Diet Digestibility, Rate of Passage, and Eating and Rumination Behavior of Jersey and Holstein Cows

P. C. Aikman,¹ C. K. Reynolds, and D. E. Beever²

School of Agriculture, Policy and Development, University of Reading, Earley Gate, Reading RG6 6AR, United Kingdom

ABSTRACT

Diet digestibility and rate of passage, eating and rumination behavior, dry matter intake (DMI), and lactation performance were compared in 6 Jersey and 6 Holstein multiparous cows. Cows were fed gestation diets according to body weight (BW) beginning 7 wk before expected calving and ad libitum amounts of a lactation diet postpartum. Diet digestibility and rate of passage were measured in 5-d periods at wk 5 prepartum and wk 6 and 14 of lactation. Eating and ruminating behavior was measured over 5-d periods at wk 5 and 2 prepartum and wk 2, 6, 10, and 14 of lactation. Milk yield and DMI were higher in Holsteins, but milk energy output per kilogram of metabolic BW ($BW^{0.75}$) and intake capacity (DMI/kg of BW) did not differ between breeds. Holsteins spent longer ruminating per day compared with Jerseys, but daily eating time did not differ between breeds. Jerseys spent more time eating and ruminating per unit of ingested feed. The duration and number of meals consumed did not differ between breeds, but the meals consumed by Jerseys were distributed more evenly throughout each 24-h period, providing a more regular supply of feed to the rumen. Feed passed through the digestive tract more quickly in Jerseys compared with Holsteins, suggesting particle breakdown and rumen outflow were faster in Jerseys, but this may also reflect the relative size of their digestive tract. Neutral detergent fiber digestibility was greater in Jerseys, despite the shorter rumen retention time, but digestibility of dry matter, organic matter, starch, and N did not differ between breeds. Utilization of digested N for tissue retention was higher at wk 5 prepartum and lower at wk 14 of lactation in Jerseys. In contrast to numerous published studies, intake capacity of Jerseys was not higher than that of Holsteins, but in the present study, cows were selected on the basis of equal expected

milk energy yield per kilogram of metabolic BW. Digestibility of neutral detergent fiber and rate of digesta passage were higher in Jerseys, probably as a consequence of increased mastication per unit of feed consumed in Jerseys and their smaller size.

Key words: rumination, digestibility, rate of passage, Jersey

INTRODUCTION

The number of Jersey cattle is increasing in the United Kingdom, where, in common with many other countries, farmers are seeking to increase milk protein and fat concentrations to meet market demands. There are also indications that Jerseys are less susceptible to the metabolic disorders and infertility that increasingly afflict high-producing Holstein herds (Alban, 1995; Washburn et al., 2002). Current guidelines for feeding dairy cows in the United Kingdom (Thomas, 2004) and United States (NRC, 2001) do not make specific recommendations for Jerseys, due in part to a lack of research comparing the digestive physiology and nutrition of modern Jersey and Holstein cows. However, a limited number of studies have reported physiological differences between Jerseys and larger dairy breeds. Oldenbroek (1988) found that Jerseys utilized high-fiber diets more efficiently than larger breeds, whereas Ingvarsen and Weisbjerg (1993) and Rodriguez et al. (1997) found that Jerseys had a greater intake capacity per unit of BW. Feed passage rate through the digestive tract was faster in Danish Jerseys compared with Friesians in the study of Ingvarsen and Weisbjerg (1993), but there was no difference in diet digestibility. Dürst et al. (1993) noted that Jerseys ate smaller, more frequent meals than Friesian and Simmental cows, whereas Welch et al. (1970) reported that, on a metabolic BW ($BW^{0.75}$) basis, Jerseys tended to spend longer ruminating each unit of fiber ingested than other dairy breeds. These studies suggest that the eating and rumination patterns of Jerseys are different from those of larger dairy breeds in a manner consistent with greater intake capacity and rate of digesta passage. However, the genetic potential of dairy cows, especially with re-

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¹Corresponding author: p.c.aikman@reading.ac.uk

²Current address: R. Keenan and Co. Ltd., Borris, County Carlow, Ireland.

Table 1. Composition of TMR fed to Jersey and Holstein cows during the far-off (wk 5 and 4 before expected calving date), close-up (wk 3 to 1 before expected calving date), and lactation periods

Component, g/kg of DM	Period		
	Far off	Close up	Lactation
Grass silage	660	160	311
Corn silage	—	408	311
Grass hay (chop length >100 mm)	220	188	—
Dry cow rolls ¹	120	—	—
Minline Transition meal ²	—	76	—
Canola meal	—	—	114
Wheat	—	46	86
Corn gluten	—	—	60
Soybean meal	—	72	47
Molassed sugar beet pulp	—	46	35
Megalac ³	—	—	15
Molasses	—	—	13
Spray vegetable fat	—	—	4
Minerals	—	4	4
Chemical analysis			
CP	146	166	173
NDF	523	412	386
ADF	348	232	222
Ash	84	93	69
Estimated ME, MJ/kg of DM	11.4	11.4	12.0
Starch	22	202	187
Ca	4.5	9.1	8.4
P	4.5	4.2	4.5
K	33.5	16.6	18.7
Mg	2.8	3.5	2.8

¹Pelleted compound feed, based on wheatfeed, heat-treated canola meal and wheat (BOCM Pauls Ltd., Bristol, UK).

²Anionic protein and mineral supplement for late gestation cows (BOCM Pauls Ltd.).

³Calcium salts of palm fatty acids (Volac International Ltd., Royston, UK).

spect to levels of milk production, has increased considerably in the years since these studies were published, along with the physiological demands of lactation. Therefore, the objectives of the present study were to compare DMI, eating and rumination behavior, diet digestibility, and rate of passage in Jersey and Holstein cows during late gestation and early lactation.

MATERIALS AND METHODS

Animals, Housing, and Diets

Six third-parity Jersey cows (BW 462 ± 18 kg) and 6 third-parity Holstein cows (BW 678 ± 18 kg) were enrolled in the study approximately 7 wk before their expected calving dates (ECD). The cows were housed in tie stalls with flexible neck yokes and rubber matting bedded with wood shavings for the duration of the study, except for the period around parturition. Cows were moved to straw-bedded yards when parturition was imminent and remained there for up to 2 d postcalving. Cows were milked twice daily at 0630 and 1600 h.

