THE INFLUENCE OF DIETARY ROUGHAGE LEVEL ON EFFICIENCY OF GROWTH AND MUSCLE DEPOSITION IN BULLS AND STEERS

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Bulls and implanted steers fed three dietary roughage levels (20% 50%, and 80% alfalfa-brome hay) were compared for various measures of efficiency in beef production. Cattle were about 1 yr of age at the start of the trial and bulls were heavier than steers (290 kg vs. 269 kg). There were four pens, each containing three cattle in every sex × dietary roughage combination. Animals in a pen were slaughtered when pen means approximated 450 kg or 580 kg. Increasing the level of roughage in the diet (20% to 80%) resulted in a significant decrease ($P < 0.05$) in both daily gain and liveweight gain per 100 MJ DE. The 50% roughage diet produced intermediate results. At a constant liveweight there was no significant ($P < 0.05$) effect of dietary roughage level on carcass muscle. Bulls produced 9% more muscle than steers at a constant liveweight. Muscle gain per 100 MJ DE decreased significantly ($P < 0.05$) with roughage level, and was higher for bulls than steers. For a constant amount of feed energy (24 148 MJ DE) bulls fed the 20% roughage diets produced 26.8 kg more carcass muscle ($P < 0.05$) than bulls fed the 80% roughage diet. Similarly, steers fed the 20% roughage diet produced 16.1 kg more carcass muscle ($P < 0.05$) than steers fed the 80% roughage diet. Bulls produced 23% more muscle than steers for a constant digestible energy intake (24 148 MJ DE). The overall results thus indicate that dietary roughage and sex-type cause large differences in the amount of carcass muscle produced for a constant energy intake.

Des taurillons et des bouvillons implantés, exposés à des régimes alimentaires comportant trois proportions de fourrage grossier (20, 50 et 80% de foin brome-luzerne), ont été comparés pour diverses aptitudes bouchères. Au début de l'expérience, les bêtes avaient environ un an et les taurillons étaient plus lourds que les bouvillons (290 contre 269 kg). Chaque combinsaison de traitement sexe × aliment était mesurée sur quatre parquets composés de trois bêtes chacun. Les animaux étaient abattus quand le poids moyen par parquet était soit de 450 ou de 580 kg. L'accroissement de la proportion de fourrage (20–80%) a donné lieu à une diminution significative ($P < 0.05$) du GMQ et de la valorisation de l'énergie consommée (gain/100 MJ ED). Le régime à 50% de fourrage a fourni des résultats intermédiaires. A poids vif constant, on n'a pas observé d'effet significatif dû à la proportion de fourrage sur la production de maigre, mais les taurillons produisaient plus de maigre que les bouvillons. Le gain pondéral de maigre par 100 MJ ED a diminué significativement quand la proportion de fourrage augmentait et il était plus élevé chez les taurillons que chez les bouvillons. Pour un même niveau d'ingestion d'énergie (24 181 MJ ED), les taurillons, recevant le régime à 20% de fourrage ont produit 26.8 kg de maigre de plus que les taurillons recevant le régime à 80%. Pour les

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bouvillons, l'avantage correspondant était de 16.1 kg. A niveau d'ingestion iso-énergétique, les taurillons produisaient 23% plus de maigre que les bouvillons. Ces résultats font ressortir les fortes différences que la proportion de fourrage dans la ration et le "sexe" de l'animal peuvent avoir sur la production de maigre pour un même niveau d'ingestion d'énergie alimentaire.

It is now well established that increasing the roughage component in feedlot diets decreases average daily gain, increases feed intake and feed per unit of gain and decreases the rate of fattening, so that optimum slaughter weight would be higher to reach a certain level of fatness (Arthaud et al. 1977; Price et al. 1978; Price et al. 1980). However, as discussed in the first paper of this series (Jones et al. 1981), most previous work has been based on a constant endpoint analysis. Thus, the changes leading to treatment differences are obscured, and differences caused by feeding rations of varying dietary energy concentration have not been fully explained. Also, it has been common in many scientific publications to consider the liveweight performance and carcass composition of meat animals as separate entities and there are few estimates of the actual biological efficiency of producing muscle in cattle under various feeding regimes. Additionally, in numerous studies (Field 1971; Arthaud et al. 1977) it has been demonstrated that bulls gain more rapidly, convert feed to lean meat more efficiently, and have less waste fat than steers, but, there are few estimates of the biological efficiency of producing muscle in both bulls and steers under feedlot conditions.

The following study was designed to examine the effects and interactions of dietary energy and sex-type (bulls, steers) on the biological efficiency of producing meat from beef cattle.

