
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Effect of genotype and diet on feed conversion efficiency of dairy cows during a 600-day extended lactation

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ABSTRACT

This study investigated the effect of genotype and diet on the gross feed conversion efficiency (FCE) of cows milked for 600-day extended lactations (24-month season) compared with 300-day lactations (12-month season). North American (NA) and New Zealand (NZ) Holstein-Friesians (HF) grazed pasture and were supplemented with either 0, 3 or 6 kg DM concentrate/cow/day. In a normal 12-month season, gross FCE was greater for NZ HF compared with NA HF cows when fed 0 or 3 kg DM concentrate (96 and 104 vs. 90 and 99 kg milksolids (MS)/t dry matter intake (DMI), respectively), but similar when fed 6 kg DM (101 kg MS/t DMI). However, during an extended 24-month season, NZ HF cows had a lower gross FCE than NA HF when fed 6 kg DM concentrate (86 vs. 99 kg MS/t DMI, respectively) and similar FCE when fed 0 or 3 kg DM (85 and 94 vs. 86 and 99 kg MS/t DMI, respectively). Regardless of diet, gross FCE in an extended lactation was 98% of that obtained in a normal season for NA HF cows, but only 88% for NZ HF, indicating that NA HF are better suited to converting feed into high MS production in extended lactations.

Keywords: genotype; supplements; extended lactation; feed conversion efficiency.

INTRODUCTION

Gross feed conversion efficiency (FCE) is a measure of milk production output per unit of feed input and is, therefore, an important driver of dairy farm productivity and profitability. Genotype x environment interactions have been reported for the efficiency of milk production whereby the ranking, or the extent of differences, between cow strains within a breed differs between different dairy farm systems (Kolver *et al*., 2002; 2005). New Zealand (NZ) Holstein-Friesian (HF) cows performed better than North American (NA) HF cows when grazing pasture at a low stocking rate, but NA HF were more efficient than NZ HF when fed a total mixed ration (TMR) diet (Kolver *et al*., 2002). The NA HF cows also gave higher milk production responses to concentrate supplements than NZ HF cows (Kolver *et al*., 2005). North American HF cows appear to have a larger relative feed deficit and therefore maintain a lower body condition score (BCS) and produce less milksolids (MS) as a percentage of live weight (LW) (Kolver *et al*., 2005). Farm system comparisons (Macdonald *et al*., 2005; 2008) showed that NA HF cows were less suited to low-input pastoral systems with seasonal calving, due to their large feed requirements, low BCS and poor reproductive performance, which reduces efficiency and farm profitability.

Genotype x environment interactions also have implications for management systems that use extended calving intervals to increase lactation length. Extended lactations utilise the superior milk production of high genetic merit cows, reduce costs associated with calving and mating, and even out farm labour requirements. In addition, they may lead to improved lifetime FCE due to increased lactation days in a cow's productive lifetime. Recently, Kolver *et al*. (2006; 2007) showed that NA HF cows produced significantly more MS than NZ HF in an extended lactation, and when fed moderate to high levels of concentrates would produce as much in a single 600-day lactation as in two separate 300-day lactations. This paper reports on the effect of genotype and diet on gross FCE in an extended lactation compared with a normal seasonal system.

MATERIALS AND METHODS

Experimental design

Details of the experimental design and measurements have been described previously (Kolver *et al*., 2006; 2007). Briefly, a herd of 56 multiparous NA HF and NZ HF cows was milked for up to 670 days in an extended 24-month calving interval. Cows grazed generous pasture allowances (50 kg DM/cow/d) and were individually fed 0, 3 or 6 kg DM concentrate/d at milking. This resulted in six genotype x diet (G x D) treatments (NZ0, NZ3, NZ6, NA0, NA3, NA6). Cows were individually dried off on low milk production (< 5 kg milk/d), BCS and time relative to calving (Macdonald *et al*., 2005). Lactation length during the extended 24-month season (mean ± SEM; 604 ± 7.9 days in milk (DIM)) was defined as the period from calving to the actual dry-off date. Lactation length for a normal 12-month calving interval (296 ± 3.1 DIM) was calculated as the time of calving to a theoretical dry-off date based on standard decision rules.

