

## Effects of pasture and high-concentrate diets on the performance of beef cattle, carcass composition at equal growth rates, and the fatty acid composition of beef

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*ad libitum*. Gains in lean meat were similar for animals finished at pasture and those given concentrates *ad libitum*, whereas daily fat gains were 39% lower for the animals finished at pasture ( $P < 0.001$ ). At an equal rate of carcass gain, animals finished at pasture produced carcasses with a higher lean content ( $P = 0.03$ ) and a lower fat content ( $P = 0.03$ ) than those produced from the high-concentrate diet. Muscle from pasture-finished cattle had higher concentrations of omega-3 polyunsaturated fatty acids (PUFA) ( $141$  versus  $49 \pm 8.2$  mg  $100$  g<sup>-1</sup> muscle) and long-chain omega-3 PUFA ( $58$  versus  $27 \pm 3.8$  mg  $100$  g<sup>-1</sup> muscle) than muscle from concentrate-fed cattle. These results highlight the potential of high quality ryegrass pasture for finishing cattle, and meat from pasture-finished cattle as a source of omega-3 PUFA.

**Keywords** beef cattle; pasture; concentrate diets; omega-3 fatty acids

**Abstract** Two experiments were carried out to examine the effects of high quality pasture and high-concentrate diets on liveweight and carcass gain of beef cattle, carcass composition at equal carcass gain, and the fatty acid composition of beef. Heifers of late-maturing breed type (406 kg initial liveweight; Experiment 1) and steers of late-maturing breed type (460 kg initial liveweight; Experiment 2) were finished on a ryegrass pasture or a high-concentrate diet at either (1) *ad libitum*, (2) 85% of *ad libitum* intake or (3) 70% of *ad libitum* intake. The high-concentrate diet consisted of 95% barley-based concentrate and 5% barley straw. Carcass gain of the animals finished at pasture ( $648$  g day<sup>-1</sup>) was 0.78 in Experiment 1 ( $P < 0.001$ ) and 0.88 in Experiment 2 ( $P > 0.1$ ) of that of the animals given the high-concentrate diet

## INTRODUCTION

Pasture-based systems of beef production are now considered to be more environmentally beneficial and provide better animal welfare and health with less dependence on antibiotics, and hence are socially more acceptable than more intensive grain-based systems (Cheeke 1999; Meyer & Mullinax 1999; Subak 1999). However, comparisons of pasture and high-concentrate diets have generally involved pasture species of medium digestibility which have sustained low liveweight gains relative to those achieved with high-concentrate diets, and the cattle finished at pasture have produced carcasses with a low fat content (Bidner et al. 1981, 1986; Williams et al. 1983). Consequently, it is difficult to ascertain the extent to which the low fat content has been due to lower growth rate or to forage rather than grain in the diet *per se*. Pasture-finished cattle may also produce beef with a more desirable fatty acid composition in terms of its effect on human health, especially in relation to the

content of omega-3 ( $\omega$ 3) polyunsaturated fatty acids (PUFA) (Sinclair & O'Dea 1990). There is now widespread evidence that high intakes of  $\omega$ 3 PUFA have several beneficial effects on human health (Kinsella et al. 1990; Weber & Leaf 1991; Grimble 1998). Two experiments have been carried out to evaluate high quality ryegrass pasture for finishing beef cattle relative to high-concentrate diets in terms of carcass and lean growth rates and to examine the effects of high quality pasture and high-concentrate diets on carcass composition at equal growth rates and on the fatty acid composition of beef.

## MATERIALS AND METHODS

### Treatments and diets

In each of two experiments, animals received a diet of (1) 95% cereal-based concentrate and 5% chopped barley straw, *ad libitum*; (2) an intake of 85% of diet 1; (3) an intake of 70% of diet 1; (4) ryegrass pasture. The aim of the three levels of intake of the high-concentrate diet was to produce a response relationship to the level of dry matter intake (DMI), so that the carcass composition of the animals on the high-concentrate diet and those at pasture could be compared at an equal level of animal performance. This approach was adopted rather than attempting to maintain equal growth rates for the two types of diet, because it was considered that potential differences in gut fill between the diets and the variation in recorded liveweight gain (LWG) of the animals at pasture would greatly limit the possibility of achieving equal rates of carcass gain for the two diets.

The concentrate used consisted of 196 g citrus pulp, 98 g ground maize, 20 g minerals and vitamins, and, in Experiment 1, 510 g moist, propionic acid-treated rolled barley and 176 g extracted soyabean meal  $\text{kg}^{-1}$  DM, or in Experiment 2, 539 g barley and 147 g soyabean meal  $\text{kg}^{-1}$  DM. Concentrates and straw were offered once daily at 0900 h. Animals that received the diet *ad libitum* were given sufficient quantities to allow a daily refusal of approximately 50 g  $\text{kg}^{-1}$  intake. The quantity of food given to the animals on the two treatments with restricted intake was adjusted weekly to the desired intake, based on the intake of the *ad libitum*-fed animals in the previous week.

The animals on the pasture treatment in both experiments continuously grazed a perennial ryegrass sward containing the medium to late

heading cultivars 'Talbot', 'Magella', 'Menna', and 'Morene', at a target sward surface height of 10 cm. The sward had been grazed by sheep in April, prior to Experiment 1. The cattle were initially stocked at 7 animals  $\text{ha}^{-1}$ , and stocking rate was progressively reduced during the grazing season by increasing the grazing area through the inclusion of silage aftermaths in order to maintain the target sward height. Sward heights were measured fortnightly as described by Steen (1994). The grazing area received 250 kg of nitrogen  $\text{ha}^{-1}$  in five equal dressings between March and August in each experiment.

