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Comparative performance and economic appraisal of Holstein-Friesian, Jersey and Jersey×Holstein-Friesian cows under seasonal pasture-based management

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The objective of this study was to provide comparative performance data for Holstein-Friesian (HF), Jersey (J) and Jersey×Holstein-Friesian (F_1) cows under a seasonal pasture-based management system and to simulate the effect of cow breed on farm profitability. Data for a total of 329 lactations, from 162 (65 HF, 48 J and 49 F_1) cows, were available. Milk yield was highest for HF, intermediate for F_1 and lowest for J, while milk fat and protein concentrations were highest for J, intermediate for F_1 and lowest for HF. Yield of fat plus protein was highest for F_1, intermediate for HF and lowest for J. Mean bodyweight was 523, 387 and 466 kg for HF, J and F_1, respectively. Body condition score was greater for the J and F_1 compared to HF. Reproductive efficiency was similar for the HF and J but superior for the F_1. The Moorepark Dairy Systems Model was used to simulate a 40 ha farm integrating biological data for each breed group. Milk output was highest for systems based on HF cows. Total sales of milk solids and, consequently, milk receipts were higher with J and F_1 compared to HF. Total costs were lowest with F_1 cows, intermediate with HF and highest with J. Overall farm profitability was highest with F_1 cows, intermediate with HF and lowest with J. Sensitivity analysis of milk price, fat to protein price ratio and differences in cost of replacement heifers showed no re-ranking of the breed groups for farm profit.

Keywords: crossbreeding; Jersey; profitability

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Introduction

Ninety-five percent of annual grass growth in Ireland occurs between March and October. Hence, dairy production in Ireland is highly seasonal with 75% of milk supplied between April and September, and 79% of dairy calves are born between January and April (Berry *et al*. 2006). Such seasonal systems are highly dependent on cows achieving a high pregnancy rate within a short time interval following the start of the breeding period (Dillon *et al*. 2003). Breeding programmes in the US have had a considerable global impact on breeding policies. This dominance, due to an unrivalled propensity to produce high milk volume, resulted in a dramatic increase in the proportion of North American Holstein-Friesian (HF) ancestry in dairy cows globally, increasing from 8% in 1990 to 63% in 2001 in the Irish dairy herd (Evans *et al*. 2004), and increasing from 2% in 1978 to 50% in 2002 in New Zealand (Harris and Winkleman 2000; cited by Buckley, Holmes and Keane 2005). However, intense selection for milk yield has resulted in well documented adverse effects on reproductive performance (Royal *et al*. 2000; Pryce and Veerkamp 2001; Evans *et al*. 2002), particularly in seasonal production systems. Nowadays, more balanced breeding objectives are in place, incorporating survival and functional traits, as well as production traits (Miglior, Muir and Van Doormaal 2005). Thus, in Ireland, the economic breeding index (EBI; weighting in parentheses) includes milk production (0.38), fertility (0.35), calving performance (0.10), beef performance (0.07), health (0.04) and maintenance (0.06) (ICBF 2011).

Until relatively recently, crossbreeding was considered to offer little advantage to dairy producers, most likely due to the lower milk production potential of the main alternative breeds compared to HF. However, increased awareness of the importance of functional traits, particularly fertility, has led many dairy producers to include crossbreeding in their breeding plan. Crossing HF with another dairy breed can lead to improved economic efficiency via the introduction of favourable genes, the removal of negative effects associated with inbreeding depression and capitalising on hybrid vigour (Begley, Pierce and Buckley 2009). In Ireland, increasing interest in crossbreeding followed findings from the studies of Walsh *et al*. (2008) and Begley *et al*. (2009). The popularity of crossbreeding in New Zealand is attributed to high productivity in pasture-based systems (Penno 1998), superior reproductive performance (Auldist *et al*. 2007), longer survival (Harris *et al*. 1999) and consequential benefits in terms of profit (Lopez-Villalobos *et al*. 2000). Consequently, crossbred cows (Jersey×HF; F_1) now account for a significant proportion (33%) of the national herd in New Zealand (LIC 2008).

Specifically, the Jersey (J) breed would appear to offer potential for crossbreeding under Irish conditions; with its suitability to intensive grazing systems (Penno 1998; Prendiville *et al*. 2010), the prospect of improved reproductive performance and concentration of milk solids, particularly now given the introduction of multi-component pricing systems of payment. The Irish Cattle Breeding Federation (ICBF) has across-breed evaluations in place. However, a general coefficient of hybrid vigour for each animal is applied and issues such as low reliability of predicted transmitting ability (PTA) estimates exist for many of the J bulls available. It is essential, within the context of the seasonal calving system, to ascertain whether differences in profit generating capability exist between the current-day Holstein-Friesian and crossbred types.

From a practical perspective interest is specifically in crosses between other dairy breeds and Holstein-Friesian, which currently account for 94% of dairy females in Ireland (ICBF 2009). The objective of this study was to provide comparative performance data for HF, J and F_1 cows under seasonal pasture-based management and to model the breed effects on overall farm profitability.

