate diet. Evans et al. (1975) also reported increased plasma concentrations of propionate in cows fed a high-concentrate diet. In the present trial, elevated insulin for steers consuming a high-concentrate diet ad libitum in the growing phase indicates that there was an increased uptake of glucose by peripheral tissues. Smith and Crouse (1984) demonstrated that glucose provides 50 to 75% of the acetyl units for in vitro lipogenesis in the intramuscular fat depot. Consequently, a higher ultrasound marbling score for steers fed a high-grain diet ad libitum at 218 d of age may have been a result of the starch fermentation. Huntington (1997) estimated that for cattle consuming high-concentrate diets, approximately 44% of their total glucose need comes from organic acid absorption from the rumen (predominantly propionate) and subsequent conversion to glucose in the liver, 33% comes from postruminal glucose absorption, and 23% of their total glucose need comes from other carbon sources, such as amino acids, and subsequent conversion to glucose in the liver. Thus, it is unknown if increased glucose for steers consuming a high-concentrate diet ad libitum was a result of increased liver conversion of propionate, small intestinal absorption of glucose, or conversion of amino acids.

Serum glucose (Figure 3) was not different among treatments at 279 d of age ($P > 0.10$), indicating that growing phase diet did not have residual effects on serum glucose in the finishing phase. Insulin at 279 d of age (Figure 4) was different only at 3 h postfeeding, also indicating that there is little residual effect of growing phase diet in the finishing phase. Steers programmed to gain 1.2 kg/d in the growing phase had the greatest concentration of insulin, whereas steers fed a high-forage diet ad libitum during the growing phase had the lowest concentration of insulin at 3 h postfeeding at 279 d of age. Steers programmed to gain 0.8 kg/d and steers fed a high-concentrate diet ad libitum during the growing phase had intermediate insulin concentrations that were not different from the other two treatments at 3 h postfeeding. As mentioned previously, limit-fed cattle typically consume the majority of their feed within the first 3 h of feed delivery; perhaps intake patterns for steers previously limit fed remained after they were switched to diets fed ad libitum.

Experiment 2. Steers on all treatments were in the feedlot for 273 d; thus, final age was not different ($P > 0.73$) among treatments (Table 4). As expected,

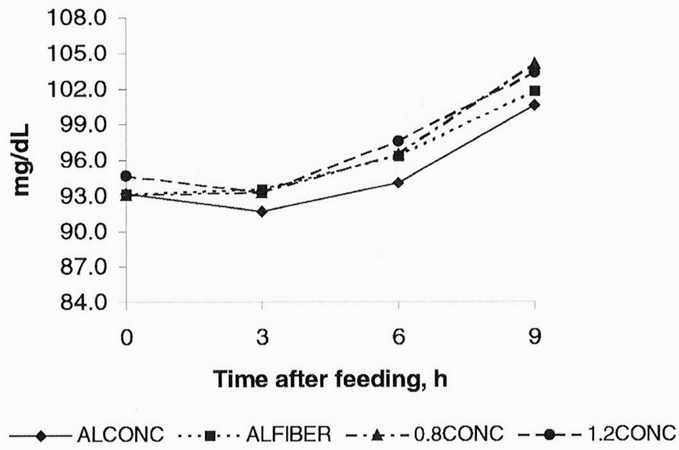

Figure 3. Effect of growing phase source of energy and rate of gain (from 119 to 218 d of age) on subsequent serum glucose concentration (mg/dL) when all steers were fed a common diet (at 279 d of age; n = 10 steers per treatment). ALCONC = high-concentrate diet fed ad libitum; ALFIBER = high-fiber diet fed ad libitum; 0.8CONC = high-concentrate diet limit fed to gain 0.8 kg/d; 1.2CONC = high-concentrate diet limit fed to gain 1.2 kg/d.

steers fed the high-concentrate diet ad libitum gained the fastest ($P < 0.01$) during the growing phase, followed by steers programmed to gain 1.2 kg/d. Steers fed the high-forage diet ad libitum and steers programmed to gain 0.8 kg/d both gained the slowest, as was planned. As a result, steers fed the high-grain

