An evaluation of production efficiencies among lactating Holstein-Friesian, Jersey, and Jersey × Holstein-Friesian cows at pasture

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ABSTRACT

The objectives of this study were 1) to investigate production and energetic efficiencies among lactating dairy Holstein-Friesian (HF), Jersey (J), and Jersey × Holstein-Friesian (F₁) cows over a total lactation at pasture and 2) to measure the associations among efficiency variables and performance traits. Data from 110 cows were available (37 HF, 36 J, and 37 F₁). Breed groups were not balanced for parity; 16 HF, 10 J, and 9 F₁ were in parity 1, whereas the remainder were in parity 2. Milk production, body weight (BW), body condition score (BCS), and estimates of dry matter intake (DMI) corresponding to 51, 108, 149, 198, and 233 d in milk were available. Breed group had a significant effect on all the production parameters investigated: milk yield, solids-corrected milk (SCM), milk fat, protein and lactose concentrations, and milk solids (MLKS; fat + protein yield). Daily MLKS yield was similar for HF and J (1.33 and 1.28 kg/d, respectively). There was a tendency for F₁ (1.41 kg/d) to produce more MLKS compared with HF. The HF breed had higher BW throughout the study compared with F₁ and J. Mean BCS was higher for F₁ (3.00) and J (2.93) compared with HF (2.76). Mean DMI was similar with HF (16.9 kg) and F₁ (16.2 kg) and was lowest with J (14.7 kg). Breed group had a significant effect on all the efficiency parameters investigated: total DMI per 100 kg of BW, SCM per 100 kg of BW, MLKS per 100 kg of BW, and MLKS per total DMI, which tended to be highest for J. Production efficiency based on net energy intake per MLKS was most favorable for F₁ and J compared with HF [12.5, 13.0, and 14.1 UFL, respectively, where 1 UFL is defined as the net energy content of 1 kg of standard barley for milk production (O'Mara, 2000)]. Significant estimates of hybrid vigor were evidenced for milk yield, milk lactose content, SCM, MLKS, net energy for lactation, BW, BCS, and net energy intake per MLKS. The correlations examined indicated that

production efficiency was positively associated with MLKS yield.

Key words: Jersey, feed efficiency, crossbreeding, hybrid vigor

INTRODUCTION

Efficient conversion of feed input to product is critical to economic profitability of the dairy production business. Total feed costs account for approximately 80% of the total variable costs associated with milk production (Shalloo et al., 2004). Therefore, in theory, overall farm profit could be increased by improving cow efficiency with regard to the conversion of energy intake to milk production. Breeding objectives globally have evolved of late, with increased emphasis being placed on survival and functional (health) traits as well as on production performance (Miglior et al., 2005). Selection in dairy cattle, for the most part, has not incorporated feed intake or feed efficiency as selection traits per se, predominantly because of a lack of information on nutrient intake and utilization by individual cows (Ngwerume and Mao, 1992).

Production efficiency can be defined in various ways. Gross efficiency, a commonly used measure of efficiency for lactating dairy cows, is usually expressed as the ratio of milk yield or milk solids (MLKS; kg of fat and protein) per unit of feed intake (Lopez-Villalobos et al., 2008). Other studies use net efficiency, which represents, in some form, the ratio of milk energy to total energy intake, having accounted for the energy required for maintenance, BW change, and other energy uses (Schwager-Suter et al., 2001). Alternatively, residual feed intake (RFI), first proposed by Koch et al. (1963), is the unexplained (remaining) energy from the total net energy intake (NEI), having accounted for all net energy uses. The RFI value denotes the difference in the utilization of energy by the cow relative to the population or group mean. Usually, it is represented as the difference between actual feed intake and that predicted based on the requirements for maintenance, milk production, BW, BW change, and, where appropriate, stage of pregnancy, with a more negative value signifying greater efficiency.

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Differences in DMI and varying measures of feed conversion efficiency (**FCE**) between dairy cows of various pure breeds have been reported previously (Oldenbroek, 1988; Mackle et al., 1996; Rastani et al., 2001). Although many studies deal with comparisons between Holsteins (**H**) and Jerseys (**J**), the majority date back to the late 1980s and early 1990s (Grainger and Goddard, 2004) and few include the J $\times$ Holstein-Friesian (**F₁**). The review by Grainger and Goddard (2004) reported that in 8 out of 11 studies, pure J cows consumed more DM per 100 kg of BW compared with H or Friesian (**F**) cows. These studies represented evaluations undertaken from 14 to 300 DIM and varied from farm system comparisons over 3 yr to short-term calorimetry experiments. Furthermore, studies varied from indoor experiments, where cows were offered a TMR diet, to pasture-based environments. The mean result indicated that J cows consumed 5.1% more than H and F cows when expressed as DM per kilogram of metabolic BW. This implies that J cows have a high intake capacity per unit of BW.