MATERIALS AND METHODS

Seventy-two mixed-breed commercial cattle (36 bulls, 36 steers) were purchased from one herd a few weeks before weaning in October 1976. The cattle were of a Charolais-British mixed breed-type. The experimental procedure has been described elsewhere in detail by Price et al. (1980). Briefly, weaned calves were overwintered on alfalfa-brome hay and supplementary grain, and grew at an average of about 0.5 kg per day. At approximately 1 yr of age the cattle were transported to the Beef Cattle Test Station at Ellerslie, Alberta where the steers were all implanted with Synovex S (Syntex Agric Business Inc.). The 36 bulls and 36 implanted steers were allotted, within sex, to 24 pens each containing three animals; the pens were balanced within sex for liveweight. Each pen was randomly assigned to one of three experimental diets, and one of two slaughter weights (450 or 580 kg). The three experimental diets contained 20, 50, or 80% alfalfa-brome hay prepared with a hammer mill equipped with a 3.8-cm screen (Price et al. 1980). The hay was mixed with rolled barley, vitamins and minerals at the time of feeding. Digestibility measurements were made using a combined total collection and grab sampling technique to estimate the digestible energy content of the three diets (Mathison 1978).

Most of the cattle remained healthy throughout their stay in the feedlot. One steer in the 20% roughage group was removed from the experiment because of ill-health.

Feed consumption was recorded daily, and the cattle were weighed every second Tuesday. Feed conversion ratios were expressed on a pen basis as weight of feed required for each kilogram of body weight gained, adjusted to a constant initial weight. There were only four pen means used for the analyses involving feed intake data. The constant initial weight used was the starting weight of the bulls as these were heavier than the steers at the start of the trial (Price et al. 1980). Cumulative feed amounted to the total pen feed adjusted to the above constant starting weight to when the animals in a pen were slaughtered. Muscle weights at the start of the trial were estimated from an initial slaughter group described by Price et al. (1970). When the pen average weight reached the designated slaughter weight, the cattle were weighed on three consecutive days and delivered to the packing plant immediately after the last weighing. Slaughtering at a pen weight imposes a liveweight variation within the pen. Water was restricted approximately 16 h before weighing although feed was continuously available.

The carcasses were appraised and graded in the normal manner, following slaughter and overnight chilling. The right side of each carcass was then partially dissected in order to estimate the weight of muscle in the side (Price and Berg 1976).

The experimental design was multiway: three roughage levels (20, 50, 80%), two sex-types (bulls, steers), with four pens per treatment combination, each pen having three animals. To investigate the biological efficiency of producing meat during the feedlot period of growth, various relationships were considered to have importance. These included the relationships between liveweight and age, liveweight gained on trial and cumulative feed, carcass muscle and liveweight, and carcass muscle and cumulative feed as outlined by Jones et al. (1981). Treatment effects (roughage level, sex-type) were evaluated by comparison of the regression coefficients obtained from a least squares analysis of covariance. Least squares analysis of covariance was used to calculate individual regression coefficients for each roughage-sex group (Gujarati 1970; Mehlenbacher, unpublished). In all analyses, residual mean square was used as error. Treatment means were then compared after adjusting to the mean of the covariate. Differences among adjusted means were tested for significance using the Student-Newman-Keuls test (Steel and Torrie 1960) using a technique to adjust for the unequal subclass numbers.

RESULTS

The relationships between liveweight and age are shown in Table 1. Average daily gains were highest for animals fed the 20% roughage diet and lowest for animals fed the 80% roughage diet within sex-type. The 50% roughage diets produced intermediate results in both steers and bulls. Bulls grew faster than steers at each roughage level and there was no significant roughage level × castration interaction. When the liveweights were adjusted to a constant age of 475 days, large differences were manifest among roughage levels and between sexes. This amounted to a difference of 51 kg in favor of bulls on low versus high roughage diets and to a difference of 31 kg for the same comparison in steers .

The relationships between liveweight gained on trials and feed intake expressed in energy terms are presented in Table 2. Response per unit of feed energy was highest for animals fed the 20% roughage diets and lowest for animals fed the 80% roughage diet within sex. The 50% roughage diets produced intermediate results in both bulls and steers. Bulls had a higher response per unit of feed energy input than steers for each roughage level, and there was no evidence of a significant roughage level × castration interaction. When the liveweight gained on trial data were adjusted to a constant amount of feed energy (13 548 MJ DE) large differences existed among roughage levels and between sex-types. This amounted to a difference of 44 kg in favor of bulls on low roughage diets and to a difference of 31 kg for the same comparison in steers.