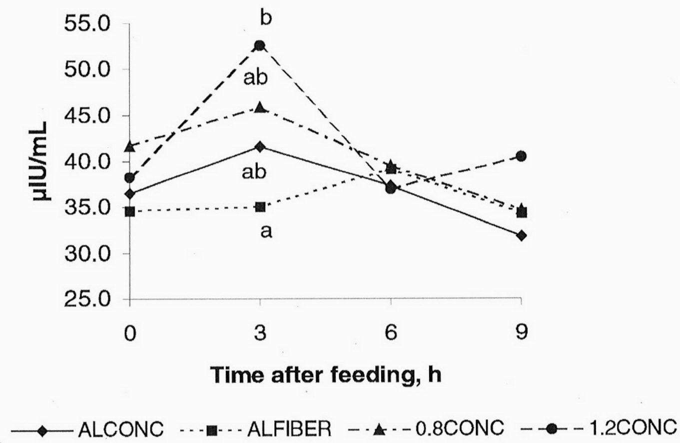

Figure 4. Effect of growing phase source of energy and rate of gain (from 119 to 218 d of age) on subsequent serum insulin concentration (µIU/mL) when all steers were fed a common diet (at 279 d of age; n = 10 steers per treatment). ALCONC = high-concentrate diet fed ad libitum; ALFIBER = high-fiber diet fed ad libitum; 0.8CONC = high-concentrate diet limit fed to gain 0.8 kg/d; 1.2CONC = high-concentrate diet limit fed to gain 1.2 kg/d. [a,b]Within a timepoint, means that do not have a common superscript differ ($P < 0.10$).

Table 4. Effect of growing phase source of energy and rate of gain on performance in Exp. 2 (University of Illinois)[a]

	Treatment[b]					
Item	ALCONC	ALFIBER	1.2CONC	0.8CONC	SE	$P <$
No. of animals	52	53	51	50		
Age at early weaning time, d	124	116	118	116	5.69	0.73
Age at normal weaning time, d	223	215	217	215	5.69	0.73
Age at slaughter, d	397	389	391	389	5.69	0.73
Days on feed, d	273	273	273	273	—	—
Final implant to slaughter, d	132	132	132	132	—	—
Body weight, kg						
d 119	141.5	136.0	131.7	132.5	4.41	0.39
d 218	293.6^{w}	248.6^{xy}	259.1^{x}	246.2^{y}	5.02	0.01
Slaughter	504.3^{w}	488.2^{wx}	471.2^{x}	476.4^{x}	7.68	0.04
ADG, kg/d						
d 119 to 217	1.55^{w}	1.16^{x}	1.31^{y}	1.15^{x}	0.02	0.01
d 218 to slaughter	1.21^{w}	1.37^{x}	1.22^{w}	1.30^{y}	0.03	0.01
d 119 to slaughter	1.33^{w}	1.29^{wx}	1.25^{x}	1.25^{x}	0.02	0.06
Daily DMI, kg/d						
d 119 to 217	6.4^{w}	6.1^{x}	5.1^{y}	4.3^{z}	0.10	0.01
d 218 to slaughter	8.6^{w}	9.0^{x}	8.4^{w}	8.5^{w}	0.09	0.04
d 119 to slaughter	7.8^{w}	7.9^{w}	7.2^{x}	7.0^{x}	0.24	0.01
Cumulative DMI, kg						
d 119 to 217	636.4^{w}	608.8^{x}	508.9^{y}	425.1^{z}	11.08	0.01
d 218 to slaughter	1,496.1^{w}	1,560.8^{x}	1,458.5^{w}	1,481.3^{w}	23.22	0.04
d 119 to slaughter	2,132.5^{w}	2,169.6^{w}	1,967.3^{x}	1,906.4^{x}	66.62	0.01
Gain:feed, g:kg						
d 119 to 217	241^{w}	189^{x}	255^{y}	269^{z}	3.87	0.01
d 218 to slaughter	140^{w}	153^{x}	145^{y}	154^{x}	1.81	0.01
d 119 to slaughter	170^{w}	163^{x}	173^{w}	180^{y}	1.93	0.01

[a]Steers were implanted with Compudose (25.7 mg of estradiol; provided courtesy of VetLife, Overland Park, KS) at 119 d of age and with Revalor-S (24 mg of estradiol, 120 mg of trenbolone acetate; provided courtesy of Intervet, Millsboro, DE) at 260 d of age.