### Animals and management

Fifty heifers, ( $406 \pm 4.2$  kg initial liveweight) crosses of the continental beef breeds (mainly Charolais crosses) were used in Experiment 1. They were purchased approximately 2 months prior to the experiment and were given medium digestibility grass silage *ad libitum* during this pre-experimental standardisation period. At the beginning of the experiment they were divided into five groups of 10 animals according to liveweight. One animal from each group was slaughtered initially, to provide an estimate of the initial carcass weight and composition of the remaining animals. Three animals were chosen at random from within each of the five groups and allocated to the pasture treatment. Two of the six remaining animals in each group were allocated at random to each of the three high-concentrate diets. The animals on the pasture treatment were immediately turned out to pasture on 10 May, while those on the high-concentrate diets were housed in slatted floor pens at a stocking density of 2.5  $\text{m}^2$  per animal and were individually fed through electronically operated Calan doors (American Calan Inc, USA).

Sixty-five steers, ( $460 \pm 4.5$  kg initial liveweight), crosses of the continental beef breeds, were used in Experiment 2. They were purchased approximately 7 months before the experiment and for a 2-month standardisation period prior to the experiment they were given high-digestibility grass silage (80% of DMI) and artificially dried grass (20% of DMI). At the beginning of the experiment, they were divided into five groups of 13 animals according to liveweight. One animal from each group was slaughtered initially. The remaining 12 animals in each group were further divided into two groups of six animals according to liveweight. From each of the 10 subgroups, two animals were allocated at random to each of the pasture treatment

and the high-concentrate diet offered at 70% of *ad libitum* intake, and one animal to each of the other two high-concentrate diets. The animals on the pasture treatment were immediately turned out to pasture on 10 April, while those on the three high-concentrate diets were housed and fed as described for Experiment 1. Although animals of the individual breed crosses could not be identified with certainty, on the basis of the information which was available, there was a similar representation of breed crosses on each treatment in both experiments. The animals used in both experiments, except the pre-experimental slaughter groups, were treated for internal and external parasites. The diet treatments were imposed for 127 and 140 days in Experiments 1 and 2, respectively, and the animals were slaughtered in a commercial abattoir at the end of the experiments.

### Measurements

Quantities of concentrates and straw offered were recorded daily and refusals were removed and recorded twice per week. Concentrates and straw were sampled daily for determination of oven DM concentration and dried samples were composited weekly for determination of nitrogen, acid detergent fibre (ADF), neutral detergent fibre (NDF), and ash concentrations (Table 1). Approximately 20 subsamples of grass, which were designed to be as representative as possible of the grass consumed by the cattle, were plucked twice per week from the area grazed by the animals on the pasture treatment, and were bulked on each occasion to form a composite sample for determination of nitrogen, ADF, NDF, ash, and water-soluble carbohydrate concentrations (Table 1). Methods of chemical analyses of feeds were as described by Steen (1989).

The animals were weighed, without restriction

of food or water, on 2 consecutive days immediately before the treatments were imposed and prior to slaughter, and LWG was calculated by difference using the mean of the two values. They were also weighed every 2 weeks during the experiments to monitor performance. After slaughter the omental, mesenteric, perinephric, and retroperitoneal fats (non-carcass fats) in each animal were removed and weighed. Perinephric and retroperitoneal fats were not included in carcass weights. The carcasses were graded visually for fatness using the 5-point scale of the European Carcass Classification Scheme. After chilling they were divided between the 10th and 11th ribs and the depth of subcutaneous fat at points located at 0.25, 0.50, and 0.75 across the maximum width of the *m. longissimus* muscle, the amount of marbling fat in the surface of the *m. longissimus*, and the area of the *m. longissimus* were determined as described by Steen & Kilpatrick (1995). The fore-rib joint from the left side of each carcass (which was removed without trimming as described by Kempster et al. (1980)) was dissected into separable lean, separable fat, and bone using the method described by Cuthbertson et al. (1972). The composition of the carcass of each animal was estimated from the composition of its fore-rib joint using the equations given by Steen & Robson (1995).

Relationships between liveweight (LW) and weight of carcass (CW), lean, fat, and bone for the animals slaughtered initially were developed using least squares regression analysis, to estimate the initial weight of carcass and tissues in the animals used in the feeding experiment. However, with the exception of the relationship for carcass weight in Experiment 2, these relationships were not significant and so the mean contents of carcass (Experiment 1 only), lean, fat, and bone in the liveweight of the initial slaughter groups were used

**Table 1** Chemical composition of foods (g kg<sup>-1</sup>).

	Experiment 1			Experiment 2		
	Concentrate	Straw	Grass	Concentrate	Straw	Grass
Dry matter	859	848		853	857	
Composition of dry matter						
Crude protein	167	34	236	157	37	226
Neutral detergent fibre	192	859	495	197	871	587
Acid detergent fibre	91	525	227	97	551	240
Ash	60	64	86	59	37	92
Water-soluble carbohydrate			152			141

to estimate the initial weights of tissues in the animals used in the feeding experiment. The relationship used to estimate CW from LW in Experiment 2 was:

$$\text{CW (kg)} = 0.644 (\text{SE } 0.163) \text{ LW} - 44.5 (\text{SE } 75.5) \\ (R^2 = 0.78; P = 0.029)$$

The estimated initial weights of carcasses and tissues in each experiment were used to calculate carcass, lean, fat, and bone gains for each animal used in the corresponding feeding experiment.

The left side of the carcasses from the animals slaughtered initially and from 40% of the carcasses from each treatment in Experiment 1 (i.e., 4, 4, 4, and 6 from Treatments 1 to 4, respectively) and 30% from each treatment in Experiment 2 (i.e., 3, 3, 6, and 6 from Treatments 1 to 4, respectively) were selected as being representative in terms of fatness

of all of the carcasses from each treatment on the basis of their carcass fat classification. Within each treatment, the number of carcasses chosen from each fat class was in proportion to the total number of carcasses in each fat class. Then, within each fat class and treatment, carcasses were selected at random. The selected carcasses were stored at  $-20^\circ\text{C}$ , sawn into pieces, the frozen tissues from the dissected rib-joint from each side were returned to the remainder of the side, and the total side was put through a shredder and a mincer in the frozen state. The minced material was sampled for chemical analyses as described by Steen et al. (1998), except that three separate composite samples were taken from each of the fore and hind quarters.