Materials and Methods

The study was conducted at the Ballydague research farm (52°08'N, 8°26'W) from 2006 to 2008. A total of 329 lactations were available, involving 162 (65 HF, 48 J and 49 F_1) cows. The number of lactations for HF, J and F_1 cows were 112, 106 and 111, respectively. Across the 3 years a total of 16, 18 and 9 sires were represented in the HF, J and F_1 groups, respectively. All F_1 animals were sired by J bulls. Eight J sires were common to both J and F_1 cows and accounted for 58% and 90% of the J and F_1 animals, respectively. The weighted mean (s.d.) PTA for the HF sires, accounting for the number of daughters in the herd, for yield (kg) of milk, fat and protein, the concentrations (g/kg) of fat and protein, calving interval (days) and survival (%) were: +189 (93.8), +10 (4.5), +9 (2.9), +5.4 (1.08), +5.8 (0.48), −0.80 (2.990) and 0.96 (1.800), respectively (www.ICBF.com, August 2011). Corresponding values for the J sires were: −319 (108.1), +14 (6.5), +1 (4.8), +5.7 (1.43), +2.6 (0.70), −5.11 (2.069) and 3.37 (1.139), respectively. The corresponding mean values for EBI and sub-indices for milk, fertility, calving, beef, health and maintenance for the HF sires were: €78, €52, €21, €16, €-12, €-2 and €2, respectively, and for J sires were: €153, €52, €101, €6, €-66, €-3 and €63, respectively. All sires were available in Ireland. The EBI and sub-indices for milk, fertility, calving, beef, health and maintenance for the cows in the current study were: €82, €41, €34, €16, €-7, €-1 and €1, respectively, for HF; €139, €31, €108, €5, €-63, €-3 and €61, respectively, for J and €134, €56, €69, €15, €-36, €-2 and €31, respectively, for F_1.

Cow management

The cows were managed on a permanent grassland site consisting of a sward with almost 100% perennial ryegrass (*Lolium perenne*). The soil type on the farm is a free draining acid brown earth of sandy loam to loam texture. Cows were turned out to grass from early February, remained at pasture until mid-November, and were housed during the winter months. For the first 2 years of the study cows were grazed as a single herd under a rotational grazing system similar to that described by Dillon *et al*. (1995). Cows were allocated to fresh pasture every 24 h. In mid-April of year 1, cows (within breed group) were randomly assigned to one of two grass-based feeding systems (high and low concentrate allowance; HC and LC, respectively) based on calving date, pre-experimental yield of milk solids (mean of 2 weeks) and body weight. Concentrate supplementation per cow, on a dry matter (DM) basis, was 658 and 1072 kg for the LC and HC groups, respectively. In year 2, all cows were managed in the same system as the LC treatment of year 1, but concentrate DM input averaged only 240 kg per cow. Concentrate supplementation was greater in year 1 due to a prolonged period of moisture deficit on the farm during the summer. In year 3, cows were randomly assigned, within breed, to a 3×3 factorial experiment involving the HF, J and F_1 breed groups under three stocking rate systems. Concentrate DM input averaged 352 kg per cow and was similar across all treatment groups. The HF and F_1 animals were stocked at 2.5, 2.75 and 3.0 per hectare for the low stocking rate (LS), medium stocking rate (MS) and high stocking rate (HS), respectively. The corresponding stocking rates for J cows were 2.75, 3.0 and 3.25 per hectare. Variations in stocking rate were based on the differences in DM intake between the breed groups reported by Prendiville, Pierce and Buckley (2009). Concentrate ingredient composition (g/kg) was similar in each year of the study: citrus pulp 300, barley 237, corn (*Zea mays*) gluten feed 213, soybean meal 140, vegetable fat 30, caned molasses 50 and minerals 30.

During the winter non-lactating period, animals were housed in either a conventional indoor housing system or on one of three types of out-wintering pad: an uncovered pad, a covered pad (both having a concrete standing area with a feeding barrier) or an uncovered pad with access to a self-feed silage pit (O'Driscoll *et al*. 2008). Animals were randomly assigned to one of these wintering facilities based on breed group, expected calving date, body weight (BW) and body condition score (BCS). Primiparous cows were allowed a 10 week dry period while an 8 week period was deemed sufficient for multiparous cows. All cows were dried off by mid-December. All animals were offered grass silage *ad libitum* during winter plus dry cow minerals at a rate of 100 g/day. When deemed necessary during February to May and September to November, calcined magnesite (Nutribio, Cork, Ireland) was dusted on the paddocks to prevent magnesium deficiency. Cows were milked twice daily (0700 and 1545) and concentrates, when required, were offered in two equal feeds, one at each milking.

Animal measurements

Milk yield was recorded daily throughout the study using electronic milk meters (Dairymaster, Causeway, Co. Kerry, Ireland). Milk composition was determined weekly from successive morning and evening milk samples using a Milkoscan 203 (Foss Electric, DK-3400 Hillerød, Denmark). Milk fat to protein ratio was calculated on the basis of total lactation yields. Solids corrected milk yield (SCM) was calculated as described by Tyrrell and Reid (1965). Body weight was recorded weekly using a calibrated weighing scale (Dairymaster, Causeway, Co. Kerry, Ireland) and BCS was assessed every 3 to 4 weeks on a scale of 1 to 5 (1 being extremely thin and 5 being extremely fat, with increments of 0.25) as described by Lowman, Scott and Sommerville (1976).