[b]ALCONC = High-concentrate diet fed ad libitum; ALFIBER = High-forage diet fed ad libitum; 1.2CONC = High-concentrate diet limit fed to gain 1.2 kg/d; 0.8CONC = High-concentrate diet limit fed to gain 0.8 kg/d.

[w,x,y,z]Within a row, means that do not have a common superscript differ ($P < 0.10$).

diet ad libitum were the heaviest, and steers programmed to gain 0.8 kg/d were the lightest at 218 d of age ($P < 0.01$). Steers programmed to gain 1.2 kg/d and steers fed the high-forage ad libitum were intermediate in weight, with steers fed the high-forage diet ad libitum not differing in weight from steers programmed to gain 0.8 kg/d ($P > 0.10$). During the finishing period, steers fed the high-forage diet during the growing phase gained the fastest ($P < 0.01$), followed by steers programmed to gain 0.8 kg/d during the growing phase. Steers fed the high-concentrate diet ad libitum and steers programmed to gain 1.2 kg/d gained the slowest ($P < 0.01$) in the finishing phase. Average daily gains of steers fed high-concentrate diets ad libitum and steers programmed to gain 1.2 kg/d in the growing phase decreased 21.9 and 6.9%, respectively, from the growing to the finishing phase. Cattle fed ad libitum generally maintain gains in the finishing phase, and cattle programmed to gain 1.2 kg/d generally produce a compensatory growth response upon realimentation (Knoblich et al., 1997; Loerch and Fluharty, 1998; Rossi et al., 2001). Cattle were fed outdoors; thus, maximal growth potential may not have been achieved in the finishing phase of this trial, and the earlier age at time of nutrient restriction may have played a role in a lack of compensatory growth response. Steers fed the high-forage diet ad libitum and steers programmed to gain 0.8 kg/d during the growing phase experienced compensatory growth that exceeded the growth rate of steers previously fed ad libitum, which is in contrast to Exp. 1, but similar to most reports where cattle are switched from restricted to ad libitum intake (Knoblich et al., 1997; Loerch and Fluharty, 1998; Rossi et al., 2001). Time on feed at slaughter differed in Exp. 1 because steers were slaughtered at a constant fat thickness, whereas time on feed did not differ in this experiment or in previous reports (Knoblich et al., 1997; Loerch and Fluharty, 1998; Rossi et al., 2001).

From 119 d of age to slaughter, steers with controlled growth rates gained the least, and steers fed the high-concentrate diet ad libitum gained the most ($P < 0.01$). Gain from 119 d of age to slaughter for steers fed a high-forage diet during the growing phase was intermediate and did not differ ($P > 0.10$) from steers fed the high-grain diet ad libitum during the growing phase or from steers limit fed during the growing phase. As a result, steers fed the high-grain diet

Table 5. Effect of growing phase source of energy and rate of gain on carcass characteristics in Exp. 2 (University of Illinois)[a]