Concern for decreased additive genetic merit for fertility and health within the H breed has resulted in renewed global interest in crossbreeding (Hansen, 2006; Walsh et al., 2007). In Ireland, interest in crossbreeding with J is fueled by inadequate reproductive performance within Holstein-Friesian (**HF**) herds, a need to maximize MLKS production per hectare, and, more recently, the introduction by most milk processors of a multicomponent index system of milk payment (Shalloo, 2007). A 5-yr study evaluating the performance of HF, J, and F₁ under Irish grass-based production conditions was established by Teagasc Moorepark at the Ballydague research farm in 2006. This study provided a unique opportunity to investigate the reputed feed efficiency differences between the HF and J and, importantly, their cross.

The difficulty in measuring feed intake, especially from pasture-based environments, might imply that efficiency measures, particularly RFI, may not be economically viable in dairy breeding schemes (McNaughton and Pryce, 2008). Efficiency measurements taken at one point in time, when considered over the total lactation or total lifetime, may not hold true. Because estimating feed efficiency is a costly process, it is of considerable interest to elucidate whether relationships exist between feed efficiency and traits that can be easily measured (or that are already included in selection goals), such as production potential. The objectives of this study were therefore 1) to estimate production and energetic efficiencies among lactating dairy HF, J, and F₁ cows over a total lactation at pasture and 2) to measure the associations among the efficiency variables and performance traits that might elucidate relationships

between efficiency and more easily measured traits, such as milk production.

MATERIALS AND METHODS

Data from 110 cows were available: 37 HF, 36 J, and 37 F₁. Breed groups were not balanced for parity; 16 HF, 10 J, and 9 F₁ were in parity 1, whereas the remainder were in parity 2. Mean calving date for all cows was February 18. A total of 13, 13, and 6 sires were represented in the HF, J, and F₁, respectively. All F₁ animals were sired by J bulls and out of HF cows. The HF sires were of North American HF (84%) and New Zealand (16%) origin. The proportion of HF in the trial HF cows was 89% (SD 11.3). The mean PTA (across breed) and standard deviations (in parentheses) for the HF sires used were as follows: +179 kg (110.3), +10 kg (4.7), +9 kg (3.1), +0.06% (0.11), and +0.06% (0.05) for milk yield, fat yield, protein yield, and fat and protein concentration, respectively (<http://www.icbf.com>; accessed April 2009). Comparable PTA for the J sires (SD in parentheses) were as follows: -364 kg (164), +12 kg (8), -1 kg (7), +0.59% (0.20), and +0.25% (0.08). The J sires were of New Zealand (64%) and Danish (36%) origin. Of the 13 J sires, 4 were represented in both the J and F₁ cows. These 4 sires accounted for 21 and 31 of the J and F₁ cows, respectively. All sires were representative of the sires commonly used in Ireland.

Feeding System and Cow Management

The experimental region was a permanent grassland site consisting of a sward with almost 100% perennial ryegrass (*Lolium perenne* L.). The soil type on the farm was free-draining acid brown earth of sandy loam to loam texture. Cows were turned out to grass in early February until mid-November and were housed during the winter months. A 10-wk dry period was given to first-lactation animals, whereas an 8-wk dry period was deemed sufficient for multiparous animals. During the winter, all animals were offered grass silage ad libitum and dry cow minerals at a rate of 100 g/cow per day. During the risk periods (February to May and September to November) calcined magnesite (Nutribio, Cork, Ireland) was dusted on the paddocks at a rate of 60 g/cow per day to prevent magnesium deficiency. Cows grazed as a single herd under a rotational grazing system, as described by Dillon et al. (1995). The cows were allocated fresh pasture every 24 h. Concentrate supplementation over the lactation totaled 240 kg of DM/cow, and it was offered as a supplement in early lactation until pasture growth met demand (Kennedy et al., 2007). All concentrate supplementation was offered

on a flat-rate basis in individual stalls twice daily during milking. Cows were milked twice daily at 0700 and 1545 h, with concentrates offered in 2 equal feeds on a flat-rate basis during each milking. The composition of the concentrate was citrus pulp, 300 g/kg; barley, 237 g/kg; corn (*Zea mays*) gluten feed, 213 g/kg; soybean meal, 140 g/kg; vegetable fat, 30 g/kg; caned molasses, 50 g/kg; and minerals, 30 g/kg.