Due to an outbreak of bovine viral diarrhoea, the reproductive data from year 3 were not included in the analysis. However, reproductive performance in 2009 was available and was included as a third year's data. The management practices in 2009 were as described for 2008. Breeding commenced in late April each year and lasted for 13 weeks; tail paint was used to aid heat detection. Cows were artificially inseminated (AI) by the same experienced technician throughout the study. Semen from 2 straws per bull was examined before the breeding season to ensure the use of semen with good sperm motility as well as with a high proportion of live sperm. Only bulls found to have semen with greater than 50% sperm motility and greater than 60% live sperm were used in AI. Holstein-Friesian cows were inseminated with semen from either HF or J bulls, while J cows were inseminated with J semen (common to that used on the HF). The F_1 cows were inseminated with semen from F_1 bulls in 2006 and 2007 and semen from Norwegian Red bulls in 2009. Four bulls per breed were used each year, on average. Cows not observed in oestrus within 28 days after insemination were scanned, via transrectal ultrasonography using an Aloka SDD 500V scanner with a 5-MHz transducer (Aloka Ltd., Tokyo, Japan), to confirm pregnancy status. Subsequently, all cows were examined again at day 60 post-insemination and 150 days after the start of breeding.

Indicators of reproductive efficiency included: 24 day submission rate (SR24; proportion of cows submitted in the first 24 days of the breeding season), calving to first service interval (CSI; days), conception rate to first service (CON1; proportion of cows that conceived to first service based on ultrasonic imaging at day 30 post AI), pregnancy rate to first service (PREG1; proportion of cows pregnant to first service based on ultrasonic imaging at day 150), in-calf rate after 6 weeks (PREG6W; proportion of cows pregnant in the first 6 weeks of the breeding season based on ultrasonic imaging at day 150), in-calf rate after 13 weeks (PREG13W; proportion of cows pregnant after the 13 week breeding season based on the ultrasonic imaging at day 150), calving to conception interval (CCI; based on results of ultrasonic imaging at day 150), number of services per cow and embryo mortality (proportion of cows that did conceive but did not remain pregnant, as identified by the 60 or 150 day ultrasonic image).

Sward measurements

Forty pre- and post-grazing sward height measurements were taken in all paddocks using a rising plate meter (Urban and Caudal 1990). Pre-grazing herbage yield (above 4 cm) was determined on each paddock during years 1 and 3 of the study, based on four strips of grass (0.95 m wide, 5.5 to 7 m long) cut with an Agria mower (Agria-Werke GmbH, Möckmuhl, Germany). In year 2, pre-grazing herbage yield (above 4 cm) was determined for each paddock based on five quadrats (0.25 m × 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, weighed and a sub-sample (~100 g) dried overnight at 60 °C for DM determination. A further sub-sample was used for chemical analysis. Composite herbage samples were analyzed *in vitro* for acid detergent fibre (ADF) (Clancy and Wilson 1966), crude protein, neutral detergent fibre (NDF), organic matter digestibility (OMD) (Morgan, Stakelum and Dwyer 1989) and ash. Grass budgeting was done weekly to aid grassland management decisions. Pre-grazing herbage DM yield (above 4 cm) was targeted between 1400 and 1600 kg/ha. Annual pasture growth was established in a separate study using plots that received fertilizer N (calcium ammonium nitrate) input of 650 kg/ha as described by Corrall and Fenlon (1978). This experiment was conducted nearby at the Animal and Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland (52°09'N, 8°16'W).

Statistical analyses

Feed treatments, though not of direct interest, were categorised into four groups, based on similarity, for the purpose of statistically analysing milk production and reproductive performance variables. The first treatment consisted of cows on the HC diet in year 1. The second group consisted of the LC group in year 1, all animals in year 2 and animals on the MS treatment in year 3. Feed treatments 3 and 4 included animals in the LS and HS groups in year 3, respectively. The data for milk production traits, and for CSI, CCI and number of services per cow were analysed using Proc MIXED (SAS 2002). The linear model included breed group, feed treatment, year and parity. Calving date was fitted as a continuous covariate. Cow was included as a random effect. Contrast statements were also used to compare the performance of the F_1 to the mid-parent mean, thus estimating hybrid vigour.

Body weight and BCS during lactation were categorised into 10 lactation stages: weeks 2 to 4, weeks 5 to 8, weeks 9 to 12, weeks 13 to 16, weeks 17 to 20, weeks 21 to 24, weeks 25 to 28, weeks 29 to 32, weeks 33 to 36, and weeks 37 to 44. The linear model used for these variables included the fixed effects for breed group (HF, J and F_1), parity, year, feed treatment, lactation stage and the interaction between breed group and stage of lactation. Calving date and lactation length were included as covariates. Cow was included as a random effect.

The categorical variables CON1, PREG1, PREG6W, PREG13W and embryo mortality were analysed using generalised estimating equations (Proc GENMOD; SAS 2002). The HF breed group was designated as the reference category for the odds ratios. Hence, the reproductive success of J and F_1 were compared to that of HF.

Economic analysis

The Moorepark Dairy Systems Model (MDSM) (Shalloo *et al*. 2004), a stochastic budgetary simulation model, was used to simulate a model farm integrating biological data for each breed group. This model incorporates animal inventory and valuation, milk production, feed requirement, land, labour, variable and fixed costs. Variable costs (including fertilizer, contractor charges, medical and veterinarian, artificial insemination, silage and reseeding) and fixed costs (machinery maintenance and running costs, farm maintenance, car, telephone, electricity and insurance) were evaluated at current prices (Teagasc 2008). The economic analysis was based on a 40 ha land base with 13 t/ha of grass DM available for grazing. Annual application of fertilizer N was assumed to be 250 kg/ha. Milk price was set at 27 c/L for milk having fat and protein concentrations of 33.0 g/kg and 36.0 g/kg, respectively (Binfield *et al*. 2008), and a ratio for the value of protein to fat of 2.6 to 1.