Measurements and calculation of gross FCE

During lactation, milk yield (kg) and composition (fat, protein, lactose) were recorded daily and weekly, respectively, and LW and BCS (1-10 scale, where 1 = Emaciated and 10 = Obese) were recorded weekly and fortnightly, respectively. The metabolisable energy (ME) (in MJ ME/kg dry matter (DM)) of pre-graze pasture and offered and refused concentrate was measured once a month on weekly bulked samples by near infrared spectroscopy (Feedtech, Palmerston North, New Zealand). The ME requirements for individual cows were back-calculated weekly for maintenance, milk production, LW gain/loss, and walking activity using equations from Holmes *et al*. (2002) and Nicol and Brookes (2007). Maintenance ME requirements were calculated as 0.56 MJ ME/kg metabolic LW ($LW^{0.75}$) per day with a correction made for the ME of the feed (add/subtract 5% for diets below/above 11 MJ ME/kg DM). The ME requirements for walking activity were calculated as 0.615 km walked x 0.0036 MJ ME/kg LW per day (2.86% correction for ME of the feed). The ME requirements for LW gain and loss were calculated as 38 MJ ME/kg LW (5% correction) and -28 MJ ME/kg LW (8% correction), respectively. Milk production ME requirements were calculated as kg milk x ((0.376 x fat% + 0.209 x protein % + 0.976) x 1.1)/k_l, where k_l is the net efficiency of use of ME for milk production with a value of 0.64 for diets at 11 MJ ME/kg DM. Weekly dry matter intake (DMI) was calculated for each cow from the sum of the ME requirements using the average MJ ME per kg DM content of the feed, and corrected for measured concentrate intakes.

To determine total DMI for a normal 12-month season, and in an extended 24-month season, the summed total of DMI during the respective lactations was added to the sum of DMI estimated from ME requirements (Holmes *et al*., 2002; Nicol & Brookes, 2007) during the dry period (365 or 730 days less the lactation length of each cow for the normal or extended seasons, respectively). Total maintenance ME requirements during the dry period were calculated as 0.55 MJ ME/kg $LW^{0.75}$ per day multiplied by the number of days dry. All cows were assumed pregnant so as not to unfairly advantage non-pregnant cows with lower ME requirements (refer to Kolver *et al*. (2006; 2007) for actual pregnancy rates). Total pregnancy ME requirements were calculated as 60 MJ ME/kg calf birth weight using calf birth weights of 35.8 ± 1.12 kg LW and 41.0 ± 0.92 kg LW for NZ HF and NA HF cows, respectively. Cows were assumed to finish the normal 12-month or extended 24-month season at the same LW as they started the lactation. Therefore, the net LW change between the start of the lactation and drying-off was assumed to be either gained (48 MJ ME/kg LW) or lost (-28 MJ ME/kg LW) accordingly in the dry period. The average ME of the feed during the dry period was assumed to be 11 MJ ME/kg DM for a pasture-only diet.

Gross FCE was presented in the following ways: kg milksolids (MS) per t DMI; kg energy corrected milk (ECM) per t DMI, where ECM = kg milk x (383 x fat% + 242 x protein % + 783.2)/3140 (Tyrrell & Reid, 1965); kg fat corrected milk (FCM) per t DMI, where FCM = kg milk x (0.4 + 0.5 x fat%) (Gaines & Davidson, 1923); and MJ ME milk per MJ ME intake. Other measures of efficiency presented include: MS efficiencies, calculated as kg MS per 100 kg LW, and kg MS per kg $LW^{0.75}$; total DMI per 100 kg LW; and total DMI per kg $LW^{0.75}$.

