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The effect of Holstein-Friesian, Jersey × Holstein-Friesian, and Norwegian Red × (Jersey × Holstein-Friesian) cows on dry matter intake and production efficiencies in pasture-based systems

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ABSTRACT

The objective of this study was to investigate the effect of cow genotype and parity on dry matter intake (DMI) and production efficiencies in pasture-based systems. Three dairy cow genotypes were evaluated over 3 yr; 40 Holstein-Friesian (HF), 40 Jersey × HF (JEX), and 40 Norwegian Red × JEX (3WAY) each year, with each genotype grazed in equal numbers on 1 of 4 grazing treatments in a 2 × 2 factorial arrangement of treatments [diploid or tetraploid perennial ryegrass (*Lolium perenne* L.) with or without white clover (*Trifolium repens* L.)]. A total of 208 individual cows were used during the experiment. The effect of parity (lactation 1, 2, and 3+) was also evaluated. Individual DMI was estimated 8 times during the study, 3 times in 2015 and in 2017, and twice in 2016, using the n-alkane technique. Days in milk at each DMI measurement period were 64, 110, and 189, corresponding to spring, summer, and autumn. Measures of milk production efficiency calculated were total DMI/100 kg of body weight (BW), milk solids (kg fat + protein; MSo)/100 kg of BW, solids-corrected milk (SCM)/100 kg of BW, and unité fourragère lait (net energy requirements for lactation equivalent of 1 kg of standard air-dry barley; UFL) available for standard (4.0% fat and 3.1% protein content) milk production after accounting for maintenance. During the DMI measurement periods HF had a greater milk yield (23.2 kg/cow per d) compared with JEX and 3WAY (22.0 and 21.9 kg/cow per d, respectively) but there was no difference in MSo yield. Holstein-Friesian and JEX, and JEX and 3WAY had similar DMI, but HF had greater total DMI than 3WAY (DMI was 17.2, 17.0, and 16.7 kg/cow per d for HF, JEX, and 3WAY, respectively). Jersey × Holstein-Friesian cows were the most efficient for total DMI/100 kg of BW, SCM/100 kg of BW, and MSo/100 kg of BW (3.63, 4.96, and 0.39 kg/kg of BW) compared with HF (3.36, 4.51, and 0.35 kg/kg of BW) and 3WAY (3.45, 4.63, and 0.37 kg/kg of BW), respectively. Unité fourragère lait available for standard milk production after accounting for maintenance was not different among genotypes. As expected, DMI differed significantly among parities with greater parity cows having higher DMI and subsequently higher milk and MSo yield. Although all 3 genotypes achieved high levels of DMI and production efficiency, JEX achieved the highest production efficiency. Some of the efficiency gains (SCM/100 kg of BW, MSo/100 kg of BW, and total DMI/100 kg of BW) achieved with JEX decreased when the third breed (Norwegian Red) was introduced.
Key words: pasture-based systems, dry matter intake, dairy cow genotype, production efficiency

INTRODUCTION

Within pasture-based grazing systems the efficient conversion of feed input into product is critical for economic profitability (Prendiville et al., 2009). In spring-calving, pasture-based systems, typically found in Ireland and other temperate regions of the world, this is influenced by pasture growth and utilization, calving rate, and the proportion of feed purchased and brought onto the farm (Ramsbottom et al., 2015; Macdonald et al., 2017; Hanrahan et al., 2018). At the individual cow level, multiple environmental and management factors affect DMI and the conversion of feed into product in pasture-based grazing systems (Dillon et al., 2006), some of which have been discussed in a companion paper (McClearn et al., 2021). There are also several cow level factors that influence DMI, such as milk yield, stage of lactation, BW, and cow genotype (Bargo et al., 2003; Dillon et al., 2006).

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In spring-calving, pasture-based systems, the ideal cow should consistently calve in early spring to match feed demand with pasture supply, achieve a high intake of grazed pasture throughout lactation, and subsequently convert this pasture efficiently into high quality milk (Buckley et al., 2005; Berry, 2015). Crossbreeding traditional Holstein-Friesian (**HF**) with Jersey has become popular in some temperate grazing regions due to the benefits of heterosis leading to improved milk composition, reproductive performance, and economic performance of Jersey × HF (**JEX**) crossbred cows (Prendiville et al., 2011; Vance et al., 2013; McClearn et al., 2020a,b). The suitability of JEX cows for pasture-based systems is due to their lower BW and greater gastrointestinal tract size relative to their BW compared with HF cows (Prendiville et al., 2009; Beecher et al., 2014). This leads to increased DMI per unit BW and greater production efficiencies for JEX cows compared with HF and make JEX cows uniquely suited for intensive grazing systems (Prendiville et al., 2009; Buckley et al., 2014; Coffey et al., 2017). Lopez-Villalobos et al. (2000) hypothesized that a 3-way rotational crossing system could increase profitability for pasture-based systems in New Zealand. Shonka-Martin et al. (2019a) recently reported that DMI during the first 150 DIM was greater for Holstein than for a 3-way rotational cross (made up of Montbéliarde, Viking Red, and Holstein) cows in a TMR-based system. However, there is a paucity of information regarding the effect of introducing a third genotype into a rotational crossing system on DMI and subsequent production efficiencies within pasture-based systems.

Dry matter intake is also influenced by milk yield per cow and BW, with larger and higher producing cows requiring a greater energy and therefore DMI (Dillon et al., 2006). Milk yield and BW are closely linked to parity as younger animals produce less milk and are lighter than older parity animals (Berry, 2015; McClearn et al., 2020a). Few studies present the results of differences in DMI between animals differing in parity (Bines, 1976; Jarrige et al., 1986; Kennedy et al., 2003) and the data collected in this study present an opportunity to investigate the interactions between cow genotype and parity on DMI and milk production efficiencies.

The hypotheses of this experiment were (1) JEX and a 3-way cross of Norwegian Red × JEX (**3WAY**) would have similar DMI but greater production efficiencies than HF and (2) older parity cows would have greater DMI and production efficiencies than younger parity cows. Therefore, the objective of this study was to investigate the performance of 3 dairy cow genotypes, HF, JEX, and 3WAY, in terms of DMI and production efficiencies over a 3-yr period in pasture-based, spring-calving systems. A secondary objective of the study was to investigate the effect of cow parity within each aforementioned genotype for the same production variables.