Default parameters for the model farm are outlined in Table 1. Milk yield was adjusted for parity structure, while milk fat, protein and lactose concentrations were as observed at Ballydague. Mean calving date was assumed to be 26 February, 26 February and 20 February for the HF, J and F_1 breed groups, respectively, to reflect the differences in CCI observed at Ballydague. Sale values of milk, cull cows and calves were based on current prices (Teagasc 2008). Interest earned on cash flow in the current account is distinguished from other farm receipts. Labour requirement was divided between time associated with the cow and other farm tasks (milking, grassland management, maintenance, calf care, cleaning, veterinary and miscellaneous).

Replacement rate was the proportion of cows that failed to become pregnant

Table 1. Assumptions used for the farm model

Item	Value
Milk yield (kg)	
Holstein Friesian	5651 (41.2, 34.9)[†]
Jersey	4220 (53.2, 40.3)
Jersey × Holstein-Friesian	5272 (47.7, 38.8)
Carcass weight (kg)	
Holstein Friesian	244
Jersey	149
Jersey × Holstein-Friesian	214
Concentrate cost (€/t)	200
Opportunity cost of land (€/ha)	267
Housing cost (€/cow)	600
Labour unit cost (€/month)	1905

[†]Concentrations (g/kg) of fat and protein, respectively.

(involuntary culling) by the end of the breeding season plus a voluntary culling rate of 10% of the remaining animals. Due to the similarity (not found to be statistically different) in reproductive performance between the HF and J their replacement rates were assumed identical (26%); a lower value (19%) was used for the F_1 group.

It was assumed that all calves were fed 4 L of whole milk per day and were sold from the farm at 4 weeks of age. Female calves realised the same value across breeds (€330) while male J calves had no value, male calves from F_1 cows were valued at €30 and male HF calves were valued at €80. All replacements were assumed to be brought onto the farm at the time of first calving at a cost of €1,540 each.

Cull cow values (weighted for parity structure) were based on BW at the end of lactation, an assumed kill-out rate for each breed group (420, 400 and 380 g/kg for HF, F_1 and J, respectively), based on the findings of Minchin *et al*. (2009), and carcass values (€/kg) of 1.50, 1.25 and 1.00 for HF, F_1 and J, respectively (Dawn Meats Group, personal communication).

Farm profit was determined by subtracting total revenue from total costs, having accounted for interest on earnings. Sensitivity analysis was carried out on milk price, fat to protein ratio and replacement heifer cost to investigate the effects of differences in profitability between the groups. Milk prices of 20 and 33 c/L were investigated in addition to the default of 27 c/L as well as an increased relative value of protein to fat (3.3:1). Different replacement heifer costs were also examined to explore the implications of replacement rate differences between breed groups.

Results

Total grass DM production averaged 12.7, 14.7 and 15.5 t/ha compared to an average value of 15 t/ha for the years 1997 to 2006. Pre- and post-grazing heights, pre-grazing yield and chemical analysis of the grass offered during the 3 years of the study are presented in Table 2. The nutritive value of the herbage offered was high.

Production

The interaction between breed group and feeding treatment was not significant for any of the animal performance variables investigated. Milk yield was highest ($P<0.001$) for HF and lowest for J (Table 3). Yield of milk was intermediate for F_1 ($P<0.001$). Milk fat and protein concentrations were highest ($P<0.001$) for J and lowest for HF, while milk fat and protein concentrations were intermediate for F_1 ($P<0.001$). Lactose concentration was higher for F_1 and J compared to the HF ($P<0.01$). Fat yield was higher for F_1

Table 2. Pre- and post-grazing sward surface height, pre-grazing herbage dry matter yield and chemical composition of herbage dry matter (DM)

Item	Mean†	s.d.
Pre-grazing sward surface height (cm)	12.0	2.93
Post-grazing sward surface height (cm)	5.4	1.32
Pre-grazing herbage DM mass (kg/ha)	1706	606.3
Crude protein (g/kg DM)	220	29.9
Acid detergent fibre (g/kg DM)	253	29.6
Neutral detergent fibre (g/kg DM)	445	30.7
Organic matter digestibility (g/kg DM)	782	41.8

† Across the 3 years.

Table 3. Milk production traits, calving-to-service interval and calving-to-conception interval for cows of three breed groups

Item	Breed group†			s.e.	Significance	Hybrid vigour	s.e.	Significance
	HF	J	F_1					
Milk yield (kg)	5342[a]	4233[b]	4973[c]	69.1	***	185	75.6	*
Milk composition (g/kg)								
Fat	40.6[a]	52.6[b]	47.2[c]	0.56	***	0.64	0.638	
Protein	35.1[a]	40.4[b]	38.1[c]	0.24	***	0.35	0.267	
Lactose	45.7[a]	46.3[b]	46.7[b]	0.16	**	0.70	0.184	***
Fat yield (kg)	218[a]	221[a]	234[b]	3.3	**	14.7	3.68	***
Protein yield (kg)	188[a]	170[b]	189[a]	3.0	***	10.0	2.63	***
Milk solids yield (kg)	407[a]	392[b]	424[c]	6.6	*	24.6	5.95	***
Solids-corrected milk yield (kg)	5120[a]	4807[b]	5272[a]	83.7	***	309	73.8	***
Body weight (kg)	523[a]	387[b]	466[c]	4.9	***	11	5.7	*
Body condition score	2.79[a]	2.95[b]	3.01[b]	0.034	***	0.14	0.030	***
Calving to service interval (days)	76[a]	69[b]	75[a]	2.7	*	2	2.6	
Calving to conception interval (days)	90	86	84	3.6		−4	3.1	