Statistical analyses

Data from the 2 x 3 factorial design were analysed for normal and extended lactation seasons using GenStat (Payne *et al*., 2007). The residual maximum likelihood (REML) procedure was used with a mixed model that included genotype, diet (linear and quadratic contrasts), and interactions between genotype and diet (linear and quadratic contrasts) as fixed effects, with cow and cow sire as random effects. Significant effects were declared at $P < 0.05$ and trends at $P < 0.10$.

RESULTS

Normal lactation

During a normal 12-month calving interval, NA HF cows had greater milk production, a greater average lactation LW and greater total DMI per cow and per kg $LW^{0.75}$, but gained less BCS and LW during lactation, and had a lower average BCS, compared with NZ HF cows (Table 1a). Supplementation with increasing levels of concentrate (0 to 6 kg DM/cow/d) produced linear increases in milk and MS yields, average lactation BCS, and MS efficiencies per unit LW. There were also linear and quadratic trends of diet for BCS change during lactation, and a linear trend for LW change and total DMI. The G x D_{Linear} interactions indicated that NA HF cows produced more milk and MS than NZ HF cows at the highest level of supplementation, giving them a greater MS response to concentrate. Gross FCE expressed as kg MS per t DMI was greater ($P < 0.10$) for NZ HF compared with NA HF cows, but not other gross FCE parameters (Table 1a). For all measures of gross FCE, linear and quadratic increases were detected with increasing levels of concentrate. The G x D_{Linear} interactions showed that increases in MS efficiencies per unit LW and gross FCE with increasing supplementation were linear up to 6 kg DM concentrate for NA HF cows, but this response peaked at 3 kg DM concentrate before decreasing at 6 kg DM concentrate for NZ HF cows.

TABLE 1: Milk and milksolids (MS) yields, live weight (LW), body condition score (BCS; 1-10 scale), dry matter intake (DMI) and gross feed conversion efficiency (FCE) for New Zealand (NZ) and North American (NA) Holstein-Friesians grazing pasture and fed 0, 3 or 6 kg DM concentrate/cow/day, corresponding to six genotype x diet (G x D) treatments (NZ0, NZ3, NZ6, NA0, NA3, NA6), in (a) a normal[1] seasonal system and (b) an extended[2] lactation system. SED = Standard error of the difference between treatment means.

