Effects of Sire Growth Potential, Growing-Finishing Strategy, and Time on Feed on Performance, Composition, and Efficiency of Steers[1,2]

**R. E. Short*,[3], E. E. Grings*, M. D. MacNeil*, R. K. Heitschmidt*,
C. B. Williams†, and G. L. Bennett†**

*Fort Keogh Livestock and Range Research Laboratory, ARS, USDA, Miles City, MT 59301 and
†Roman L. Hruska U.S. Meat Animal Research Center, ARS, USDA, Clay Center, NE 68933

ABSTRACT: Beef production systems that increase use of unharvested forages and use animals with greater potential for gain affect age and size of animals placed on a finishing regimen. This experiment was conducted to evaluate effects of genetic potential for gain, age at the start of a finishing period, and time on feed on composition, quantity, and quality of beef produced and efficiency of production during finishing. Crossbred cows were bred by AI to Charolais or Line 1 Hereford bulls that represented potentially high (HG) or moderate growth (MG) rates, respectively, to produce spring- or fall-born calves. Steer calves from these matings were placed on an individually fed finishing diet at three ages (A). Spring-born steers were started at 6 or 18 mo of age (A6 and A18), and fall-born steers were started at 12 mo of age (A12). Slaughter times (T) were at 0, 90, 180, and 270 d for A6; 68, 136, and 204 d for A12; and 0, 45, 90, and 135 d for A18. Data collected on each animal included feed intake, growth, chemical composition of the complete body and carcass, and quantitative and qualitative assessment of the meat produced. Four steers of each sire group were slaughtered in each of the 11 A-T treatment groups, and the experiment was repeated for 2 yr in the A12 groups and 3 yr in the A6 and A18 groups (n = 237). Steers sired by HG bulls were larger and produced larger carcasses and more carcass protein than MG-sired steers (S, $P < .05$ or .01). Steers sired by MG bulls were fatter, had higher quality grades, and accumulated fat at a faster rate than HG-sired steers, and this effect was greater in older steers (G and GA, $P < .05$ or .01). Sire growth potential did not affect gain, intake, live weight efficiency, tenderness, or taste panel scores ($P > .2$). Steers sired by HG bulls were more efficient at producing carcass weight and carcass protein at A12 and A18 than were MG-sired steers. At the end of the finishing period, older (A18), HG-sired steers were too large with insufficient fat by current industry standards, and younger (A6), MG-sired steers were too small. Our conclusions are that both HG- and MG-sired steers can produce acceptable carcasses for current market standards with comparable efficiencies of live-weight gain, but the growing and finishing strategy must be adapted to the genotype.

Key Words: Cattle, Steers, Age, Genotypes, Growth, Body Composition

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J. Anim. Sci. 1999. 77:2406–2417

Introduction

Production of beef is the primary means for ranchers to market grass and is accomplished using a wide variety of resources and production and manage-

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[1] This research was part of a national thrust for reducing fat in beef in cooperation with USDA-ARS Grazinglands Research Laboratory, El Reno, OK, and it was conducted under a cooperative agreement between USDA, ARS and the Montana Agric. Exp. Sta. Mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA, Montana Agric. Exp. Sta., or the authors and does not imply its approval to the exclusion of other products that may also be suitable. The USDA, ARS, Northern Plains Area, is an equal opportunity/affirmative action employer and all agency services are available without discrimination.

[2] We gratefully acknowledge donations of Charolais semen for this project from Valley View Charolais Ranch, Polson, MT; Wienk Charolais Ranch, Lake Preston, SD; and Mary E. Malzahn, Perry, OK. We give special thanks to those who meticulously and diligently provided input into this research and who really made all of this possible: Andy Schafer and Butch Arnoldt, animal care and feeding; Brooke Shipp, feed and slaughter data collection; Kay Theer and Pat Tammen, taste panel data collection; Jeff Waechter, proximate analyses; and MaryEllen French, data summaries and manuscript preparation.

[3] To whom correspondence should be addressed: Rt. 1, Box 2021 (phone: 406/232-8235; fax: 406/232-8209; E-mail: bshort@larrl.ars.usda.gov).

Received August 31, 1998.
Accepted March 4, 1999.

ment systems. In the Northern Great Plains, beef production has evolved into primarily cow/calf operations with spring-born calves marketed shortly after weaning in the fall, although some calves may be retained and fed on ranches (backgrounded) for a period of time after weaning. These retained calves are sold during the winter or kept over and grazed on pasture as yearlings before being finished as long yearlings. Grazing yearlings, either purchased or raised on the ranch, is an alternative way to market grass. The production system must also take into account restraints placed on the end product (carcass beef) of the market system in the United States that deal mainly with carcass weight and grade (age and fatness).

Efficiency (economic, biological, and[or] energetic) and sustainability (decreased high cultural energy inputs [range forage] vs increased cultural energy inputs [cereal and oil grains]) are both affected by the choice of production system. Efficiency and market acceptability can also be affected by the genotype of the animal when potential for rate and composition of gain are different.

All of these variables have a potential impact on steers during a finishing period (Coleman et al., 1993; Owens et al., 1995). This experiment was conducted with steers produced from different systems to determine the effect that sire genotype (high vs moderate growth rate potential) and beef production system (age at the start of the finishing period) have on growth, composition, and production efficiency.

Materials and Methods

Steer calves for this study were produced by breeding crossbred cows (various crosses of Angus, Charolais, Hereford, Red Angus, and Tarentaise) at random to either Charolais bulls with high yearling weight indexes (high growth potential sires, **HG**, with moderate potential for fat accretion) or to Line 1 Hereford bulls with average yearling weight indexes (moderate growth potential sires, **MG**, with higher potential for fat accretion). Semen from the HG bulls was available commercially, and the semen from MG bulls was obtained from our own Line 1 herd.

Calves from these matings were born in April (spring-born) or October (fall-born), castrated shortly after birth, and weaned in late September (spring-born) or April (fall-born). After weaning, a random sample of the spring-born steers was put directly on a finishing diet at 6.0 ± .43 mo of age (**A6**), and another random sample was put on a growing diet during the winter, grazed on range forage during the summer (May through September), and put on a finishing diet in late September at 18.5 ± .48 mo of age (**A18**). The fall-born steers were grazed on range forage during the summer with the spring-born yearling steers and then put on a finishing diet in September at 12.0 ± .39 mo of age (**A12**). Diets are shown in Table 1.

Table 1. Content of diets fed during the growing and finishing phases

Component[a]	Calf finished	Yearling finished	
		Growing	Finishing[b]
Corn silage, %	40.0	56.7	19.3
Grass hay, %	0	39.3	0
Barley, %	56.2	0	77.9
Supplement %[c]	3.8	4.0	2.8
Energy, Mcal ME/kg	2.79	2.31	2.88

[a] On a dry matter basis.
[b] Used for spring- (A18) and fall-born (A12) yearlings.
[c] Contained soybean meal (51.9%) and mineral mix (48.1%).