MATERIALS AND METHODS

Experimental Design and Treatments

The experiment was conducted at Teagasc Clonakilty Agricultural College (latitude: 51°63′N; longitude: −08°85′E; 25–70 m above sea level) over 3 yr from 2015 to 2017. A randomized block design was used, with a 2 × 2 factorial arrangement of 2 perennial ryegrass (*Lolium perenne* L.; **PRG**) ploidies (tetraploid and diploid) each sown with and without white clover (*Trifolium repens* L.), to give 4 separate grazing treatments: a tetraploid PRG-only sward, a diploid PRG-only sward, a tetraploid PRG-sward with white clover, and a diploid PRG-sward with white clover as described by McClearn et al. (2019). Briefly, a dairy grazing platform of 43.6 ha was used with 75% of the experimental area reseeded in 2012 and 25% reseeded in 2013 by full cultivation (plowing and tilling). Diploid swards were sown at a rate of 30 kg/ha and tetraploid swards were sown at a rate of 37 kg/ha. In the white clover paddocks a 50:50 mix of the medium-leaved white clover cultivars ‘Chieftain’ and ‘Crusader’ were sown at 5 kg/ha. Four farmlets were created with 20 paddocks per grazing treatment. Paddocks for each treatment were balanced for location block, soil type, and soil fertility throughout the farm. Each farmlet was 10.9 ha and stocked at 2.75 cows/ha.

Animals

Three cow genotypes were used for this experiment: HF, JEX, and 3WAY (McClearn et al., 2020a). Briefly, during the experiment HF cows were either mated with a HF sire to produce a HF cow or a Jersey sire to produce F_1 (first cross generation) crossbred JEX cows. The 3WAY cows were produced from F_1 JEX cows mated with a Norwegian Red sire. Before this experiment, a parent herd containing HF and JEX cows was bred using the same breeding program described above to produce the cows for this study. During the experiment, each year, a minimum of 3 high Economic Breeding Index (**EBI**) HF, Jersey, and Norwegian Red sires were used from the Irish Cattle Breeding Federation active bull list, selected from the top 20 bulls within each breed. Every year 10 cows of each genotype were balanced according to parity (1, 2, or 3+), calving date, BW, BCS, and EBI and randomly assigned to 1 of the 4 grazing treatments, giving a single combined herd of 30 cows per grazing treatment and a total of 40 cows of each genotype on the experiment. Cows were re-randomized each year onto the respective grazing treatments, with a proportion of the initial cows used in 2015 remaining for the duration of the experiment. Each year 20% of the cows on the experiment were primiparous, with the same parity structure maintained for each grazing treatment and genotype. A total of 208 individual cows were used during the experiment. The EBI and PTA for each cow were calculated as the parental average EBI from the January 2019 Irish Cattle Breeding Federation evaluation run. This is to exclude own animal performance, which would have been affected by grazing treatment. The overall EBI differed between genotypes, as the EBI, milk, fertility, calving, beef, maintenance, management, and health subindices of the HF cows were €115, 39, 42, 2, 32, −9, 9, and 1, respectively, the JEX cows were €131, 52, 31, 1, 37, −28, 37, and 5, respectively, and the 3WAY cows were €159, 43, 63, 4, 37, −17, 26, and 2, respectively.

Grazing Management

All treatments were grazed in a spring calving rotational system. Cows were grazed day and night as they calved from February onward as soon as weather conditions allowed. Typically, grazing began in early February and finished in mid November each year. Cows were supplemented with 4-kg concentrate (fresh weight of a standard 14% CP dairy concentrate) postcalving, fed in 2 equal amounts during morning and evening milking. This was gradually reduced when grass growth on the treatments met demand [47 kg of DM/ha per day; daily pasture allowance/cow (17 kg of DM/cow) × stocking rate (2.75 cows/ha)], usually in mid April. Grazing management was achieved by weekly monitoring of average farm cover (using the "cut and weigh" method and visual estimation) for each treatment and using the online application "PastureBase" to aid in decision making (Hanrahan et al., 2017). Target pregrazing pasture mass was calculated separately for each grazing treatment using the following formula:

$$\text{target pregrazing pasture mass} = (\text{stocking rate} \times \text{ideal rotation length} \times \text{daily pasture allowance per cow}) + \text{residual pasture mass},$$

where ideal rotation length during main grazing season = 21 d and daily pasture allowance (>4.0 cm) = 17 kg of DM/cow per day (O'Donovan and McEvoy, 2016).

If a pasture deficit occurred across all treatments then concentrate supplementation was increased for all groups. However, if a pasture deficit occurred in less than all 4 treatments then silage produced from each treatment was used to supplement the deficit to each individual treatment group. During periods of inclement weather conditions (excessive rainfall), where grazing conditions were poor, on-off grazing was practiced (Kennedy et al., 2009).

Residency time within paddocks (between 1 to 2 d) was determined by targeting a postgrazing sward height of 3.5 to 4.0 cm for the first and final grazing rotation and a target of 4.0 to 4.5 cm throughout the main grazing season. Cows within treatments were moved to their following paddocks when the target postgrazing sward height was reached. No mechanical correction, by mowing of paddocks postgrazing, took place over the 3 years and all excess forage was removed and conserved as silage. Inorganic nitrogen was applied equally across all 4 treatments in the form of urea or calcium ammonium nitrate at a rate of 250 kg of nitrogen/ha per yr. Inorganic phosphorus and potassium were applied at similar rates across all 4 treatments based on yearly soil test results.

Pasture Measurements

Grazing data were collected from all paddocks grazed during the DMI measurement periods across the 3 yr. Pregrazing pasture mass was determined before grazing by harvesting 2 strips (approximately 10 m × 1.2 m) to a height of 4.0 cm using an Etesia mower (Etesia UK Ltd.). The harvested forage was weighed and a 100-g subsample was dried at 90°C for 15 h to determine DM. Ten sward heights were taken before and after each strip of forage was harvested using a Jenquip rising plate meter (Jenquip), and used to calculate sward density as follows:

$$\text{sward density (kg of DM/cm per ha)} = \text{pasture yield (kg of DM/ha)}/[\text{precutting height (cm)} - \text{postcutting height (cm)}],$$

Pregrazing sward height and postgrazing sward height were also calculated across whole paddocks before and after grazing using a plate meter taking compressed sward heights at 30 locations pregrazing and 50 compressed sward heights following grazing.