Measurement	Treatment						SED	Significance (P value)[3]			
	NZ0	NZ3	NZ6	NA0	NA3	NA6		Genotype	$Diet_L$	$Diet_Q$	G x D_L
(a) Normal seasonal system											
Days in milk	302	295	300	297	282	300	12	NS	NS	NS	NS
Milk yield (kg/cow)	5,936	6,911	6,996	6,398	7,481	8,738	474	<0.01	<0.001	NS	<0.05
MS yield (kg/cow)	489	551	530	494	556	625	38	NS	<0.01	NS	<0.10
LW change[4] (kg/cow)	6.6	29.6	48.8	-26.5	-6.4	19.9	31.9	<0.10	<0.10	NS	NS
BCS change[4] (units/cow)	1.04	-0.81	2.29	-1.44	-0.89	-0.21	1.04	<0.01	0.10	<0.10	NS
Average lactation LW (kg/cow)	499	510	519	568	546	603	33	<0.01	NS	NS	NS
Average lactation BCS (units/cow)	4.45	4.57	5.34	4.02	3.55	4.47	0.43	<0.05	<0.05	<0.10	NS
MS efficiency (kg MS/100 kg LW)	97	107	99	87	100	106	6	NS	<0.05	NS	<0.05
MS efficiency (kg MS/kg $LW^{0.75}$)	4.59	5.12	4.81	4.28	4.87	5.20	0.27	NS	<0.01	NS	<0.10
Concentrate DMI (t/cow)		0.90	1.73		0.84	1.74	0.43	NS	<0.001		NS
Response (kg MS/t concentrate DMI)		69	24		73	75					
Total DMI (t/cow)	5.05	5.30	5.21	5.47	5.65	6.11	0.32	<0.05	<0.10	NS	NS
Total DMI (t DMI/100 kg LW)	1.00	1.04	0.98	0.97	1.02	1.04	0.04	NS	NS	NS	NS
Total DMI (t DMI/kg $LW^{0.75}$)	0.047	0.050	0.047	0.047	0.049	0.051	0.018	<0.10	NS	NS	NS
FCE (kg MS/ t DMI)	96	104	101	90	99	102	2	<0.10	<0.001	<0.01	<0.05
FCE (kg ECM/t DMI[5])	1,272	1,380	1,343	1,216	1,332	1,375	29	NS	<0.001	<0.01	<0.05
FCE (kg FCM/t DMI[6])	1,273	1,376	1,320	1,216	1,328	1,357	32	NS	<0.001	<0.01	<0.05
FCE (MJ ME milk/MJ ME intake)	0.58	0.62	0.60	0.56	0.60	0.61	0.01	NS	<0.01	<0.05	<0.05
(b) Extended lactation system											
Days in milk	595	608	567	623	605	630	27	<0.10	NS	NS	NS
Milk yield (kg/cow)	8,908	1,0929	9,931	10,814	13,962	15,448	1,101	<0.001	<0.01	NS	<0.05
MS yield (kg/cow)	762	919	789	881	1109	1180	90	<0.001	<0.05	<0.10	<0.05
LW change[4] (kg/cow)	126	203	181	92	118	175	41	NS	<0.01	NS	NS
BCS change[4] (units/cow)	1.96	2.54	3.22	0.52	0.65	1.37	0.74	<0.001	<0.01	NS	NS
Average lactation LW (kg/cow))	530	566	566	614	616	645	32	<0.05	<0.05	NS	NS
Average lactation BCS (units/cow)	5.43	5.80	6.68	4.85	4.32	5.48	0.44	<0.01	<0.01	0.05	NS
MS efficiency (kg MS/100 kg LW)	144	163	135	145	188	183	16	<0.01	NS	<0.05	<0.05
MS efficiency (kg MS/kg $LW^{0.75}$)	6.90	7.95	6.63	7.19	9.28	9.23	0.76	<0.01	NS	<0.05	<0.05
Concentrate DMI (t/cow)		1.82	3.12		1.80	3.61	0.15	<0.05	<0.001		<0.05
Response (kg MS/t concentrate DMI)		86	9		127	83					
Total DMI (t/cow)	8.84	9.77	9.02	10.15	11.16	11.81	0.57	<0.001	<0.05	NS	<0.05
Total DMI (t DMI/100 kg LW)	1.67	1.73	1.55	1.66	1.89	1.83	0.09	<0.01	NS	<0.05	<0.05
Total DMI (t DMI/kg $LW^{0.75}$)	0.080	0.084	0.076	0.082	0.093	0.092	0.004	<0.001	NS	<0.05	<0.05
FCE (kg MS/t DMI)	85	94	86	86	99	99	5	<0.01	<0.10	<0.05	0.05
FCE (kg ECM/t DMI[5])	1,117	1,230	1,133	1,143	1,309	1,322	60	<0.01	<0.05	<0.05	<0.10
FCE (kg FCM/t DMI[6])	1,107	1,216	1,110	1,128	1,284	1,293	60	<0.01	<0.10	<0.05	<0.10
FCE (MJ ME milk/MJ ME intake)	0.51	0.55	0.50	0.52	0.59	0.59	0.03	<0.01	NS	<0.05	<0.10

[1]A normal 12-month calving interval, i.e., calving to the theoretical dry-off date (0 to 300 days in milk) and the theoretical dry period thereafter.
[2]An extended 24-month calving interval, i.e., calving to the actual dry-off date (0 to 600 days in milk) and the dry period thereafter.
[3]L= linear and Q= quadratic contrasts; G x D_L = genotype x $diet_L$ interaction; NS= non-significant P >0.10.
[4]LW and BCS change between the start of the lactation (1 week post-calving) and dry-off.
[5]kg energy corrected milk (ECM) per t DMI, where ECM = kg milk x (383 x fat% + 242 x protein % + 783.2)/3140 (Tyrrell & Reid, 1965).
[6]kg fat corrected milk (FCM) per t DMI, where FCM = kg milk x (0.4 + 0.5 x fat%) (Gaines & Davidson, 1923).