Animal Measurements

Throughout the year, milk yield was recorded daily using electronic milk meters (Dairymaster, Causeway, Co. Kerry, Ireland), with milk constituents determined from successive morning and evening samples of milk taken weekly, and was analyzed using a MilkoScan 203 instrument (DK-3400, Foss Electric, Hillerød, Denmark). Individual DMI measurements were carried out using the *n*-alkane technique (Mayes et al., 1986) as modified by Dillon (1993). The procedure was carried out as described by Berry et al. (2007). Body weight was recorded weekly using a calibrated weighing scale (Dairymaster, Causeway, Co. Kerry, Ireland) and twice weekly during the measurement periods to minimize the effect of variations in gut fill. Daily BW change during the measurement periods was calculated as the difference between the BW during the week of measurement plus the previous 2 wk and the BW during the week of measurement plus the following 2 wk, divided by 14 (Buckley et al., 2000). Body condition score was measured approximately every 3 to 4 wk throughout the study (always within 1 wk of intake measurement), by a single evaluator, on a scale of 1 to 5 (with 1 being extremely thin and 5 being extremely fat) with increments of 0.25, similar to the scoring described by Lowman et al. (1976).

Sward Measurements

Throughout the grazing season, 40 pre- and post-grazing sward heights were recorded on all paddocks with a rising plate meter (Urban and Caudal, 1990). Pregrazing herbage yields (>4 cm) were determined for each paddock based on 5 quadrats (0.25 × 0.25 m) of grass cut using an electronic shears, as described by O'Donovan et al. (2002). The herbage from each cut was collected and weighed, and a subsample (approximately 100 g) was dried overnight at 60°C for DM determination. The remainder of the sample was freeze-dried and used for chemical analysis. Composites of the samples were bulked for each week of the experiment. During the intake periods, herbage samples representing the grass grazed by the animals were manually collected on d 6 to 11 to facilitate analysis by the *n*-alkane technique (Mayes et al., 1986).

Grass budgeting was carried out weekly to monitor grass growth. Pasture quality was maintained by removing surplus grass as baled silage. Average pregrazing yields (>4 cm) were 1,377 kg of DM/ha during the experimental period.

Chemical Analysis

Composite herbage samples were analyzed in vitro for ADF (Clancy and Wilson, 1966), CP, NDF, OM digestibility (Morgan et al., 1989), and ash. During the winter period, a composite sample of grass silage was analyzed for ash, CP, NDF, and modified ADF. Concentrates were sampled weekly and bulked per month and were subsequently analyzed for ash, crude fiber, CP, and NDF.

Feed Efficiency

Individual DMI was measured for each cow on 5 occasions during lactation (except for 10 late-calving cows, which had only 4 measurements during lactation)—from mid-March to mid-May (targeting each cow between 6 and 8 wk of lactation), in early June, in mid-July, in early September, and in early October—providing a total of 540 records. These estimates of DMI corresponded to 51 (SD 5.8), 108 (SD 19.2), 149 (SD 20.4), 198 (SD 21.0), and 233 (SD 20.4) DIM, respectively. With the exception of the first intake measurement for each cow, in which cows were offered 2 kg of concentrate DM/cow per day, cows were offered grass only. Based on the chemical analysis of the grass samples (representative of the grass consumed by the cows), the concentrations of net energy in the grass (UFL/kg of DM) were 1.06 for March, April, and May; 1.09 for June and July; 1.08 for September; and 1.01 for October, where 1 UFL is defined as the net energy content of 1 kg of standard barley for milk production (O'Mara, 2000). The net energy value of the concentrates offered was 1.20 UFL/kg of DM.

Solids-corrected milk yield (kg) was calculated as described by Tyrrell and Reid (1965). The measures of gross efficiency calculated were as follows: MLKS (kg/100 kg of BW), SCM (kg/100 kg of BW), MLKS (kg/kg of DMI), and total DMI (**TDMI**/100 kg of BW). Energetic efficiencies examined included NEI/MLKS, indicating the energy required to produce 1 kg of MLKS; $(NEI - NE_M)/MLKS$, representing the energy required to produce 1 kg of MLKS after accounting for NE_M ; and $[NEI - (NE_M + \Delta NE_M)]/MLKS$, representing the energy required to produce 1 kg of MLKS after adjusting the energy requirements for maintenance and BW change. Energy balance (**EB**) was defined as the difference between energy intake and energy required

Table 1. Pre- and postgrazing sward surface heights, pregrazing herbage yield, and chemical composition of herbage offered

Item	Mean	SD
Pregrazing sward surface height (cm)	11.4	1.60
Postgrazing sward surface height (cm)	5.1	0.76
Pregrazing herbage yield (kg of DM/ha)	1,377	306.6
CP (g/kg of DM)	199.5	11.55
ADF (g/kg of DM)	218.9	26.62
OM digestibility (g/kg of OM)	809.1	69.7
NDF (g/kg of DM)	435.1	34.2

for production, maintenance, and BW change (Faverdin et al., 2007).

Residual feed intake was estimated by regressing energy intake on its assumed components:

$$Y = \beta_0 + \beta_1 (\text{SCM}) + \beta_2 (\text{BW}^{0.75}) + \beta_3 (\text{ADG}) \\ + \beta_4 (\text{BCS}) + \text{RFI}.$$

The BCS nearest the week of intake measurement was included in the model based on the findings of Yan et al. (2006), who showed that BCS influenced the energy requirement for maintenance.