The relationship between carcass muscle content and liveweight is shown in Table 3. There were no treatment differences ($P > 0.05$) in the amount of muscle relative to liveweight. Bulls fed the 50% roughage diet had the highest value for muscle gain per kilogram liveweight and steers fed the 20 and 50% roughage diets the lowest. The weights of muscle adjusted to a constant liveweight (514 kg) are also shown in Table 3. At 514 kg, the three roughage diets produced no significant differences ($P > 0.05$) in carcass muscle when the comparison was made within sex-type. Bulls produced more carcass

Table 1. Regressions of liveweight on age and the means of liveweight adjusted to a constant animal age (475 days)

	Bulls			Steers		
Roughage level	20%	50%	80%	20%	50%	80%
n	12	12	12	11	12	12
Regression coefficient (kg/day)	1.65*a*±0.07	1.44*ab*±0.06	1.15*c*±0.04	1.35*bc*±0.06	0.96*d*±0.03	0.92*d*±0.03
Liveweight means (kg)	469*a*±5	441*b*±4	418*c*±3	418*c*±4	390*d*±3	387*d*±3

*a-d*Means or regression coefficients that do not have a common letter differ significantly ($P < 0.05$).

Table 2. Gain per unit of feed energy and the means of liveweight gained on the trial adjusted to a constant energy intake (13 548 MJ DE)

	Bulls			Steers		
Roughage level	20%	50%	80%	20%	50%	80%
Regression coefficient (kg/100 MJ DE)	1.50*a*±0.04	1.32*b*±0.03	1.18*c*±0.02	1.23*bc*±0.03	1.02*d*±0.02	0.97*d*±0.02
Liveweight gained on trial (kg)	204*a*±2	179*b*±2	160*c*±2	167*c*±2	139*d*±1	132*d*±1

*a–d*Means or regression coefficients that do not have a common letter differ significantly ($P < 0.05$).

Table 3. Muscle† per kilogram liveweight and muscle weight adjusted to a constant liveweight (514 kg)

	Bulls			Steers		
Roughage level	20%	50%	80%	20%	50%	80%
Regression coefficient (kg muscle/kg liveweight)	0.32*a*±0.11	0.54*a*±0.11	0.33*a*±0.07	0.26*a*±0.15	0.26*a*±0.08	0.29*a*±0.07
Muscle weight (kg)	187.5*a*±3.6	194.4*a*±3.6	184.8*ab*±3.6	173.9*bc*±3.8	172.9*c*±3.6	171.8*c*±3.6

†Carcass muscle weight was estimated from 2 × side muscle weight predicted from sample muscle weights (Jones et al. 1978).
*a–c*Means or regression coefficients that do not have a common letter differ significantly ($P < 0.05$).

muscle than steers at a constant liveweight.

The relationship between carcass muscle content and feed intake on an energy basis is presented in Table 4. Animals fed the 20% roughage diet produced more muscle than animals fed the 50 and 80% roughage diets per unit of feed energy, when the comparisons were made within sex-type. Bulls tended to have a greater weight of muscle produced than steers for a unit of feed energy, but the comparisons were not significantly different. At a constant energy intake, bulls fed the 20% roughage diet produced 10.2 kg more carcass muscle than bulls fed the 50% roughage diet, which in turn produced 6.4 kg more carcass muscle than steers fed the 80% roughage diet. Bulls consistently produced a larger amount of carcass muscle than steers for the same amount of feed energy.

DISCUSSION

The relationship observed in this experiment have shown that average daily gains were highest for animals fed diets with low inclusions of roughage. This would essentially agree with other results (Agriculture Canada 1971; Price et al. 1978, 1980). However, the design and analysis employed also allowed examination of liveweight at any chosen age covered in the experiment. The arithmetic mean of the covariate (age) was considered an appropriate endpoint for the comparison of treatment differences. Thus, bulls fed the low roughage diets (20%) were 12% heavier than

Table 4. Muscle† per unit of digestible energy and muscle weights adjusted to a constant energy intake (24 148 MJ DE)

	Bulls			Steers		
Roughage level	20%	50%	80%	20%	50%	80%
Regression coefficient (kg muscle/100 MJ DE)	0.32*a*±0.04	0.17*bc*±0.03	0.17*bc*±0.03	0.26*ab*±0.04	0.08*bc*±0.03	0.08*bc*±0.02
Muscle weight (kg)	115.1*a*±3.8	104.9*a*±3.3	88.3*b*±2.9	91.8*b*±3.1	82.1*bc*±3.2	75.7*cd*±3.3

†Carcass muscle weight was estimated from 2 × side muscle weight predicted from sample muscle weights (Jones et al. 1978).
*a–d*Means or regression coefficients that do not have a common letter differ significantly ($P < 0.05$).

bulls fed high roughage diets (80%) at a constant age. Similarly, steers fed low roughage diets (20%) were 8% heavier than steers fed high roughage diets (80%) at a constant age. As a whole, bulls were 11% heavier than steers at a constant age for this experiment.