From enrollment in the study until 21 d before ECD, the cows were fed a far-off TMR (Table 1). Beginning

21 d before ECD, the cows were fed a close-up TMR (Table 1) and remained on this until calving. The amount of both far-off and close-up diets offered was adjusted weekly to meet ME and protein requirements for maintenance and stage of gestation, with no change in BW (NRC, 1988). After parturition, cows were offered a lactation TMR ad libitum (Table 1). All diets were prepared in a rotary paddle mixer (Winget Ltd., Bolton, UK). Feed offered was set at 111% of the consumption on the previous day. Refusals were removed at 0730 h, and daily rations were offered in 2 equal portions at 0800 and 1600 h. Fresh weight offered was adjusted 3 times per week to account for changes in forage DM concentration. All diet changes were made incrementally over 4 d to allow for digestive adaptation. Dry matter intake was measured daily for the duration of the study.

Measurements and Sampling

Total tract digestibility, N balance, and rate of digesta passage were measured simultaneously over 5 d during wk 5 before ECD and lactation wk 6 and 14. Feces and urine collection, sampling, and processing were as described by Sutton et al. (1997). Rate of digesta passage was measured using Cr-mordanted grass silage, prepared according to the method of Uden et al. (1980). On d 1 of each fecal collection period, animals were fed an amount of Cr-mordanted grass silage corresponding to 1% of DMI on the previous day, before the morning feed was offered. Starting 2.5 h after consumption of the Cr-mordanted grass silage, all voided feces were collected into plastic bags. The bags were changed a total of 22 times, at intervals of 6.5, 9.5, 13, 19, 25, 28.5, 32, 36.5, 43, 49, 53, 57, 61, 67, 71.5, 76.5, 82, 89, 97, 105, 113, and 120 h after Cr dosing. The feces in each bag were mixed thoroughly, and a 400-g subsample was dried for 48 h at 100°C before milling through a 1-mm screen.

To monitor patterns of intake and rumination, 5 daily recordings of total jaw movements were made for each cow during wk 5 and 2 before ECD and wk 2, 6, 10, and 14 of lactation using IGER Behavior Recorders (Rutter et al., 1997). Each recording commenced before the morning feed and continued for approximately 23.75 h.

Milk yield was recorded daily for the duration of the study. Samples of milk for determination of composition were taken from 10 consecutive milkings during wk 6 and 14 of lactation and from 2 consecutive milkings on Monday, Wednesday, and Friday each week at other times. Milk samples were preserved with potassium dichromate (Lactabs, Thompson and Capper, Runcorn, UK) and stored at 4°C until subsequent analysis. Cows

Table 2. Body weight and DMI of Holstein and Jersey cows during dry and lactation periods

Item	Breed		SEM	<i>P</i> <		
	Holstein	Jersey		Breed	Week	Breed × week
Dry period (wk 5 to 1 prepartum)						
BW, kg	694	482	18.4	0.001	0.001	0.044
DMI, kg/d	11.37	7.92	0.422	0.001	0.002	0.069
DMI, % of BW	1.64	1.65	0.055	0.953	0.036	0.279
Lactation (wk 2 to 14)						
BW, kg	642	443	18.3	0.001	0.068	0.001
DMI, kg/d	22.29	15.39	0.512	0.001	0.001	0.232
DMI, % of BW	3.47	3.48	0.071	0.955	0.001	0.531

were weighed weekly, at the same time of day each time, for the duration of the study.

Dry matter concentrations of all forage and concentrate components were determined daily and weekly, respectively, by drying for 24 h at 100°C. Forages were sampled daily, frozen, and a weekly composite sample was created. Concentrate components were sampled weekly, frozen, and monthly composite samples were created.

Laboratory Analyses

Concentrations of NDF and ADF in dried, ground feed, and feces samples were determined in duplicate using the ANKOM 8/98 and 9/99 methods, respectively (Pelican Scientific, Alford, Chester, UK), based on the method of Van Soest et al. (1991). Ash contents of feed and fecal samples were determined in duplicate by placing dried ground samples in a muffle oven at 550°C overnight. Starch concentration of dried, ground feed, and fecal samples was determined as described by Sutton et al. (1997). Nitrogen concentration of feed, urine, and fecal samples was determined using the macro Kjeldahl method (Bradstreet, 1969). Metabolizable energy concentrations of forages were calculated from neutral detergent-cellulase digestibility, which was predicted by near-infrared reflectance spectroscopy. Metabolizable energy concentration of concentrates was estimated from neutral detergent cellulase plus gamanase digestibility and oil concentration (MAFF, 1993).

Fecal Cr concentration was measured by reducing 1.0 g of dried milled feces to ash at 550°C. The ashed samples were digested at 300°C with 3 mL of a solution containing 4.5 *M* sulfuric acid, 3.8 *M* orthophosphoric acid, and 0.02 *M* manganese (II) sulfate, with the addition of 2 mL of 0.3 *M* potassium bromate during digestion. Samples were made up to 50-mL volume with distilled water before the absorbance was measured at 357.9 nm on an atomic absorption spectrophotometer (Varian Associates Ltd., Walton-on-Thames, UK).

Fat, protein, and lactose concentrations of individual milk samples were determined using a Milkoscan Analyser (Foss Products Ltd., York, UK).

