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Estimating milk production and energy-use efficiency of pasture-grazed Holstein and Jersey cows using mathematical models

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Abstract

The efficiency of feed use for milk production is critical for sustainable and profitable pasture-based dairy systems. The aim of this study was to estimate milk production and energy-use efficiencies of pasture-grazed Holstein and Jersey cows. Lactation records of 122 Holstein and 99 Jersey cows varying from parities 1 to 6 that were managed under similar feeding and environmental conditions were collected from 2005 to 2014. Feed intake and nutrient requirements of the cows were calculated using the National Research Council and the Cornell Net Carbohydrate and Protein System equations. Holsteins had a higher milk yield/kg dry matter intake (1.36±0.01 *vs.* 1.27±0.01 kg), whereas Jerseys had higher efficiencies in milk fat (52.4±0.3 *vs.* 58.4±0.4 g), milk protein (42.7±0.3 *vs.* 45.1±0.3 g), and energy-corrected milk (1.30±0.01 *vs.* 1.36±0.01 kg) per kg dry matter intake. Jersey cows also had a higher dry matter intake/kg body weight (3.13±0.02 *vs.* 3.51±0.02%). During transition and early lactation stages, Holstein and Jersey cows were in negative energy balance for 102.4±2.3 *vs.* 74.2±2.3 days, with the lowest energy reserves (-53.9 MJ *vs.* -39.7 MJ) reached at 22.3±0.9 *vs.* 24.6±0.9 days post-calving, respectively. Compared to Holsteins, Jersey cows used proportionally less net energy intake to produce 100 g milk fat (13.7±0.10 vs. 12.5±0.10), 100 g milk protein (16.7±0.14 vs.16.2±0.15) and a 1-kg energy-corrected milk (5.52±0.04 vs. 5.35±0.04), making them a better breed for pasture-based dairy systems as they possess more production and feed-use efficiency traits, which are desirable in pasture-based production systems.

Keywords: energy balance, energy corrected milk, energy intake, feeding and environment

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Introduction

Feed efficiency is a biological traits that is referred to as a trait of economic importance on a dairy farm. This is because, although the capacity to secrete milk is determined by the metabolic ability of the mammary tissues, maximum rates of milk synthesis are largely influenced by the continuous supply of nutrients, their digestion, and conversion efficiency for synthesis of the precursors for supply to the mammary tissue (Boyd & Kensinger, 1998; Cai *et al.,* 2018). This therefore makes the efficiency with which feed is converted to milk a critical element for farm profitability and sustainability. A cow with a high feed-use efficiency presents with higher feed intake per unit liveweight, has lower maintenance energy requirements, partitions more metabolizable energy to milk than to body tissue, and loses less energy in faeces, urine, or methane for a given intake (Grainger & Goddard, 2004). The weight loss should, however, be on a short-term basis as long-term weight loss may predispose the cow to metabolic disorders and poor reproductive performance.

For milk synthesis, energy is the most essential nutrient, being the major determinant of milk volume as it is responsible for regulating osmotic pressure in the mammary system (Liu *et al.*, 2013; Lin *et al.*, 2016), is a precursor of milk fat (Gorewit, 1988; Rezaei *et al.,* 2016), and is a supplier of energetic precursors for protein synthesis to manufacture milk protein (Mepham, 1982; Bionaz *et al.*, 2012). Despite being essential, energy is often the most limiting nutrient (VandeHaar *et al.,* 2016) as the

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recommended inclusion rate of non-fibre carbohydrates in lactating dairy cows' diet is 30–45% on a dry matter basis (Batajoo & Shaver, 1994; Afzalzadeh *et al.*, 2010; Hall *et al.*, 2010). The energy deficiency effects become more pronounced in grazing animals as the bulk of pasture grazed consists of cellulose. Approximately 20–70% of cellulose may not be digestible, resulting in only 10–35% of energy intake being captured as net energy (Varga *et al.,* 1997). Consequently, there is less available energy for maintenance and production functions such as milk production, growth, and pregnancy. Moreover, the excess fibre in the diet of grazing animals results in longer physical fill of the rumen due to prolonged feed retention time and hence reduces intake to below the required levels. The efficiency in digesting fibre and partitioning the available net energy to maintenance and production functions is therefore of significance in cows on pasture.

In South Africa, milk prices are determined by milk processors, based mainly on specific amounts of fat and protein (Anonymous, 2017). The two components have a major effect on the quality and quantity of dairy products produced. Holsteins and Jerseys are the dominant dairy breeds in commercial herds; their differences in production and feed-use efficiency may have economic consequences and requires investigation. Several studies that compare the two breeds have been conducted (Mackle *et al.*, 1996; Muller & Botha, 1998; Rastani *et al.,* 2001; Thomson *et al.,* 2001; Anderson *et al.,* 2007; Aikman *et al.,* 2008; Prendiville *et al.,* 2009; Kristensen *et al.,* 2015; Olijhoek *et al.*, 2018). Breed variability in performance efficiencies between countries has been observed, indicating that research that compares the performance efficiencies of Holstein and Jersey cows from different countries should not be applied directly to another country due to differences in production systems, available feeds, and climatic conditions. Moreover, the duration of the conducted studies ranges from one season of the year to one lactation period or a year. A longitudinal study that will provide a repeated measure of milk production and feed-use efficiency on the same subjects at different lactation stages in different parities will provide information on the consistency and persistency of these variations in cows and therefore substantiate the available literature. The aim of this study was to estimate and compare energy use and milk production efficiencies of pasture-grazed Holstein and Jersey cows in a Mediterranean-type climatic region.

Materials and methods

Details of experimental animals, experimental area, diet, and management of experimental animals were presented in Bangani *et al.* (2022); only a summary will be provided in this paper. Lactation records of 122 Holstein and 99 Jersey cows that were managed under similar feeding and environmental conditions were used. The records were compiled as part of the National Milk Recording and Improvement Scheme under the Animal Production Institute of the Agricultural Research Council to estimate breeding values for sires, cows, and heifers for a genetic profile of individual herds. Collected records included cow birth date, calving date, lactation number, kg body weight (BW), kg milk yield (MY), % milk fat (MF), and % milk protein (MP). Milk was corrected for its fat and protein content to energy-corrected milk (ECM) using the equation of Tyrell & Reid (1965) (Table 1). The use of data was approved by the Information Officer for the Supply of Biological Specimens and other Data (Ref. No. 2015/001), Directorate: Animal Sciences, Western Cape Department of Agriculture, South Africa. Mathematical models from the National Research Council (NRC, 2001) and the Cornell Net Carbohydrate and Protein System (CNCPS) were used to predict feed intake, nutrient composition, and animal requirements from the secondary data (Table 1). Both the NRC and CNCPS models use equations from peer reviewed scientific articles (Fox *et al.,* 2004; Tedeschi *et al.,* 2014), making them suitable to use in this study.