Pregrazing pasture mass above 4 cm was calculated using sward density according to the following equation (Delaby et al., 1998):

$$\text{pregrazing yield (kg of DM/ha)} = [\text{pregrazing sward height (cm)} - 4\text{ cm}] \times \text{sward density (kg of DM/cm per ha)}.$$

Chemical Analysis of Pasture

Chemical analysis of selected pasture simulating a sample of that grazed by the cows was manually collected using Gardena hand shears (Accu 60; Gardena International GmbH) before grazing in each paddock during the DMI measurement periods. This was done following close observation of the grazing animals' previous days' defoliation height to mimic the animals grazing patterns. Samples were stored at −20°C before being freeze-dried and milled through a 1-mm sieve using a Cyclotec 1093 Sample Mill (Foss) before conducting chemical analysis. The pasture samples were analyzed for ash concentration (by incinerating a subsample in a muffle furnace at 500°C for 12 h), ADF, NDF (Van Soest, 1963), CP (AOAC, 1990), and organic matter digestibility (**OMD**; Morgan et al., 1989).

White Clover Contribution

Sward white clover proportion was estimated in each paddock before grazing tetraploid PRG with white clover and diploid PRG with white clover paddocks during the DMI measurement periods. Gardena hand shears were used to take 15 random pasture samples cut to 4.0 cm throughout the paddock. This was mixed, and two 70-g cut-samples were weighed and separated by hand into white clover and PRG and other plant fractions, and dried at 60°C for 48 h to give proportions on a DM basis.

Animal Measurements

Cows were milked twice daily at approximately 0700 and 1530 h. Weekly milk production was derived from individual milk yields (kg) recorded at each milking (Dairymaster, Causeway). Milk fat, protein, and lactose concentrations were determined once weekly from a consecutive evening and morning milk sample for each cow and tested using infrared spectrophotometry (Milkoscan 203, Foss Electric). Milk solids yield per cow (kg fat + protein; **MSo**) and solids-corrected milk (**SCM**; Tyrrell and Reid, 1965) were also calculated. Cows were weighed in the week before, during the week of, and in the week after the DMI measurement period, upon exit from the parlor after morning milking using an electronic scale (Tru-Test Ltd.). Body condition score was assessed on the same timeline as cow BW, by the same individual throughout the study on a scale of 1 to 5 in increments of 0.25 (where 1 = emaciated, 5 = extremely fat) as outlined by Edmonson et al. (1989).

DMI and Production Efficiencies

Individual DMI was estimated 8 times during the study, 3 times in 2015 and in 2017 (spring, summer, and autumn), and twice in 2016 (spring and autumn), due to operational constraints. The n-alkane technique of Mayes et al. (1986) as modified by Dillon and Stakelum (1989), was used. During each DMI measurement period cows were on average 64, 110, and 189 DIM, corresponding to spring, summer, and autumn, respectively, each year. All cows were dosed twice daily, after milking, for 11 consecutive days with a paper bullet containing 760 mg of C32-alkane (n-dotriacontane). From d 7 to 11 of dosing, fecal samples were collected from each cow twice daily at the time of morning and evening milking, either in the paddock the hour before milking by observing the cows and collecting the fecal sample when cows voided or by rectal grab sampling after milking. Fecal samples were stored at −18°C until the end of the collection period. Fecal samples from each cow were then thawed, bulked together, dried at 60°C for 48 h, milled through a 1-mm screen using a Cyclotec 1093 Sample Mill (Foss) and analyzed for alkane concentration as per the methodology of Mayes et al. (1986). Briefly, after solvent extraction and purification, the alkanes were analyzed using GC (Dove and Mayes, 2006). For each treatment approximately 15 individual pasture samples were manually collected using Gardena hand shears mimicking the grazing defoliation pattern observed on previously grazed swards, before each grazing event on d 7 to 11. The pasture samples were stored at −18°C. Frozen pasture samples were bowl-chopped, freeze-dried at −50°C to a constant weight, milled through a 1-mm screen using a Cyclotec 1093 Sample Mill (Foss), and analyzed for alkane concentration similarly to the feces samples. Cows were fed 0.18 kg of DM/cow concentrate during the DMI measurements periods with the exception of 2 DMI measurement periods; spring 2015 where they received 0.88 kg of DM/cow and spring 2016 where they received 3.55 kg of DM/cow, due to low pasture growth rates before the DMI measurement periods. Pasture comprised the remainder of the diet for all DMI measurement periods (no silage was fed during the DMI measurement periods). The alkane concentration of the concentrate fed was analyzed as described previously. In the tetraploid PRG with white clover and diploid PRG with white clover paddocks, pasture samples were taken and manually separated into PRG and white clover fractions, frozen, and milled as described previously. These fractions were then analyzed to provide individual alkane concentrations for PRG and white clover. The ratio of dosed C32-alkane to pasture C33 (tritricontane) was used to estimate DMI using the equation described by Mayes et al. (1986) as follows:

$$\text{Daily pasture intake}\left(\text{kg of DM/cow}\right) = \frac{F_i/F_j \times \left(D_j + I_s \times S_j\right) - I_s \times S_i}{P_i - \left(F_i/F_j \times P_j\right)},$$

where F_i, S_i, and P_i are the concentrations (mg/kg of DM) of the natural odd-chain n-alkanes in feces, supplement, and pasture, respectively; F_j, S_j, and P_j are the concentrations (mg/kg of DM) of the even-chain n-alkane in feces, supplement, and pasture, respectively; D_j is the dose rate (mg/d) of the even-chain n-alkane; and I_s is the daily supplement intake (kg of DM/d). When calculating DMI for the tetraploid PRG with white clover and diploid PRG with white clover treatments, a weighted average pasture C33 concentration, based on the proportion of PRG and white clover in the sward during the DMI measurement period, was used to account for the different C33 concentration of PRG and white clover (Dove and Mayes, 1991). Therefore, the proportion of white clover and PRG consumed by the cows was accepted as not differing substantially from that measured in the sward.