During the commercial dissection of the

**Table 2** Food intake, animal performance and carcass assessments for heifers (Experiment 1). AL, *ad libitum*; subcutaneous fat depth, average fat depth (mm) at three points over the *m. longissimus* muscle; marbling score, 8-point scale, 1 = leanest, 8 = fattest; carcass fat classification, 5-point scale, 1 = leanest, 5 = fattest.

Intake level:	Diet				SEM		P
	High-concentrate			Pasture	n = 10	n = 15	
	AL n = 10	85% AL n = 10	70% AL n = 10	AL n = 15			
Dry matter intake (kg day <sup>-1</sup> )	9.0	8.0	7.0	–	0.08	0.07	<0.001
Initial liveweight (kg)	403	406	406	406	8.8	7.2	1.00
Final liveweight (kg)	561	565	531	529	6.7	5.5	<0.001
Liveweight gain (g day <sup>-1</sup> )	1245	1253	986	969	59.4	48.5	<0.001
Cold carcass weight (kg)	316	314	297	294	3.9	3.2	<0.001
Carcass weight (g kg <sup>-1</sup> liveweight)	564	557	561	555	6.1	5.0	0.72
Carcass gain (g day <sup>-1</sup> )	831	808	676	647	34.1	27.9	<0.001
Lean gain (g day <sup>-1</sup> )	446	448	368	383	30.9	25.2	0.14
Fat gain (g day <sup>-1</sup> )	332	290	258	190	18.8	15.3	<0.001
Bone gain (g day <sup>-1</sup> )	65	74	56	72	5.7	4.6	0.11
Subcutaneous fat depth (mm)	8.9	7.8	7.9	6.5	0.64	0.52	0.04
Marbling score	3.0	2.6	2.6	2.2	0.21	0.17	0.04
Area of <i>m. longissimus</i> (cm <sup>2</sup> )	68.4	71.9	70.5	65.6	2.5	2.1	0.24
Carcass fat classification	3.9	3.7	3.6	3.5	0.15	0.12	0.25
Non-carcass fat (kg)	42.1	37.5	35.0	28.0	1.51	1.23	<0.001
Composition of fore-rib joint (g kg <sup>-1</sup> )							
Separable lean	601	609	615	633	10.7	8.7	0.13
Separable fat	270	251	250	212	11.6	9.5	0.002
Bone	129	139	137	155	4.1	3.3	<0.001
Estimated carcass composition (g kg <sup>-1</sup> )							
Lean	631	638	640	654	6.6	5.4	0.05
Fat	229	216	214	187	7.4	6.1	<0.001
Bone	138	142	142	151	2.0	1.6	<0.001
Chemical composition of carcass (g kg <sup>-1</sup> )							
Water	525	534	543	548	14.3	11.7	0.61
Protein	186	187	191	195	3.9	3.2	0.33
Lipid	228	228	209	201	17.3	14.2	0.55
Ash	55	54	53	57	1.9	1.5	0.29

carcasses, 100-g samples of muscle were taken from the *m. gluteobiceps*, *m. semimembranosus*, and *m. deltoideus* muscles in the left side of each carcass and stored at  $-20^{\circ}\text{C}$  until required for chemical analyses. Prior to chemical analyses, samples of muscle and carcasses were homogenised in a commercial food blender. Total lipid concentrations were determined in duplicate by the method of Bligh & Dyer (1959). Oven DM concentrations of tissues were determined on 5-g samples in triplicate by drying at  $102 \pm 2^{\circ}\text{C}$  for 48 h in a forced-air oven. Ash concentrations were determined on the residue of the dried samples by dry ashing at  $600^{\circ}\text{C}$  for 8 h. Crude protein concentrations were determined in triplicate by the Kjeldahl method using selenium as a catalyst, a salt/acid ratio of 0.7:1, and a conversion factor for nitrogen to crude protein of

6.25. Lipids were extracted with a 2:1 (V:V) chloroform:methanol mixture. After saponification with methanolic sodium hydroxide and esterification with boron trifluoride, the concentrations of individual fatty acids, within the range  $\text{C}_{14}$ – $\text{C}_{24}$  were determined as their methyl esters by gas liquid chromatography on a Varian 3600 instrument fitted with a  $50 \text{ m} \times 0.33 \text{ mm}$  i.d. open tubular fused silica column coated with BPX70 (70% cyanopropyl siloxane) at a thickness of  $0.25 \mu\text{m}$  (SGE (UK) Ltd). A  $1\text{-}\mu\text{l}$  sample was injected at a split ratio of 50:1 with a 48 position autosampler at an initial column temperature of  $140^{\circ}\text{C}$ , followed by ramping at  $2^{\circ}\text{C min}^{-1}$  to  $220^{\circ}\text{C}$  for 15 min, giving a total run time of 55 min. Injector and flame ionisation detector temperatures were both  $250^{\circ}\text{C}$  and helium was used as a carrier gas.

**Table 3** Food intake, animal performance and carcass assessments for steers (Experiment 2). AL, *ad libitum*; subcutaneous fat depth, average fat depth (mm) at three points over the *m. longissimus* muscle; marbling score, 8-point scale, 1 = leanest, 8 = fattest; carcass fat classification, 5-point scale, 1 = leanest, 5 = fattest.