The dry matter intake (DMI) for each cow was estimated using the NRC (2001) equation (Table 1). It was calculated as the sum of the concentrate mixture and pasture intake. The concentrate mixture was offered at 7 kg/day and contained 170 g/kg crude protein on an as-fed basis. Individual cow pasture intake could not be directly measured as cows from both breeds grazed as one herd. It was therefore calculated as the difference between the estimated DMI and concentrate offered. The CP content of the pasture averaged 184 g/kg dry matter. Although the NRC (2001) formula was developed for Holstein cows, it was also used to estimate the DMI of Jersey cows in this study. This is because the NRC (2001) formula uses predictor variables that influence feed intake which apply to both breeds, e.g., body weight, lactation stage, and milk production, which are corrected to account for the difference in milk yield and composition. The efficiency of DMI use was estimated as kg MY/kg DMI, g MF/kg DMI, g MP/kg DMI, kg ECM/kg DMI, and kg DMI/kg BW.

For estimating the energy content of feed, the net energy (NE) contents of ingredients were obtained from the feed formulation software package, Nutritional Dynamic System (NDS) Professional (NDS version 6.5, 2008 to 2018). The software package uses the CNCPS biological model as a formulation and evaluation platform (NDS Professional, version 6.5, 2008 to 2018). The ingredients and their NE values in megajoules (MJ)/kg were: wheaten bran (6.78), barley (8.37), maize (8.52), cottonseed oilcake meal (7.18), soybean oilcake meal (9.47), fishmeal (9.16), urea (0), molasses (7.30), wheat straw (1.54), limestone (0), and salt (0). The proportions of NE contributions from feed ingredients were summed up, making an average NE content of 7.81 MJ/kg for the concentrate. For the kikuyu over-sown with annual ryegrass, the metabolizable energy (ME) value used (9.43 MJ ME/kg DM) was obtained from Botha *et al.* (2008). Because approximately one-third of ME is lost as heat during the fermentation, digestion, and metabolism of nutrients (VandeHaar, 2011), pasture NE was calculated as two thirds of its ME, i.e., 6.28 MJ/kg. The net energy intake (NEI) was calculated as the sum of NE contributions from the concentrate mixture offered and estimated pasture intake.

The energy requirements of cows, i.e., net energy for maintenance (NE_m), energy for lactation (NE_L), and energy for growth (NE_g) were calculated using the equations from the CNCPS and NRC (2001) (Table 1). Energy balance (EB) was calculated as (NEI – (NE_m + NE_L + NE_g)). Although the ME for pregnancy is part of EB, it was not included in the equation as the area of interest was body mobilisation of energy reserves, i.e., transition and early lactation stages. Cows whose estimated energy demands exceeded NEI were declared to be in a negative energy balance (NEB). To determine the number of days the cow was in NEB, the days in milk (DIM) in which the first positive EB was recorded was used to represent the duration of NEB. For NEB magnitude, the NEB nadir was defined as the lowest NEB point achieved by the cow. The number of days to reach NEB nadir was the DIM in which the lowest NEB value was recorded. The efficiency of NE use was calculated as NEI/100 g MF, NEI/100 g MP, NEI/kg ECM, and NEI/kg $BW^{0.75}$.

Table 1 Equations used to determine dry matter intake, energy corrected milk and partitioned energy

Variable	Equation	Sub-equations	Reference
DMI	$((0.372 \times 4\%\ FCM) + (0.0968 \times BW^{0.75})) \times (1-e^{(-0.192 \times (WOL + 3.67)})$	$1-e^{(-0.192(WOL+3.67)}$ = adjustment for depressed DMI during early lactation FCM = (15×kg MF) + (0.4×MY)	NRC, 2001
ECM	(12.95×MF kg/day) + (7.65×TP kg/day) + (0.327×MY kg/day)	TP = %MP×0.93	Gaines, 1928 Tyrell & Reid, 1965
NE_m	$(0.08 \times BW^{0.75})$ + activity + grazing in good pasture	Activity = 10% NE_m Grazing in good pasture factor = 0.0012 Mcal/kg BW	NRC, 2001; Linn, 2003
NE_L	kg MY × ((0.0929×MF) + (0.0547×MP) + (0.0395×ML))	ML default value = 4.85%	NRC, 2001; Linn, 2003; Tylutki *et al.,* 2008
NE_g	$22.02 \times ((BW/0.8 \times BW^{0.75}) \times ADG^{1.097}$	ADG = target weight/days ICP Target weight = (Mature BW × growth factor) – BW Growth factor: primiparous 0.85, 2nd lactation 0.92, 3rd lactation 0.96 and 1 for 4+ cows	NRC, 2001; Ross *et al.,* 2015

ADG: average daily gain, **BW:** body weight, **$BW^{0.75}$:** metabolic body weight (kg), **DMI:** dry matter intake (kg), **FCM:** fat-corrected milk (kg/day), **ICP:** inter-calving period, **MF:** milk fat (%), **ML:** milk lactose (%), **MP:** milk protein (%), **MY:** milk yield, **NE_g:** net energy for growth, **NEI:** net energy intake, **NE_L:** net energy for lactation, **NE_m:** net energy for maintenance, **TP**: true protein, **WOL:** week of lactation (energy calculations were converted from Mcal/day to MJ/day)

Data were analysed using the repeated measures ANOVA in the PROC MIXED procedure of Statistical Analysis System (SAS) Enterprise Guide, version 7.1. A compound symmetry structure for the residuals was used as a covariance structure for repeated measures over time within cows. The equation that was used for statistical analysis was as follows:

$$Y_{ijk} = \mu + B_i + P_j + LS_k + (B \times P)_{ij} + (B \times LS)_{ik} + (B \times P \times LS)_{ijk} + cow_l(B_i) + \varepsilon_{ijkl}$$

The response variables (Y_{ijk}) were the milk yield and its components. The effect of the cow was fitted as a random effect and nested within the breed ($Cow_l(B_i)$). The fixed effects were breed (B_i), parity (P_j), lactation stage (LS_k), and their interactions. The between-breeds, between-parity, and between-lactation stage variations and their interactions were compared using the Bonferroni test and were declared different at P <0.05.