† Holstein-Friesian = HF; Jersey = J; Jersey × Holstein-Friesian = F_1.
[abc] Means without a superscript in common are significantly different.

compared to HF and J (P<0.01). Protein yield was similar for HF and F_1 and lowest for J (P<0.001). The ratio of fat to protein was highest (P<0.001) for milk from J (1.31:1), intermediate for F_1 (1.24:1) and lowest for HF (1.16:1). Yield of milk solids was greater for HF than J (P<0.05). The F_1 cows produced 4.2% and 8.2% more milk solids than HF and J, respectively. The yield of SCM was similar for HF and F_1 and lowest for J (P<0.001).

The F_1 cows produced more milk (P<0.05), milk solids (P<0.001) with a higher lactose concentration (P<0.001) and also a greater yield of SCM (P<0.001) compared to the mid-parent mean (Table 3). These differences yielded hybrid vigour percentages of 3.7%, 1.5%, 5.8% and 5.9% for milk yield, lactose concentration, milk solids yield and yield of SCM, respectively.

Body weight and body condition score

Mean BW of HF cows was 35% greater than for J and 12% greater than F_1 (P<0.001) (Figure 1). Body weight was lowest at stage 2 for all breed groups. Body weight at the end of lactation averaged 554, 432 and 509 kg for the HF, J and F_1, respectively. The BCS of J and F_1 cows in stage 1 of lactation were similar (3.10 and 3.11, respectively) but greater than HF (2.95; P<0.05). In mid-lactation (stage 6), BCS was lowest for HF (2.67), intermediate for J (2.76) and highest for F_1 (2.90; P<0.001). Body condition score was different for all breed groups in stage 10 of lactation; 2.62, 2.82 and 2.93 for the HF, J and F_1, respectively.

Body weight and BCS were greater for the F_1 compared to the average of the parental breed groups. Estimates of hybrid vigour corresponded to 11 kg

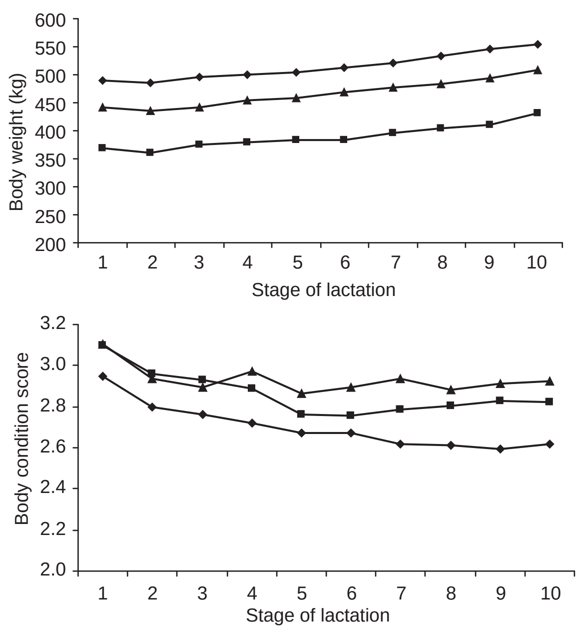

Figure 1. Body weight and body condition score of Holstein-Friesian (◆), Jersey (■) and Jersey × Holstein-Friesian (▲) cows through lactation (lactation stages were defined as 1 = weeks 2 to 4, then successive 4 week periods to stage 9 and stage 10 = weeks 37 to 44).

(2.4%) and +0.14 (4.6%) for BW and BCS, respectively.

Reproductive performance

The interval from calving to first service was essentially equal for the HF and F_1 and shorter ($P<0.05$) for J. Calving-to-conception interval was similar for the breed groups (Table 3). The number of services per cow was lower ($P<0.01$) for F_1 (1.69) than HF or J (2.11 and 2.14, respectively). Results from the analysis of breed effects on categorical fertility variables are summarised in Table 4. Submission rate did not differ significantly among the breed groups . The values for CON1 were 0.50, 0.52 and 0.65 for the HF, J and F_1 cows, respectively; the value for F_1 cows was significantly greater ($P<0.05$) than that for HF but J and HF did not differ significantly. The values for PREG1 were 0.41, 0.47 and 0.62 for HF, J and F_1, respectively; the value for F_1 was greater than that for HF ($P<0.01$). The mean values for PREG6W were 0.51, 0.56 and 0.70 for the HF, J and F_1 cows, respectively, with F_1 being significantly greater than HF ($P<0.05$). Pregnancy rate was 0.82, 0.76 and 0.90 for HF, J and F_1, respectively. The likelihood of J cows being pregnant at the end of the 13 week breeding season was not significantly different from that for HF. However, PREG13W for F_1 was significantly greater ($P<0.05$) than for HF. Embryo mortality was similar across the breed groups: 0.07, 0.06 and 0.07 for the HF, J and F_1, respectively.