Calculations

Daily ME intake was determined by multiplying DMI by the estimated ME concentration of the TMR. Milk energy yield was calculated as daily milk yield (kg) multiplied by the energy value of milk (MJ/kg), calculated from fat, protein, and lactose concentrations using the equation of Tyrrell and Reid (1965). The mean daily ME requirement of each animal was computed for each week of lactation using the principles described by Agnew et al. (2004), in which net energy required for BW gain or derived from BW loss is taken into account as appropriate. Lactating cows were not pregnant, and no allowance was made for activity. The mean daily tissue energy balance (**TEB**, MJ/d) for each animal for each week of lactation was computed as follows:

$$\text{TEB} = \text{ME intake} - \text{ME requirement.}$$

Jaw movement recordings were analyzed with proprietary software (Rutter, 2000) to identify periods of eating and ruminating, the total time spent in each activity, and the number of boluses produced during rumination. To determine patterns of feed intake, the total eating activity was divided into meals. The duration (in seconds) of gaps between episodes of eating behavior was noted for each daily jaw movement recording. The gap duration frequencies from the 5 individual 24-h recordings were then added together to produce an overall frequency for each gap duration per cow period. A 2-process model (Sibly et al., 1990) was fitted to natural logarithms of the frequency of each gap duration using the NLIN procedure of SAS (2001) to determine an intermeal interval for each cow period. The intermeal intervals were statistically analyzed using repeated measures in SAS (2001). There were no breed differences, but the intermeal interval differed (*P* =

0.007) between the far-off (wk 5 before ECD), close-up (wk 2 before ECD), and lactation (wk 2, 6, 10, and 14) measurement periods of the study, and the intermeal intervals used were 792, 648, and 486 s, respectively. Bouts of eating behavior that lasted for 2 min or longer, that were separated by the appropriate intermeal interval or less, and had no other behavior type between them, were joined and counted as 1 meal. The daily distribution of eating behavior was assessed by dividing each 24-h recording period into six 4-h intervals and determining the proportion of the total daily eating behavior that occurred in each interval.

Parameters to describe rate of passage were calculated by fitting the multicompartamental model proposed by Dhanoa et al. (1985) to the natural logarithms of the fecal Cr concentrations over time using the line plus exponential curve fitting function of Genstat 6.1 (VSN International Ltd., Hemel Hempstead, UK). The model describes digesta flow through an infinite number of gastrointestinal compartments, or pools, each with an associated fractional outflow rate. The reciprocal of the fractional outflow rate is the mean retention time (h) of digesta in that compartment. In the model, the 2 smallest fractional outflow rates, k_1 and k_2 , represent the 2 pools within the gastrointestinal tract with the longest retention times, whereas transit time (TT; h) describes passage through the remaining, minor, pools. Total mean retention time (TMRT; h), representing the mean retention time of particles in the entire digestive tract, was calculated as:

$$\text{TMRT} = (1/k_1) + (1/k_2) + \text{TT}.$$

Assuming k_2 describes the rate at which large particles are broken down to small particles within the rumen, and k_1 represents outflow rate of small particles from the rumen (Gasa et al., 1991), mean rumen retention time (RMRT; h) was calculated as:

$$\text{RMRT} = (1/k_1) + (1/k_2).$$

Consequently, TT describes the passage time of digesta through the section of the digestive tract posterior to the rumen.

Statistical Analyses

Daily means of all variables were calculated for each cow and each week of the study as appropriate. The fixed effects of breed on measurements repeated within cows over week pre- or postcalving were tested using the MIXED procedure of SAS (2001) and the covariance structure (compound symmetry, heterogeneous compound symmetry, spatial power, autoregressive order

one, heterogeneous autoregressive order one, or unstructured) chosen based on Bayesian information criteria. Cows were included as random factors in the model. Dry matter intake and BW were analyzed separately for pre- and postcalving periods and are presented as least squares means. Production and intake data from wk 1 of lactation were not included in the statistical analysis, because animals were in straw-bedded yards for 48 h postcalving where measurement of individual DMI and milk yield was not possible. For digestibility, N balance, and rate of passage, the fixed effects of breed, week (wk 5 before ECD and 6 and 14 of lactation), and their interaction were tested. For eating, ruminating, and meal measurements, the fixed effects of breed, stage (dry or lactating), week within stage, and breed $\times$ week within stage interaction were tested. The six 4-h intervals used to describe the temporal distribution of eating activity were analyzed as discrete variables repeated within cows. When animals were fed restricted amounts of feed during the dry period, eating activity primarily occurred immediately after fresh feed was placed in front of the animals. Consequently, data from the 2 dry period measurements is not included in the analysis of the temporal distribution of eating activity.

RESULTS

Calving and Health

All cows calved without assistance with the exception of 1 Holstein, which required major assistance with a breech presentation. One Jersey was treated with i.v. calcium borogluconate for milk fever 24 h postcalving but was recumbent for less than 12 h. A second Jersey had a seriously depressed DMI for 10 d postcalving, with no clinical signs of any medical condition. All data relating to this animal in the first 2 wk of lactation were omitted from the statistical analysis. Cases of mastitis resulting in depressed DMI and milk yield were treated with antibiotics in 1 Holstein and 1 Jersey during wk 11 and 12 of lactation, respectively. The data for these animals for both the affected week and the following week were omitted from the analysis.

DMI and BW

Holsteins were more than 200 kg heavier than Jerseys in the dry period ($P = 0.001$), and DMI was greater in Holsteins ($P = 0.001$) compared with Jerseys, but during the dry period, DMI as a percentage of BW was similar ($P = 0.953$) between breeds (Table 2), because cows were fed according to BW. There was an interaction for the effects of breed and week ($P = 0.044$), because Holsteins gained more BW throughout the pre-

Figure 1. Body weight of Holstein (●) and Jersey (□) cows between wk 5 prepartum and wk 14 of lactation.

Figure 2. Estimated daily tissue energy balance in Holstein (●) and Jersey (□) cows between wk 2 and 14 of lactation.

partum period compared with Jerseys, who gained no BW in the last 3 wk before calving (Figure 1). After calving, Jerseys again weighed and consumed around 30% less than the Holsteins ($P = 0.001$), and DMI as a percentage of BW was not different ($P = 0.955$) between the breeds (Table 2). Jerseys gained no BW during the first 14 wk of lactation, whereas Holsteins gained small amounts of BW (breed $\times$ week interaction, $P = 0.001$).

Milk Production and Estimated Tissue Energy Balance

Yields of milk and milk fat, protein, lactose, and energy were higher ($P < 0.013$) in Holsteins compared with Jerseys (Table 3). Milk fat, protein, and energy concentrations were higher ($P < 0.003$) in Jerseys (Table

3), and milk lactose concentration was higher in Jerseys after wk 6 of lactation (data not shown, breed $\times$ week interaction, $P = 0.027$). Milk energy output per unit of metabolic BW did not differ ($P = 0.203$) between breeds. There was no overall difference in calculated TEB (MJ/d or MJ/kg of $BW^{0.75}$ per d) between the 2 breeds ($P > 0.371$, Table 3), although TEB was more negative in Holsteins than in Jerseys during wk 2 and 3 of lactation (Figure 2). Tissue energy balance increased in both breeds as lactation progressed ($P = 0.001$), although both breeds were estimated to be in negative energy balance for the duration of the study (Figure 2).