Results and discussion

Cows in parities 4 and beyond were grouped into one group of parity four and higher (parity 4+) for each breed (Bangani *et al.,* 2022). Detailed results on milk, its components, and DMI are presented in Bangani *et al.* (2022). Below are the descriptive statistics for the data used (Table 2).

Table 2 Mean (±SE) descriptive statistics of Holstein and Jersey cows used in the investigation

Parameters	Holsteins	Jerseys
No of cows	122	99
No. of records	2315	2261
Milk (kg/day)	23.8±0.22	17.9±0.24
Milk fat (%)	3.89±0.03	4.66±0.03
Milk protein (%)	3.17±0.02	3.59±0.02
Body weight (kg)	567±3.49	411±3.84
Mature body weight (kg)	589±4.84	428±5.37
Total dry matter intake (kg/day)	17.8±1.08	14.4±0.116

In all parities and lactation stages, the efficiency of converting DMI to MY was higher in Holstein than Jersey cows (Figure 1, Table 3). These results concur with what has been reported in previous studies, e.g., in primiparous cows in South Africa that were on TMR (Muller & Botha, 1998); and in two groups of cows in New Zealand that were either on *ad libitum* pasture, or restricted pasture plus a concentrate (Thomson *et al.*, 2001). This indicates that although genetic improvement in MY traits for both Holstein and Jersey cows has been achieved over time, the difference in MY production efficiency between the two breeds remains unchanged. The kg MY/kg DMI for first and second lactation did not differ in Jersey cows (P >0.05); an increase was observed in the third lactation, with third and subsequent lactations being similar. In Holstein cows, MY/kg DMI increased from first to third lactation, with efficiency being similar in third and parity 4+ cows (Figure 1, Table 3).

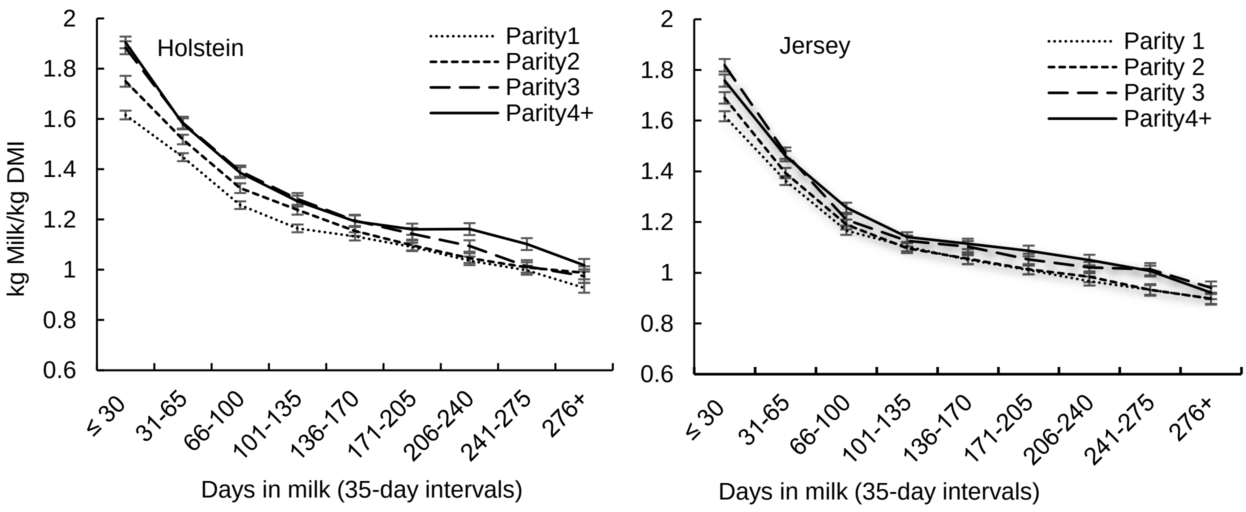

Figure1 Least squares means (±SE) of milk production efficiency (kg MY/kg DMI) of Holstein and Jersey cows as affected by parity and days in milk

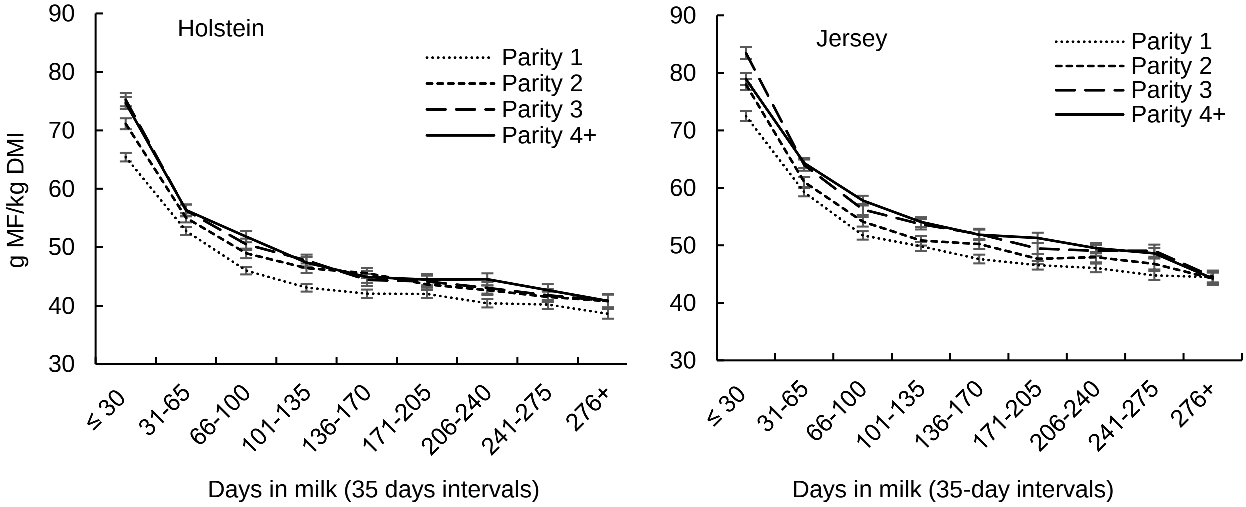

Figure 2 Least squares means (±SE) of milk fat production efficiency (g MF/kg DMI) of Holstein and Jersey cows as affected by parity and days in milk.