Statistical Analysis

The lactation was subsequently divided into 6 stages: fewer than 61 DIM, 60 to 121 DIM, 120 to 161 DIM, 160 to 191 DIM, 190 to 231 DIM, and greater than 230 DIM. The data were analyzed using the MIXED procedure of SAS (version 9.1; SAS Institute Inc., Cary, NC). The linear model included the fixed effects of breed group (HF, J, and F₁), parity, and lactation stage. Calving day of year was fitted as a continuous covariate. Cow was included as a random repeated effect. A compound symmetry structure for the residuals was determined using Akaike's information criterion as the most appropriate residual covariance structure for repeated measures over time within cows. Multiple comparisons were adjusted using the Bonferroni test. A contrast statement in the MIXED procedure was used to determine if significant differences existed between the F₁ and the HF and J (midparent mean). Partial Pearson correlations between variables while adjusting for breed group, parity, lactation stage, and calving day of year were determined within and across breed groups using the CORR procedure of SAS.

RESULTS

Feed Analysis and Sward Measurements

Annual pasture growth was measured using 650 kg of nitrogen fertilizer/ha, as described by Corral and

Figure 1. Daily herbage growth rates at Moorepark: 1997 to 2006 and 2007.

Fenlon (1978). This experiment was conducted nearby at Moorepark Dairy Production Research Centre (Fermoy, Co. Cork, Ireland; 50°09' N; 8°16' W). Total grass production averaged 14.7 tonnes of DM/ha, compared with 15 tonnes for the average of 1997 to 2006. Hence, total grass production was typical of a normal year (Figure 1). Table 1 shows the pre- and postgrazing heights, pregrazing yield, and chemical analysis of the grass offered during the measurement periods. Table 2 shows the chemical composition of the sward deemed to have been selected by the animals.

Milk Production and Composition

The effect of dairy cow breed on mean milk production performance across the 6 stages of lactation is presented in Table 3. Breed group had a significant effect on all the production parameters investigated: yield of milk ($P < 0.01$); fat and protein yield ($P < 0.01$; MLKS); and milk fat ($P < 0.001$), protein ($P < 0.001$), and lactose yield ($P < 0.01$). Milk yield was highest with HF (18.3 kg/d) and lowest with J (13.8 kg/d). Milk yield of F₁ was intermediate, at 16.7 kg/d. Milk fat and protein contents were highest ($P < 0.001$) with J (5.33 and 4.06%), intermediate with F₁ (4.75 and 3.84%), and lowest with HF (3.96 and 3.49%). Lactose content was higher for F₁ (4.60%) than for HF (4.49%).

Table 2. Chemical composition of herbage sampled to represent that selected by the animals

Item	Mean	SD
CP (g/kg of DM)	208.3	31.1
ADF (g/kg of DM)	223.7	28.1
OM digestibility (g/kg of OM)	908.4	18.4
NDF (g/kg of DM)	373.5	25.1

Table 3. Effect of dairy cow breed¹ on mean daily milk production performance and lactation energy requirements

Trait	Breed group			SEM ²	P-value
	HF	J	F ₁		
Milk yield (kg)	18.3 ^a	13.8 ^b	16.7 ^c	0.32	<0.01
Fat (%)	3.96 ^a	5.33 ^b	4.75 ^c	0.07	<0.001
Protein (%)	3.49 ^a	4.06 ^b	3.84 ^c	0.03	<0.001
Lactose (%)	4.49 ^a	4.53 ^{ab}	4.60 ^b	0.02	<0.01
Yield of milk solids (kg)	1.33 ^{ab}	1.28 ^a	1.41 ^b	0.02	<0.01
SCM (kg)	16.9 ^a	15.7 ^b	17.5 ^a	0.30	<0.05
NE _L (UFL ³)	8.11 ^a	7.45 ^b	8.32 ^a	0.14	<0.01

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹HF = Holstein-Friesian; J = Jersey; F₁ = Jersey × Holstein-Friesian.

²SEM = pooled SEM.

³One UFL is defined as the net energy content of 1 kg of standard barley for milk production (O'Mara, 2000).

Lactose content for J (4.53%) was intermediate. Production of SCM was similar for F₁ and HF (17.5 and 16.9 kg/d, respectively) and lowest for J (15.7 kg/d; $P < 0.01$). Daily MLKS production was similar for HF and J (1.33 and 1.28 kg/d, respectively). There was a tendency, however, for F₁ (1.41 kg/d) to produce more MLKS ($P = 0.094$) compared with HF. Corresponding NE_L requirements for milk production were similar for F₁ and HF and were lowest for J, at 8.32, 8.11, and 7.45 UFL, respectively ($P < 0.01$). Hybrid vigor was estimated at 0.69 kg/d ($P = 0.072$), 0.09% ($P < 0.01$), 1.25 kg/d ($P < 0.001$), 0.10 kg/d ($P < 0.001$), and 0.54 UFL/d ($P < 0.01$) for milk yield, milk lactose content, SCM, MLKS, and NE_L, respectively.