Measures of milk production efficiency were calculated based on the net energy system (Faverdin et al., 2011), where 1 unité fourragère lait (**UFL**) of energy is defined as the net energy content of 1 kg of standard air-dry barley for milk production, equivalent to 1,700 kcal. The measures of milk production efficiency were energy (UFL) intake, UFL required for maintenance, UFL available for standard (4.0% fat and 3.1% protein content) milk production after accounting for maintenance, UFL required to produce 1 kg of milk, MSo per kg UFL intake before and after accounting for maintenance, total DMI (**TDMI**; kg)/100 kg of BW, SCM (kg)/100 kg of BW, MSo (kg)/100 kg of BW, and MSo (kg)/kg of TDMI. Energy balance was defined as the difference between energy intake and energy required for production, maintenance, and BW change (Faverdin et al., 2011)

Statistical Analysis

Grazing and nutritive value characteristics were analyzed using PROC MIXED (SAS, version 9.3, SAS Institute Inc.), with the effects of year, DMI measurement period, PRG ploidy, and white clover treatment included as fixed effects and the associated interactions, such as PRG ploidy × white clover treatment, DMI measurement period × white clover treatment, DMI measurement period × PRG ploidy, and the triple interaction DMI measurement period × PRG ploidy × white clover treatment, were included in the model. Tukey's test was used to determine differences between treatment means. Variance components was the covariance structure used as it minimized the Akaike information criterion value. Statistical significance was considered at $P \leq 0.05$ and trends were considered at $0.05 < P \leq 0.10$.

Daily milk yield, pasture DMI (**PDMI**), TDMI, energy intake, energy balance, TDMI/100 kg of BW, SCM/100 kg of BW, MSo/100 kg of BW, and MSo/kg of TDMI were analyzed using PROC MIXED in SAS (SAS Institute Inc.). Analysis took into account the effects of year, DMI measurement period, PRG ploidy, white clover treatment, genotype, and parity as fixed effects and the associated interactions, PRG ploidy × white clover treatment, DMI measurement period × white clover treatment, DMI measurement period × PRG ploidy, DMI measurement period × PRG ploidy × white clover treatment, year × PRG ploidy, year × white clover treatment, and genotype × parity, were included in the model. Individual cow was the experimental unit, considered as a random effect in the model, and DMI measurement period (spring, summer, or autumn) was the repeated measure. Tukey's test was used to determine differences between treatment means. Statistical significance was considered at $P \leq 0.05$ and trends were considered at $0.05 < P \leq 0.10$.

A separate, global analysis, was also undertaken to investigate the effect of animal characteristics (mean BW, genetic merit for MSo yield, parity, and genotype) on PDMI and TDMI using analysis of covariance.

RESULTS

Sward Measurements

Grazing characteristics and sward nutritive value during the DMI measurement periods is presented in Table 1. Year had a significant effect on all grazing characteristics with the exception of OMD and NDF, while there was a tendency for year to affect ADF (Table 1). Pregrazing pasture mass was 1,679 kg of DM/ha (>4.0 cm), on average, across all DMI measurement periods with no difference in pregrazing pasture mass between measurement periods. Measurement period had an effect on pregrazing sward height, postgrazing sward height, and pasture allowance ($P < 0.001$). Pregrazing sward height was greatest in autumn and pasture allowance was greater in autumn than summer ($P = 0.007$), with no difference in pasture allowance observed between spring and summer, and spring and autumn. Postgrazing sward height increased significantly from spring to summer and summer to autumn

Table 1. Grazing characteristics and sward nutritive value on average over all DMI measurement periods and within each DMI measurement period

Item	Average	Measurement period[1]			SEM	P-value	
		Spring	Summer	Autumn		Year	Measurement period
Pregrazing pasture mass (kg of DM/ha)	1,679	1,636	1,712	1,689	65.3	0.006	0.698
Pregrazing sward height (cm)	8.91	8.22	9.92	9.61	0.214	0.032	<0.001
Postgrazing sward height (cm)	4.00	3.73	4.08	4.19	0.093	0.007	<0.001
Pasture allowance (kg of DM/cow)	15.8	15.1	15.0	17.2	0.52	0.004	0.003
OM digestibility (g/kg of DM)	807	817	808	797	22.4	0.131	<0.001
CP (g/kg of DM)	197	207	198	185	4.1	<0.001	0.009
NDF (g/kg of DM)	381	356	402	385	9.9	0.207	0.007
ADF (g/kg of DM)	219	197	230	230	4.0	0.076	<0.001
Ash (g/kg of DM)	80	73	84	80	1.5	0.005	<0.001

[1]Spring = 64 DIM; summer = 110 DIM; autumn = 189 DIM.

($P < 0.001$). There was seasonal variation in OMD ($P < 0.001$), with the highest OMD values observed in spring, intermediate in summer, and lowest in autumn. Crude protein, NDF, ADF, and ash were all affected by measurement period ($P < 0.05$).

Animal Performance

None of the interactions associated with genotype or parity were significant so only main effects are presented (sward effects and interactions within this study have previously been published by McClearn et al., 2021). Milk yield was significantly affected by cow genotype ($P < 0.001$) with HF having the highest daily yield (23.2 kg/cow) during the DMI measurement periods, compared with JEX (22.0 kg/cow) and 3WAY (21.9 kg/cow), which were similar (Table 2). However, milk fat content was greater for JEX (4.54%) compared with HF (4.22%) and 3WAY (4.34%) cows. Milk protein content was greater for JEX (3.80%) and 3WAY (3.76%) cows compared with HF cows (3.62%). Fat yield was greater for JEX compared with 3WAY, HF was similar to both JEX and 3WAY, and protein yield was not different among genotypes. This resulted in similar daily MSo yields among all genotypes ($P = 0.12$), although there was a tendency for 3WAY cows to have a lower SCM than JEX ($P = 0.061$). Body weight was significantly different between genotypes with JEX being the lightest (470 kg), 3WAY (485 kg) intermediate, and HF (514 kg) the heaviest. There was a tendency for BCS to be lower for HF cows compared with JEX and 3WAY cows ($P = 0.079$).