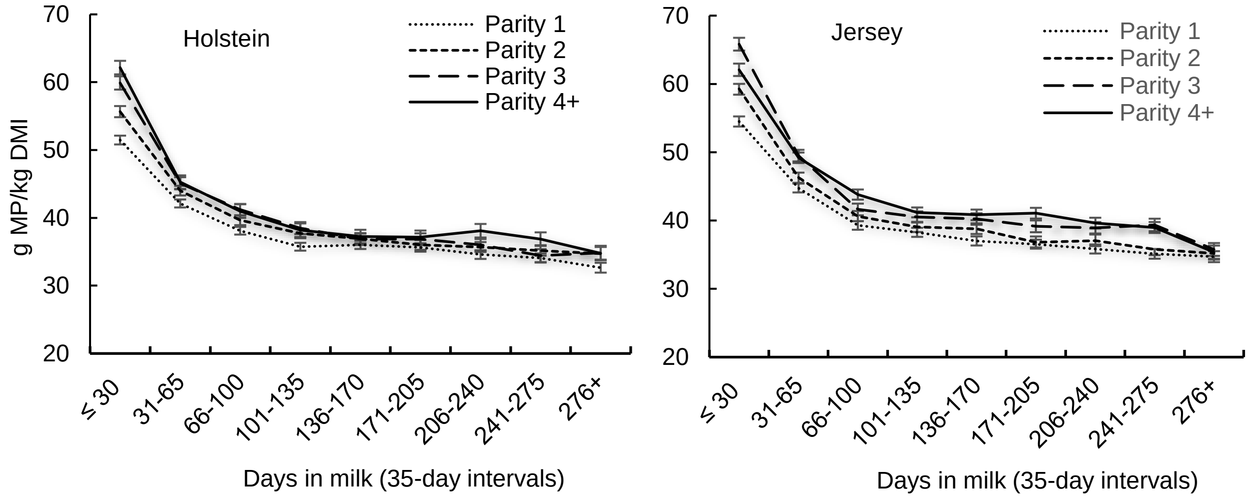

Figure 3 Least squares means (±SE) of milk protein production efficiency (100 g MP/kg DMI) of Holstein (H-MP/kg DMI) and Jersey (J-MP/kg DMI) cows as affected by parity and days in milk

In both breeds, however, a downward trend was observed in kg MY/kg DMI as lactation stages advanced (Figure 1), suggestive of homeorhetic regulation, i.e., nutrient partitioning in dairy cows to prioritise a physiological need, which Bauman & Currie (1980) define as the “orchestrated changes for the priorities of a physiological state”. At the onset of lactation, the most critical role is the synthesis and secretion of high amount of milk; nutrient use is thus altered to prioritise this function (Bauman & Currie, 1980). This results in high milk production efficiency during transition and early lactation stages although it happens at the expense of body reserves. In mid- and late-lactation stages, nutrient partitioning shifts towards building body reserves and supporting pregnancy in preparation for the next calving, and therefore incurs a decrease in milk production efficiency. Strategic feeding of the cow to align with the lactation stage may be beneficial in improving her performance efficiency.

The efficiency of converting DMI to both MF and MP was higher in Jerseys compared to Holsteins in all production stages, i.e., parity and lactation stages (Table 3, Figures 2 and 3), with a mean test-day yield of 52.4±0.5 *vs* 58.4±0.4 g MF/kg DMI and 42.7±0.3 *vs* 45.1±0.3 g MP/kg DMI in Holsteins and Jerseys, respectively. Higher efficiency for MF/kg DMI in Jersey cows was reported by Mackle *et al.* (1996) on cows that grazed on pasture in New Zealand, and Thomson *et al.* (2001) in cows on either *ad libitum* pasture or restricted pasture, but these authors reported no breed effect in efficiency ratios for MP/kg DMI. Holstein MF/kg DMI was lower in the first parity compared to the subsequent parities, whose MF production efficiency did not differ. With Jerseys, MF/kg DMI increased gradually, reaching its peak in the third lactation, then levelled. In both breeds, MP/kg DMI increased up to third lactation; parities 3 and 4+ did not differ (Table 3). As lactation stages progressed, g MF/kg DMI and g MP/kg

DMI decreased. This can be associated with the decreasing trend observed in MY with advancing lactation stages (Figure 2 and 3).

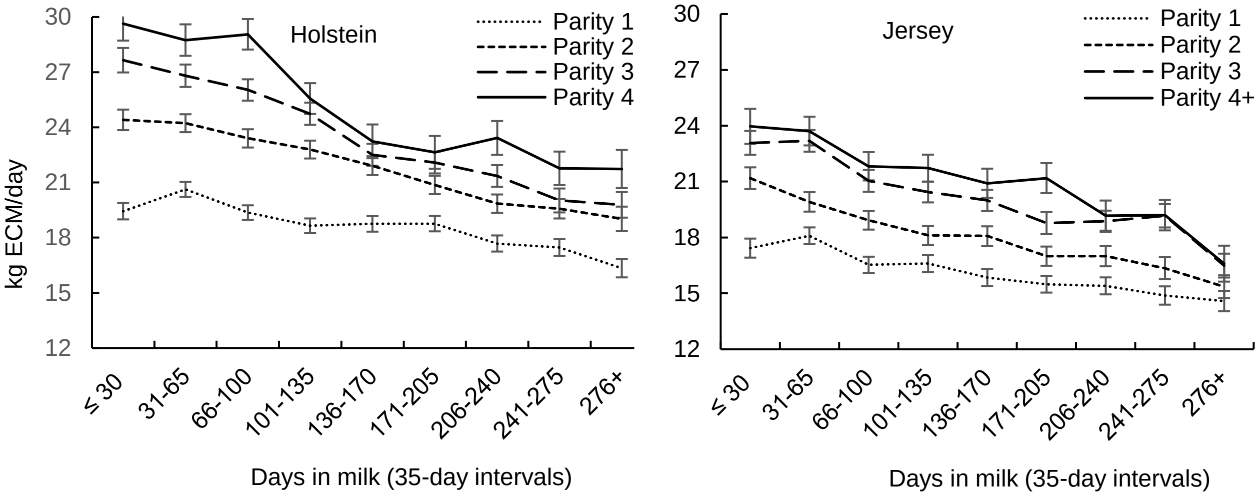

Figure 4 Least squares means (±SE) of energy-corrected milk (kg ECM/day) of Holstein and Jersey cows as affected by parity and days in milk