Item	Treatment[b]				SE	$P <$
	ALCONC	ALFIBER	1.2CONC	0.8CONC		
Fat thickness, cm						
d 218[c]	0.47[x]	0.35[y]	0.39[z]	0.33[y]	0.01	0.01
Slaughter	1.11[x]	1.02[xy]	0.99[xy]	0.90[y]	0.05	0.06
Longissimus muscle area, cm^2						
d 218[c]	49.7[x]	43.9[y]	47.1[z]	45.2[z]	1.03	0.01
Slaughter	76.1	74.8	74.8	75.5	0.97	0.59
Hot carcass weight, kg	307.4[x]	296.8[xy]	285.7[y]	288.7[y]	5.01	0.03
Dressing percent	60.9	60.8	60.6	60.6	0.23	0.70
Kidney, pelvic, and heart fat, %	2.1[x]	2.4[y]	2.2[x]	2.2[x]	0.06	0.02
Yield grade	2.8[x]	2.8[xy]	2.6[yz]	2.5[z]	0.08	0.04
Yield grade distribution						
Yield grade 1, %	3.5	1.8	11.8	15.2	4.19	0.11
Yield grade 2, %	64.4	69.8	66.2	76.6	8.41	0.75
Yield grade 3, %	30.4	26.3	22.0	8.5	7.35	0.21
Yield grade 4, %	1.7	2.1	0.0	0.0	1.42	0.58
Marbling score at d 218[c]	244.1	245.0	247.2	247.1	24.36	0.99
Marbling score at slaughter[d]	354.1	356.6	332.3	352.4	19.64	0.81
Quality grade						
Select, %	24.6	32.3	41.0	39.2	8.14	0.46
Low choice, %	61.2[x]	44.7[xy]	35.3[y]	38.0[y]	7.03	0.07
Average choice, %	6.0	7.3	9.7	5.7	4.17	0.93
High choice, %	8.2	15.7	14.0	17.1	6.15	0.80

[a]Steers were implanted with Compudose (25.7 mg of estradiol; provided courtesy of VetLife, Overland Park, KS) at 119 d of age and with Revalor-S (24 mg of estradiol, 120 mg of trenbolone acetate; provided courtesy of Intervet, Millsboro, DE) at 260 d of age.

[b]ALCONC = High-concentrate diet fed ad libitum; ALFIBER = High-forage diet fed ad libitum; 1.2CONC = High-concentrate diet limit fed to gain 1.2 kg/d; 0.8CONC = High-concentrate diet limit fed to gain 0.8 kg/d.

[c]Measured via ultrasound.

[d]Practically devoid = 100 to 199, slight = 200 to 299, small = 300 to 399, modest = 400 to 499, moderate = 500 to 599.

[x,y,z]Within a row, means that do not have a common superscript differ ($P < 0.10$).

ad libitum during the growing phase were the heaviest and limit-fed steers were the lightest at slaughter ($P < 0.04$). Slaughter weight for steers fed the high-forage diet during the growing phase was intermediate and did not differ ($P > 0.10$) from steers fed the high-grain diet ad libitum during the growing phase or from steers limit fed during the growing phase.

Daily and cumulative DMI in the growing phase was highest for cattle fed ad libitum, with grain-fed steers consuming the most, and due to intake restriction, cattle programmed to gain 0.8 kg/d consuming the least ($P < 0.01$). In the finishing phase, steers previously fed a high-forage diet ad libitum consumed 4.4 to 6.7% more daily DM and 65 to 102 kg more cumulative DM than steers previously fed a high-concentrate diet (ad libitum or restricted) in the growing phase ($P < 0.04$). Steers previously consuming a high-forage diet may have had more digestive capacity in the early part of the finishing phase. From 119 d of age to slaughter, daily and cumulative DMI was greater ($P < 0.01$) for steers fed diets ad libitum during the growing phase compared with steers with controlled growth rates during the growing phase. Cattle programmed to gain 0.8 kg/d were the most efficient in the growing phase ($P < 0.01$), followed by steers programmed to gain 1.2 kg/d. Steers fed the high-concentrate diet ad libitum were intermediate in efficiency, whereas steers fed the high-forage diet ad libitum were the least efficient in the growing phase. Cattle that gained the least in the growing phase (steers fed a high-fiber diet ad libitum and steers programmed to gain 0.8 kg/d) were the most efficient in the finishing phase ($P < 0.01$). Cattle fed the high-concentrate diet ad libitum were the least efficient in the finishing phase, whereas steers programmed to gain 1.2 kg/d had intermediate efficiency. Steers programmed to gain 0.8 kg/d during the growing phase were the most efficient ($P < 0.01$) from 119 d of age to slaughter, followed by steers programmed to gain 1.2 kg/d and steers fed a high-grain diet ad libitum in the growing phase. In agreement with Exp. 1, steers fed a high-fiber diet during the growing phase were the least efficient ($P < 0.01$) from 119 d of age to slaughter.