Eating and Ruminating

Dry matter and NDF intakes of Jerseys during feeding behavior measurements were approximately two-

Table 3. Milk yield and composition and estimated tissue energy balance of Holstein and Jersey cows between wk 2 and 14 of lactation

Item	Breed		SEM	$P <$		
	Holstein	Jersey		Breed	Week	Breed $\times$ week
Milk yield, kg/d	42.6	25.3	1.15	0.001	0.044	0.657
Milk component yield, g/d						
Fat	1,622	1,323	69.5	0.013	0.445	0.903
Protein	1,314	910	37.4	0.001	0.102	0.263
Lactose	1,981	1,200	46.7	0.001	0.001	0.130
Milk composition, g/kg						
Fat	38.5	52.4	1.95	0.001	0.205	0.267
Protein	31.0	36.0	0.86	0.003	0.001	0.241
Lactose	46.8	47.6	0.37	0.166	0.001	0.027
Milk energy						
Concentration, MJ/kg	3.01	3.64	0.071	0.001	0.090	0.293
Output, MJ/d	126.3	92.5	3.64	0.001	0.312	0.807
MJ/kg of $BW^{0.75}$ /d	0.992	0.950	0.021	0.203	0.702	0.952
Tissue energy balance						
MJ/d	-28	-26	3.9	0.720	0.001	0.769
MJ/kg of $BW^{0.75}$	-0.223	-0.272	0.037	0.371	0.001	0.910

Table 4. Dry matter intake, NDF intake, and time spent in eating and ruminating behavior by Holstein and Jersey cows at wk 5 and 2 before expected calving date (dry) and wk 2, 6, 10, and 14 of lactation

Item	Dry			Lactating			<i>P</i> <			
	Holstein	Jersey	SEM	Holstein	Jersey	SEM	Breed	Stage ¹	Week ²	Breed × stage
DMI, kg/d	10.19	7.12	0.58	22.01	14.71	0.51	0.001	0.001	0.001	0.001
NDF intake, kg/d	4.56	3.29	0.24	8.00	5.41	0.21	0.001	0.001	0.001	0.001
Time spent eating										
min/d	212	229	19	360	382	16	0.382	0.001	0.056	0.837
min/kg of DM	20.7	34.0	2.3	16.6	26.6	1.9	0.001	0.002	0.001	0.337
min/kg of NDF	46.3	71.5	8.1	45.4	72.1	3.3	0.004	0.983	0.569	0.879
Eating rate, g of DM/min	50.8	36.8	5.6	62.9	38.9	2.9	0.005	0.037	0.141	0.136
Time spent ruminating										
min/d	477	443	17	623	538	16	0.020	0.001	0.028	0.002
min/kg of DM	48.0	64.4	2.1	28.9	37.8	2.4	0.002	0.001	0.001	0.006
min/kg of NDF	104.7	138.3	5.5	78.9	102.4	4.8	0.002	0.001	0.004	0.125
Boluses										
total/d	734	725	50	676	684	26	0.992	0.192	0.307	0.821
per kg of DM	75	107	7	31	47	2	0.001	0.001	0.001	0.140
per kg of NDF	159	226	11	86	130	7	0.001	0.001	0.185	0.213
Total time spent chewing, min/kg of BW	1.02	1.42	0.08	1.54	2.09	0.07	0.001	0.001	0.026	0.036
Total meals/d	5.4	6.3	1.0	14.0	14.1	0.7	0.602	0.001	0.478	0.626
Mean meal length, min	53.7	47.5	7.6	27.0	27.6	2.0	0.649	0.001	0.136	0.517

¹Dry vs. lactating.²Week within stage.

thirds those of the Holsteins ($P = 0.001$, Table 4 and Figure 3). Time devoted to eating behavior was greater ($P = 0.001$) during lactation than in the dry period in both breeds, but time spent eating did not differ between breeds ($P = 0.382$). The larger DMI in Holsteins meant that their rate of eating was markedly faster than that of the Jerseys ($P = 0.005$), and, as a consequence, the time spent consuming each unit of DM ($P = 0.001$, Figure 3) or NDF ($P = 0.004$) was less compared with the Jerseys. Ruminating times per kilogram of DMI ($P = 0.002$, Figure 3) or NDF intake ($P = 0.002$)

were also greater in Jerseys. Total times spent ruminating in the dry and lactating periods were, respectively, 8.0 and 10.4 h/d for Holsteins and 7.4 and 9.0 h/d for Jerseys. For total time spent ruminating, the difference between breeds was greater during lactation compared with the dry period (breed × stage interaction, $P = 0.002$), but the opposite was true for time spent ruminating per kilogram of DM (breed × stage interaction, $P = 0.006$). A similar effect of breed ($P = 0.001$) was observed in the number of boluses produced for each unit of DM or NDF, although the total boluses processed

Table 5. Apparent total tract digestibility of dietary components by Holstein and Jersey cows measured at wk 5 before expected calving date (−5) and wk 6 and 14 of lactation

Item	Holsteins			Jerseys			SEM	<i>P</i> <		
	−5	6	14	−5	6	14		Breed	Week	Breed × week
DM										
Intake, kg/d	8.63	22.67	22.93	6.62	14.70	15.45	0.79	0.001	0.001	0.001
Digestibility, g/kg	695	710	716	707	725	720	11	0.266	0.224	0.843
OM										
Intake, kg/d	7.93	21.16	21.43	6.10	13.74	14.40	0.74	0.001	0.001	0.001
Digestibility, g/kg	716	730	737	726	747	743	10	0.192	0.128	0.821
Starch										
Intake, kg/d	0.22	4.37	4.14	0.15	2.76	2.67	0.10	0.001	0.001	0.001
Digestibility, g/kg	897	963	964	890	971	962	7	0.956	0.001	0.486
NDF										
Intake, kg/d	4.72	7.91	8.12	3.58	5.26	5.63	0.25	0.001	0.001	0.003
Digestibility, g/kg	693	547	565	709	584	595	19	0.008	0.001	0.750
ADF										
Intake, kg/d	2.97	4.67	4.91	2.23	3.17	3.43	0.16	0.001	0.001	0.008
Digestibility, g/kg	626	476	496	625	504	501	23	0.416	0.001	0.600
N										
Intake, g/d	194	585	594	146	375	405	21	0.001	0.001	0.001
Digestibility, g/kg	667	676	680	652	694	684	11	0.801	0.076	0.352