Extended lactation

During the extended 24-month calving interval, NA HF cows had greater milk and MS production, greater MS and total DMI efficiencies per unit LW, and had a greater average lactation LW, concentrate DMI, total DMI and MS response to concentrate, compared with NZ HF cows (Table 1b). The NA HF cows also gained a similar amount of LW, but less BCS, and had a lower average BCS during lactation than NZ HF cows. Increasing levels of concentrate linearly increased milk and MS production, total DMI, average LW and BCS, and LW and BCS gain during lactation. Quadratic effects of diet were detected for MS and total DMI efficiencies per unit LW. The G x D_{Linear} interactions detected for milk and MS yield, concentrate DMI, total DMI, and MS and total DMI efficiencies per unit LW indicated that differences between genotypes increased with increasing concentrate supplementation.

For all measures of gross FCE, NA HF cows were more efficient than NZ HF and there was a quadratic effect of diet (Table 1b). There was also a linear diet effect for gross FCE expressed as kg MS, kg ECM, or kg FCM per t DMI, but not for MJ ME milk per MJ ME intake. The G x D_{Linear} interactions for all gross FCE parameters showed that differences between genotypes were greatest at 6 kg DM concentrate/d. Milksolids production, total DMI and gross FCE (kg MS per t DMI) in an extended 24-month season expressed as a percentage of what would be obtained during two normal 12-month seasons was greater for NA HF than NZ HF cows (94%, 96% and 98% vs. 79%, 89% and 88%, respectively), regardless of dietary treatment.

DISCUSSION

This study identified G x D interactions where the ranking, or the extent of differences, between NZ HF and NA HF cows with increasing concentrate supplementation differed in an extended 24-month calving interval system when compared with a normal 12-month calving interval system. The results showed that in a normal 12-month season with generous pasture allowances throughout, the greatest gross FCE was achieved by NZ HF cows fed moderate levels of concentrate (104 kg MS/t DMI) and by NA HF cows fed high levels of concentrate (102 kg MS/t DMI). The ranking for gross FCE for the remaining treatments was NZ6 and NA3 (100 kg MS/t DMI), followed by NZ0 (96 kg MS/t DMI), and then NA0 (90 kg MS/t DMI). However, in an extended 24-month season, NA HF cows fed moderate to high levels of concentrates had the highest gross FCE (99 kg MS/t DMI), closely followed by NZ HF cows fed moderate levels of concentrates (94 kg MS/t DMI). Lower FCE values (86 kg MS/t DMI) were achieved by NZ HF cows fed high levels of concentrates and either genotype fed no concentrates.

In a normal 12-month season, the NA HF cows produced increasingly greater yields of milk and MS, when compared with NZ HF cows, as the level of concentrates increased. The NA HF cows continued to respond at the highest concentrate level with increased milk and MS production, higher MS efficiencies per unit LW and increased gross FCE measures. In contrast, for NZ HF cows fed a 6 kg DM concentrate diet, LW and BCS gain during lactation increased but there were no further increases in milk and MS production compared with the 3 kg DM concentrate diet, resulting in a small MS response to concentrate. The MS efficiencies per unit LW and gross FCE for NZ HF cows peaked at 3 kg DM concentrate, with declines at 6 kg DM concentrate indicating a high substitution of supplement for pasture and greater nutrient partitioning towards BCS gain.