Individual animal nutrient intake was estimated using chromic oxide marker techniques (Adams et al., 1991) while animals were on pasture (preweaning and pasture data reported previously by Grings et al., 1996; Short et al., 1996). During the growing and finishing periods, steers were in pens of six but were individually fed using an electronic gate system (Calan-Broadbent Feeding System, American Calan, Northwood, NH).

Steers were slaughtered at the beginning and at three equally spaced times (**T**) during the finishing period (A6 at 0, 90, 180, and 270 d; A18 at 0, 45, 90, and 135 d on feed) for spring-born calves and at three equally spaced times for fall-born steers (A12 at 68, 136, and 204 d on feed). There were four HG- and four MG-sired steers slaughtered at each time period within each year, and the experiment was repeated over three consecutive years (1990, 1991, and 1992). Fall-born steers were included in only the last 2 yr. There was a total of 237 steers included in the study, but data were only available from 177 steers for growth and intake traits (steers slaughtered at time 0 did not contribute to these data) and from 190 steers for taste panel traits (data were not collected from fall-born steers).

Carcass (USDA, 1975) and body composition (AOAC, 1990) data were collected after slaughter. In order to obtain an estimate of carcass quantity and quality and carcass and body composition, the following protocol was used. Live weight (shrunk overnight, **LWT**) and body condition score (**BCS**, Bellows et al., 1971) were obtained before slaughter. Immediately after slaughter, contents of the rumen and intestines were removed (manually and[or] flushed) to obtain empty body weight (**EB**), and all noncarcass components (blood, head, liver, heart and lungs, rumen and intestinal fat, rumen, intestines, feet, hide, and offal) were weighed and ground. The hide, head, and feet were cut into smaller pieces to facilitate grinding. Grinding was accomplished by passing all material through a large grinder (Autio, model GHP 50, Astoria, OR) three times with a thorough mixing between each pass. The first pass used a plate with 1.6-cm holes, and the last two passes used a plate with .5-cm holes. On the last pass, 10 grab samples of approximately .5 kg each were taken sequentially as the material came out of the grinder. These samples were pooled and became Pool 1. The carcass was split in half, each half was weighed, and both halves were placed in a cooler overnight at –.5°C and then at .5°C for 2 d.

After the 3-d cooling period, the halves were reweighed and processed. The loss in weight from hot carcass weight to cold carcass weight was assumed to be water loss and was taken into account when calculating carcass and total body composition. A rib roast (9 to 12 ribs) was removed from the left side, wrapped, aged at .5°C for another 11 d, and then frozen at –20°C for future qualitative analysis.

The right half of the carcass was cut into hind and front quarters between the 12th and 13th ribs to collect longissimus muscle area (**LMA**), fat thickness, marbling score (in this scoring system 1 = devoid to 28 = abundant+; with a small– [Choice–] = 11], and USDA quality grade data. The right side was then completely deboned and processed to obtain four separate pools in order to obtain composition data and to facilitate marketing of edible product. A standing rib roast (9, 10, 11, and 12 rib) was removed, weighed, and deboned, and the non-bone material was reweighed, double-ground (through .1- and .05-cm plates in a commercial meat grinder), and subsampled (Pool 2). The rib section was processed separately to generate data for future analysis on the relationship of the composition of this segment to carcass and total body composition. The kidney, pelvic, and heart (**KPH**) fat and fat trim (if needed to reduce fat content of ground carcass for marketing purposes) were weighed, double-ground, and subsampled (Pool 3). The remainder of the right half was deboned and the non-bone material was weighed, double-ground, and subsampled (Pool 4). All of the bone, ligaments, cartilage, and tendons removed from the right side (including that from the rib section) were combined, triple-ground through the large grinder used for non-carcass components, and subsampled (Pool 5).

Subsamples of the five pools were wrapped in cheesecloth, weighed, sealed in plastic bags, and frozen at –20°C. These samples and the rib roasts from the left side were shipped to the Roman L. Hruska U.S. Meat Animal Research Center, Clay Center, NE for analysis. The five pools were analyzed for moisture, fat, and ash by standard AOAC (1990) procedures as described by Ferrell et al. (1986). Each of the five pools was analyzed for water, fat, protein, and ash. Fat-free organic matter (**FFOM**) was calculated as the residual and would be primarily protein. The chemical analyses for the five pools were used to mathematically reconstitute empty body and carcass composition.

Rib sections were subjected to sensory and shear evaluations. The procedures followed those described by Crouse et al. (1989). Two 2.5-cm-thick steaks from each carcass were used for sensory evaluation, and one was used for shear force measurement. They were thawed approximately 24 h in a refrigerator (2 to 5°C) and cooked on Faberware (Bronx, NY) Open Hearth electric broilers.

Steaks for shear force evaluation were scored for color after removal from the broiler and cooled at 2 to 5°C for 3 h, and six cores were used for measurement. Steaks for sensory evaluations were wrapped in foil and held in a convection oven at 70°C. Cooking was staggered so that holding time was less than 30 min. Samples (three cubes) were scored by a trained seven-member descriptive attribute panel. Statistical analyses were conducted using the mean score from the seven panelists.

The care and management of the animals used in this study were approved by our Animal Care and Use Committee.

Statistical Analyses

All analyses were conducted with the GLM procedures of SAS (1990). Included in the model were the effects of year (**Y**; 1990, 1991, and 1992), sire growth potential (**G**, HG vs MG), age of the steers at the beginning of the finishing period (**A**; 6, 12, and 18 mo), GA, linear regression of time on feed (T), quadratic effect of time on feed (**T^2**), and the two- and three-way interactions of T and T^2 with G and A. The effects of Y were often significant but were considered irrelevant because they did not interact with other variables and are not shown in the results.

Results and Discussion

Growth and Efficiency (Figure 1, Appendix Tables 1 and 2)

Sire growth potential, age, and the linear regression of time on feed all had major effects on all three weight variables (LWT, Panel a; empty body weight, Panel c; and carcass weight, Panel e; $P < .01$). Steers sired by HG bulls were larger than those sired by MG bulls, and weights increased with age at the beginning of the test and with time on feed. The increase with time on feed was greater with increasing age (TA, $P < .05$, Panel a or $P < .01$, Panels c and e), and, in the case of empty body weight, that relationship was nonlinear (T^2A, $P < .05$).