Steers fed the high-concentrate diet ad libitum during the growing phase were the fattest at 218 d of age and at slaughter ($P < 0.01$ and $P < 0.06$, respectively; Table 5). Steers fed the high-forage diet ad libitum and steers programmed to gain 0.8 kg/d were the leanest; steers programmed to gain 1.2 kg/d had an intermediate amount of fat thickness at 218 d of age. At slaugh-

Table 6. Effect of growing phase source of energy and rate of gain on rumen pH and volatile fatty acid concentration (μmol/mL)

Time, h	Treatment[a] ALCONC	ALFIBER	1.2CONC	0.8CONC	SE
			pH[bc]		
0	6.05[w]	6.79[x]	6.57[x]	6.69[x]	0.16
3	5.71[w]	5.57[w]	5.72[wx]	5.98[x]	0.16
6	5.47[w]	5.66[w]	5.67[w]	6.14[x]	0.16
9	5.36[w]	6.02[x]	5.67[y]	6.13[x]	0.16
			Acetate[bc]		
0	33.65[w]	40.31[w]	25.97[x]	23.01[x]	4.42
3	38.13[w]	65.69[x]	37.16[w]	38.42[w]	4.42
6	41.17[w]	65.76[x]	40.49[w]	34.72[w]	4.42
9	41.11[w]	59.11[x]	40.56[w]	36.37[w]	4.42
			Propionate[b]		
0	29.95[w]	9.03[xy]	15.15[x]	5.94[y]	3.87
3	31.16[w]	17.99[xy]	22.73[x]	14.29[y]	3.87
6	36.40[w]	19.42[x]	28.47[y]	12.28[z]	3.87
9	38.21[w]	17.81[x]	30.00[y]	12.39[x]	3.87
			Butyrate		
0	6.88	6.17	5.32	6.14	1.09
3	6.94[w]	8.83[xy]	7.66[wx]	9.50[y]	1.09
6	7.75[w]	8.79[wx]	9.91[x]	8.84[wx]	1.09
9	7.86[w]	8.75[wy]	10.67[x]	9.92[xy]	1.09
			Isobutyrate[b]		
0	0.64	0.59	0.59	0.60	0.08
3	0.59[w]	0.41[x]	0.52[wx]	0.62[w]	0.08
6	0.59[w]	0.35[x]	0.71[w]	0.69[w]	0.08
9	0.62[w]	0.45[x]	0.69[w]	0.73[w]	0.08
			Valerate[b]		
0	1.61[w]	0.52[x]	0.99[y]	0.53[x]	0.26
3	1.36[wx]	0.94[w]	1.43[x]	1.18[wx]	0.26
6	1.63[w]	1.04[x]	1.93[w]	1.07[x]	0.26
9	1.72[w]	1.15[x]	2.01[w]	0.96[x]	0.26
			Isovalerate[b]		
0	0.98[w]	0.97[w]	1.29[wx]	1.98[x]	0.89
3	0.75[w]	0.72[w]	1.01[w]	2.24[x]	0.89
6	0.79[w]	0.56[w]	1.37[w]	2.42[x]	0.89
9	0.85[w]	0.67[w]	1.44[w]	2.74[x]	0.89

[a]ALCONC = High-concentrate diet fed ad libitum; ALFIBER = High-forage diet fed ad libitum; 1.2CONC = High-concentrate diet limit fed to gain 1.2 kg/d; 1.8CONC = High-concentrate diet limit fed to gain 0.8 kg/d.
[b]Diet effect ($P < 0.10$).
[c]Diet × time effect ($P < 0.10$).
[w,x,y,z]Means within a row that do not have a common superscript differ ($P < 0.10$).