The liveweight response per unit of feed energy was highest for animals fed the 20% roughage diet for both bulls and steers. Thus, animals that grew the fastest were the most efficient, which would agree with other results (Preston and Willis 1974; Levy et al. 1974). Efficiency of feed utilization is generally considered to be controlled by two factors. One is the feed requirement for maintenance, and the other is the feed cost and composition of the liveweight gain (Boaz et al. 1974). In this experiment the efficiency of the animals fed the 20% roughage diet must have been only marginally offset by the composition of their gain, and more dependent on their quicker rate of growth in the feedlot. When the results were evaluated for a constant feed energy input, the higher regression coefficients associated with the feeding of low roughage diets were, as expected, linked with the highest amount of liveweight gained on trial. Thus, bulls fed the low roughage diet (20%) gained 27% more liveweight than bulls fed the high roughage diet (80%) for a constant feed energy input. Similarly, steers fed the low roughage diet (20%) gained 26% more liveweight than steers fed the high roughage diet (80%) for a constant feed energy input. Bulls gained 24% more liveweight than steers for a constant amount of feed energy in this experiment with no evidence of any sex × roughage level interaction. These results are essentially the same as those found by Price et al. (1978, 1980).

The relationships between liveweight and muscle showed large variation in the computed regression coefficients, but no statistically significant difference was found. Further work would provide a better estimate of the relationship between liveweight and muscle. The values were similar to those reported by Jones et al. (1980), and lower than those found by Berg et al. (1978). Muscle weight at a constant liveweight showed no differences among roughage levels, when the comparison was made within sex. These results would support the 'homeomyosis hypothesis' suggested by Price (1977). Briefly, the basis of this hypothesis is that muscle bulk is maintained at a genetically determined allometric relationship with liveweight (muscle weight is often predicted as being one-third liveweight). The animals fed the 80% roughage diet were undoubtedly leaner than those fed the 20% roughage diet (Price et al. 1980). When the analysis was conducted at constant liveweight, dressing percentage was also taken into account with the result that gutfill would be larger, and empty body weight lower in animals fed the 80% roughage diet. Price (1977) suggested as part of the 'homeomyosis hypothesis' that the weight of any group of muscles will depend on the weight of the part of the body it has to support. In other words, there were only small differences in carcass muscle between animals fed different levels of roughage since the load the musculature had to support was essentially the same on all treatments at a constant liveweight. Bulls produced more muscle than steers on all the diets, so other factors such as hormones may also affect these relationships (Butterfield and Berg 1072). Muscle weight at a constant liveweight has been proposed as a net index for beef production (Berg et al. 1978) as it combines dressing percentage and lean meat yield into one figure.

There are few reports in the literature on the energy costs of muscle production under feedlot conditions. Precise measurements have been made on individual animals (Webster 1976), but these have been collected mainly to estimate the energy cost of maintenance and production. The results of this study showed rates of muscle gain per unit of feed energy similar to those reported by Jones et al. (1981). Muscle per unit of feed energy declined with increasing roughage level, with higher values for bulls than steers. Consequently, for a common energy intake, animals fed different levels of dietary roughage differed widely in the amount of muscle produced. Bulls fed the 20% roughage diet produced 30% more muscle than bulls fed the 80% roughage diet for the same intake of digestible energy. Similarly, steers fed the low roughage diet produced 21% more muscle than steers fed the high roughage diets. Overall, bulls produced 23% more muscle than steers for a constant energy input. These figures illustrate the importance of high average daily gain, and the feeding of high energy diets to maximize energetic efficiency of muscle gain in beef production.

This trial was mainly set up to study the effects of dietary roughage in the feedlot for beef cattle. While it has been shown that is it quite possible to produce carcasses in the A grade (Price et al. 1980) by feeding high levels of dietary roughage, this study indicates that this will be associated with a large increase in the energy cost of muscle production. In the field this means that the price differential has to be large between grain energy and roughage energy to warrant using high levels of roughage in feedlot diets.

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