Economic evaluation

Herd size was weighted for BW and milk production per cow to ensure the 40 ha farm limit was observed (Table 5). Consequently, more J than HF or F_1 cows were required. Milk output was highest for the system based on HF cows, intermediate with F_1 cows and lowest with J cows. However, output of milk solids was highest with J and F_1, an additional 3162 and 2264 kg milk solids, respectively, compared to HF. Milk price was highest with J, lowest with HF and intermediate with F_1. Milk receipts were €13 115 and €14 141 greater for systems based on F_1 and J, respectively, compared to system with HF cows.

Labour and feed costs were similar with HF and F_1 but higher with J. Replacement costs were lowest with F_1, highest with J (due to the larger herd size and similar reproductive efficiency to HF) and intermediate for HF. Overall farm profitability was highest for the system based on F_1 animals, intermediate with HF and lowest with J. At a milk price of 27 c/L, profitability was €18 179 higher with F_1 animals than with HF while with J animals profitability was reduced by €9076 compared with HF. Profit per kilogram of milk, per kilogram of milk solids and per hectare

Table 4. Effect of breed group on odds ratio, relative to HF, for fertility variables

Variable	Breed group		Significance	
	J	F_1	HF v J	HF v F_1
Submission rate (24 day)	1.89 (0.86, 4.16)†	1.72 (0.81, 3.67)		
Conception rate to first service	1.09 (0.65, 1.82)	1.89 (1.06, 3.40)		*
Pregnancy rate to first service	1.24 (0.74, 2.08)	2.35 (1.33, 4.16)		**
In-calf rate at 6 weeks	1.24 (0.70, 2.18)	2.32 (1.28, 4.19)		*
In-calf rate at 13 weeks	1.24 (0.74, 2.08)	2.35 (1.33, 4.15)		*
Embryo mortality	0.99 (0.36, 2.73)	0.80 (0.27, 2.36)		

† 95% confidence interval.

Table 5. Physical and financial components for farm system (40 ha) based on Holstein-Friesian (HF) Jersey (J) or Jersey × Holstein-Friesian (F_1) cows

	Breed group		
	HF	J	F_1
No. of cows calving	96	114	97
Labour cost (€)	27760	32811	28463
Stocking rate (cows/ha)	2.28	2.70	2.34
Milk production (L)	528070	466206	495258
Milk output (L)	517194	453347	484325
Milk fat output (kg)	21943	24875	23817
Milk protein output (kg)	18607	18837	19397
Milk composition (g/kg)			
Fat	41.2	53.2	47.7
Protein	34.9	40.3	38.8
Milk price (c/L)	30.68	38.12	35.47
Feed cost† (c/L milk)	5.8	6.7	6.3
Milk sales (€)	158675	172816	171790
Livestock sales (€)	28675	22696	21674
Interest earned (€)	115	0	243
Total variable cost (€)	83395	93450	70798
Total fixed cost (€)	66571	73639	67231
Farm profit (€)	37499	28423	55678
Profit/Milk solids (€/kg)	0.92	0.65	1.29
Profit (€/ha)	938	711	1392

† Includes cost of silage grass fertilizer and concentrate (see Shalloo *et al*. 2004).

were highest for the system based on F_1 cows, intermediate with HF and lowest with J cows.

Sensitivity analysis showed that at a milk price of 20 c/L, both HF and J systems would be unprofitable (Table 6), while the F_1 system would yield a modest profit. The financial loss was greater with J than with HF. At the higher milk price (33 c/L) farm profit was higher for all breed groups. In this scenario, the superiority of the system based on F_1 cows increased. When the ratio of the value of protein to that of fat was increased the difference in profitability between systems based on F_1 and HF declined slightly while the difference between the HF and J systems increased slightly. Reducing the cost of replacement heifers resulted in a slight reduction in the difference in profitability between both the J and HF systems and the system based on F_1 animals. When the replacement cost was increased the opposite occurred.

Discussion

With the exception of the first year of the study, grass growth recorded at Moorepark was similar to the mean over the previous 10 years. Due to the inadequate grass growth, concentrate supplementation was higher than anticipated in the first year. Annual concentrate supplementation per cow was targeted to be 300 kg. The chemical analysis of the herbage offered (Table 2), pre-grazing yield and post-grazing sward surface height clearly indicate that for the most part sufficient quantities of

Table 6. Sensitivity of key economic variables to variation in milk price, the ratio of the value of fat to that of protein and cost of replacement heifers

Variable	Farm performance	Breed group		
		HF	J	F_1
Milk price (c/L)				
20	Milk sales (€)	117 374	129 441	128 181
	Farm profit (€)	−4 072	−15 224	11 788
	Profit/Milk solids (€/kg)	−0.10	−0.34	0.27
33	Milk sales (€)	194 085	210 003	209 179
	Farm profit (€)	73 139	65 844	93 307
	Profit/Milk solids (€/kg)	1.80	1.51	2.16
Fat:protein price ratio				
3.3:1	Milk sales (€)	157 951	170 912	170 621
	Farm profit (€)	36 769	26 508	54 501
	Profit/Milk solids (€/kg)	0.91	0.61	1.26
Cost of replacement heifer (€)				
1750	Livestock costs (€)	44 209	52 253	30 608
	Farm profit (€)	32 129	22 076	51 959
	Profit/Milk solids (€/kg)	0.79	0.51	1.20
1200	Livestock costs (€)	30 316	35 830	20 988
	Farm profit (€)	46 193	38 699	61 699
	Profit/Milk solids (€/kg)	1.14	0.89	1.43

quality pasture were available to the animals (O'Donovan, Delaby and Peyraud 2004).