Even though HG-sired steers were larger than MG-sired steers, there were no differences due to sire growth potential in ADG (Panel b, $P = .12$), intake (Panel d, $P > .4$), or efficiency of live-weight gain (Panel f, $P > .8$). Age affected ADG, intake, and efficiency of live-weight gain (A; Panel b, $P < .05$, or

Panels d and f, $P < .01$). In general, as age of steer going into the feedlot increased, ADG increased, intake increased, and efficiency decreased. Energy intake increased linearly with time on feed, but that effect was dependent on age (T and TA, Panel f, $P < .01$). Efficiency of live-weight gain seemed to decrease with time on feed, but that effect was not significant (Panel f, $P > .2$).

Increased ADG has been observed for older cattle placed on finishing diets compared with cattle placed directly on a finishing diet after weaning and is considered to be due to compensatory gains (Dikeman

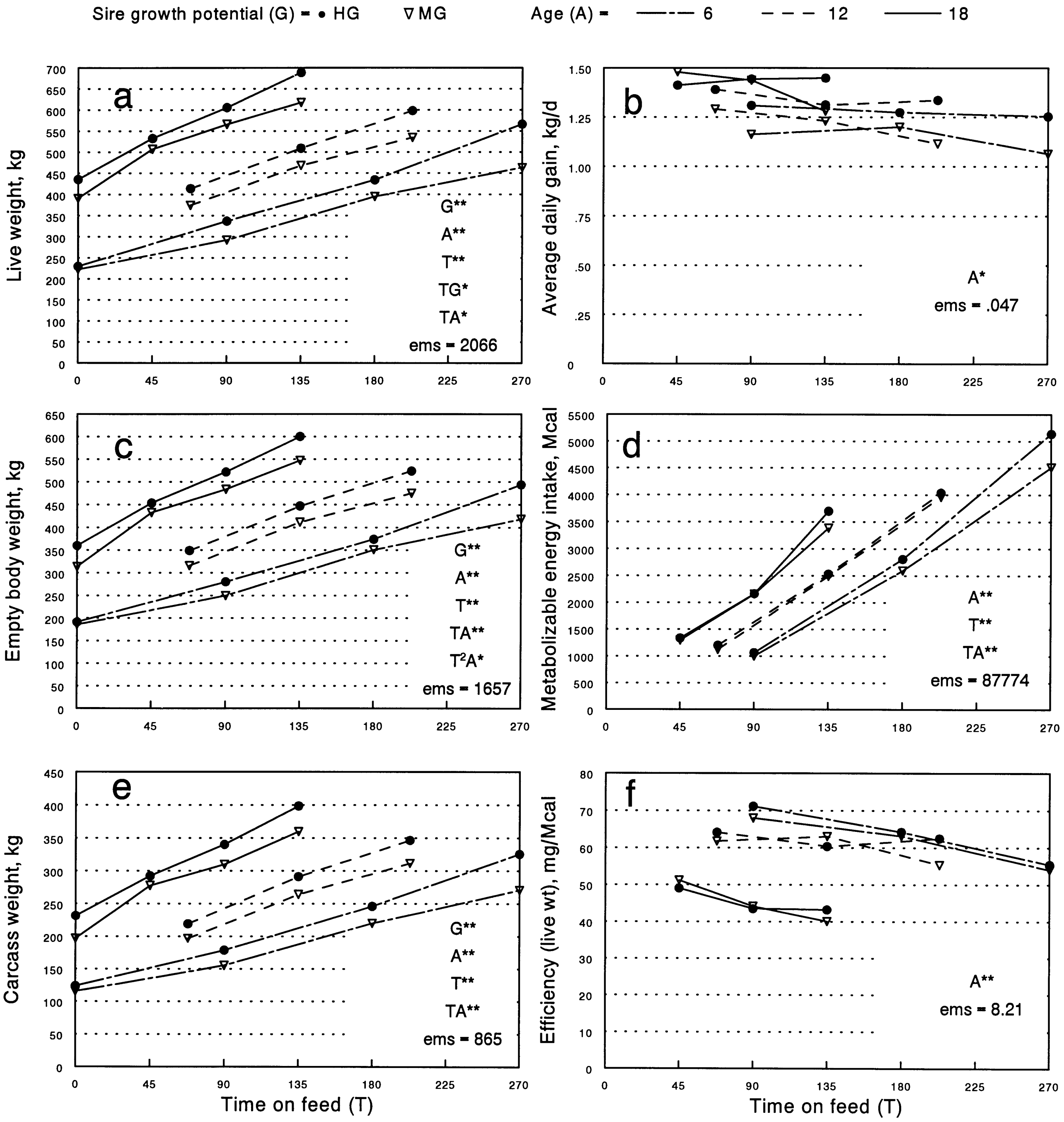

Figure 1. Effects of sire growth potential (G; high growth [HG] vs moderate growth [MG]), age at the beginning of the finishing period (A; 6, 12, or 18 mo), time on feed (T; 0 to 270 d), and their interactions on live weight (Panel a), average daily gain (Panel b), empty body weight (Panel c), energy intake (Panel d), carcass weight (Panel e), and efficiency of live weight (Panel f). Significance of variables (*$P < .05$ or **$P < .01$) and the error mean square (ems) are noted for each variable.

et al., 1985; Harris et al., 1997; Lunt and Orme, 1987). However, these increased gains do not improve efficiency of live-weight gain due to increased maintenance costs of the older cattle (Dikeman et al., 1985). Coleman et al. (1995b) observed changes in weight, gain, and efficiency with time on feed similar to those reported here.

Efficiency is a complex trait affected by age, size, sex, body composition, rate of gain, and previous gain. Steers sired by MG bulls were fatter (Figure 3, Panels b and d) and smaller (Figure 1, Panel a) but very similar in rate of gain and efficiency (Figure 1, Panels b and f) compared to steers sired by HG bulls. The anticipated effects of live weight and fatness may be offset by the relationship between composition of gain and efficiency demonstrated by Geay (1984), wherein efficiency of energy utilization decreases as proportion of protein in gain increases. If we assume that efficiency of energy utilization for growth of fat is .75 and of protein is .20 (kg; Geay, 1984), that fat contains 9.5 Mcal/kg and protein 5.7 Mcal/kg (Brouwer, 1965), and that gain as fat is 100% fat and gain as protein is 22% protein, then efficiency of gain for lean is 6.5 Mcal/kg, compared with 12.7 Mcal/kg for fat. Owens et al. (1995) concluded that the differential efficiency between fat and lean was even larger. They estimated that the energetic efficiency for fat accretion is 1.7 times greater than for protein accretion, but efficiency of lean tissue gain is four times greater than that of fat tissue gain. Using these assumptions, the data reported here agree with the data summarized by Geay (1984).