Intake level:	Diet				SEM		P
	High-concentrate			Pasture	n = 10	n = 20	
	AL n = 10	85% AL n = 10	70% AL n = 20	AL n = 20			
Dry matter intake ( $\text{kg day}^{-1}$ )	8.9	7.4	6.3	–	0.08	0.05	<0.001
Initial liveweight (kg)	460	459	460	460	10.6	7.5	1.00
Final liveweight (kg)	632	619	575	613	7.7	5.4	<0.001
Liveweight gain ( $\text{g day}^{-1}$ )	1237	1148	822	1100	57.5	40.7	<0.001
Cold carcass weight (kg)	355	341	317	342	5.4	4.1	<0.001
Carcass weight ( $\text{g kg}^{-1}$ liveweight)	563	551	552	559	7.2	5.1	0.51
Carcass gain ( $\text{g day}^{-1}$ )	739	634	461	648	40.4	28.5	<0.001
Lean gain ( $\text{g day}^{-1}$ )	367	315	251	373	41.6	29.4	0.03
Fat gain ( $\text{g day}^{-1}$ )	281	234	129	182	17.6	12.4	<0.001
Bone gain ( $\text{g day}^{-1}$ )	76	72	62	70	7.6	5.4	0.42
Subcutaneous fat depth (mm)	8.3	9.3	7.2	7.8	0.92	0.65	0.32
Marbling score	2.6	2.8	2.2	2.3	0.20	0.14	0.04
Area of <i>m. longissimus</i> ( $\text{cm}^2$ )	72.8	67.6	66.9	73.2	2.8	2.0	0.09
Carcass fat classification	3.4	3.5	3.1	3.4	0.15	0.11	0.12
Non-carcass fat (kg)	46.5	36.0	28.6	34.1	1.95	1.38	<0.001
Composition of fore-rib joint ( $\text{g kg}^{-1}$ )							
Separable lean	579	588	612	622	13.6	9.6	0.07
Separable fat	265	253	212	220	11.8	8.3	<0.001
Bone	156	159	176	159	6.6	4.6	0.03
Estimated carcass composition ( $\text{g kg}^{-1}$ )							
Lean	617	624	642	645	8.2	5.8	0.02
Fat	229	218	189	197	7.3	5.2	<0.001
Bone	143	148	155	147	3.1	2.2	0.01
Chemical composition of carcass ( $\text{g kg}^{-1}$ )							
Water	538	571	583	585	7.6	5.4	<0.001
Protein	178	184	191	193	2.7	1.9	0.003
Lipid	220	194	170	177	7.4	5.2	<0.001
Ash	55	51	55	55	2.6	1.9	0.60

### Statistical analyses

Animal and carcass data from each experiment were analysed by analysis of covariance (ANCOVA) using initial liveweight as a covariate. Data on the chemical composition of meat were analysed by analysis of variance (ANOVA), as the inclusion of initial liveweight as a covariate tended to increase the standard errors and *P* values for these data. One animal was removed from the *ad libitum* high-concentrate treatment in Experiment 1 because it became lame after 9 weeks on the diet. Data for this animal were excluded from all statistical analyses. The carcass composition of the animals which were at pasture or given a high-concentrate diet was also compared when the data were adjusted to an equal rate of carcass gain. The procedure was as follows. (1) A least squares linear regression relationship between carcass gain and DMI was produced for the animals on the three concentrate treatments. Tests were also made for curvilinear relationships with DMI, but these proved non-significant, and so the linear relationships were used. (2) From this the DMI of the high-concentrate diet required to sustain a carcass gain equivalent to that obtained for the grazing treatment (648 g day<sup>-1</sup>) was estimated. (3) Further relationships were developed between each of the carcass parameters and DMI for the three concentrate treatments. (4) From these, values for the various carcass parameters were predicted for the concentrate-fed

animals at the estimated DMI from (2) above. (5) Differences between these predicted values for the concentrate-fed animals and the actual values for the pastured animals were then tested for statistical significance using a paired *t*-test for the heifers and steers separately and for the combined data. Although carcass growth rate for the animals at pasture was similar to that of the 70% of *ad libitum* concentrate diet in Experiment 1, and the 85% of *ad libitum* in Experiment 2, comparison between the pasture and concentrate treatments using the regression procedure generally gave a much stronger statistical comparison than comparison of the pasture treatment with individual concentrate treatments. A similar procedure was used to compare the fatty acid composition of muscle from concentrate-fed and pastured animals, except that data for the concentrate-fed animals were adjusted to the same total lipid content in the muscle as those obtained for the pastured animals.

### RESULTS

Reducing the food intake of the concentrate-fed animals from *ad libitum* to 70% of *ad libitum* reduced (*P* < 0.001) LWG and carcass gain in both experiments. The LWG and carcass gain of the animals at pasture were significantly lower than those of cattle given the high-concentrate diet *ad*

**Table 4** Effect of diet on carcass composition and tissue gains at equal carcass gain (648 g day<sup>-1</sup>). Subcutaneous fat depth, average fat depth (mm) at three points over the *m. longissimus* muscle; marbling score, 8-point scale, 1 = leanest, 8 = fattest.

Diet	Experiment 1 (heifers)				Experiment 2 (Steers)				Combined Experiments 1 and 2	
	High-concentrate	Pasture	SED	<i>P</i>	High-concentrate	Pasture	SED	<i>P</i>	SED	<i>P</i>
Subcutaneous fat depth (mm)	7.4	6.5	0.68	0.23	8.3	7.8	0.67	0.43	0.53	0.20
Marbling score	2.5	2.2	0.21	0.13	2.6	2.3	0.20	0.25	0.14	0.06
Area of <i>m. longissimus</i> (cm <sup>2</sup> )	69.1	65.6	2.53	0.18	69.2	73.2	2.04	0.07	1.69	0.68
Non-carcass fat (kg)	31.2	28.0	2.87	0.52	39.0	34.1	2.64	0.08	1.93	0.07
Estimated carcass composition										
Lean (g kg <sup>-1</sup> )	647	655	9.0	0.43	625	645	8.5	0.04	6.2	0.03
Fat (g kg <sup>-1</sup> )	204	187	11.4	0.19	217	197	9.8	0.08	7.3	0.03
Bone (g kg <sup>-1</sup> )	145	151	2.3	0.02	147	147	2.4	0.66	1.7	0.25
Lean gain (g day <sup>-1</sup> )	368	383	23.9	0.57	327	373	24.3	0.06	17.2	0.06
Fat gain (g day <sup>-1</sup> )	227	190	29.9	0.25	233	182	26.9	0.10	19.7	0.04
Bone gain (g day <sup>-1</sup> )	58	72	5.8	0.04	73	70	5.7	0.68	4.2	0.26
Composition of muscle										
Dry matter (g kg <sup>-1</sup> )	260	259	3.7	0.70	255	253	2.8	0.42	2.2	0.39
Protein (g kg <sup>-1</sup> )	212	215	0.30	0.24	215	219	0.39	0.13	0.25	0.05
Lipid (g kg <sup>-1</sup> )	39	39	4.2	0.90	30	27	2.9	0.31	2.4	0.53

*libitum* in Experiment 1 (Table 2), but not in Experiment 2 (Table 3).