Differences in milk production and composition between J and HF cows have been well documented (L'Huillier, Parr and Bryant 1988; Oldenbroek 1988; Mackle *et al*. 1996). The breed differences recorded in the present study are consistent with previous reports; milk yield highest for HF, and both milk fat and protein concentrations highest for J. The difference of 21% for milk yield observed between the HF and J in the present study is similar to the difference of 23% reported by Mackle *et al*. (1996). Consistent with the findings of Auldist *et al*. (2007), Heins *et al*. (2008) and Vance *et al*. (2009), milk yield was higher for HF than F_1, but milk fat and protein concentrations were higher for F_1. In the current study, however, the yield of milk solids was 4.2% higher for F_1 than HF, indicating that in a grass-based system F_1 cows can be at least as productive on a per cow basis as HF cows, and hybrid vigour was 25 kg or 5.8%. Ahlborn-Breier and Hohenboken (1991) reported hybrid vigour estimates of 6.1% and 7.2% for milk yield and fat yield, respectively, for F_1 cows, which are consistent with the results of the current study for similar traits.

The BW of HF cows in the current study was 26% and 11% greater than J and F_1, respectively. Ahlborn and Bryant (1992) and Thomson, Kayand and Bryant (2001) reported differences of 20% and 22% in BW between Friesian and J cows, and between HF and J cows, respectively. Auldist *et al*. (2007) and Heins *et al*. (2008) found differences in BW between HF and F_1 cows of 8% and 7%, respectively. The estimated hybrid vigour of 11 kg for BW concurs with the findings of Livestock Improvement (1997, unpublished data; cited by Lopez-Villalobos *et al*. 2000), who reported estimates of 7.7 kg for cows in New Zealand.

Rastani *et al*. (2001) found no difference in BCS between Holstein and J cows in an indoor system. However, consistent with the findings of the present study, Washburn *et al*. (2002) reported a higher BCS for J than HF. Heins *et al*. (2008) and Vance *et al*. (2009) also reported that F_1 cows had a higher BCS than HF cows. Body condition score has been shown to be positively correlated with reproductive performance (Buckley *et al*. 2003).

The mean of 73 days for CSI in the current study is in line with that recommended (O'Farrell and Harrington 1999) to achieve optimum reproductive performance in a seasonal system. Below optimum reproductive performance by HF cows has been documented previously (Harris and Kolver 2001; Lucy *et al*. 2001) and it is now widely accepted that this is due to former selection programmes, where increased milk production was the sole objective. Pasture-based systems are highly dependent on cows becoming pregnant within a short breeding period thus ensuring a 365-day calving interval and maintaining synchrony between grass supply and demand. The CCI for HF in the current study represents a slippage in calving date of approximately 5 days/year. The mean calving date of spring-calving dairy cows in Ireland has increased by 8 days between 2002 and 2006 (CMMS 2006). Continuation of this trend will reduce lifetime production, increase the rate of involuntary culling and reduce the rate of genetic progress, ultimately reducing profitability. Improvements in reproductive performance will increase the longevity of dairy cows, thus enabling cows to mature and achieve greater milk yield and also reduce replacement rate.

The present dataset consisted of 329 lactations over three years. Despite this relatively small dataset there was a significant breed effect observed for some of the reproductive traits investigated. With the exception of Washburn *et al*. (2002), which involved a smaller dataset than the current study, no other study exists that involved comparing the reproductive performance of J and HF/Holstein cows. Washburn *et al*. (2002) reported a higher conception rate for J than Holstein cows, 59.6% and 49.5%, respectively, and a higher pregnancy rate for J compared to Holstein cows, 78.1% and 57.9%, respectively. However, Washburn *et al*. (2002) also reported that 14% of Holstein cows in that study were not detected in oestrus or inseminated during the breeding period in contrast to the J cows where 'almost' all cows were inseminated at least once. The inferior reproductive performance of the Holstein cows in that study may be attributed to a greater potential for milk production. In contrast, no significant difference in reproductive efficiency was observed between HF and J cows in the present study. While the authors acknowledge the limited nature of the present study with regard to drawing strong conclusions on cow fertility, the potential impact of the favourable effects associated with Jersey crossbreds in the present study are highlighted. The superior reproductive performance (Lopez-Villalobos *et al*. 2000; Heins *et al*. 2008) of F_1 cows compared to HF was confirmed in the current study. This is consistent with the findings of Auldist *et al*. (2007). In New Zealand, Harris *et al*. (1999) showed that F_1 cows remained in the herd for an additional 247 days compared to the mean of the parental breeds. Grainger and Goddard (2004) reported greater feed efficiency for J cows compared with Holstein or Friesian cows. Prendiville, Pierce and Buckley (2009) confirmed the higher intake capacity of J compared to the HF and also showed that production efficiency, based on net energy intake per unit of milk solids produced, was lower for F_1 and J than for HF. Inferior reproductive efficiency of J compared to HF cows means that the greatest success in terms of lifetime efficiency will be achieved by F_1 cows.