In order to estimate efficiency on an individual animal basis, the output variable must be measured at the beginning and end of the test period, and the input variable must be measured on individual animals during the test period. The only output variable for which beginning and end measurements were available was live weight. All other output variables were measured only at slaughter. Live weight gain may not be the best measure of output because of the inedible components that it includes. Many of the variables measured, such as carcass weight and amount of protein (FFOM), should be used to more accurately assess output of edible product, but without initial values it is not possible to make those comparisons.

Carcass Data (Figure 2, Appendix Tables 1 and 2)

Longissimus muscle area (Panel a) was larger in HG- than in MG-sired steers, and it increased with age and time on feed (G, A, and T; $P < .01$). The increase with time on feed was greater with HG- than with MG-sired steers (TG, $P < .05$) and with older steers (TA, $P < .01$), but these effects were interrelated (TGA, $P < .05$).

Dikeman et al. (1985) found cattle with moderate growth potential to have similar LMA when direct-finished to 430 kg LWT or backgrounded and finished to 522 kg LWT, but LMA was greater in backgrounded compared with direct-finished cattle of high growth potential. This indicated that the cattle with moderate growth potential had reached mature weight while the cattle with higher growth potential were still growing. In our study, however, LMA of direct-fed and yearling-fed steers of moderate growth potential would have been fairly similar at the LWT end points used by Dikeman et al. (1985), but it continued to increase in yearling-fed cattle with additional time on feed.

Fat thickness (Panel b) and yield grade score (Panel c) are both estimates of external fat, and the treatment effects were similar for both variables. For both variables, sire growth potential and age were significant (G and A; $P < .01$). Older steers and those sired by MG were fatter. The age effect depended on sire growth potential (GA, $P < .05$ or .01); the sire growth potential effect was more pronounced as age increased. External fat (fat thickness and yield grade) increased with time on feed, but that increase depended on age and sire growth potential (T, TG, and TA; $P < .05$ or .01) and their interrelationships (TGA, $P < .05$; 12-mo-old steers sired by MG had a more pronounced response to time on feed at A12). Older steers and those sired by MG increased external fat more quickly, except that yield grade for 18-mo-old steers reached a plateau at older ages (T^2A, $P < .05$).

These data support the model of Williams et al. (1995), who concluded that British-cross calves may not meet a criterion of a minimum 250-kg carcass at a carcass fat composition of 28% fat when placed directly into the feedlot at weaning and fed for high rates of gain.

Marbling score (Panel d) is an estimate of intramuscular fat, and it was higher in MG-sired steers and older steers (G and A, $P < .01$). Marbling score also increased with time on feed and that increase was not linear, especially with 18-mo-old steers (T, TA, T^2, and T^2A, $P < .01$), for which the rate of increase decreased with time on feed.

Cutability (Panel e) is an estimate of trimmed wholesale cuts as a percentage of carcass weight and is usually inversely related to fatness. Cutability was lower in older and MG-sired steers, and it decreased with time on feed (G, A, and T; $P < .05$ or .01). The time on feed and sire growth potential effects were more pronounced in 12-mo-old steers (GA, TG, TA, and TGA, $P < .05$ or .01), and there was a leveling off of the rate of decrease in A18 (T^2A, $P < .05$) at the end of the finishing period.

Dressing percentage (Panel f) is an estimate of carcass yield and generally increases with fatness. Dressing percentage increased with age (A, $P < .05$), but the main response was an increase with time on feed, and that increase was dependent on age (T, $P < .01$ and TA, $P < .05$). Dressing percentage in steers fed at younger ages increased at a slower rate.

The changes with time on feed observed for these carcass traits are similar to those observed by Coleman et al. (1995b).

Empty Body and Carcass Composition (Figure 3, Appendix Table 1)

The amount of fat in the empty body (Panel a) was greater in MG- than in HG-sired steers, was greater with increasing age, and increased linearly with time