Figure 3. (a) Mean DMI and (b) number of minutes spent eating and (c) ruminating each kilogram of DM by Holstein (black bars) and Jersey (white bars) cows through the transition from restricted intake of a high-NDF diet in wk 5 prepartum to ad libitum intake of a lower NDF lactation diet, with restricted intake of an intermediate diet at wk 2 prepartum.

per day did not differ between breeds ($P = 0.992$, Table 4). When the times spent eating and ruminating were combined and expressed as total minutes spent chewing per kilogram of BW, Jerseys spent significantly longer chewing ($P = 0.001$, Table 4), and the increase in chewing time per kilogram of BW after calving was greater for Jerseys (breed $\times$ stage interaction, $P = 0.036$).

The total number of meals per day and the mean meal length did not differ between breeds (Table 4) but

Figure 4. Mean percentage of total daily eating time occurring within 4-h intervals in Holstein (black bars) and Jersey (white bars) cows during wk 2, 6, 10, and 14 of lactation. Breeds tended to differ between 0800 and 1200 h ($P < 0.093$) and 2400 and 0400 h ($P < 0.060$).

were affected ($P = 0.001$) by stage relative to calving. In the dry period, cows of both breeds consumed their limited amounts of feed in a small number of long meals. In contrast, when animals were fed ad libitum during lactation, the feed was consumed in a greater number of meals.

In both breeds, there were substantial periods of eating activity in response to the provision of fresh feed at 0800 and 1600 h, with 50 to 55% of total daily eating activity occurring within the 4-h period following each feeding (Figure 4). Eating activity was more evenly distributed throughout each 24-h period in Jerseys, however, because they tended to spend less time eating between 0800 and 1200 h ($P = 0.093$) and more time between 2400 and 0400 h ($P = 0.060$) compared with the Holsteins. There were no differences between the breeds within the other 4 intervals.

Total Tract Digestibility and N Balance

There were no effects of breed ($P > 0.192$) on apparent digestibilities of DM, OM, starch, ADF, or N, and there were no breed $\times$ week interactions ($P > 0.352$, Table 5), although DM and OM digestibility were numerically higher in Jerseys. Apparent digestibility of NDF was higher ($P = 0.008$, Table 5) in Jerseys than in Holsteins. Week relative to calving had an effect ($P < 0.001$) on apparent digestibility of starch, NDF, and ADF, reflecting the changes in diet composition after calving, but there were no significant breed $\times$ week interactions.

Nitrogen intake was higher in Holsteins compared with Jerseys ($P = 0.001$, Table 5), and the total amounts digested, excreted in urine, retained for use in metabolic processes (balance), and secreted in milk were also

Table 6. Nitrogen balance (g/d) in Holstein and Jersey cows measured at wk 5 before expected calving date (–5) and wk 6 and 14 of lactation

Item	Holstein			Jersey			SEM	<i>P</i> <		
	–5	6	14	–5	6	14		Breed	Week	Breed × week
Digested	128	395	404	96	261	277	15	0.001	0.001	0.001
Urine	125	192	211	81	130	163	12	0.001	0.001	0.312
Balance	5	203	190	15	130	114	12	0.001	0.001	0.001
Milk	—	206	196	—	132	137	7	0.001	0.586	0.135
Tissue	5	–4	–11	15	–1	–23	13	0.982	0.007	0.322
Utilization of apparently digested N, %										
Urine	96.6	48.7	52.8	84.5	50.2	58.7	3.1	0.634	0.001	0.075
Balance	3.4	51.3	47.3	15.3	49.8	41.4	3.0	0.645	0.001	0.078
Milk	—	52.4	49.2	—	50.5	49.4	1.9	0.652	0.226	0.560
Tissue	3.5	–1.1	–2.2	15.5	–0.8	–8.0	3.6	0.496	0.004	0.082

larger ($P = 0.001$, Table 6). Overall body tissue N balance was not affected by breed ($P = 0.982$), but both breeds had positive tissue N balances precalving and negative tissue N balances during lactation (week effect, $P < 0.007$). Tissue N balance as a portion of digested N was higher in the dry period and declined more steeply as lactation progressed in Jerseys compared with Holsteins (breed × week interaction, $P = 0.082$), reflecting differences in the portion of digested N excreted in urine (breed × week interaction, $P = 0.075$).

Digesta Kinetics

The fractional outflow rate of digesta from the rumen (k_1) was faster in Jerseys compared with Holsteins ($P = 0.022$, Table 7), although this effect was largely attributable to differences noted precalving. Overall, outflow rate was similar pre- and postcalving in Holsteins but substantially higher precalving compared with postcalving in Jerseys (breed × week interaction, $P = 0.062$). The rate of particle breakdown within the rumen (k_2) was numerically higher in Jerseys compared with Holsteins at wk 14 of lactation, but it was similar at the other measurement points ($P = 0.123$, Table 7). The RMRT was lower in Jerseys compared with Holsteins ($P = 0.008$), but whereas RMRT was higher precalving compared with postcalving in Holsteins, it increased marginally after calving in the Jerseys (breed × week interaction, $P = 0.070$; Table 7). Overall rate of passage of digesta through the posterior section of the digestive tract (TT) did not differ between breeds ($P = 0.497$, Table 7), and a significant reduction in TT was observed postcalving in both breeds (week effect, $P = 0.001$). The decline in TT continued between wk 6 and 14 of lactation in Jerseys but remained constant in Holsteins (breed × week interaction, $P = 0.055$). The TMRT was less ($P = 0.020$) in Jerseys compared with Holsteins (Table 7), with the largest difference of 10.4 h observed in the precalving period (breed × week, $P = 0.020$). A

decrease in TMRT was observed between the dry and lactation periods in both breeds, but the magnitude of the decrease was greater in Holsteins.