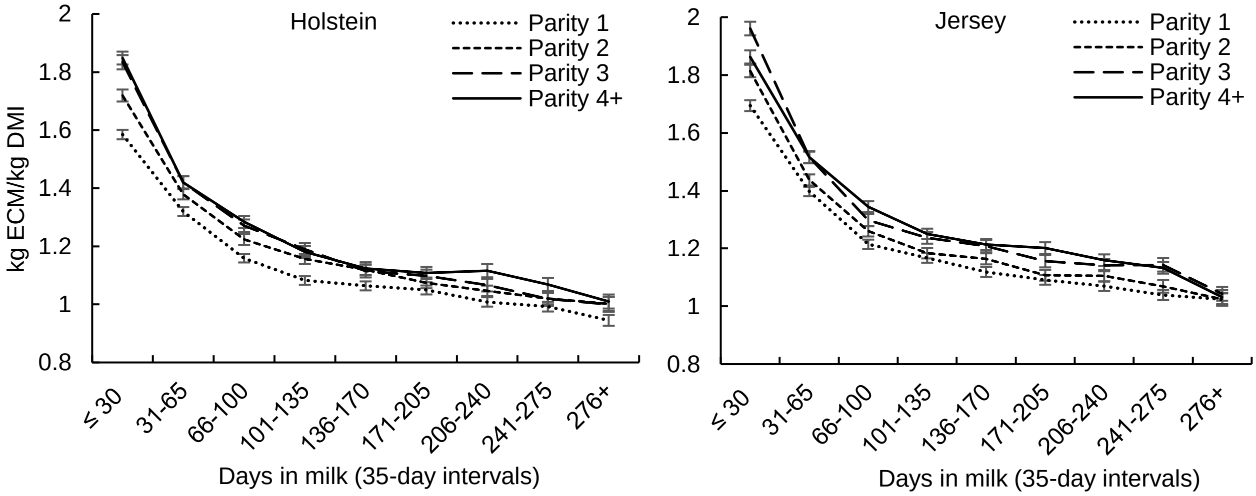

Figure 5 Least squares means (±SE) of production efficiency of energy-corrected milk (kg ECM/kg DMI) of Holstein and Jersey cows as affected by parity and days in milk

After correcting milk for its fat and protein content, the mean ECM was 22.7±5.9 kg/day in Holsteins and 19.4±4.8 kg/day in Jerseys. This indicates that Jersey cows produced on average 85.5% the ECM of Holsteins, a higher proportion compared to the average 74.1% MY reported by Bangani *et al.* (2022) in the same herd. This increase in proportion is attributable to the high solid component of the Jersey milk. The ECM increased with parity but decreased with lactation stage (Figure 4). Because of the increase in the amount of ECM produced, Jersey cows produced higher ECM/kg DMI and ECM/kg BW (Table 3) compared to Holsteins. The low DMI conversion efficiency to solid corrected milk in Holsteins compared to Jerseys was also reported by Mackle *et al.* (1996). Kristensen *et al.* (2015) also reported higher efficiency in Jerseys compared to Holsteins in cows that were in a total mixed or partial mixed ration for six months in Denmark. Olijhoek *et al.* (2018), however, reported no difference between the two breeds when they were allocated in two feeding levels, i.e., either high or low concentrate diets. Both ECM/kg DMI and ECM/kg BW increased with parity (Table 3) but decreased with lactation stage. This was expected as the milk production efficiency parameters (MY/kg DMI, g MF/kg DMI and g MP/kg DMI) all increased with parity and decreased with lactation stage.

Holstein cows had a lower DMI/kg BW than Jersey cows (Table 3, Figure 6). In agreement, several authors reported lower DMI/kg BW in Holsteins compared to Jerseys that were on: TMR in South Africa (Muller & Botha, 1998); two feeding systems in New Zealand, i.e., either *ad lib* pasture or restricted pasture plus a concentrate (Thomson *et al.,* 2001); TMR in the United States of America (Anderson *et al.,* 2007); pasture in Ireland (Prendiville *et al.,* 2009); or either a total mixed or partial mixed ration in Denmark (Kristensen *et al.,* 2015). In contrast, these authors reported no difference in DMI/kg BW between Holstein and Jersey cows that were on: TMR in the United States of America (Rastani *et al.,* 2001); TMR in the United Kingdom (Aikman *et al.,* 2008); or TMR based on silage in the United States of America (Knowlton *et al.,* 2010).

The high DMI/kg BW observed in Jersey cows in this study suggests that Jersey cows would be more suitable for pasture production systems in comparison to Holstein cows as energy in pasture is often limiting. It is suggestive of higher energy intake which may provide better energy reserves, thus preventing excessive lipolysis and the effects of negative energy balance, especially after calving. Moreover, cows that eat more often produce more as the excess food above maintenance is partitioned to production. Aikman *et al.* (2008) associated the higher DMI/kg BW in Jerseys with the higher passage rate of digesta in this breed compared to Holsteins. In agreement, Ingvartsen and Weisberg (1993), observed a 21% higher passage rate in Danish Jerseys compared to Holsteins. Retief (2000) and Bangani (2002) reported higher effective dry matter and neutral detergent fibre degradability in Jerseys compared to Holsteins at all fractional outflow rates, suggesting that with the higher DMI in this breed, extraction of nutrients from the digesta is also high. Parity had no effect on DMI/kg BW (Table 3, Figure 6), however, this parameter increased with lactation stage, reaching a peak in mid-lactation, thereby coinciding with the peak estimated DMI, and thereafter lowering in the late lactation stage (Figure 6). The lower DMI/kg BW in late lactation stage is attributable to a decrease in DMI with decreasing milk production, accompanied by an increase in BW as the cows regain their body condition and some may even be pregnant.