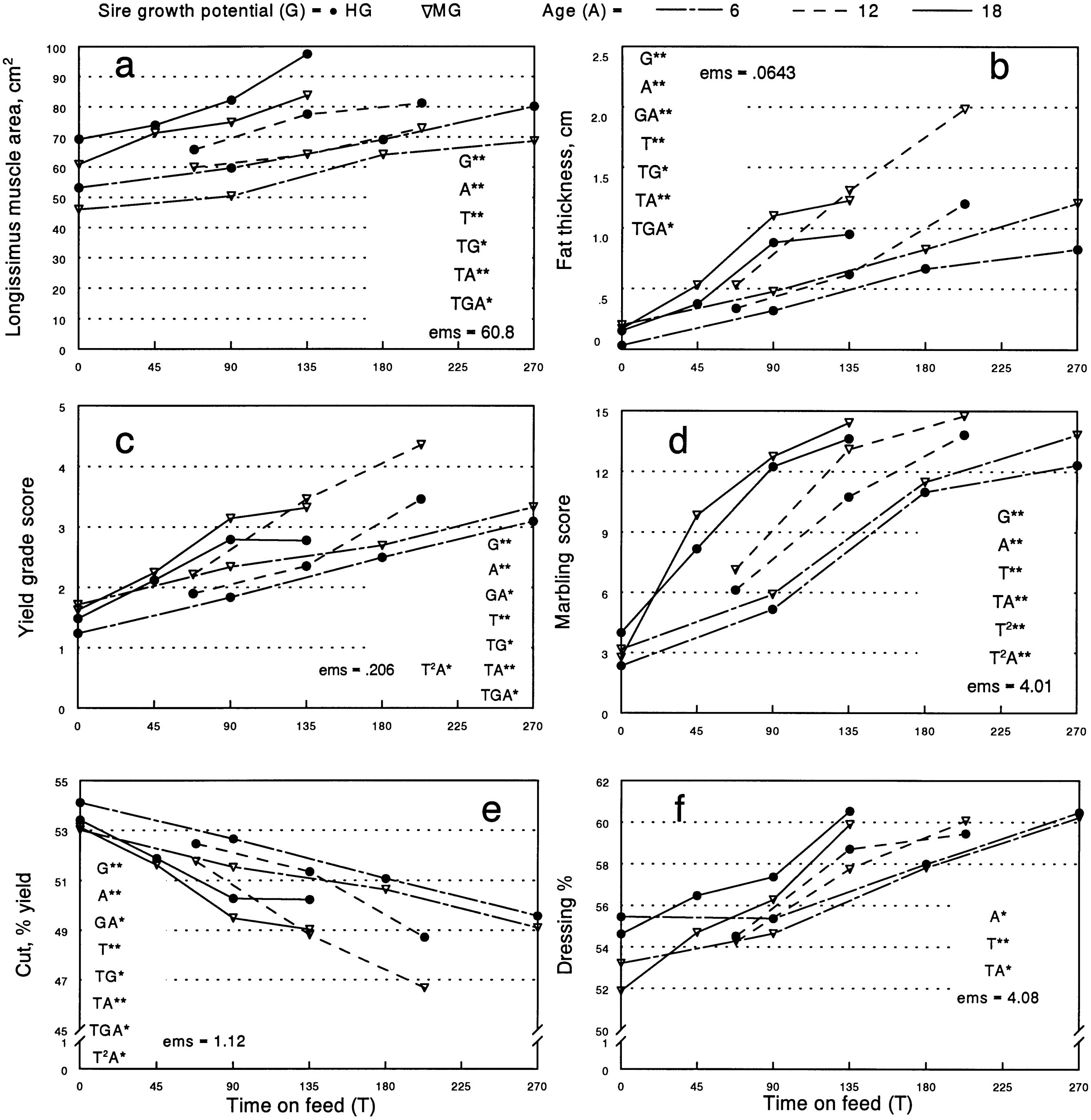

Figure 2. Effects of sire growth potential (G; high growth [HG] vs moderate growth [MG]), age at the beginning of the finishing period (A; 6, 12, or 18 mo), time on feed (T; 0 to 270 d) and their interactions on longissimus muscle area (Panel a), fat thickness (Panel b), yield grade score (Panel c), marbling score (Panel d, in this scoring system 1 = devoid to 28 = abundant+; with a small– [Choice–] = 11), cutability (Panel e, weight of trimmed wholesale cuts/ carcass weight × 100), and dressing percentage (Panel f, carcass weight/live weight × 100). Significance of variables (*$P < .05$ or **$P < .01$) and the error mean square (ems) are noted for each variable.

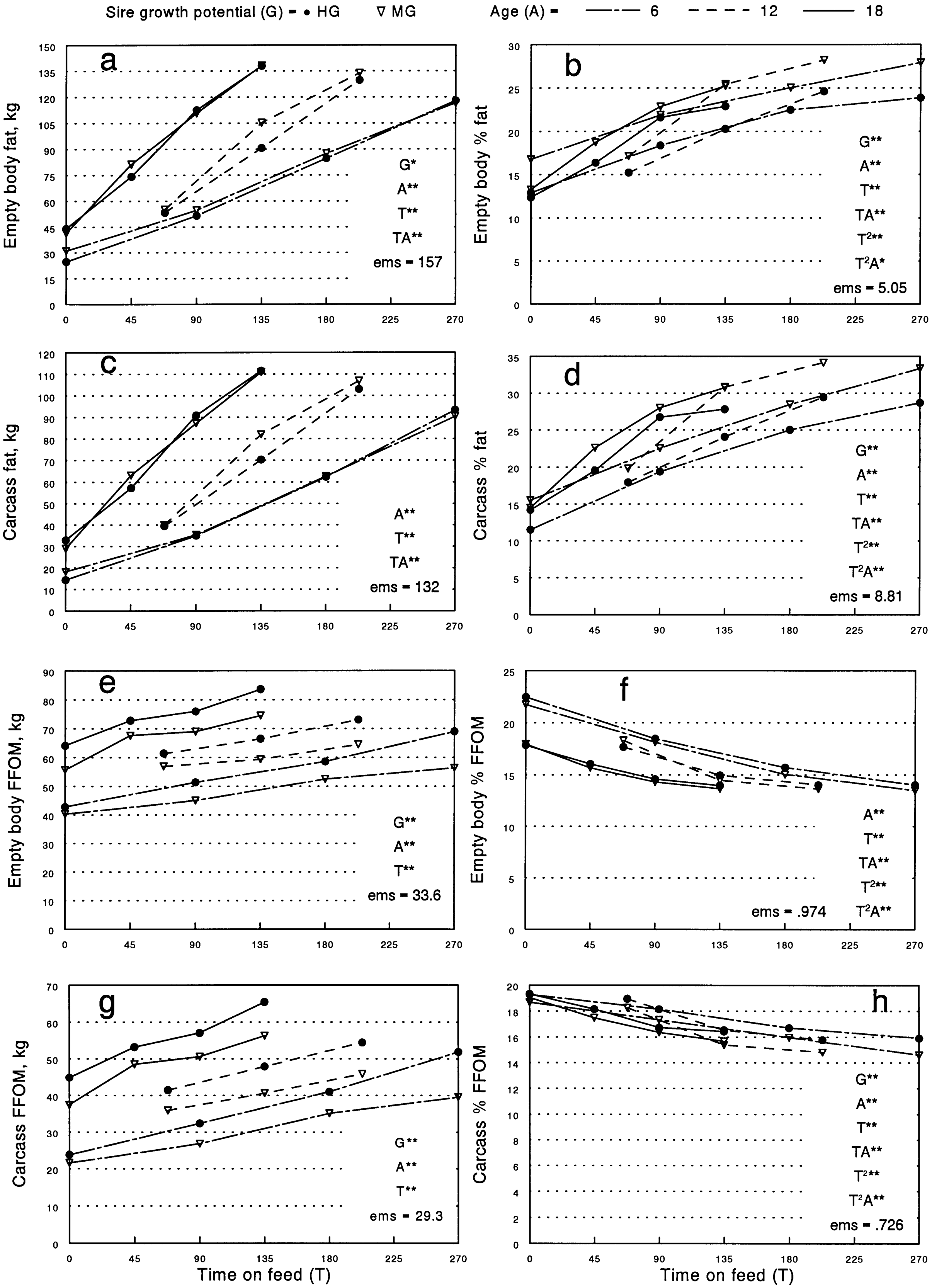

Figure 3. Effects of sire growth potential (G; high growth [HG] vs moderate growth [MG]), age at the beginning of the finishing period (A; 6, 12, or 18 mo), time on feed (T; 0 to 270 d), and their interactions on amount and percentage of empty body fat (Panels a and b), amount and percentage of carcass fat (Panels c and d), amount and percentage of empty body fat-free organic matter (FFOM; protein) (Panels e and f), and amount and percentage of carcass FFOM (Panels g and h). Significance of variables (*$P < .05$ or **$P < .01$) and the error mean square (ems) are noted for each variable.

on feed (G, A, and T; $P < .05$ or .01). However, the increase with time on feed was more rapid as age increased (TA, $P < .01$). As can be seen in Panel b, when empty body fat was put on a percentage basis, the magnitude and relationship of these effects were changed but still significant (G, A, T, and TA; $P < .01$). In addition, empty body percentage fat increased nonlinearly and was dependent on age (T^2, $P < .01$ and T^2A, $P < .05$).

When only the carcass was analyzed, the same factors that affected EB affected both amount of fat (Panel c) and percentage fat (Panel d), except that the effects were more exaggerated and sire growth potential did not affect amount of fat (for amount of fat in the carcass, A, T, and TA, $P < .01$; for percentage fat in the carcass, G, A, T, TA, T^2, and T^2A, $P < .01$).