In Experiment 1, the animals finished at pasture produced carcasses with a lower fat content than those produced from the high-concentrate diet offered *ad libitum*, as indicated by subcutaneous fat depth ( $P < 0.01$ ), marbling score ( $P < 0.01$ ), and the estimated lean ( $P < 0.05$ ) and fat ( $P < 0.001$ ) contents in the carcasses. The carcasses of the animals which were finished at pasture in Experiment 2 had a higher estimated lean content ( $P < 0.01$ ) and a lower estimated fat content ( $P < 0.001$ ) than those given concentrates *ad libitum*. The higher estimated lean content in the carcasses of the pastured cattle resulted in estimated gains in lean meat being similar ( $P > 0.1$ ) for the animals finished at pasture and those given the high-concentrate diet *ad libitum*, the former being 94% of the latter on average over the two experiments. However, daily gains in separable fat were much lower for the animals at pasture in both experiments ( $P < 0.001$ ), being 57 and 65% of those for the high-concentrate diet offered *ad libitum* in Experiments 1 and 2, respectively.

When pasture and the high-concentrate diet were compared using data from the two experiments, adjusted to an equal rate of carcass gain (Table 4), pastured animals still produced carcasses with a higher lean and lower fat content ( $P = 0.03$ ) than those produced from the high-concentrate diet, although there was no significant difference between the diets in terms of subcutaneous fat depth, eye-muscle area, or the lipid content of the muscles. However, lean gains were higher ( $P = 0.06$ ) and fat gains were lower ( $P = 0.04$ ) for the pastured animals, which also produced less ( $P = 0.07$ ) non-carcass fat.

The carcasses which were selected from each treatment for determination of chemical composition were representative of all the carcasses for the appropriate treatment in terms of their estimated lean and fat content. For example, on average over the two experiments, the mean estimated carcass fat contents of all carcasses of the animals given concentrates or finished at pasture were 216 and 192 g kg<sup>-1</sup> respectively, while the corresponding fat contents of the carcasses selected for determination of chemical composition were 216 and 193 g kg<sup>-1</sup> respectively. However, data for the chemical composition of the carcasses (Tables 2 and 3) should be treated with caution as they are based on a limited number of replicates, as described previously. Nevertheless, differences

between the treatments in the protein and lipid contents of the carcasses followed similar trends to differences in carcass separable lean and fat contents. For example, in Experiment 2, carcasses from the pasture treatment had higher protein and water contents and a lower lipid content than those produced from the high-concentrate diet offered *ad libitum*. There were similar trends in the results of Experiment 1, but the effects were not significant. On average over the two experiments, the protein and lipid contents of the carcasses from the pasture treatment were 7% higher and 16% lower, respectively, than those of the carcasses from the animals given concentrates *ad libitum*. These are close to the differences in separable lean and fat contents for these two treatments, which were 4% higher and 16% lower, respectively, for the pasture treatment.

It was not appropriate to calculate gains in chemical constituents for individual animals because the animals for which data are available were not totally representative of all the animals on the treatments in terms of growth rate. However, an estimate of protein and lipid gains can be obtained by applying the chemical composition data given in Tables 2 and 3 to the mean carcass weights of the animals on each treatment, and using the same approach for the animals slaughtered initially, to estimate the initial weights of these constituents. This approach gives protein gains of 132, 132, 116, and 121 g day<sup>-1</sup> for Treatments 1–4, respectively, in Experiment 1 and lipid gains of 297, 293, 217, and 195 g day<sup>-1</sup> respectively, for these treatments. Corresponding values for Experiment 2 are 109, 105, 90, and 129 g day<sup>-1</sup> for protein gains and 261, 176, 88, and 136 g day<sup>-1</sup> for lipid gains. On average over the two experiments, protein gains were similar for the concentrate diet offered *ad libitum* (121 g day<sup>-1</sup>) and the pasture treatment (125 g day<sup>-1</sup>) while lipid gains for the pasture treatment were only 59% of those for the concentrate diet *ad libitum*. While these data should be treated with caution because they are based on a limited number of replicates, again, the proportional differences between the treatments are close to those for separable lean and fat as discussed above.

There were no biologically important differences between muscles in the fatty acid composition of the lipid, and so the mean composition for the three muscles has been presented (Tables 5 and 6). Total  $\omega 3$  PUFA were taken as the sum of C<sub>18:3 $\omega$ 3</sub>, C<sub>18:4 $\omega$ 3</sub>, C<sub>20:5 $\omega$ 3</sub>, C<sub>22:5 $\omega$ 3</sub>, and C<sub>22:6 $\omega$ 3</sub>, with these contributing 53, <1,

15, 29, and 3% of total  $\omega 3$  PUFA, respectively, on average across all treatments. Total  $\omega 6$  PUFA were taken as the sum of  $C_{18:2\omega 6}$ ,  $C_{18:3\omega 6}$ ,  $C_{20:3\omega 3}$ ,  $C_{20:4\omega 6}$ , and  $C_{22:4\omega 6}$ , with these contributing 78, 1, 0, 20, and 1% of the total  $\omega 6$  PUFA, respectively. When the data were adjusted to a constant lipid content in the muscle (Table 6), there was no significant difference between the pasture- and high-concentrate treatments in terms of the concentration of saturated fatty acids (SFA). However, compared with the high-concentrate diets, muscle from the cattle finished at pasture had a lower concentration of monounsaturated fatty acids (MUFA) in Experiment 1, and a higher concentration of PUFA when the data for the two

experiments were combined. The contents of total  $\omega 3$  PUFA and long-chain  $\omega 3$  PUFA ( $C_{20}$  and  $C_{22}$ ) in lipids were higher ( $P < 0.001$ ) for the pasture-finished than for the concentrate-finished cattle, whereas the concentration of  $\omega 6$  PUFA was lower ( $P < 0.001$ ) for the pasture treatment (Table 6). Consequently, the ratio of  $\omega 6:\omega 3$  PUFA in lipids was lower ( $P < 0.001$ ) for the pasture treatment.