ter, steers programmed to gain 0.8 kg/d were the leanest, whereas steers fed the high-forage diet ad libitum and steers programmed to gain 1.2 kg/d had an intermediate amount of fat thickness. Steers fed the high-concentrate diet ad libitum had the largest longissimus muscle area at 218 d of age ($P < 0.01$), followed by steers fed a high-forage diet ad libitum. Limit-fed cattle had the smallest longissimus muscle areas at 218 d of age. Differences in longissimus muscle area at 218 d of age did not translate into differences at slaughter ($P > 0.59$) despite greater carcass weights ($P < 0.03$) for steers fed the high-concentrate diets ad libitum in both phases. Limit-fed steers had the smallest ($P < 0.03$) carcasses, and steers fed the high-forage diet ad libitum had intermediate carcass weights that did not differ from steers fed the high-concentrate diet (either ad libitum or limit-fed). Cattle fed grain in the growing phase had less ($P < 0.02$) kidney, pelvic, and heart fat compared with cattle fed the high-forage diet. Steers fed the high-concentrate diet ad libitum in the growing phase had the highest ($P < 0.04$) yield grade, followed by steers fed the high-forage diet ad libitum and steers programmed to gain 1.2 kg/d. Steers programmed to gain 0.8 kg/d in the growing phase had the lowest yield grade and tended to have the highest ($P = 0.11$) percentage of cattle grading yield grade 1. Steers fed ad libitum (concentrate or fiber) in the growing phase tended to have the lowest percentage of cattle grading yield grade 1. No difference existed for the percentage of steers grading yield grade 2, 3, or 4 ($P > 0.21$). Marbling score was not affected ($P > 0.81$) by growing phase dietary regimen at 218 d of age or at slaughter. The percentage of carcasses grading select did not differ among treatments;

however, steers fed the high-concentrate diet ad libitum during the growing phase had the greatest percentage of carcasses grading low choice, whereas limit-fed steers had the lowest percentage of cattle grading low choice. The percentage of cattle grading average or high choice did not differ ($P > 0.61$) among treatments. Improved marbling scores for Exp. 2 compared to Exp. 1 may be a result of cattle spending more time on a high-concentrate diet, but they were lower than those previously reported for early-weaned steers (Myers et al., 1999a,b,c). Steers in Exp. 2 spent less time on feed than those reported by Myers et al. (1999a,b,c).

Experiment 3. Ruminal pH changed differently (diet × time effect, $P < 0.10$) for different diets throughout the day (Table 6). Ruminal pH for steers fed the high-grain diet ad libitum declined steadily throughout the day, whereas pH for forage- and limit-fed steers dropped rapidly by 3 h postfeeding and started recovering by 6 h postfeeding. Murphy et al. (1994a) observed a similar rapid decline in ruminal pH when high-concentrate diets were limit fed and concluded that the limit-fed cattle consumed a greater percentage of daily feed allotment within the first 2 h after feeding. Ruminal pH of steers fed high-forage diets ad libitum declined faster than expected and reached a lower than expected pH. Steers consuming the 30% chopped brome grass hay and 55% soy hull diet may have been able to sort out the soy hulls initially, causing the rapid decline in pH. Declining pH in forage-fed steers may have been a consequence of increasing acetate (Table 6), whereas declining pH in steers fed a high-grain diet ad libitum may have been a consequence of increasing propionate. Declining pH in limit-fed cattle may have been a consequence of increases in a combination of VFA.

Implications

Starch fermentation increases propionate and insulin in early-weaned steers fed a high-concentrate diet ad libitum and in steers programmed to gain 1.2 kg/d. Increased serum insulin, would likely lead to increased uptake of glucose by peripheral tissues. Subsequently, marbling score, as measured by ultrasound, may be increased for steers fed a high-concentrate diet ad libitum during the growing phase. Total energy intake affects partitioning of fat deposition in the growing phase, but these differences diminish during the finishing phase. Marbling score of early-weaned steers at slaughter was not affected by the feeding regimen in the growing phase. Physiological maturity was hastened in steers fed a high-concentrate diet throughout the trial due to their rapid growth rate. Controlling growth rate by limit-feeding grain-based diets extended the growth curve slightly, but feeding a fiber-based diet for 99 d did not allow the growth curve of early-weaned calves to be extended.

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