Protein was estimated as FFOM. In the EB (Panel e), HG-sired steers had more FFOM than MG-sired steers, and FFOM increased with age and time on feed (G, A, and T; $P < .01$). On a percentage basis in the EB (Panel f), FFOM was not affected by sire growth potential, but there was a decrease with age and time on feed (A, T, and TA, $P < .01$). The decrease with time on feed was nonlinear and dependent on age (T^2 and T^2A, $P < .01$) in that the decrease became less as time on feed increased, and the decreased rate was more evident as age increased.

The effects of sire growth potential, age, and time on feed on FFOM in the carcass (Panel g) were similar to that in the EB, except that the effects were somewhat more exaggerated (G, A, and T; $P < .01$). When FFOM was expressed as a percentage of carcass (Panel h), the effects were less pronounced than when FFOM was a percentage of EB, although the effects were still highly significant (A, T, TA, T^2, and T^2A, $P < .01$). The exception was that sire growth potential became significant on a percentage basis; HG-sired steers had a higher percentage of FFOM than MG-sired steers (G, $P < .01$).

Coleman et al. (1995a) reported composition data collected in a similar manner to that reported here and found similar changes with time on feed.

Tenderness and Taste Panel Data (Figure 4, Appendix Table 2)

Data for these variables were only available for 6- and 18-mo-old steers. Shear force (Panel a; lower values = more tender) was similar at the beginning of the feeding period for both ages. As time on feed increased, there was a steady decrease for 6-mo-old steers as opposed to a rapid decrease then no decrease for 18-mo-old steers (A, $P < .01$ and T^2A, $P < .05$). Ease of fragmentation scores from the taste panel (Panel b) also are measures of tenderness. These results were similar to those of the shear test in that tenderness increased with time on feed, but the effect was linear, and the age effect was not related to time on feed (A, $P < .05$ and T, $P < .01$).

Aalhus et al. (1992) reported that shear force values decreased with increasing time on feed. Several other researchers have found improved tenderness with increasing time on a high-energy diet for 56 (Miller et al., 1987), 70 (Aberle et al., 1981), or 75 d (Coleman et al., 1995b). Only minor improvements were observed after those times. In our study, there was a dramatic difference in the rate at which shear force decreased with time on feed. For the yearling cattle, Warner-Bratzler shear force decreased with feeding up to 90 d but did not decrease beyond that time; Warner-Bratzler shear force values decreased more slowly in A6 steers. In contrast, Dikeman et al. (1985) reported that cattle placed directly on a finishing diet were more tender and had less connective tissue than cattle backgrounded for 140 to 180 d before finishing.

Taste panel flavor intensity (**FI**) score (Panel c) increased nonlinearly with time on feed (T and T^2, $P < .01$). Juiciness score from the taste panel (Panel d) was not as consistent as flavor intensity score, although there were nonlinear changes with time on feed (T, $P < .05$ and T^2, $P < .01$). Coleman et al. (1995b) reported only minor changes in FI and juiciness with time on feed in steers that were gaining more rapidly before the finishing phase than the A18 steers in our study. Their results were more comparable to the later stages of the A6 steers in our study.

General Discussion

The criterion of a carcass weight of 250 to 400 kg with a yield grade of less than 3 was used to evaluate the systems used in this study. The A6 steers did not reach an acceptable carcass weight until 180 d of finishing or longer, but by 270 d they were above yield grade 3. Even though it was not feasible to produce an acceptable MG-A6 steer, the HG-A6 steers were potentially acceptable when fed between 180 and 250 d on a finishing diet.

For the A12 steers, carcasses were too light at 68 d of finishing and were greater than yield grade 3 by 136 d (MG) or 204 d (HG) of finishing. Within the constraints given, it was not feasible to produce acceptable carcasses from MG-A12 steers within our systems. High-growth-potential A12 steers produced an acceptable product when finished for approximately 90 to 170 d.

For A18 steers, the criterion was met with MG steers finished for 45 d and HG steers finished for 45 to 135 d. However, HG steers finished for 135 d were just under the maximum carcass weight. Van Koevering (1995) reported a quadratic response in ADG to time on feed in British × Continental crossbred steers with linear increases in both fat depth and marbling scores as feeding increased from 105 through 147 d. These researchers suggested that a period of 119 to 133 d with a 1.36 kg/d gain is appropriate for British × Continental crossbred yearling steers.