DISCUSSION

Jerseys are often reported to have a greater intake capacity (DMI/kg of BW) than larger dairy breeds, but these comparisons must also consider differences in milk energy yield, diet composition, and their effects on appetite. Studies comparing Jerseys with larger breeds found their intake capacity was greater (Ingvarsen and Weisbjerg, 1993; Muller and Botha, 1998), but the Jerseys used produced considerably more milk energy relative to metabolic BW. West et al. (1997) also noted that Jerseys had a higher overall intake capacity than Holsteins, but they reported a significant breed × diet composition (forage source) interaction. The DMI of Jerseys was reduced when grass-based diets with lower digestibility were fed, but the DMI of Holsteins was not affected. Intake capacity did not differ in the present study, in which the productive potential of each breed, expressed as milk energy output per unit of metabolic BW, was comparable. This agrees with the review of Conrad et al. (1964), who reported that DMI of lactating dairy cows could be predicted by diet digestibility after adjusting for BW and milk energy output. Rastani et al. (2001) also observed no difference in intake capacity in a study using animals with similar production levels and fed similar diets to those used in the present study, although milk energy output per unit of metabolic BW was slightly higher in Holsteins in their study.

In the present study, the combined time spent in eating and ruminating per unit of BW was greater in Jerseys, despite there being no difference in DMI per unit of BW between the 2 breeds. Jerseys have smaller mouths than Holsteins, so they require a larger number of mouthfuls to process an equal volume of feed. Partial confirmation of this can be obtained by dividing DMI

Table 7. Mean digesta kinetics in Holstein and Jersey cows measured at wk 5 before expected calving date (–5) and wk 6 and 14 of lactation

Item	Holstein			Jersey			SEM	<i>P</i> <		
	–5	6	14	–5	6	14		Breed	Week	Breed × week
k_1 ¹	0.031	0.030	0.031	0.044	0.035	0.032	0.002	0.022	0.046	0.062
k_2 ²	0.081	0.128	0.136	0.089	0.121	0.160	0.007	0.196	0.001	0.123
RMRT ³ (h)	46.0	41.6	40.2	35.0	37.8	37.6	1.9	0.008	0.684	0.070
TT ⁴ (h)	32.5	14.7	15.4	33.1	17.9	14.6	1.2	0.497	0.001	0.055
TMRT ⁵ (h)	78.5	56.3	55.6	68.1	55.6	52.2	1.8	0.020	0.001	0.020

¹Rate (proportion per hour) at which particles pass out of the rumen.

²Rate (proportion per hour) at which large particles are reduced to small particles within the rumen.

³Mean retention time of particles within the rumen.

⁴Time taken for digesta to pass through the section of the digestive tract posterior to the rumen.

⁵Total mean retention time of digesta in the entire digestive tract.

by the number of boluses regurgitated during rumination to give an approximation of the average bolus size of 26.0 and 17.5 g of DM for Holsteins and Jerseys, respectively. In common with many other measurements, including BW and DMI, the average bolus size in Jerseys was around two-thirds of that of the Holsteins. Therefore, the longer time spent by Jerseys eating and ruminating per unit of BW must be due to more than a difference in mouth size.

Energy costs associated with eating and ruminating have been determined as 30 and 9 J/min per kilogram of BW, respectively (Susenbeth et al., 1998). The total energy expended by chewing activity in Holsteins can be calculated as 7.3 MJ/d during the dry period and 10.4 MJ/d during lactation, corresponding to 5.7 and 4.0% of daily ME intake in the respective periods. The equivalent energy expenditures by Jerseys were 5.2 and 7.2 MJ/d for dry and lactation periods, accounting for 5.8 and 4.1% of ME intake, respectively. The smaller body size of the Jerseys enabled them to chew for longer per unit of DM without expending a greater proportion of their daily ME intake than the Holsteins.

In general, the time spent eating each kilogram of DM was constant throughout the trial, irrespective of dietary NDF concentration or DMI. The notable exception to this was the behavior of Jerseys at wk 5 prepartum, in which they spent over 40 min ingesting each kilogram of DM, compared with an average of around 26 min in the other periods. Reasons for this difference before calving are not certain, but the 2 breeds may have responded differently to the amount of long fiber (220 g of grass hay/kg of DM) in the far-off TMR.

The decline in time spent ruminating each kilogram of ingested DM, which was observed in both breeds as they moved from restricted feed intakes in the dry period to ad libitum intakes during lactation, was due in part to the differences in forage type and quantity in the far-off, close-up, and lactation diets. It may also

be indicative of the physical constraints that limit the amount of time an animal can spend chewing in any 24-h period. Holsteins ruminated for around 10.5 h in the lactation periods and were therefore approaching the 11 h/d maximum possible rumination time observed by Welch (1982), whereas Jerseys ruminated for around 9.0 h. Jerseys therefore had the opportunity to achieve a greater degree of feed particle size reduction, because the time they spent ruminating was 86% of the total spent by Holsteins, yet their feed intake and mouth size were only around 67% of those of the Holsteins. This was probably a contributory factor to the greater NDF digestibility and faster rumen passage rate observed in the Jerseys.

In common with observations made by Dürst et al. (1993), peaks in eating activity occurred after fresh food was placed in front of the cows, even if food remained in the manger from the previous feed, as happened at afternoon feeding during the lactation periods. Dürst et al. (1993) observed that Jerseys ate a greater number of smaller, more frequent meals than Holstein or Simmental cows, but in the present experiment, the total number of meals and their duration did not differ between breeds. Differences were detected in the distribution of eating activity throughout each 24-h period, however, with Jerseys tending to spend less time eating between 0800 and 1200 h and more between 2400 and 0400 h. It is likely that Jerseys reached the limit for rumen fill more quickly in the period of intense feeding after the 0800 h feed and compensated for this by eating for longer periods later. Although information on the variation in eating rate throughout each 24-h period was not available, the distribution of eating activity observed in the Jerseys suggests that supply of ingested feed to the rumen was more regular in this breed. Cyclical peaks in rumen fermentation and the production of VFA would therefore have been minimized, and fluctuations in rumen pH would have been less severe in

Jerseys compared with Holsteins. This behavior is likely to confer metabolic advantages on Jerseys in situations in which diets likely to induce subacute ruminal acidosis are fed, but we are not aware of published research comparing rumen pH and VFA production in Jersey and Holstein cows challenged with such diets.