BW and BCS

The HF breed had significantly higher BW throughout the study compared with the F₁ and J breeds ($P < 0.001$). Body weight was 498, 369, and 448 kg for HF, J, and F₁, respectively (Table 4). Body weight change was similar for the 3 breed groups, corresponding to energy requirements of 1.35, 0.78, and 1.11 UFL for HF, J, and

F₁, respectively. Mean BCS was significantly higher ($P < 0.001$) for F₁ (3.00) and J (2.93) compared with HF (2.76). Hybrid vigor was estimated at 15 kg ($P < 0.01$) for BW and 0.16 ($P < 0.001$) for BCS.

TDMI and Efficiency Parameters

Breed group had a significant effect ($P < 0.001$) on TDMI (Table 5) across the different stages of lactation ($P < 0.001$). Intake was similar for HF (16.9 kg) and F₁ (16.2 kg) and was lowest for J (14.7 kg). These intakes corresponded to NEI values of 17.8, 15.6, and 17.1 UFL for HF, J, and F₁, respectively.

Dairy cow breed had a significant effect on all the gross efficiency parameters investigated (Table 5): TDMI per 100 kg of BW ($P < 0.01$), SCM per 100 kg of BW ($P < 0.01$), MLKS per 100 kg of BW ($P < 0.001$), and MLKS/TDMI ($P < 0.001$). Estimated TDMI/100 kg of BW was highest with J (3.99 kg), lowest with HF (3.39 kg), and intermediate with F₁ (3.63 kg). Production of SCM per 100 kg of BW was highest with J, intermediate with F₁, and lowest with HF (4.30, 3.95, and 3.41 kg, respectively). Similarly, the highest yield

Table 4. Effect of dairy cow breed¹ on mean BW, energy required for maintenance, BW change, and BCS

Trait	Breed group			SEM ²	P-value
	HF	J	F ₁		
BW (kg)	498 ^a	369 ^b	448 ^c	4.68	<0.001
NE _M (UFL ³)	5.18 ^a	4.14 ^b	4.79 ^c	0.04	<0.001
BW change (kg/d)	0.27	0.14	0.21	0.05	NS
ΔNE _M (UFL)	1.35	0.78	1.11	0.17	NS
BCS	2.76 ^a	2.93 ^b	3.00 ^b	0.03	<0.001

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹HF = Holstein-Friesian; J = Jersey; F₁ = Jersey × Holstein-Friesian.

²SEM = pooled SEM.

³One UFL is defined as the net energy content of 1 kg of standard barley for milk production (O'Mara, 2000).

Table 5. Effect of dairy cow breed¹ on total DMI, corresponding energy intake, and gross efficiency measures

Trait	Breed group			SEM ²	P-value
	HF	J	F ₁		
Total DMI (kg)	16.9 ^a	14.7 ^b	16.2 ^a	0.23	<0.001
Energy intake (UFL ³)	17.8 ^a	15.6 ^b	17.1 ^a	0.24	<0.001
TDMI ⁴ /100 kg of BW (kg)	3.39 ^a	3.99 ^b	3.63 ^c	0.05	<0.01
SCM/100 kg of BW (kg)	3.41 ^a	4.30 ^b	3.95 ^c	0.07	<0.01
Milk solids/100 kg of BW (kg)	0.27 ^a	0.35 ^b	0.32 ^c	0.06	<0.001
Milk solids/TDMI (kg)	0.079 ^a	0.088 ^b	0.087 ^b	0.0011	<0.001

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹HF = Holstein-Friesian; J = Jersey; F₁ = Jersey × Holstein-Friesian.

²SEM = pooled SEM.

³One UFL is defined as the net energy content of 1 kg of standard barley for milk production (O'Mara, 2000).

⁴TDMI = total DMI.

of MLKS per 100 kg of BW was achieved by J, at 0.35 kg/100 kg of BW. The HF breed had significantly lower output of MLKS per 100 kg of BW compared with F₁ ($P < 0.001$; 0.27 and 0.32 kg, respectively). Production expressed as MLKS/TDMI was more favorable for J and F₁ (0.088 and 0.087 kg/kg) than for HF (0.079 kg/kg; $P < 0.001$).

Estimates of EB were similar for HF, J, and F₁ (4.19, 3.72, and 3.71 UFL, respectively; Table 6). Estimated RFI was not different across the breed groups. Production efficiency expressed as NEI/MLKS was more favorable ($P < 0.05$) for F₁ and J compared with HF (12.5, 13.0, and 14.1 UFL, respectively). Adjustment for maintenance ($P < 0.01$) and, subsequently, energy required for BW change ($P < 0.01$) were more favorable for F₁ than for HF, with J similar to both breeds. Hybrid vigor was estimated at 0.003 kg/kg ($P < 0.05$), -1.05 UFL/d ($P < 0.01$), -0.07 UFL/d ($P < 0.01$), and -0.66 UFL/d ($P < 0.05$) for MLKS/TDMI, NEI/MLKS, (NEI – NE_M)/MLKS, and [NEI – (NE_M + Δ NE_M)/MLKS], respectively.