## DISCUSSION

The chemical composition of the concentrates used in both experiments is typical of rations produced from barley, soyabean meal, citrus pulp, and maize

**Table 5** Effect of diet on the chemical composition of muscle (mean values for *m. deltoideus*, *m. semimembranosus*, and *m. gluteobiceps*) (g kg<sup>-1</sup> muscle unless otherwise stated). AL, *ad libitum*; SFA, total saturated fatty acids; MUFA, total monounsaturated fatty acids; PUFA, total polyunsaturated fatty acids; total  $\omega 3$  PUFA,  $C_{18:3\omega 3} + C_{18:4\omega 3} + C_{20:5\omega 3} + C_{22:5\omega 3} + C_{22:6\omega 3}$ ; total  $\omega 6$  PUFA,  $C_{18:2\omega 6} + C_{18:3\omega 6} + C_{20:3\omega 6} + C_{20:4\omega 6} + C_{22:4\omega 6}$ ; long-chain  $\omega 3$  PUFA,  $C_{20:5\omega 3} + C_{22:5\omega 3} + C_{22:6\omega 3}$ ; long-chain  $\omega 6$  PUFA,  $C_{20:3\omega 6} + C_{20:4\omega 6} + C_{22:4\omega 6}$ .

Intake level:	Diet				SEM		P
	AL	85% AL	70% AL	Pasture AL	n = 10	n = 20	
<b>Experiment 1</b>							
Dry matter (g kg <sup>-1</sup> )	270	261	261	259	4.0	3.3	0.20
Crude protein (g kg <sup>-1</sup> )	209	214	211	215	1.9	1.6	0.05
Total lipid (g kg <sup>-1</sup> )	50	37	43	39	4.3	3.5	0.15
Fatty acids (g kg <sup>-1</sup> total lipid)							
SFA	478	449	452	473	14.1	11.5	0.33
MUFA	455	472	464	429	14.4	11.7	0.10
PUFA	67	80	84	99	8.1	6.6	0.03
Total $\omega 3$ PUFA	11	12	15	37	2.5	2.1	<0.001
Total $\omega 6$ PUFA	56	69	70	62	5.9	4.8	0.33
Long-chain $\omega 3$ PUFA	6	6	8	14	1.3	1.1	<0.001
Long-chain $\omega 6$ PUFA	9	12	12	13	1.6	1.3	0.15
$\omega 6:\omega 3$ ratio	5.2	6.5	5.0	1.7	0.47	0.38	<0.001
$\omega 3$ PUFA (mg 100 g <sup>-1</sup> muscle)	53	42	59	128	5.5	4.5	<0.001
Long chain $\omega 3$ PUFA (mg 100 g <sup>-1</sup> muscle)	27	19	30	49	3.1	2.5	<0.001
<b>Experiment 2</b>							
Dry matter (g kg <sup>-1</sup> )	257	253	252	253	3.4	2.4	0.62
Crude protein (g kg <sup>-1</sup> )	216	211	216	219	3.3	2.4	0.30
Total lipid (g kg <sup>-1</sup> )	34	27	24	27	3.0	2.1	0.12
Fatty acids (g kg <sup>-1</sup> total lipid)							
SFA	418	430	449	417	8.6	6.1	0.03
MUFA	470	432	417	434	11.4	8.1	0.05
PUFA	111	138	134	148	14.0	9.9	0.22
Total $\omega 3$ PUFA	17	23	20	61	4.2	2.9	<0.001
Total $\omega 6$ PUFA	94	115	114	87	11.3	8.0	0.06
Long-chain $\omega 3$ PUFA	11	14	11	26	2.2	1.6	<0.001
Long-chain $\omega 6$ PUFA	17	24	25	23	2.9	2.0	0.11
$\omega 6:\omega 3$ ratio	6.1	5.4	6.6	1.5	0.89	0.63	<0.001
$\omega 3$ PUFA (mg 100 g <sup>-1</sup> muscle)	50	55	47	154	12.2	8.6	<0.001
Long-chain $\omega 3$ PUFA (mg 100 g <sup>-1</sup> muscle)	29	34	27	66	5.9	4.2	<0.001

grain in the proportions used, based on the protein, fibre, and ash contents of these feeds given by the Ministry of Agriculture, Fisheries, and Food (MAFF 1990). The composition of the pasture is also typical of the composition of high quality perennial ryegrass as given by MAFF (1990). The metabolisable energy (ME) content of grass (MJ kg<sup>-1</sup> DM) has been estimated as 15.9–0.019 × ADF content (g kg<sup>-1</sup> DM) (MAFF 1975, equation 61). Using this equation, the estimated ME content of the pasture in Experiments 1 and 2 was 11.5 MJ kg<sup>-1</sup> DM. This value is well within the range (9.1–13.5 MJ kg<sup>-1</sup> DM) given by MAFF (1990) for perennial ryegrass, but is somewhat higher than the values given by the National Research Council (1984) for other grass species in the early vegetative stage.