There was a significant effect of parity on milk and MSo yield, which increased linearly with parity (Table 3). Parity 1 had the lowest daily milk (19.3 kg/cow) and MSo yield (1.54 kg/cow), parity 2 cows were intermediate (22.9 kg/cow milk and 1.84 kg/cow MSo yield), and parity 3+ had the highest milk (25.0 kg/cow) and MSo yield (2.02 kg/cow). There was no effect of parity on milk fat content, but milk protein content was lowest ($P = 0.014$) in parity 1 cows (3.68%) compared with parity 2 cows and similar between parity 2 and 3+ animals (3.76% and 3.74%, respectively). Fat and protein yield increased as parity increased ($P < 0.001$). First parity animals were lightest, parity 2 were intermediate, and parity 3+ were heaviest ($P < 0.001$),

Table 2. Effect of Holstein-Friesian (HF), Jersey × HF (JEX), and Norwegian Red × JEX (3WAY) cows on milk yield, solids-corrected milk (SCM), milk solids yield, milk composition, BW, and BCS

Item	Genotype			SEM	P-value
	HF	JEX	3WAY		Genotype
Daily milk yield (kg/cow)	23.2[a]	22.0[b]	21.9[b]	0.25	<0.001
Daily SCM yield (kg/cow)	23.1	23.1	22.4	0.25	0.047
Fat concentration (%)	4.22[a]	4.54[b]	4.34[a]	0.054	<0.001
Protein concentration (%)	3.61[a]	3.80[b]	3.76[b]	0.023	<0.001
Daily fat yield (kg/cow)	0.97[ab]	0.99[a]	0.95[b]	0.013	0.037
Daily protein yield (kg/cow)	0.83	0.83	0.82	0.009	0.493
Daily milk solids[1] (kg/cow)	1.81	1.82	1.77	0.020	0.119
BW (kg)	514[a]	470[b]	485[c]	4.5	<0.001
BCS	2.94	2.97	2.99	0.016	0.079

[a–c]Means within a row with different superscripts are significantly different ($P > 0.05$).

[1]Milk solids = kg fat + protein.

Table 3. Effect of dairy cow parity on milk yield, solids-corrected milk (SCM), milk solids yield, milk composition, BW, and BCS

	Parity				*P*-value
Item	1	2	3+	SEM	Parity
Daily milk yield (kg/cow)	19.3[a]	22.9[b]	25.0[c]	0.21	<0.001
Daily SCM yield (kg/cow)	19.6[a]	23.4[b]	25.6[c]	0.22	<0.001
Fat concentration (%)	4.35	4.35	4.40	0.046	0.590
Protein concentration (%)	3.68[a]	3.76[b]	3.74[ab]	0.020	0.014
Daily fat yield (kg/cow)	0.83[a]	0.99[b]	1.09[c]	0.012	<0.001
Daily protein yield (kg/cow)	0.71[a]	0.85[b]	0.92[c]	0.007	<0.001
Daily milk solids[1] (kg/cow)	1.54[a]	1.84[b]	2.02[c]	0.017	<0.001
BW (kg)	456[a]	489[b]	523[c]	3.5	<0.001
BCS	2.99[a]	2.94[b]	2.98[a]	0.014	0.006

[a–c]Means within a row with different superscripts are significantly different ($P > 0.05$).

[1]Milk solids = kg fat + protein.

whereas parity 2 animals had a lower BCS than parity 1 and 3+ animals ($P = 0.006$).

Dry Matter Intake

Pasture DMI differed significantly among genotypes (Table 4); HF had a higher PDMI (16.5 kg/cow) than 3WAY (15.9 kg/cow), whereas JEX (16.2 kg/cow) were similar to both HF and 3WAY. Total DMI followed a similar trend. Consequently, daily energy intake was significantly different ($P = 0.046$) among genotypes, with HF having a higher energy intake (17.6 UFL/d) than 3WAY (17.1 UFL/d), with JEX (17.4 UFL/d) not different from either HF or 3WAY. However, this did not affect daily energy balance, as all genotypes were similar ($P = 0.97$) and daily energy balance increased throughout the year for every genotype. Total DMI and PDMI increased linearly as parity increased ($P < 0.001$; Table 5). Parity 3+ had the highest PDMI (18.1 kg/cow), parity 2 cows were intermediate (16.7 kg/cow), with parity 1 having the lowest (13.8 kg/cow). Consequently daily energy intake was significantly affected by parity ($P < 0.001$), with older parity animals having higher energy intakes (17.9 and 19.3 UFL/d for parity 2 and 3+, respectively, vs. 14.9 UFL/d for parity 1 cows). Daily energy balance was also significantly different ($P < 0.001$) among parities with lower energy balance observed for parity 1 animals (−0.1 UFL/d) compared with parity 2 and 3+ (1.6 and 1.8 UFL/d, respectively).

Unité fourragère lait required for maintenance was greatest for HF, intermediate for 3WAY, and lowest for

Table 4. Effect of Holstein-Friesian (HF), Jersey × HF (JEX), and Norwegian Red × JEX (3WAY) cows on pasture and total DMI, energy intake, and energy balance

	Genotype				*P*-value
Item	HF	JEX	3WAY	SEM	Genotype
Pasture DMI (kg)	16.5[a]	16.2[ab]	15.9[b]	0.14	0.034
Spring	15.6	15.1	15.1	0.19	
Summer	16.6	16.7	16.1	0.22	
Autumn	17.2	16.9	16.6	0.19	
Total DMI (kg)	17.2[a]	16.9[ab]	16.7[b]	0.14	0.039
Spring	17.2	16.6	16.7	0.19	
Summer	17.1	17.2	16.7	0.22	
Autumn	17.2	17.0	16.6	0.19	
Daily energy intake (UFL[1])	17.6[a]	17.4[ab]	17.1[b]	0.14	0.046
Spring	17.9	17.4	17.4	0.20	
Summer	17.6	17.7	17.2	0.23	
Autumn	17.3	17.1	16.7	0.20	
Energy balance (UFL)	1.0	1.2	1.1	0.13	0.697
Spring	0.2	0.2	0.3	0.20	
Summer	0.6	1.1	0.8	0.24	
Autumn	2.3	2.3	2.3	0.20	

[a,b]Means within a row with different superscripts are significantly different ($P < 0.05$).

[1]UFL = unité fourragère lait (the net energy content of 1 kg of standard barley; that is, 1,700 kcal; Faverdin et al., 2011).