Correlations

Correlations between the various animal performance and efficiency variables across the 3 breed groups are presented in Table 7. Milk yield was positively associated with MLKS yield, SCM per 100 kg of BW, MLKS per 100 kg of BW, MLKS/TDMI, and NEI/MLKS. Moderate correlations were obtained between milk yield, BW, TDMI, and TDMI per 100 kg of BW. Similarly, MLKS was positively correlated with SCM per 100 kg of BW, MLKS per 100 kg of BW, and MLKS/TDMI. Weak correlations between BW and all the variables investigated were evident. Weak associations between RFI and all other variables were also observed.

DISCUSSION

The chemical analysis of the feeds and the grazing measurements are typical of a spring production system in Ireland. The chemical analysis of the herbage offered (Table 1) and assumed to have been selected (Table

Table 6. Effect of dairy cow breed¹ on energy balance, residual feed intake (RFI), and net energy intake (NEI) per unit of milk solids (MLKS) production

Trait	Breed group			SEM ²	P-value
	HF	J	F ₁		
Energy balance (UFL ³)	4.19	3.72	3.71	0.15	NS
RFI (UFL)	–0.28	0.10	–0.32	0.17	NS
NEI/MLKS (UFL)	14.1 ^a	13.0 ^b	12.5 ^b	0.32	<0.05
(NEI – NE _M)/MLKS (UFL)	9.8 ^a	9.3 ^{ab}	8.8 ^b	0.23	<0.01
[NEI – (NE _M + Δ NE _M)/MLKS] (UFL)	8.7	8.5	7.9	0.27	NS

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Holstein-Friesian = HF; Jersey = J; Jersey × Holstein-Friesian = F₁.

²SEM = pooled SEM.

³One UFL is defined as the net energy content of 1 kg of standard barley for milk production (O'Mara, 2000).

2), pregrazing yield, and postgrazing sward surface heights clearly indicated that sufficient quantities of high-quality pasture were allocated to the animals over the course of the experiment (O'Donovan et al., 2004).

Animal Performance Characteristics

In the current study, differences in milk yield and milk composition (in particular, fat and protein concentrations) were apparent between HF and J. Such differences were expected based on previous studies. Mackle et al. (1996) reported higher milk yields for F, whereas milk fat and protein contents were highest with J. Oldenbroek (1988) reported milk yields of 6,432 and 3,872 kg for H and J cows, respectively, offered a complete diet (roughage with 50% concentrates on a DM basis). In that study, milk fat and protein concentrations were significantly higher with J (69.1 and 42.1 g/kg) compared with HF (40.9 and 33.8 g/kg). Auldist et al. (2007) showed that F₁ (J × H) cows had a lower daily milk yield with higher milk contents compared with H. More recently, Heins et al. (2008) reported milk yields of 4,644 and 4,388 kg over the first half of lactation for H and F₁ (J × H), respectively, although 147-d fat plus protein yield was similar for both breeds (302 and 309 kg). The current study indicates that hybrid vigor between the J and HF breeds exists for milk yield traits. This is in line with the findings of Ahlborn-Breier and Hohenboken (1991), who reported hybrid vigor influencing milk yield and milk fat yield. However, the authors do acknowledge the limited nature of their study with regard to drawing strong conclusions.

In the current study, BW differences were consistent with the findings of Washburn et al. (2002), who reported BW of 568 and 387 kg for lactating H and J cows at pasture. Both Heins et al. (2008) and Auldist et al. (2007) reported BW differences of 33 and 40 kg, respectively, between H and F₁ cows. In the present study, HF cows weighed 50 kg more than F₁ and 129 kg more than J. Hybrid vigor was estimated at 3.2%, or an additional 15 kg. This also concurs with the findings of Lopez-Villalobos et al. (2000), who reported estimates for BW of 7.7 kg for F₁ (J × H) in New Zealand. Similarly, in the current study, the J and F₁ cows were found to maintain higher BCS compared with the HF cows. Hybrid vigor, estimated at 0.16 units of BCS or 5%, was observed. Washburn et al. (2002) also found that J cows maintained higher BCS relative to H cows during lactation. Auldist et al. (2007) reported that F₁ cows in their study had higher BCS compared with H cows.