Interpretation of rate of passage data, particularly the allocation of k_1 and k_2 to specific compartments within the gastrointestinal tract, is subject to much debate. In a study comparing the kinetics of 2 types of marker, Gasa et al. (1991) proposed that k_1 should be interpreted as describing passage of particles out of the rumen and k_2 as describing the breakdown of large particles within the rumen. In the present study, only 1 type of marker and 1 sampling site were used, but the behavioral data, a source of information not available to Gasa et al. (1991), provides evidence in support of the interpretation proposed by those authors. Undigested feed took longer to pass through the entire gastrointestinal tract in Holsteins compared with Jerseys, due wholly to the longer RMRT in the larger breed. The probability that the rumen is the main determinant of variations in passage rate and digestibility between the 2 breeds fits with the observed differences in eating and rumination behavior. Particle size reduction was probably more effective in Jerseys, because total chewing time per unit of DM and NDF was significantly longer when compared with Holsteins, and this is confirmed by the estimated rate of particle breakdown (k_2), which was numerically faster in Jerseys. Estimated passage rate of particles out of the rumen (k_1) was significantly higher in Jerseys, and this was due in part to their ability to reduce particle size more efficiently than Holsteins. However, particle size is not the sole determinant of passage rate out of the rumen: Poppi et al. (1980) observed that, despite a mean reticulo-omasal orifice size in cattle of 35 mm, particles larger than 1.2 mm rarely passed out of the rumen. The specific gravity of feed particles increases once fermentative activity passes its peak, and the particles subsequently sink within the rumen and pass through the reticulo-omasal orifice. Increased chewing time facilitates fermentation by increasing saliva production and by exposing a greater feed surface area to rumen microbes, thus increasing passage rate.

The tendency of the Jersey to spread feed intake more evenly throughout the day, combined with the greater chewing time per unit of DM or NDF, may also have contributed to the faster rumen passage rate by enhancing rumen motility, thus stimulating digesta passage out of the rumen. As noted by Van Soest (1994), smaller ruminants must compensate for their reduced gastrointestinal capacity, relative to their metabolic BW, either by faster digestion and passage or a more concentrated

diet. In dairy cows, including Jerseys, gut mass is proportional to BW (Brody, 1945). Therefore, the reduced retention time for digesta in Jerseys may also be attributable to a smaller, shorter digestive tract.

There are suggestions from this study that Jerseys and Holsteins partition N differently. Jerseys tended to retain more digestible N than Holsteins in the dry period and, although both breeds mobilized body N during lactation, N balance tended to be more negative in the Jerseys. Kauffman and St-Pierre (2001) observed a tendency toward lower retention of ingested and absorbed N in lactating Jerseys compared with Holsteins. The possibility that Jerseys use N less efficiently than Holsteins during lactation, and hence excrete more via the urine, suggests that the breeds would differ in their response to type and concentration of dietary protein. This may be related to differences in the dynamics of rumen digesta flow and rate of passage and may also have implications for the application of current nutritional recommendations for Holsteins to Jerseys. Further studies investigating type and concentration of dietary protein would be necessary to ascertain whether N partitioning really does differ between breeds.

Tissue energy balance remained negative for the duration of the study in both breeds, although it was considerably more negative in Holsteins in the early weeks of lactation. Rastani et al. (2001) also found that TEB was less negative in Jerseys than in Holsteins in early lactation, and in their study, Jerseys achieved energy equilibrium by wk 8 of lactation, compared with wk 11 in Holsteins. Although the diet and animal productivity levels were similar to those in the present study, milk energy output per unit of metabolic BW was lower in Jerseys than in Holsteins in the study of Rastani et al. (2001), and this was clearly responsible for the less negative energy balance in the Jerseys.

In the present study, the method of calculating TEB was based primarily on Holstein data, because appropriate information relating to Jerseys is not available. The ME required for maintenance was calculated on a metabolic BW basis (Agnew et al., 2004), which is adequate if the relationship between maintenance requirement and body size is similar in both breeds. However, of the limited research available, 1 study (Solis et al., 1988) found that maintenance requirements of nonlactating Jerseys were higher than those of larger breeds, whereas Oldenbroek (1988) suggested the opposite for lactating cows. In the present study, Holstein cows gained BW throughout the dry period measurements, but the BW of Jerseys was relatively constant. This suggests that either the maintenance energy requirement of the nonlactating Jerseys was higher or that the ME derived from the diet fed was lower for the Jerseys than for the Holsteins, although there was

no evidence of this from the measurements of whole tract digestibility of nutrients.

CONCLUSIONS

In the present study, intake capacity (kg of DMI/kg of BW) did not differ between Holstein and Jersey cows of proportionally equal milk energy production (MJ/kg of BW^{0.75}). Feed passed through the gastrointestinal tract more quickly in Jerseys compared with Holsteins, and estimated particle breakdown and subsequent passage out of the rumen were faster in Jerseys. This difference in rate of passage was associated with increased eating and rumination time per kilogram of DM or NDF consumed. Despite the faster passage time, digestibility of dietary components was similar or, in the case of NDF, higher in Jerseys compared with Holsteins. This was likely a result of differences in the eating and ruminating behavior of the 2 breeds. The distribution of meals throughout the day and increased chewing time per unit of feed consumed for Jerseys provided a more regular supply of feed to the rumen and probably stimulated saliva flow. In addition, physical constraints on the total time animals are able to spend eating and ruminating penalized Holsteins more than Jerseys, because they had a greater volume of feed to process. As a result, Jerseys were able to spend proportionally longer ruminating each unit of ingested feed, which could contribute to more effective particle size reduction, faster passage rate, and improved digestibility. The fractional utilization of digested N for body tissue retention in Jerseys differed from that of Holsteins by being higher in the dry period and lower at wk 14 after calving, suggesting differences in N utilization between the 2 breeds.

This study supports the view that Holstein-derived data is not wholly appropriate when used to formulate diets for lactating Jerseys. The potentially different protein requirements of Jerseys compared with Holsteins as they progress from late gestation into lactation, along with the observed differences in fiber digestibility, indicate that the overall lactational performance of Jerseys could be improved through appropriate modifications to overall diet composition. Finally, the greater capacity of the Jersey to utilize dietary fiber may be of increased importance in the future as fibrous by-product feedstuffs become more available.