Table 5. Effect of dairy cow parity on total and pasture DMI, daily energy intake, and daily energy balance

Item	Parity			SEM	*P*-value
	1	2	3+		Parity
Pasture DMI (kg)	13.8[a]	16.7[b]	18.1[c]	0.13	<0.001
Spring	12.5	15.8	17.5	0.19	
Summer	13.9	17.0	18.5	0.22	
Autumn	15.0	17.3	18.4	0.19	
Total DMI (kg)	14.5[a]	17.4[b]	18.9[c]	0.13	<0.001
Spring	14.1	17.3	19.1	0.18	
Summer	14.5	17.5	19.1	0.22	
Autumn	15.0	17.4	18.5	0.18	
Daily energy intake (UFL[1])	14.9[a]	17.9[b]	19.3[c]	0.13	<0.001
Spring	14.7	18.1	19.9	0.18	
Summer	14.9	18.0	19.5	0.22	
Autumn	15.2	17.5	18.5	0.18	
Daily energy balance (UFL)	−0.1[a]	1.6[b]	1.8[b]	0.13	<0.001
Spring	−1.3	0.7	1.4	0.20	
Summer	−0.4	1.4	1.4	0.25	
Autumn	1.4	2.8	2.7	0.20	

[a–c]Means within a row with different superscripts are significantly different ($P < 0.05$).

[1]UFL = unité fourragère lait (the net energy content of 1 kg of standard barley; that is, 1,700 kcal; Faverdin et al., 2011).

JEX ($P < 0.001$; Table 6). Unité fourragère lait available for milk after maintenance was not different among genotypes ($P = 0.106$). Unité fourragère lait used per kilogram of standard milk produced, MSo per UFL of net energy intake, and MSo per UFL available after maintenance were unaffected by genotype ($P > 0.05$). Total DMI, SCM, and MSo/100 kg of BW were all significantly different among genotypes (Table 6). Total DMI/100 kg of BW was highest for JEX (3.63 kg), with HF and 3WAY significantly lower than JEX but similar to each other (3.37 and 3.45 kg, respectively). Solids-corrected milk and MSo/100 kg of BW followed a similar trend with both highest for JEX, with HF and 3WAY lower than JEX but similar to each other. Milk solids/kg TDMI was not affected by genotype ($P = 0.208$).

Parity had a significant effect on all efficiency measures with the exception of MSo/kg of UFL intake and MSo/kg of TDMI (Table 7). Unité fourragère lait required for maintenance and UFL available for milk after maintenance were lowest for parity 1, intermediate for parity 2, and greatest for parity 3+ cows ($P < 0.001$). Unité fourragère lait used/kg milk produced, MSo/UFL available after maintenance, TDMI/100 kg

Table 6. Effect of Holstein-Friesian (HF), Jersey × HF (JEX), and Norwegian Red × JEX (3WAY) cows on energy and gross production efficiencies

Item	Treatment			SEM	*P*-value
	HF	JEX	3WAY		Genotype
UFL[1] required for maintenance	5.4[a]	5.1[b]	5.2[c]	0.03	<0.001
UFL available for milk[2] after maintenance	11.9	12.0	11.6	0.13	0.106
UFL used/kg of milk produced	0.49	0.49	0.49	0.006	0.972
Milk solids[3]/UFL of NEI[4] (g)	103	106	104	1.0	0.222
Milk solids/UFL available after maintenance (g)	158	157	157	1.8	0.934
Total DMI/100 kg of BW (kg)	3.37[a]	3.63[b]	3.45[a]	0.031	<0.001
SCM[5]/100 kg of BW (kg)	4.51[a]	4.97[b]	4.63[a]	0.058	<0.001
Milk solids/100 kg of BW (kg)	0.35[a]	0.39[b]	0.37[a]	0.005	<0.001
Milk solids/total DMI (kg)	0.106	0.108	0.107	0.0011	0.208

[a–c]Means within a row with different superscripts are significantly different ($P < 0.05$).

[1]UFL = unité fourragère lait (the net energy content of 1 kg of standard barley; that is, 1,700 kcal; Faverdin et al., 2011).

[2]Standard milk (4.0% fat and 3.1% protein content).

[3]Milk solids = fat + protein kg.

[4]Milk solids produced per UFL of net energy intake.

[5]SCM = solids-corrected milk.

Table 7. Effect of cow parity on energy and gross production efficiencies

Item	Parity			SEM	P-value
	1	2	3+		Parity
UFL[1] required for maintenance	5.0[a]	5.2[b]	5.4[c]	0.03	<0.001
UFL available for milk[2] after maintenance	9.1[a]	12.6[b]	13.8[c]	0.12	<0.001
UFL used/kg of milk produced	0.44[a]	0.51[b]	0.52[b]	0.006	<0.001
Milk solids[3]/UFL of NEI[4] (g)	104	104	105	1.0	0.622
Milk solids/UFL available after maintenance (g)	176[a]	149[b]	149[b]	1.8	<0.001
Total DMI/100 kg of BW (kg)	3.25[a]	3.60[b]	3.60[b]	0.029	<0.001
SCM[5]/100 kg of BW (kg)	4.38[a]	4.83[b]	4.90[b]	0.049	<0.001
Milk solids/100 kg of BW (kg)	0.34[a]	0.38[b]	0.39[b]	0.004	<0.001
Milk solids/total DMI (kg)	0.107	0.107	0.107	0.0010	0.873

[a–c]Means within a row with different superscripts are significantly different ($P < 0.05$).

[1]UFL = unité fourragère lait (the net energy content of 1 kg of standard barley; that is, 1,700 kcal; Faverdin et al., 2011).

[2]Standard milk (4.0% fat and 3.1% protein content).

[3]Milk solids = fat + protein kg.

[4]Milk solids produced per UFL of net energy intake.

[5]SCM = solids-corrected milk.

of BW, SCM/100 kg of BW, and MSo/100 kg of BW were lower for parity 1 animals compared with parity 2 and 3+ animals ($P < 0.001$).

When the effects of animal characteristics on PDMI and TDMI were analyzed, several significant results were observed. Body weight had a positive effect on both PDMI and TDMI, with coefficients of +1 kg of PDMI/100 kg of BW and +1 kg of TDMI/100 kg of BW observed. Genetic merit for MSo yield tended to have a significant effect ($P = 0.058$) on PDMI and TDMI as a 10-kg increase in genetic merit for MSo yield increased both PDMI and TDMI by 0.20 kg. The effect of genotype was significant ($P = 0.011$) but inconsistent with a +0.05, +0.20, and −0.25 kg effect on PDMI and TDMI observed for HF, JEX, and 3WAY, respectively. Parity had a classical effect on both PDMI and TDMI as a −2.0, +0.5, and +1.5 kg effect on PDMI and TDMI was observed for parity 1, 2, and 3+ animals, respectively.