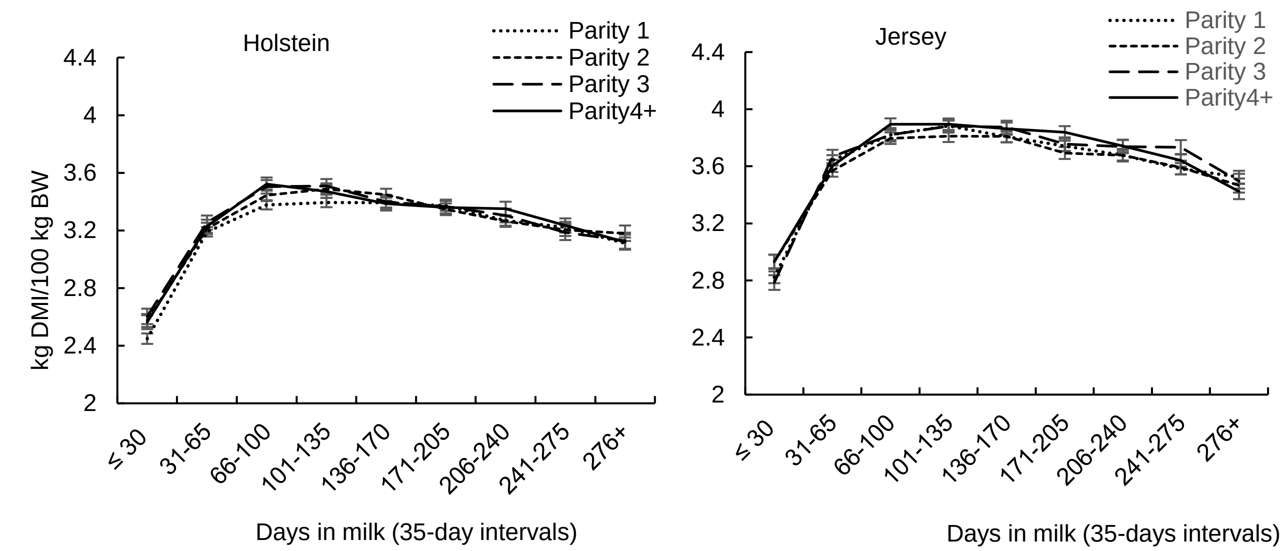

Figure 6 Mean ±SE of efficiency of dry matter intake for body weight use (kg DMI/100 kg BW) of Holstein and Jersey cows as affected by parity and lactation stage

The overall mean estimated NEI was 120±0.7 *vs.* 99±0.7 MJ/day, whereas estimated net energy requirements for maintenance were 79±0.4 *vs.* 61±0.4 MJ/day; lactation, 72±0.7 *vs.* 61±0.7 MJ/day; and growth, 9.4±3.0 and 2.6±2.1 MJ/day in Holstein and Jersey cows, respectively. The estimated energy balance implied that cows were in a negative energy balance (NEB) state in transition and early lactation stages, achieving a positive energy balance in mid-lactation (Figure 7). This is in line with expectation as the cows are transitioning from a pregnant, non-lactating state to synthesising and producing large amounts of milk. The nutrient requirements of the cow rise rapidly for the initiation of milk synthesis after calving, followed by the high milk production, which peaks in early lactation while DMI is still lagging (Drackley *et al.*, 2005).

To offset the energy deficiency resulting from producing large amounts of milk while DMI is low, dairy cows undergo increased levels of fat mobilisation, which involves lipolysis (Rodriguez *et al.,* 2020).

During lipolysis, non-esterified fatty acids (NEFA) are released from adipose tissue into the bloodstream to be used as substrate for milk fat synthesis and as an energy source in tissues to compensate for the increased energy demands (Wathes *et.al,* 2007; Block, 2010; Rodriguez *et al.,* 2020), resulting in tissue NEB.

The estimated NEB intensity was higher in Holstein cows, reaching nadir at -53.9±0.8 MJ compared to -39.7±0.8 MJ in Jersey cows (Figure 7). In agreement, Rastani *et al.* (2001) reported a tissue energy balance nadir of −6.19 Mcal/day (-26 MJ/day) in Jerseys and −12.9 Mcal/day (-54 MJ/day) in Holsteins. Friggens *et al.* (2007) also reported a less intense NEB in Jerseys compared to Holsteins that were fed either a normal or low-density energy TMR in Denmark, whereas Washburn *et al.* (2002), reported lower body condition scores (which can be seen as a proxy for NEB intensity) in Holsteins compared to Jerseys that were kept either on pasture or under intensive systems. Holsteins had a lower DMI/kg BW, which suggests a lower energy intake that may result in excessive depletion of body reserves to compensate for the insufficiency. The NEB intensity also increased with parity in both breeds. In agreement, Gallo *et al.* (1996) and Friggens *et al*. (2007) reported less marked depletion and faster recovery of body reserves in primiparous cows compared to multi-parous ones, whereas Lee & Kim (2006) observed an increase in loss (P <0.01) and delayed recovery of body condition with increase in parity (P <0.01) in cows that were on TMR. Macrae *et al.* (2019) and Walter *et al.* (2022) reported lower post-partum plasma NEFA concentrations in primiparous cows compared to multiparous ones. A higher plasma concentration of NEFA is indicative of excessive fat mobilisation (Tessari *et al.,* 2020). Using plasma NEFA concentration as an index for lipid mobilisation may suggest that primiparous cows experience lower lipid mobilisation compared to multiparous ones, a possible reason for lower NEB intensity in primiparous cows.