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REFERENCES

- Agnew, R. E., T. Yan, J. France, E. Kebreab, and C. Thomas. 2004. Energy requirement and supply. Pages 11–19 in *Feed into Milk*. C. Thomas, ed. Nottingham Univ. Press, Nottingham, UK.
- Alban, L. 1995. Lameness in Danish dairy cows: Frequency and possible risk factors. *Prev. Vet. Med.* 22:213–225.
- Bradstreet, R. B. 1969. The Kjeldahl method for organic nitrogen. Acad. Press, New York, NY.
- Brody, S. 1945. *Bioenergetics and Growth*. Hafner Publ. Co., New York, NY.
- Conrad, H. R., A. D. Pratt, and J. W. Hibbs. 1964. Regulation of feed intake in dairy cows. 1. Change in importance of physical and physiological factors with increasing digestibility. *J. Dairy Sci.* 47:54–62.
- Dhanoa, M. S., R. C. Siddons, J. France, and D. L. Gale. 1985. A multicompartamental model to describe marker excretion patterns in ruminant faeces. *Br. J. Nutr.* 53:663–671.
- Dürst, B., M. Senn, and W. Langhans. 1993. Eating patterns of lactating dairy cows of three different breeds fed grass ad lib. *Physiol. Behav.* 54:625–631.
- Gasa, J., K. Holtenius, J. D. Sutton, M. S. Dhanoa, and D. J. Napper. 1991. Rumen fill and digesta kinetics in lactating Friesian cows given two levels of concentrates with two types of grass silage ad lib. *Br. J. Nutr.* 66:381–398.
- Ingvarsen, K. L., and M. R. Weisbjerg. 1993. Jersey cows have a higher feed intake capacity and higher rate of passage than Friesian cows. *Arch. Tierz.* 36:495–498.
- Kauffman, A. J., and N. R. St-Pierre. 2001. The relationship of milk urea nitrogen to urine nitrogen excretion in Holstein and Jersey cows. *J. Dairy Sci.* 84:2284–2294.
- MAFF. 1993. *Prediction of Energy Value of Compound Feedingstuffs for Farm Animals*. Booklet 1285. MAFF Publ., Alnwick, UK.
- Muller, C. J. C., and J. A. Botha. 1998. The comparative performance of primiparous Holstein Friesian and Jersey cows on complete diets during summer in a temperate climate. *S. Afr. J. Anim. Sci.* 28:161–166.
- NRC. 1988. *Nutrient Requirements of Dairy Cattle*. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
- NRC. 2001. *Nutrient Requirements of Dairy Cattle*. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
- Oldenbroek, J. K. 1988. The performance of Jersey cows and cows of larger dairy breeds on two complete diets with different roughage contents. *Livest. Prod. Sci.* 18:1–17.
- Poppi, D. P., B. W. Norton, D. J. Minson, and R. W. Hendricksen. 1980. The validity of the critical size theory for particles leaving the rumen. *J. Agric. Sci. Camb.* 94:275–280.
- Rastani, R. R., S. M. Andrew, S. A. Zinn, and C. J. Sniffen. 2001. Body composition and estimated tissue energy balance in Jersey and Holstein cows during early lactation. *J. Dairy Sci.* 84:1201–1209.
- Rodriguez, L. A., C. C. Stallings, J. H. Herbein, and M. L. McGilliard. 1997. Effect of degradability of dietary protein and fat on ruminal, blood, and milk components of Jersey and Holstein cows. *J. Dairy Sci.* 80:353–363.

- Rutter, S. M. 2000. Graze: A program to analyze recordings of the jaw movements of ruminants. *Behav. Res. Methods Instrum. Comput.* 32:86–92.
- Rutter, S. M., R. A. Champion, and P. D. Penning. 1997. An automatic system to record foraging behaviour in free-ranging ruminants. *Appl. Anim. Behav. Sci.* 54:185–195.
- SAS. 2001. Version 8.2. SAS Inst. Inc., Cary, NC.
- Sibly, R. M., H. M. R. Nott, and D. J. Fletcher. 1990. Splitting behaviour into bouts. *Anim. Behav.* 39:63–69.
- Solis, J. C., F. M. Byers, G. T. Schelling, C. R. Long, and L. W. Greene. 1988. Maintenance requirements and energetic efficiency of cows of different breed types. *J. Anim. Sci.* 66:764–773.
- Susenbeth, A., R. Mayer, B. Koehler, and O. Neumann. 1998. Energy requirement for eating in cattle. *J. Anim. Sci.* 76:2701–2705.
- Sutton, J. D., A. L. Abdalla, R. H. Phipps, S. B. Cammell, and D. J. Humphries. 1997. The effect of the replacement of grass silage by increasing proportions of urea-treated whole-crop wheat on food intake and apparent digestibility and milk production by dairy cows. *Anim. Sci.* 65:343–351.
- Thomas, C. 2004. *Feed into Milk*. Nottingham Univ. Press, Nottingham, UK.
- Tyrrell, H. F., and J. T. Reid. 1965. Prediction of the energy value of cow's milk. *J. Dairy Sci.* 48:1215–1223.
- Uden, P., P. E. Colucci, and P. J. Van Soest. 1980. Investigation of chromium, cerium and cobalt as markers in digesta rate of passage studies. *J. Sci. Food Agric.* 31:625–632.
- Van Soest, P. J. 1994. *Nutritional Ecology of the Ruminant*. 2nd ed. Cornell Univ. Press, Ithaca, NY.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Washburn, S. P., S. L. White, J. T. Green Jr., and G. A. Benson. 2002. Reproduction, mastitis and body condition of seasonally calved Holstein and Jersey cows in confinement or pasture systems. *J. Dairy Sci.* 85:105–111.
- Welch, J. G. 1982. Rumination, particle size and passage from the rumen. *J. Anim. Sci.* 54:885–894.
- Welch, J. G., A. M. Smith, and K. S. Gibson. 1970. Rumination time in four breeds of dairy cattle. *J. Dairy Sci.* 53:89–91.
- West, J. W., G. M. Hill, R. N. Gates, and B. G. Mullinix. 1997. Effects of dietary forage source and amount of forage addition on intake, milk yield, and digestion for lactating dairy cows. *J. Dairy Sci.* 80:1656–1665.