DISCUSSION

A major limiting factor affecting milk production per cow from grazed pasture is DMI (Bargo et al., 2003; Dillon, 2007). Therefore, one of the key determinants of the success of pasture-based systems is the ability of cows to graze to achieve high DMI of grazed pasture to meet their productive potential (Delaby et al., 2018). This not only occurs through the cow's ability to consume high quantities of pasture, to respond to and recover from environmental disturbances (i.e., to be robust), but also through the ability of the cow to calve annually at a time that facilitates the maximum amount of grazed pasture to be incorporated in the cow's diet (Dillon, 2007; Friggens et al., 2017; Delaby et al., 2018). McClearn et al. (2020a,b) reported on total lactation milk production, and reproductive and economic performance of the 3 genotypes used in this experiment and found similar MSo yield between HF and JEX, HF, and 3WAY but that 3WAY had lower MSo yield than JEX. Reproductive performance of all 3 genotypes was similar (McClearn et al., 2020a) but JEX were the most profitable on a per hectare basis, followed by 3WAY and HF (McClearn et al., 2020b). This paper investigated the differences in DMI and milk production efficiency between the 3 genotypes to further elucidate why the differences observed by McClearn et al. (2020a,b) occurred.

Effect of Cow Genotype on Milk Production and DMI

During the DMI measurement periods, HF had a 5.5% and a 5.9% greater daily milk yield than JEX and 3WAY, respectively, but all 3 genotypes had similar daily SCM and MSo yields due to the higher fat and protein concentration of milk from JEX and 3WAY cows. As discussed previously, total lactation milk and MSo yields followed a similar pattern although JEX cows did have a greater total lactation MSo yield than 3WAY cows (McClearn et al., 2020a). Previous research has shown similar findings whereby HF typically have greater daily and total milk yields but JEX have similar or greater MSo yields than HF due to the inherent greater milk composition associated with the Jersey breed (White et al., 2001; Prendiville et al., 2011; Vance et al., 2012). Few studies have investigated milk production from a 3-way rotational crossbreed compared with purebred Holsteins or HF. Those that have done so used different breeds than the ones used in this study but found a similar pattern to when JEX were compared with HF; typically the purebred

Holstein or HF produced greater total lactation milk yields than the 3-way rotational crosses, but both the purebred and 3-way rotational crosses produced similar total lactation MSo yields (Hazel et al., 2014; Ferris et al., 2018; Shonka-Martin et al., 2019a). In contrast, Hazel et al. (2021) reported that 2-breed crossbreeds had +2% greater MSo yields during first lactation but similar MSo in lactations 2 and 3 to their Holstein herd mates, whereas the 3 breed crossbreeds had −3.5% MSo than their Holstein herd mates in each of their first 3 lactations. Similar to the average lactation BW observed by McClearn et al. (2020a), in this study, BW during the DMI measurement periods was lowest for JEX, intermediate for 3WAY, and greatest for HF, with the HF 9.4% and 6.0% heavier than JEX and 3WAY, respectively.

In the current study HF had a significantly greater TDMI and PDMI (+ 3.0%) compared with 3WAY, with no difference in DMI observed between JEX and HF, or JEX and 3WAY. In terms of the HF and JEX genotypes, the results of the current study are similar to Prendiville et al. (2009) who compared DMI of HF and F_1 JEX cows in a pasture-based system. Prendiville et al. (2009) found no significant difference in DMI between HF and F_1 JEX cows, although a numerical difference was found with mean DMI 4.3% greater for HF (16.9 kg/cow per d) compared with F_1 JEX cows (16.2 kg/cow per d). In contrast, Coffey et al. (2017) found HF cows had a 3.8% greater DMI compared with F_1 JEX cows when the 2 genotypes were stocked at a similar BW/ha, which is likely to have penalized JEX [due to their higher stocking rate in terms of cows/ha (despite similar overall BW/ha) because of their lower BW] to a greater extent than HF. Despite the inconsistent effect of genotype on total DMI among the studies mentioned and this study, the results of the current study corroborate previous research that has shown JEX to have a clear advantage in terms of DMI capacity relative to their BW compared with HF. Beecher et al. (2014) reported that, relative to BW, F_1 JEX had greater reticulorumen and total gastrointestinal tract weight than HF and this could explain the greater DMI capacity observed for JEX cows in previous studies (Prendiville et al., 2009; Vance et al., 2012) and in the current study.

Very few studies have examined DMI of any 3-way rotational breeds. Ferris et al. (2018) compared full lactation DMI of Holstein and Swedish Red × Jersey × Holstein cows and although Holsteins had higher DMI in early lactation, both breeds had similar total lactation DMI. Shonka-Martin et al. (2019a) compared the DMI of a rotational crossbred of Montbéliarde × Viking Red × Holstein with purebred Holstein cows. They found lower DMI from crossbreds compared with HF cows from 4 to 150 DIM in their first 3 lactations, with similar MSo production and BW, and higher BCS. Hazel et al. (2021) reported that the 3-breed crossbred utilized in their study had a lower daily feed cost during lactation than Holstein, which is likely a reflection of reduced DMI for the crossbreeds although daily DMI was not measured directly in that study. Therefore, the results from this study corroborate some previous research that has shown purebred Holstein or HF cows to have greater DMI compared with 3-way rotational crossbreeds, even though the 3-way rotational crossbreds or even the purebred Holstein or HF used across studies are not directly comparable in terms of the makeup of the 3 breeds.

Effect of Parity on Milk Production and DMI

It is well established that the physiological state of an animal will influence the amount of energy it consumes and eventually will utilize; therefore, any effect of the physiological state on abdominal capacity will affect intake [e.g., young, fat, or pregnant animals will have a reduced intake capacity compared with older, thin, or nonpregnant animals (Bines, 1976)]. Jarrige et al. (1986) developed a voluntary DMI prediction equation using fill values of diets, which is particularly important in pasture-based systems. They found parity 1 animals had an intake capacity of approximately 80% of multiparous cows in grazing systems. The current study found TDMI of 14.5, 17.4, and 18.9 kg/cow per d for parity 1, 2, and 3+ cows, respectively, and a 20% and 30% reduction in TMDI for parity 1 compared with parity 2 and 3+, respectively, which is consistent with current knowledge on how a cow's performance changes over concurrent lactations. Bines (1976) observed similar differences between parities, with DMI of 13.7, 15.8, and 16.7 kg/cow per d for parity 1, 2, and 3 cows, respectively. Kennedy et al. (2003) observed higher DMI values when comparing cows in pasture-based systems receiving differing levels of concentrate supplementation, with TDMI of 14.9, 17.7, and 20.9 kg/cow per d for parity 1, 2, and 3+, respectively. Similarly Buckley et al. (2000) compared high and medium genetic merit cows throughout the first 3 yr of lactation and again found clear increases in DMI between primiparous and multiparous cows (15.7 vs. 19.6 kg/cow per d, respectively). The lower DMI capacity of parity 1 compared with parity 2 and 3+ cows resulted in lower daily milk and MSo yields (−18.7 and −29.5% for parity 1 compared with parity 2 and 3+, respectively) and is expected considering the effect of parity on milk production (Lee and Kim, 2006; Berry, 2015).