Intake and Feed Efficiency

A justification for the use of the *n*-alkane technique to predict herbage intake has been presented by Dove

Table 7. Correlations between various animal performance and efficiency variables across the 3 breed groups^{1,2}

Item	MLKS	BW	TDMI	SCM/100 kg of BW	MLKS/100 kg of BW	TDMI/100 kg of BW	MLKS/TDMI	RFI	NEI/MLKS	(NEI - NE _M)/ MLKS
Milk yield	0.80 (<0.001)	0.54 (<0.001)	0.55 (<0.001)	0.32 (<0.001)	0.25 (<0.001)	-0.01 (NS)	0.32 (<0.001)	-0.09 (<0.05)	-0.36 (<0.001)	-0.33 (<0.001)
MLKS (kg)		0.30 (<0.001)	0.50 (<0.001)	0.67 (<0.001)	0.64 (<0.001)	0.19 (<0.001)	0.58 (<0.001)	-0.07 (NS)	-0.54 (<0.001)	-0.48 (<0.001)
BW			0.51 (<0.001)	-0.46 (<0.001)	-0.50 (<0.001)	-0.49 (<0.001)	-0.15 (<0.001)	0.02 (NS)	0.05 (NS)	0.01 (NS)
TDMI				0.04 (NS)	0.03 (NS)	0.48 (<0.001)	-0.38 (<0.001)	0.30 (<0.001)	0.11 (<0.001)	0.23 (<0.001)
SCM/100 kg of BW					0.99 (<0.001)	0.51 (<0.001)	0.68 (<0.001)	-0.09 (<0.05)	-0.51 (<0.001)	-0.44 (<0.001)
MLKS/100 kg of BW						0.55 (<0.001)	0.66 (<0.001)	-0.07 (NS)	-0.51 (<0.001)	-0.43 (<0.001)
TDMI/100 kg of BW							-0.24 (<0.001)	0.30 (<0.001)	0.06 (NS)	0.22 (<0.001)
MLKS/TDMI								-0.35 (<0.001)	-0.67 (<0.001)	-0.71 (<0.001)
RFI									0.28 (<0.001)	0.33 (<0.001)
NEI/MLKS										0.98 (<0.001)

¹Correlations presented are significantly different from zero ($P < 0.05$); NS = ($P > 0.05$).

²MLKS = milk solids; TDMI = total DMI; RFI = residual feed intake; NEI = net energy intake.

and Mayes (1991) and Berry et al. (2000). The assumption in the current study is that the technique is equally effective across breeds. A difference of 13% in TDMI was observed between HF and J, with F_1 , on average, having a 4% lower intake (though not significant) compared with HF. This is consistent with the findings of L'Huillier et al. (1988), who reported that J cows consumed 12% less DM than F cows when allocated 20 kg of DM/cow per day at pasture. Mackle et al. (1996) observed an 18% difference in TDMI between HF and J cows, also under grazing conditions. More recently, a TMR study by Rastani et al. (2001) reported a difference of 26% in DMI between J and H for the first 120 d of lactation. Heins et al. (2008) presented data in which F_1 ($J \times H$) cows had intakes similar to those of pure H cows (22 and 22.7 kg, respectively). In that study, cows were individually offered a TMR diet from d 4 to 150 of lactation. González-Verdugo et al. (2005) reported similar DMI for H and F_1 at pasture. These findings are also consistent with those of the current study, in which the DMI of F_1 were similar to those of HF in a pasture-based environment.

Although J cows tend to have a reduced size (BW) and production compared with HF, J cows have the ability to achieve a higher intake per unit of BW. Mackle et al. (1996) reported that F cows had a higher intake per day compared with J cows throughout lactation, but that J cows of high and low calving BW consumed 2.4 and 5.4% more DM per 100 kg of BW, respectively. The results from the current study concur that J has a higher intake capacity compared with HF. Kolver et al. (2002) reported that in grazing systems, daily feed intake is often limited to that achievable on concentrate plus conserved forage rations. Thus, although not a measure of efficiency per se, cows suited to grazing environments must be capable of achieving a high intake per unit of BW (Buckley et al., 2005). In such systems, cows must meet their energy requirements from pasture relative to their genetic potential for milk production. Berry et al. (2009) described the robustness of a dairy cow as the ability of the animal to remain close to nutritional homeostasis or to minimize the extent and duration of EB. The higher intake per unit of BW on behalf of J may be explained by the greater weights of their gastrointestinal tracts relative to HF (Smith and Baldwin, 1974). Malcolm and Grainger (2005) concluded that J cows consumed more DM per kilogram of BW than did H and F cows (14.4% for the United States and 7.6% more for New Zealand). Anderson et al. (2007) reported DMI as a percentage of BW of 4% for HF and 4.3% for F_1 and J. Heins et al. (2008) found similar DMI as a percentage of BW for F_1 and H (4.7 and 4.5%, respectively).

High intake per unit of BW, together with low BW, facilitated higher output per unit of intake for both J and F_1 compared with HF in the present study. Grainger and Goddard (2004) showed that in 8 out of 11 studies, J cows had an average of 23% higher MLKS per unit of BW compared with HF cows. The current study is the first to present evidence of hybrid vigor for production per unit of BW. Buckley et al. (2007) reported a higher production of MLKS/TDMI for the HF, Montbeliarde $\times$ HF, and Norwegian Red (0.146, 0.142, and 0.149, respectively) when compared with pure Montbeliarde and Normande (0.132 and 0.125, respectively).