The LWG of heifers in Experiment 1 was similar to that of steers in Experiment 2 (Tables 2 and 3), in contrast to heifers normally having a lower LWG. This is likely to have been at least partly attributable to the heifers having had a lower LWG (0.6 kg day<sup>-1</sup>) during the 2 months prior to the experiment than the steers (1.1 kg day<sup>-1</sup>), and, consequently, the heifers would probably have been exhibiting some compensatory growth, while the steers are unlikely to have been exhibiting compensatory growth. The LWG of 0.97 kg day<sup>-1</sup> for heifers (Experiment 1) and 1.1 kg day<sup>-1</sup> for steers (Experiment 2) at pasture are in line with values of 1.2 kg day<sup>-1</sup> in previous studies at this institute. In those studies (Steen 1994; Steen & Kilpatrick 1998), continental cross bull

calves grazed perennial ryegrass pastures between 5 and 11 months of age, over 6 consecutive years, and the animals had also gained 1.1 kg day<sup>-1</sup> prior to the grazing season. Nevertheless, the LWG values recorded in the present studies are considerably higher than those which have generally been reported for cattle grazing other grass species (Bowling et al. 1978; Brown et al. 1979; Williams et al. 1983) or combinations of other species and ryegrass (Bidner et al. 1981, 1986; Hidiroglou et al. 1987).

In Experiments 1 and 2, carcass gains of the animals at pasture were 78 and 88% respectively, of those of the cattle given the high-concentrate diet *ad libitum*. This resulted in carcass gain for the pasture treatment being similar to that for the 70% of *ad libitum* concentrate diet in Experiment 1, and to that for the 85% of *ad libitum* concentrate diet in Experiment 2. The lower value for the pasture treatment in Experiment 1, relative to the concentrate treatments, may be at least partly attributable to an unavoidable delay of 1 month to the start of this experiment, as the nutritive value of pasture and LWG of cattle at pasture have generally been highest in spring. Furthermore, grazing conditions were poor during the first month that the animals were at pasture in Experiment 1 due to very wet weather. In a number of previous comparisons of high-concentrate diets offered *ad libitum* and pasture containing either ryegrass and other species (Bidner et al. 1981, 1986; Hidiroglou et al. 1987) or other species only (Bowling et al.

**Table 6** Effect of diet on the fatty acid composition of muscle (mean values for *m. deltoideus*, *m. semimembranosus*, and *m. gluteobiceps*; data adjusted to constant lipid content in muscle) (g kg<sup>-1</sup> lipid unless otherwise stated). SFA, total saturated fatty acids; MUFA, total monounsaturated fatty acids; PUFA, total polyunsaturated fatty acids; Total ω3 PUFA, C<sub>18:3ω3</sub> + C<sub>18:4ω3</sub> + C<sub>20:5ω3</sub> + C<sub>22:5ω3</sub> + C<sub>22:6ω3</sub>; total ω6 PUFA, C<sub>18:2ω6</sub> + C<sub>18:3ω6</sub> + C<sub>20:3ω6</sub> + C<sub>20:4ω6</sub> + C<sub>22:4ω6</sub>; long-chain ω3 PUFA, C<sub>20:5ω3</sub> + C<sub>22:5ω3</sub> + C<sub>22:6ω3</sub>; long-chain ω6 PUFA, C<sub>20:3ω6</sub> + C<sub>20:4ω6</sub> + C<sub>22:4ω6</sub>.

Diet	Experiment 1 (heifers)				Experiment 2 (Steers)				Combined Experiments 1 and 2	
	High-concentrate	Pasture	SED	P	High-concentrate	Pasture	SED	P	SED	P
SFA	455	473	10.9	0.12	436	417	6.5	0.08	6.7	0.63
MUFA	457	429	10.8	0.02	434	434	7.6	0.80	6.8	0.11
PUFA	88	99	6.8	0.13	130	148	9.6	0.08	6.1	0.02
Total ω3 PUFA	14	37	2.8	<0.001	20	61	4.3	<0.001	3.1	<0.001
Total ω6 PUFA	74	62	4.9	0.03	110	87	5.8	<0.001	4.0	<0.001
Long-chain ω3 PUFA	7	14	1.2	0.001	12	26	2.0	<0.001	1.4	<0.001
Long-chain ω6 PUFA	13	13	1.2	0.79	23	23	2.0	0.96	1.3	0.95
ω6:ω3 ratio	5.9	1.7	0.17	<0.001	6.2	1.5	0.11	<0.001	0.11	<0.001
ω3 PUFA (mg 100 g <sup>-1</sup> muscle)	49	128	6.5	<0.001	49	154	13.1	<0.001	8.2	<0.001
Long-chain ω3 PUFA (mg 100 g <sup>-1</sup> muscle)	25	49	3.3	<0.001	29	66	6.0	<0.001	3.8	<0.001

1978; Williams et al. 1983), LWG at pasture was only about 50% of that for the high-concentrate diets. Dressing percentage was also lower for the pastured animals and consequently the average proportional difference in carcass gain between the two diets was even greater than that for liveweight gain. Purchas & Davies (1974), Davies (1977), and Muir et al. (1998) reported higher LWG (78% of that for a high-concentrate diet on average) for cattle grazing perennial ryegrass/white clover pasture, but again dressing proportion was lower for the cattle at pasture and so the difference between the two diets in carcass gain was proportionally greater than for LWG. The higher LWG and carcass gains sustained by ryegrass pastures in the present studies may be at least partly attributable to the fact that sward height was controlled at a relatively high height and this maintained a continuous supply of high quality grass throughout the grazing seasons.

Although the lower fat content in the carcasses (estimated from the rib-joint dissections) of the animals finished at pasture compared with those produced from the high-concentrate diets offered *ad libitum* is in agreement with previous findings, the difference in carcass fat content between the diets is considerably smaller than that generally reported previously for comparisons involving either ryegrass pastures (Purchas & Davies 1974; Davies 1977) or other species (Bowling et al. 1978; Williams et al. 1983; Hidiroglou et al. 1987). This is most probably due to the high growth rate of the pastured animals in the present studies, especially in Experiment 2. In fact, Purchas & Davies (1974) concluded that differences in fatness between pasture and concentrate-finished cattle were likely to result from differences in LWG rather than from the difference in diet type *per se*.