The most desirable genotype is the one that returns the highest profit per unit input (Kahi *et al*. 1998). The impending removal of EU milk quotas will result in land becoming the most limiting resource under Irish conditions. The analysis presented (Tables 5 and 6) shows that with a fixed land base, and across three milk prices, F_1 animals were more profitable than the parental breeds. While there were differences in a range of characteristics compared to the HF, a lower requirement for replacement animals and higher milk receipts were the main contributors to the higher profitability with F_1. Due to EU intervention policy in 2000, protein was valued at 1.5 times the value of fat on internal EU markets, which is a considerably lower ratio than on the world market (IDB 2006). With the removal of milk quotas in 2015, Irish dairy farming will be susceptible to volatile milk prices. The value of protein relative to fat will also increase significantly (IDB 2006). Results from the present study show that increasing the value of protein to 3.3 times that of fat did not affect the ranking of the breed groups. The abolition of milk quotas in 2015 is forecast to increase demand for dairy replacement stock. Results from the current study indicate that changes in the cost of replacement animals will not result in a re-ranking of the breed groups for farm profit, although it is clear that an increase in replacement heifer cost reduces farm profit. This is exacerbated by reproductive inefficiency as exemplified by the HF and J breeds in the current study. A reduction in replacement heifer cost reduced livestock costs and consequently increased farm profit. However, the proportional increase in profit was greater for groups with poor reproductive performance.

An economic comparison by Lopez-Villalobos *et al*. (2000) also yielded increased profitability for crossbred (Jersey × Aryshire and Aryshire × (Jersey × Ayrshire) animals compared to Holstein, Jersey, Aryshire and Aryshire × Holstein cows. Consistent with the current study, that study showed that increased profitability in crossbred herds was attributed to a lower replacement rate and a greater proportion of cows surviving longer thus achieving mature milk yield. McAllister *et al*. (1994) reported that hybrid vigour is a significant contributor to lifetime economic performance.

The productive and reproductive performance of Montbeliarde and Normande cows (Dillon *et al*. 2003) compared to HF were evaluated in a previous study. These breeds are renowned for superior cull cow and calf values and, in theory, are well suited to dairy producers with a small quota (Evans *et al*. 2004). Dillon *et al*. (2003) reported that reproductive efficiency was superior for Montbeliarde and Normande animals compared to HF and an economic analysis showed that the Montbeliarde breed was the most profitable and HF the least profitable in the absence of milk quotas. However, a later study by Walsh *et al*. (2008) questioned the suitability of these breeds and their crossbreds to seasonal production systems, due to minimal improvements in reproductive efficiency and late maturing characteristics compared to HF. More recently, an on-farm study by Begley *et al*. (2009), comparing HF, Norwegian Red and Norwegian Red × HF, indicated that Norwegian Red × HF was suited to seasonal production systems and delivered improvements in health and reproductive efficiency. Given the findings of the current study, back-crossing the F_1 with either HF or J may reduce reproductive efficiency, a key component of the improved profitability of F_1 animals in the current study. Three-way crossbreeding, incorporating the Norwegian Red, could be a suitable alternative. This approach would involve systematic use of the three breeds in rotation. Such a strategy would maximise hybrid vigour and minimise recombination loss. However, an economic appraisal including all biological data and estimates of hybrid vigour is required.

The EBI reflects the relative contributions of the different traits to overall profitability, but does not reflect the added benefit from hybrid vigour, which was identified as a weakness by Evans *et al*. (2004) and Begley (2009). The EBI values of the animals in the present study can explain 56% of the calculated difference in profit between systems based on HF and F_1. The sire EBIs account for 40% of the difference in profit between the HF and F_1. Furthermore, the reproductive performance of the F_1 was superior to both J and HF, although the mean fertility sub index was €34, €108 and €56 for the HF, J and F_1, respectively. Thus, the present findings suggest that the superior reproductive performance of F_1, compared to J and HF, was primarily due to hybrid vigour, which is in contrast to that indicated by the genetic evaluations. While hybrid vigour is accounted for by ICBF in the genetic evaluation, by using a single coefficient for hybrid vigour irrespective of breed cross combination, the results of the current study suggest that part of the heterotic effect is currently being attributed to the J breed, or the specific heterosis for fertility for F_1 is likely larger than that expressed by other breed crosses. In addition, the majority of J ancestry in the Irish population is in the form of crossbred animals making the determination of breed effects more complex (http://www.agriculture.gov.ie/publications/2008). Further research is warranted to establish whether this is in fact the case, and to ensure accuracy of genetic evaluations for the J and other breeds commonly used for crossbreeding in Ireland.

The incorporation of genomic selection into the Irish cattle breeding programme is expected to accelerate within-breed improvement, particularly for fertility/survival traits. This will not diminish the value of hybrid vigour. Rather it highlights the need to identify J sires with a high EBI to capitalise on breed complementarity and hybrid vigour, which appear to offer a significant improvement in profit.

Conclusion

Results from this study indicate that F_1 (J × HF) cows are more productive, having a higher output of milk solids as well as superior reproductive efficiency, and more profitable than either HF or J cows. The observed production characteristics of the F_1 are due primarily to the complementarity of the parent breeds in conjunction with some hybrid vigour (the latter for milk yield) resulting in a high volume of high value milk. The variation in reproductive efficiency observed suggests that hybrid vigour is a major factor contributing to the superior reproductive efficiency of the F_1 animals.

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