Milk Production Efficiency

The JEX cows in this study had a higher DMI/100 kg of BW than the HF cows (3.63 vs. 3.37 kg of DM, respectively), which is similar to results observed by González-Verdugo et al. (2005). Vance at al. (2012) also found higher DMI per kg of BW in F_1 Jersey × HF cows compared with HF cows, which were on average 75 kg heavier. Prendiville et al. (2009) and Coffey et al. (2017) also explored the same production efficiencies and observed similar results for TDMI/100 kg of BW for HF (3.35 kg) and JEX cows (3.59 kg), and slightly lower but relative MSo/100 kg of BW for HF (0.31 kg) and JEX cows (0.36 kg). Furthermore, Coffey et al. (2017) found as a percentage of BW, JEX cows had higher DMI and higher feed conversion efficiency, but overall a lower DMI compared with HF cows. They also reported similar energy balances between genotypes as was seen in the present study, reflecting the lower DMI of JEX cows but also their lower maintenance energy requirement compared with HF. In the current study, although DMI was not different, the NE required for maintenance was lowest for JEX, intermediate for 3WAY, and greatest for HF, which corresponds directly to the difference in BW between HF and JEX (Prendiville et al., 2009). As discussed previously, the greater gastrointestinal tract weight of the JEX compared with HF is likely one of the main drivers of the greater DMI capacity of JEX, but other potential reasons may include differences in BW or grazing behavior (Prendiville et al., 2009; Vance et al., 2012).

In this study, 3WAY had similar production efficiencies to HF but was lower than JEX. The reduced efficiency for 3WAY compared with JEX is likely due to the greater BW of 3WAY compared with JEX and indicates that the advantage of JEX in terms of production efficiency is diluted when a third breed (Norwegian Red) is introduced into rotational crossing. Few studies have examined production efficiencies for any 3-way rotation breeds. Shonka-Martin et al. (2019a,b) recently compared a rotational crossbred of Montbéliarde × Viking Red × Holstein with Holstein cows for DMI and production efficiencies in the first 150 d of lactation. They found that the 3-breed crossbreds had greater feed conversion efficiency, ECM per kg of DMI, and net energy for lactation efficiency compared with Holstein (Shonka-Martin et al., 2019b), which is in contrast to the results observed in this study as there was no difference in any of the production efficiencies measured. It is unsurprising that there were no differences in the production efficiencies between HF and 3WAY in this study as milk and MSo yields and DMI were not different between HF and 3WAY. However, Shonka-Martin et al. (2019b) did report that Holsteins had greater DMI per kg of BW compared with 3-breed crossbreds, whereas we observed no difference in total DMI per 100 kg of BW between HF and 3WAY despite a small numerical advantage (+0.09 kg of DMI/100 kg of BW) for 3WAY due to the similar DMI and lower BW of 3WAY compared with HF. Care must be taken when comparing the results of our study and Shonka-Martin et al. (2019b) as they are not directly comparable due to the fact that the 3-breed rotational crossbreeds and the purebred Holsteins and HF used in the studies are distinctly different and the timeframe over which the studies were undertaken was also different. Our study indicates that although 3WAY had lower DMI, there was no disadvantage of 3WAY in terms of production efficiency compared with HF although some of the efficiency gains achieved with JEX were reduced when a third breed (Norwegian Red) was introduced.

The greater production efficiency of parity 2 and 3+ cows compared with parity 1 cows in terms of TDMI/100 kg of BW, SCM/100 kg of BW, and MSo/100 kg of BW is unsurprising considering the differences observed in BW, milk and MSo yield, TDMI, and energy intake between the parities. As parity increased maintenance requirements increased, but UFL available for milk after maintenance also increased due to the higher TDMI and energy intake of greater parity cows. The higher TDMI of greater parity cows, due to their greater BW, is expected and is supported by the results of this study, where both PDMI and TDMI increased by 1 kg/100 kg BW. Hurley et al. (2018) observed that the phenotypic correlation between residual energy intake (defined as net energy intake minus predicted energy requirements based on lactation performance) and energy balance was weaker for parity 1 cows compared with parity 3 cows at the same stage of lactation, suggesting primiparous cows use the ingested energy for both milk production and growth. This is supported by the fact that in this study energy used/kg milk was lower for parity 1 cows (0.44 UFL) compared with parity 2 and 3+ cows (0.52 UFL).

The result that both PDMI and TDMI increased by 1 kg/100 kg of BW is lower than the 2.2 kg/100 kg of BW reported by Stakelum and Connolly (1987) but is consistent with other previous research (Bines, 1976; Brown et al., 1977; Kennedy et al., 2003). Although genetic merit for milk yield was not associated with greater DMI in this study in contrast to previous research (Kennedy et al., 2003), genetic merit for MSo yield was, as a 10 kg increase in genetic merit for MSo yield was associated with 0.20 kg increase in DMI.

CONCLUSIONS

The study showed that cow genotype is important in grazing dairy systems as it influences DMI and production efficiency with regard to cow BW and MSo production. Under the imposed pasture-based systems, all 3 genotypes achieved relatively high levels of DMI and production efficiency, indicating that all 3 breeds are suitable for pasture-based systems; however, there were some differences in DMI and production efficiency. Holstein-Friesian and JEX, and JEX and 3WAY had similar DMI, but HF had greater DMI than 3WAY. Jersey × Holstein-Friesian cows were the most efficient for TDMI/100 kg of BW, SCM/100 kg of BW, and MSo/100 kg of BW. The results indicate that some of the efficiency gains (SCM/100 kg of BW, MSo/100 kg of BW, and TDMI/100 kg of BW) achieved with JEX decreased when the third breed (Norwegian Red) was introduced.

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