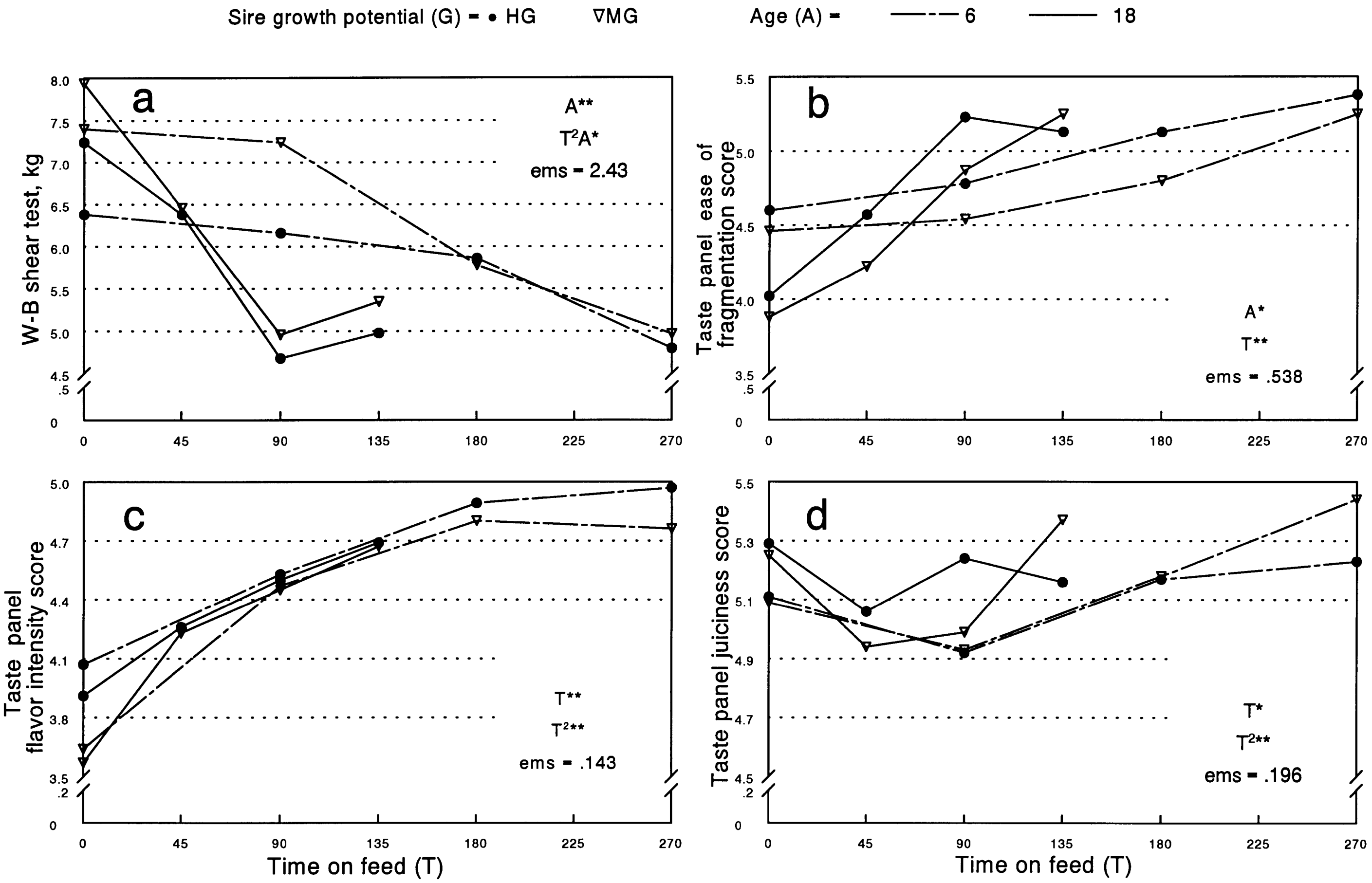

Figure 4. Effects of sire growth potential (G; high growth [HG] vs moderate growth [MG]), age at the beginning of the finishing period (A; 6, 12, or 18 mo), time on feed (T; 0 to 270 d), and their interactions on Warner-Bratzler shear test for tenderness (Panel a), taste panel score for ease of fragmentation tenderness score (Panel b), taste panel flavor intensity score (Panel c), and taste panel juiciness score (Panel d). Significance of variables (**P* < .05 or ***P* < .01) and the error mean square (ems) are noted for each variable.

Although MG steers fell within the carcass criterion at only 45 d of feeding, this may not provide the most acceptable eating experience. Warner-Bratzler shear values and taste panel ease of fragmentation scores changed dramatically between 45 and 90 d of finishing. Other researchers have reported that tenderness improves up to 56 (Miller et al., 1987), 70 (Aberle et al., 1981), or 75 d (Coleman, 1995b) on high-energy diets.

Selection of the optimum beef production system for any enterprise must also include other variables such as cholesterol and fatty acid composition of the meat (Rule et al., 1997) and, ultimately, the biological and economic efficiency of the complete production system (Grings et al., 1996; McNeley, 1996).

Implications

Current markets in the United States have established that optimum parameters for carcasses are 250 to 400 kg with a yield grade of 3 or less. Systems that produced carcasses within those parameters included steers with high and moderate growth potential, but carcasses also must be produced efficiently. Within these acceptable systems, efficiency of live weight production was greater for high-growth-potential steers started at 12 mo and fed for 136 d or started at 6 mo and fed for 180 d, and that for carcass protein was greatest for high-growth-potential steers started at 18 mo and fed for 135 d, which ranked lowest in live weight gain efficiency. The system including high-growth-potential steers fed for 180 d, starting at 6 mo, ranked high in both efficiency of live weight and carcass protein gain per unit of energy intake. Production systems must take into account genetic and management variables as well as economic and biological efficiency to determine an optimum arrangement for beef production.

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Appendix Table 1. Least squares means and standard errors for traits measured directly at slaughter. Traits such as ADG and efficiency can be calculated from these values. Number of observations for each mean can be obtained by n = (EMS)/(SE)^2

Time on feed and growth potential[a]	Live wt		Empty body						Carcass						Longissimus muscle		Fat thickness	
			Weight		Fat		FFOM[b]		Weight		Fat		FFOM[b]					
	$\bar{X}$, kg	SE	$\bar{X}$, kg	SE	$\bar{X}$, kg	SE	$\bar{X}$, kg	SE	$\bar{X}$, kg	SE	$\bar{X}$, kg	SE	$\bar{X}$, kg	SE	$\bar{X}$, cm^2	SE	$\bar{X}$, mm	SE
	Finishing period begun at 6 mo of age																	
0 d																		
H	229.7	13.12	190.9	11.75	24.7	3.62	42.8	1.67	123.7	8.49	14.3	3.31	23.8	1.56	53.12	2.251	.32	.732
M	222.4	13.12	185.5	11.75	31.1	3.62	40.3	1.67	115.6	8.49	18.1	3.31	21.6	1.56	45.97	2.251	2.01	.732
90 d																		
H	337.2	13.12	280.1	11.75	51.6	3.62	51.4	1.67	178.8	8.49	34.9	3.31	32.4	1.56	59.66	2.251	3.20	.732
M	292.4	13.12	249.7	11.75	54.8	3.62	45.1	1.67	155.2	8.49	35.4	3.31	26.9	1.56	50.40	2.251	4.78	.732
180 d																		
H	434.3	13.12	374.2	11.75	84.7	3.62	58.6	1.67	246.2	8.49	62.3	3.31	41.0	1.56	69.09	2.251	6.67	.732
M	394.8	13.12	351.1	11.75	87.6	3.62	52.5	1.67	220.2	8.49	62.7	3.31	35.2	1.56	64.14	2.251	8.26	.732
270 d																		
H	566.4	13.12	493.6	11.75	117.9	3.62	69.0	1.67	325.8	8.49	93.4	3.31	51.9	1.56	80.17	2.251	8.26	.732
M	463.8	13.76	418.7	12.32	116.6	3.79	56.4	1.75	271.1	8.90	90.3	3.47	39.6	1.64	68.71	2.251	12.06	.732
	Finishing period begun at 12 mo of age																	
68 d																		
H	414.0	17.28	349.2	15.47	53.4	4.76	61.5	2.20	219.3	11.18	39.4	4.36	41.5	2.06	65.84	2.962	3.39	.964
M	374.6	18.56	315.9	16.62	55.1	5.12	57.0	2.37	197.0	12.01	40.0	4.69	35.9	2.21	59.94	2.962	5.28	.964
135 d																		
H	509.3	16.07	447.0	14.39	90.7	4.43	66.5	2.05	291.3	10.40	70.4	4.06	47.9	1.91	77.50	2.757	6.19	.897
M	468.4	17.26	411.9	15.46	105.2	4.76	59.5	2.20	264.4	11.17	82.1	4.36	40.6	2.05	64.19	2.961	13.11	.963
203 d																		
H	598.0	17.26	523.8	15.46	129.8	4.76	73.1	2.20	346.7	11.17	103.1	4.36	54.4	2.05	81.21	2.961	12.03	.963
M	534.9	16.07	475.2	14.39	133.9	4.43	64.6	2.05	311.7	10.40	106.9	4.06	45.9	1.91	72.91	2.757	19.84	.897
	Finishing period begun at 18 mo of age																	
0 d																		
H	435.3	13.12	360.0	11.75	44.1	3.62	64.2	1.67	231.7	8.49	32.9	3.31	44.9	1.56	69.25	2.251	1.53	.732
M	399.5	13.12	313.3	11.75	41.5	3.62	55.7	1.67	197.0	8.49	28.9	3.31	37.4	1.56	60.86	2.251	1.69	.732
45 d																		
H	532.8	13.12	453.5	11.75	74.2	3.62	72.9	1.67	292.4	8.49	57.2	3.31	53.2	1.56	73.88	2.251	3.74	.732
M	507.6	13.12	432.5	11.75	81.3	3.62	67.7	1.67	277.8	8.49	63.1	3.31	48.5	1.56	71.35	2.251	5.29	.732
90 d																		
H	605.5	13.12	521.8	11.75	112.5	3.62	76.0	1.67	340.3	8.49	90.9	3.31	57.1	1.56	82.21	2.362	8.80	.768
M	566.1	13.12	483.6	11.75	110.7	3.62	69.0	1.67	310.1	8.49	87.3	3.31	50.6	1.56	74.82	2.362	11.01	.732
135 d																		
H	689.0	13.12	600.6	11.75	138.0	3.62	83.6	1.67	398.8	8.49	111.6	3.31	65.4	1.56	97.51	2.169	9.50	.706
M	617.5	13.12	547.2	11.75	138.2	3.62	74.6	1.67	360.1	8.49	111.0	3.31	56.3	1.56	83.82	2.251	12.28	.732
EMS[c]	2,066		1,657		157		33.6		865		132		29.3		60.80		6.43	