Veerkamp et al. (1995) argued that gross efficiency is a ratio of 2 quantities, implying that cows with a low MLKS output or a high DMI may have low FCE. Furthermore, gross efficiencies do not apportion the energy requirements to the separate functions (maintenance, lactation, body tissue gain, pregnancy, etc.). Berry (2009) pointed to disadvantages with ratio measures from the perspective of selection procedures. Residual feed intake accounts for maintenance, metabolic BW, ADG, and SCM for the animal relative to the population or group mean. Although RFI is viewed as a very suitable or appropriate trait to characterize feed efficiency with beef cattle, from a dairy perspective it poses enormous difficulty. For example, dairy cows mobilize body reserves in early lactation (Buckley et al., 2003) and replenish these reserves to varying degrees in late lactation or in the dry period. Large data sets would appear to be required to observe statistically relevant differences between strains or breeds. Furthermore, highly efficient dairy cows from an RFI perspective, in fact, may not be the most efficient from a production efficiency (input per saleable output) and, consequently, a profit perspective unless restricted to high-yielding cows. Nor might they be most suited to a seasonal grass-based system (Buckley et al., 2005, 2007). In any case, no difference in RFI was observed in the current study despite the diverse nature of the breed groups under investigation. The large standard error observed for RFI may simply imply that a data set larger than the one available in the current study is required to truly determine whether differences in RFI exist between the breed groups investigated.

From a practical perspective, a key determinant of production efficiency must be NEI per unit of MLKS produced (or indeed per unit of milk volume where fluid milk is the preferred output) or, broadly reversed, MLKS output per unit of intake. Results from the current study suggest that J and F_1 ($J \times HF$) cows require approximately 8 and 11% less energy, respectively, to produce 1 kg of MLKS compared with HF cows. Schwager-Suter et al. (2001) also investigated differences in

net energetic efficiency for H, J, and F_1 ($J \times H$) cows. In that study, net energy efficiency was calculated as the ratio of milk energy to total NEI after subtracting energy utilized for maintenance and body tissue change. Results from that study indicated that F_1 ($J \times H$) cows had a higher ECM-to-NEI ratio compared with those of the HF and J breeds. Furthermore, in the current study, evidence of hybrid vigor is presented for NEI per unit of MLKS (even when adjusted for NE_M and ΔNE_M), resulting in at least parity with the pure J cows.

To improve feeding system efficiency, a sound understanding of the concepts and errors associated with FCE are important (Beever and Doyle, 2007). A robust uniform approach would be most desirable. Practically, it is difficult to gather information on feed efficiency. Therefore, variables that can be correlated with feed efficiency and easily measured may be used to select indirectly for feed efficiency. Buckley et al. (2007) reported that the greatest efficiency in terms of MLKS per 100 kg of BW was achieved by HF, Montbeliarde $\times$ HF, and Norwegian Red, at 0.43, 0.41, and 0.42 (high-producing cows), respectively, compared with Montbeliarde, Normande, and Normande $\times$ HF, at 0.37, 0.33, and 0.39, respectively. This seems to comply with the hypothesis that high-yielding animals or breeds are more efficient (McNaughton and Pryce, 2008), suggesting that selection for high MLKS yield (more especially when a negative weighting is placed on milk volume, BW, or both); for example, in the New Zealand selection index, breeding worth will increase feed efficiency. The correlations measured throughout lactation in the current study indicate that increased MLKS yield is associated with higher gross efficiency measures, but also favorable production efficiency measures (NEI/MLKS and $NEI - NE_M$ /MLKS). However, correlations between MLKS and gross efficiency measures are likely to be affected by part-whole relationships (Berry, 2009). No clear relationship is apparent between BW per se and any of the measures investigated, indicating that across the current data set, efficiency was independent of animal size. In contrast, Dickinson et al. (1969) found negative correlations between feed efficiency (energy in milk/energy in feed) and BW in first-lactation animals.

CONCLUSIONS

Dairy systems in which pasture environments are core to production are dependent on cows achieving high DMI per unit of BW, with high MLKS production per unit of intake. The results from this study indicate that differences in animal production performance characteristics—milk yield and milk composition, BW, BCS, and TDMI—exist between the HF and J breeds. The reputed superior intake per unit of BW and gross production efficiency characteristics of J were

also confirmed in this study. The results also indicate that crossing HF with J will result in cows very suited to grazing systems, as evidenced by the high intake capacity at pasture, with the added benefit of improved production and feed efficiency. This is borne out of additive genetic improvement caused by the superiority of the J breed compared with the HF breed in this regard, but is also contributed to by hybrid vigor and the complementarity of the 2 breeds.

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