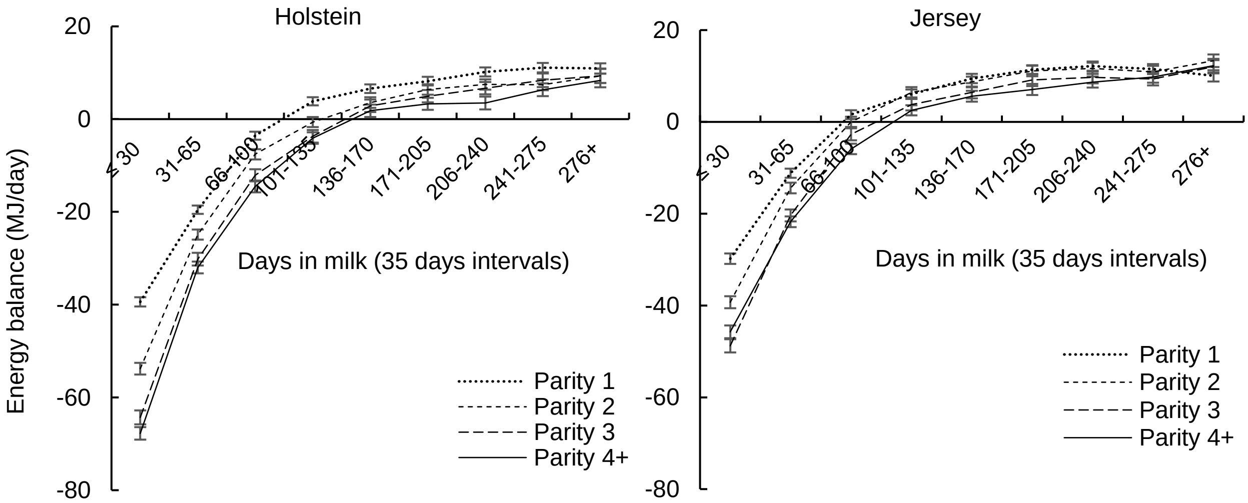

Figure 7 Least squares means (±SE) of energy balance of Holstein and Jersey cows as affected by parity and days in milk

The number of days it took to reach NEB nadir did not differ between breeds (P = 0.08); parity also had no effect (P = 0.12). The duration of NEB was, however, longer in Holsteins than Jerseys (Table 3, Figure 7). In agreement, Rastani *et al.* (2001) reported a tissue energy balance that occurred at week 1 of lactation and lasted for 7 weeks in Jerseys, whereas in Holsteins, it occurred at week 2 and endured for 11 weeks of lactation. In accord, Friggens *et al.* (2007) also reported a shorter NEB in Jerseys compared to Holsteins. The NEB duration increased with parity (P <0.01). With the higher NEB intensity observed in Holstein cows and multiparous cows, recovery was expected to be prolonged in these two groups, a possible reason for a longer NEB duration. Furthermore, the regenerative capacity of tissue in animals is known to decrease with age, hence the shorter NEB duration in primiparous cows compared to multi-parous ones.

The efficiency with which energy is used for lactation or milk production is a key driver of production efficiency (Xue *et al.*, 2011) in dairy cows. Jersey cows allocated proportionally more of the estimated NEI to lactation (NE_L/NEI) and lesser to maintenance (NE_m/NEI) and liveweight $NE_m/BW^{0.75}$ compared to Holstein cows (Table 3). According to Grainger & Goddard (2004), an efficient cow partitions more metabolizable energy to milk and has lower maintenance energy requirements.

Table 3 The mean (±SE) test-date milk production and energy use efficiency estimates of Holstein (H) and Jersey (J) cows as affected by parity