[a] H = high-growth-potential steers sired by Charolais bulls and M = moderate-growth-potential steers sired by Line 1 Hereford bulls.

[b] Fat-free organic matter (FFOM) is an estimate of protein content.

[c] Error mean square.

Appendix Table 2. Least squares means and standard errors for muscle traits and taste panel evaluations. Number of observations for each mean can be obtained by $n = (EMS)/(SE)^2$

Time on feed and growth potential[a]	Yield grade		Marbling score		Kidney, pelvic, and heart fat		Cut		Warner-Bratzler shear test		Taste panel scores: Ease of fragmentation		Taste panel scores: Flavor intensity		Taste panel scores: Juiciness		Metabolizable energy intake	
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$, %	SE	$\bar{X}$, %	SE	$\bar{X}$, kg	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$, Mcal	SE
Finishing period begun at 6 mo of age																		
0 d																		
H	1.24	.131	2.33	.578	1.38	.190	54.1	.305	6.38	.449	4.60	.211	4.07	.109	5.11	.128		
M	1.72	.131	3.17	.578	1.53	.190	53.0	.305	7.40	.449	4.46	.211	3.64	.109	5.09	.128		
90 d																		
H	1.84	.131	5.17	.578	2.10	.190	52.7	.305	6.16	.449	4.78	.211	4.53	.109	4.92	.128	1,063.5	85.52
M	2.34	.131	5.92	.578	2.66	.190	51.5	.305	7.24	.449	4.54	.211	4.47	.109	4.93	.128	996.2	89.70
180 d																		
H	2.50	.131	11.00	.578	3.30	.190	51.1	.305	5.86	.449	5.13	.211	4.89	.109	5.17	.128	2,811.3	85.52
M	2.70	.131	11.50	.578	3.27	.190	50.6	.305	5.78	.449	4.80	.211	4.80	.109	5.18	.128	2,597.2	89.70
270 d																		
H	3.10	.131	12.33	.578	4.49	.190	49.6	.305	4.80	.449	5.38	.211	4.97	.109	5.23	.128	5,140.3	85.52
M	3.33	.131	13.83	.578	3.54	.190	49.1	.305	4.97	.472	5.25	.222	4.76	.115	5.44	.134	4,508.4	89.70
Finishing period begun at 12 mo of age																		
68 d																		
H	1.90	.173	6.12	.761	2.23	.250	52.5	.401									1,199.7	112.56
M	2.22	.173	7.12	.761	2.21	.250	51.8	.401									1,123.5	112.56
135 d																		
H	2.35	.161	10.75	.708	2.90	.233	51.3	.373									2,531.6	104.75
M	3.46	.172	13.12	.760	2.97	.250	48.8	.401									2,491.7	112.52
203 d																		
H	3.46	.172	13.83	.760	4.16	.250	48.7	.401									4,036.9	112.52
M	4.36	.161	14.75	.708	4.17	.233	46.7	.373									3,962.7	104.75
Finishing period begun at 18 mo of age																		
0 d																		
H	1.49	.131	4.00	.578	1.41	.190	53.4	.305	7.24	.449	4.02	.211	3.91	.109	5.29	.128		
M	1.63	.131	2.75	.578	1.39	.190	53.1	.305	7.94	.449	3.88	.211	3.57	.109	5.25	.128		
45 d																		
H	2.12	.131	8.17	.578	2.01	.190	51.9	.305	6.38	.449	4.57	.211	4.26	.109	5.06	.128	1,333.3	104.75
M	2.25	.131	9.83	.578	2.21	.190	51.6	.305	6.46	.449	4.22	.211	4.23	.109	4.94	.128	1,294.3	104.75
90 d																		
H	2.79	.138	12.25	.578	3.10	.190	50.3	.320	4.68	.449	5.23	.211	4.50	.109	5.24	.128	2,164.7	85.52
M	3.14	.138	12.75	.578	2.97	.190	49.5	.320	4.96	.449	4.87	.211	4.45	.109	4.99	.128	2,158.2	85.52
135 d																		
H	2.78	.126	13.63	.557	3.39	.183	50.2	.294	4.97	.449	5.13	.211	4.69	.109	5.16	.128	3,698.1	85.52
M	3.32	.131	14.42	.578	3.38	.190	49.0	.305	5.35	.449	5.25	.211	4.67	.109	5.37	.128	3,388.2	85.52
EMS[b]	.206		4.008		.4339		1.115		2.43		.538		.143		.196		87,774	

[a] H = high-growth-potential steers sired by Charolais bulls and M = moderate-growth-potential steers sired by Line 1 Hereford bulls.

[b] Error mean square.