Davies (1977) compared a restricted intake of a high-concentrate diet and pasture for finishing a small number of cattle and found that the rib-joints of the pastured animals contained 63 g less fat kg<sup>-1</sup> than those from the concentrate-fed cattle, compared with 26 g less fat kg<sup>-1</sup> of rib-joint in the present studies when the values for the concentrate and pasture treatments were adjusted to the same rate of carcass gain. However, while Davies (1977) reported a LWG for the cattle at pasture, only 8% lower than for the restricted concentrate-fed animals, dressing percentage and hence carcass gain were substantially lower for the cattle finished at pasture. Furthermore, Muir et al. (1998) found no significant difference in carcass subcutaneous

fat depth or the lipid content of muscle, between cattle finished at pasture and those finished on a high-concentrate diet over a relatively short finishing period, when the data were adjusted to constant carcass weight, which is in agreement with the results of the present studies.

The fact that the pasture-finished animals had a significantly lower depth of subcutaneous fat and a lower marbling score than the concentrate-fed cattle in Experiment 1, but not in Experiment 2 (Tables 2 and 3), would appear to have been entirely due to the lower growth rate of the pasture-fed relative to the concentrate-fed animals in Experiment 1 in comparison with Experiment 2. Consequently, when the data were adjusted to a constant carcass gain (Table 4), differences between the pasture and concentrate treatments for fat depth and marbling score were similar for the two experiments, and were not significant in either experiment. These results also indicate that when the growth rate of finishing cattle at pasture is close to that of concentrate-fed cattle, as in Experiment 2, marbling score and subcutaneous fat depth can be similar for cattle finished at pasture and on a concentrate diet given *ad libitum*.

The lower fat content in the carcasses of cattle finished at pasture at constant carcass gain is in contrast to results from comparisons of grass silage-based and high-concentrate diets. In most research, high-silage diets have produced slightly fatter carcasses than high-concentrate diets (e.g., Steen & Robson 1995). Davies (1977) attributed the lower fat content in pasture-finished cattle to the lower ME content of the diet, and suggested that the concentrate-fed animals would have a greater amount of glucose entering the duodenum which could increase lipogenesis. However, if this were the case then silage-fed cattle should also produce leaner carcasses. In an experiment in which steers were given the diets used in Experiment 2, mean acetate to propionate ratios in the rumen over 24-h sampling periods were 3.7 and 2.3, respectively, for pasture and the high-concentrate diet (N. P. Lavery & R. W. J. Steen unpubl. data). However, the effects of rumen acetate:propionate ratio on carcass composition have been inconsistent. Weiss et al. (1967) also found that a high acetate:propionate ratio in the rumen was associated with leaner carcasses. In contrast, Steen & Robson (1995) working with cattle and Ørskov & Allen (1966) working with lambs found that a higher acetate to propionate ratio in the rumen was associated with fatter carcasses.

Carcass composition of cattle may also be influenced by the ratio of metabolisable energy:metabolisable protein (MP) in the diet (Lindsay & Davies 1981). Intakes of MP for the animals given the high-concentrate diet at 70% of *ad libitum* in Experiment 1 and at 85% of *ad libitum* in Experiment 2 (i.e., those with LWG similar to those of the animals at pasture) were 2.2 and 2.1 times MP requirements as given by the Agricultural and Food Research Council (1992), while MP intake for the animals finished at pasture is likely to have been considerably higher than this due to the higher protein content in the pasture than in the high-concentrate diets. Consequently, the carcass composition of the cattle given either diet would not have been affected by inadequate MP in the diet. Conversely, very high intakes of MP, such as those by the animals at pasture, have been found to increase carcass fatness in finishing beef cattle in several studies (Steen 1988). However, this effect would have tended to reduce the difference in carcass fat content between the pasture and concentrate treatments, rather than being responsible for it.

While the data in Table 4 give the difference in carcass fat content between the concentrate-fed and pasture-fed cattle at the same growth rate, it is also of interest to estimate the difference in the weight of the carcasses produced by the two diets at constant carcass fat content. In previous studies involving high-concentrate or grass silage/concentrate diets and serially slaughtered steers and heifers, carcass fat content increased by 53–57 g kg<sup>-1</sup> per 100 kg increase in carcass weight (Andersen et al. 1984; Steen & Kilpatrick 1995; R. W. J. Steen unpubl. data). Therefore, it is assumed that the carcass fat content of the animals given concentrates *ad libitum* in the present studies increased by 55 g kg<sup>-1</sup> per 100 kg increase in carcass weight. On this basis it is estimated that at constant carcass fat content the pasture-fed cattle would produce carcasses which were 54 and 45 kg heavier than those produced by the animals given concentrates *ad libitum* in Experiments 1 and 2 respectively.

The higher proportion of MUFA in the lipid of the concentrate-fed animals compared with those finished at pasture in Experiment 1, and the higher proportion of PUFA in lipid from the pasture-finished compared with the concentrate-fed animals in Experiments 1 and 2 combined (Table 6) are in agreement with previous findings (Williams et al. 1983; Marmer et al. 1984). At constant lipid content

in the muscle, the concentrations of  $\omega$ 3 PUFA in the muscle of the pastured cattle were approximately three times the concentrations in the muscle of the concentrate-fed cattle, on average over the two experiments. Marmer et al. (1984) reported concentrations of  $\omega$ 3 PUFA in muscle from pasture-finished cattle 1.3 times those in muscle from concentrate-finished cattle. The smaller difference in  $\omega$ 3 PUFA content of muscle between the diets in that study than in the present experiments may be at least partly attributable to the former study being undertaken mainly during the winter, to a difference in pasture species and quality, and to the animals in the Marmer et al. (1984) study receiving a supplement of hay during part of the pasture period while the animals at pasture in the present studies received no supplement.

The results of these studies indicate that high quality perennial ryegrass pasture has potential to produce over 80% of the daily carcass gain and similar daily lean and protein gains in beef cattle as those produced by high-concentrate diets offered *ad libitum*, whereas the production of fat was approximately 40% lower in the pasture-finished cattle. The high output of lean beef from high quality ryegrass pastures as demonstrated in these studies, combined with its positive health benefits, in terms of low fat content and high content of  $\omega$ 3 PUFA, and its positive image in terms of animal welfare and environmental impact, should give pasture-fed beef a positive image for consumers in terms of a wide range of attributes.

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