	Parity										
	1		2		3		4+		P-values		
	H	J	H	J	H	J	H	J	Breed	P	B × P
No. of records	891	737	579	541	395	437	450	546			
kg DMI/kg BW	3.09^{b} ±0.02	3.50^{a} ±0.02	3.14^{b} ±0.02	3.48^{a} ±0.02	3.15^{b} ±0.02	3.53^{a} ±0.02	3.14^{b} ±0.03	3.54^{a} ±0.03	<0.05	0.06	0.10
kg Milk/kg DMI	1.29^{c} ±0.01	1.23^{d} ±0.01	1.34^{b} ±0.01	1.24^{d} ±0.01	1.39^{a} ±0.01	1.30^{c} ±0.01	1.41^{a} ±0.01	1.30^{c} ±0.01	<0.05	<.005	<0.05
g MF/kg DMI	49.7^{e} ±0.4	55.8^{c} ±0.4	52.6^{d} ±0.4	57.7^{b} ±0.4	53.4^{d} ±0.5	60.0^{a} ±0.5	53.9^{cd} ±0.5	60.1^{a} ±0.5	<0.05	<0.05	0.09
g MP/kg DMI	40.9^{f} ±0.3	42.8^{de} ±0.3	42.5^{e} ±0.4	44.1^{bc} ±0.4	43.4^{cd} ±0.4	46.5^{a} ±0.4	44.1^{bc} ±0.4	46.8^{a} ±0.4	<0.05	<0.05	0.03
ECM (kg)	19.1^{e} ±0.2	16.7^{f} ±0.3	22.4^{c} ±0.3	18.5^{e} ±0.3	24.0^{b} ±0.3	20.7^{d} ±0.3	25.3^{a} ±0.3	21.6^{c} ±0.3	<0.05	<0.05	<0.05
kg ECM/kg DMI	1.23^{e} ±0.01	1.31^{cd} ±0.01	1.29^{e} ±0.01	1.34^{b} ±0.01	1.32^{c} ±0.01	1.40^{a} ±0.01	1.34^{b} ±0.01	1.41^{a} ±0.01	<0.05	<0.05	0.11
kg ECM/100 kg BW	3.75^{d} ±0.05	4.52^{b} ±0.05	4.00^{c} ±0.06	4.62^{b} ±0.06	4.10^{c} ±0.06	4.87^{a} ±0.06	4.14^{c} ±0.06	4.92^{a} ±0.06	<0.05	<0.05	0.07
Energy parameters											
NEI	107^{d} ±0.68	90^{g} ±0.75	119^{c} ±0.75	97^{f} ±0.80	125^{b} ±0.82	103^{e} ±0.84	129^{a} ±0.84	107^{d} ±0.84	<.01	<.01	<.01
NE_m	73^{d} ±0.39	57^{h} ±0.43	78^{c} ±0.40	61^{g} ±0.44	81^{b} ±0.41	63^{f} ±0.45	84^{a} ±0.41	65^{e} ±0.45	<.01	<.01	<.01
NE_L	61^{e} ±0.72	53^{f} ±0.79	71^{c} ±0.83	59^{e} ±0.87	76^{b} ±0.93	65^{d} ±0.93	80^{a} ±0.95	68^{c} ±0.93	<.01	<.01	0.01
Energy balance	-35.7^{b}±15.63	-23.4^{a}±13.68	-47.4^{c}±20.01	-33.1^{b}±15.64	-57.8^{d}±19.65	-44.3^{c}±14.13	-62.5^{d}±19.86	-40.4^{bc}±16.62	<.01	<.01	0.08
Days in NEB	83.7^{bc}±32.71	66.2^{d}±31.73	97.1^{a}±33.02	66.8^{d}±28.45	115.2^{a}±34.76	79.5^{cd}±28.04	113.6^{a}±32.16	84.6^{bc}±34.75	<.01	<.01	0.07
Days to NEB nadir	23.6^{c}±12.23	28.5^{a}±17.81	24.0^{cb}±13.33	24.8^{b}±13.42	22.5^{d}±11.74	20.0^{e}±12.22	19.2^{e}±10.03	24.8^{b}±12.82	0.08	0.12	0.19
NE_L/NEI	57.0^{e} ±0.4	59.2^{d} ±0.4	60.4^{d} ±0.5	61.3^{c} ±0.5	61.9b^{c} ±0.5	64.4^{a} ±0.5	62.9^{b} ±0.5	64.9^{a} ±0.5	<.01	<.01	0.09
NEI/100gMF	14.7^{a}±0.11	13.3^{bc}±0.12	13.6^{b}±0.13	12.7^{c}±0.14	13.3^{bc}±0.15	12.1^{d}±0.15	13.2^{bc}±0.15	12.0^{d}±0.15	<.01	<.01	0.24
NEI/100gMP	17.9^{a}±0.15	17.4^{ab}±0.17	16.8^{b}±0.18	16.6^{bc}±0.19	16.3^{bc}±0.21	15.5^{d}±0.20	16.0^{cd}±0.21	15.2^{d}±0.20	<.01	<.01	0.10
NEI/ECM	5.88^{a} ±0.04	5.67^{ab} ±0.05	5.52^{b} ±0.05	5.46^{b} ±0.05	5.38^{c} ±0.06	5.18^{de} ±0.06	5.29^{cd} ±0.06	5.09^{e} ±0.06	<.01	<.01	0.09
NE_m/NEI	69.1^{a} ±0.30	64.2^{c} ±0.33	67.5^{b} ±0.35	63.8^{cd} ±0.36	66.8^{b} ±0.39	63.0^{d} ±0.39	66.7^{b} ±0.40	62.4^{d} ±0.39	<.01	<.01	0.05
NEI/$BW^{0.75}$	0.68^{a} ±0.02	0.67^{b} ±0.02	0.68^{a} ±0.02	0.67^{b} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	<.01	<.03	0.04
NE_m/$BW^{0.75}$	0.47^{a} ±0.02	0.43^{c} ±0.02	0.46^{b} ±0.02	0.43^{c} ±0.02	0.45^{b} ±0.03	0.42^{d} ±0.03	0.45^{b} ±0.03	0.42^{d} ±0.03	<.01	<.01	0.05

$^{a-h}$ Means within rows with different superscripts differ at P <0.05, **Energy units:** MJ/day

BW: body weight, **$BW^{0.75}$:** metabolic weight, **DMI:** dry matter intake, **EB:** energy balance, **ECM:** energy-corrected milk, **MF:** milk fat, **MP:** milk protein

NEB: negative energy balance, **NEI:** net energy intake, **NE_L:** net energy for lactation, **NE_m:** net energy for maintenance

Attributable to the high solid component of milk produced by Jerseys, they also used proportionally less mean NEI to produce 100 g MF (13.7±0.10 vs. 12.5±0.10), 100 g MP (16.7±0.14 vs.16.2±0.15), and a kg ECM (5.52±0.04 vs. 5.35±0.04) compared to Holsteins (Table 3). In agreement, a higher efficiency of converting metabolizable energy intake to milk energy output was reported by Mackle *et al.* (1996), whereas Kristensen *et al.* (2015) reported a higher ECM/10 MJ of NEI in Jersey cows compared to Holstein cows. Using solid-corrected milk as a proxy for ECM, Blake *et al.* (1986), however, reported no difference in energy-use efficiency between the two breeds. In both breeds, the NEI used to produce 100 g MF, 100 g MP, and kg ECM also decreased with parity (Table 3), indicating higher efficiency with maturity. With lactation stages, the efficiency of energy use to produce 100g MF, 100 g MP, and kg ECM decreased by +50% from transition to late lactation stage, i.e., 10.0±0.17 to 16.4±0.12, 12.6±0.23 to 19.5±0.17, and 4.11 ±0.06 to 6.63 ±0.05 in Holsteins; and 9.3±0.17 to 15.0±0.12, 12.0±0.23 to 19.0±0.17, and 3.95 ±0.07 to 6.43±0.05 in Jerseys, respectively, indicative of shifting of nutrients from lactation towards building body reserves. Although the estimated NEI/kg $BW^{0.75}$ was higher in primiparous and second lactation Holsteins than that of Jerseys (P <0.01), there was no breed effect in later parities (Table 3). Rastani *et al.* (2001) also reported no breed effect in NEI/kg $BW^{0.75}$ (P = 0.89).

Conclusion

The difference in milk production efficiency between the two breeds was mainly as a result of the difference in milk yield and composition with Holstein cows showing a higher efficiency in milk yield while Jerseys had higher milk components per kg dry matter intake. The higher solid component of Jersey milk, which resulted in higher energy-corrected milk per kg of dry matter intake makes the Jersey cow a more production-efficient breed compared to Holstein cows. Jersey cows also possessed feed-use efficiency and energy balance traits that are desirable for a pasture-based system, e.g., higher dry matter intake per kg body weight and a shorter, less intense negative energy balance, making them a better breed for this production system. It was also evident in both breeds that production efficiency increased with parity and decreased with lactation stage, indicating the importance of a longer productive life and strategic feeding of the cow to align with the lactation stage for improved production efficiency.

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Conflict of Interest Declaration

The authors certify that they have no affiliations with any organization or entity with financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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