Gross FCE expressed as kg MS per t DMI was greater for NZ HF compared with NA HF cows at supplement levels of 0 or 3 kg DM concentrate/d, but were similar when fed 6 kg DM. The NA HF cows had lower average BCS, and LW and BCS gains during lactation across all diets and lower MS efficiencies per unit LW at the 0 and 3 kg DM concentrate diets. Together these results indicate that NA HF cows were in greater relative feed deficit than NZ HF, despite generous pasture allowances. This finding is supported by plasma hormone and metabolite profiles (Phyn *et al*., 2007), and is in line with previous studies (Kolver *et al*., 2002; Macdonald *et al*., 2005; 2008) showing that production and efficiency of NA HF cows is constrained under a pasture-based diet. In a pasture-based farm system with low levels of supplementation, NA HF cows are less likely to get in calf, lose more BCS postpartum, gain less LW during lactation, and are less efficient at producing milk as a percentage of LW compared with NZ HF cows. The larger NA HF cows cannot consume sufficient pasture to meet the extra maintenance costs associated with greater LW. They produce similar MS yields to NZ HF cows and, therefore, have lower gross FCE. However, when fed a TMR diet, NA HF cows are able to gain BCS at similar rates to NZ HF during mid and late lactation, and are more efficient at producing MS than NZ HF cows (Kolver *et al*., 2002).

In the current study, important differences between genotypes were also detected during an extended 24-month season with lactation lengths of up to 670 days. Compared with the NZ HF cows, the NA HF cows had increasingly greater yields of milk and MS per cow, concentrate and total DMI, and MS and total DMI efficiencies per unit LW, with increasing levels of concentrates. This meant that while differences between genotypes were small or non-existent at the 0 kg DM concentrate diet, they were large at the 6 kg DM concentrate diet. The same pattern was evident for all measures of gross FCE, with an average of 2 kg MS per t DMI increase in gross FCE for every additional kg concentrate fed per day to NA HF cows when compared with NZ HF cows. For NA HF cows, the response to supplements appeared to flatten between 3 and 6 kg DM concentrate/d as there were no further increases in milk and MS production, total DMI, MS and DMI efficiencies per unit LW, and gross FCE measurements, resulting in a drop in the marginal MS response to concentrate. For NZ HF cows the effect described earlier for the normal 12-month season was magnified during the extended 24-month season, such that MS yields and gross FCE of the NZ HF cows fed 6 kg DM concentrate were similar to those fed no concentrates. These animals made large gains in BCS and LW during lactation suggesting that supplementary feed was put towards adipose tissue accretion, with adverse effects on gross FCE.

Regardless of diet, gross FCE in an extended lactation was 98% of that obtained in a normal season for NA HF cows, but only 88% for NZ HF cows. North American HF cows also had greater MS production and total DMI in an extended lactation as a percentage of a normal season, compared with NZ HF cows. These findings indicate that NA HF cows were better able to maintain a high level of MS production without excessive BCS gain during the extended lactation. However, variation between individuals in each genotype indicates that some cows are well suited to extended lactations (Phyn *et al*., 2007) pointing to the possibility of selecting robust fertile cows with high MS production and high gross FCE in an extended lactation system. This may lead to further improvements in lifetime FCE due to more days in milk in a cow's productive lifetime.

Overall, these results show that in a normal seasonal system, with generous pasture allowances, NZ HF cows fed moderate levels of concentrate and NA HF cows fed high levels of concentrate will have the greatest gross FCE (~ 103 kg MS/t DMI). However, the later will still have poor reproductive performance (Kolver *et al*., 2006; 2007) constraining its suitability for seasonal pastoral systems. In an extended lactation system, NA HF cows fed moderate to high levels of concentrate were able to attain a high gross FCE (99 kg MS/t DMI) and were therefore more efficient at producing higher MS yields than NZ HF cows.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the valuable contributions of the DairyNZ Lye Farm staff, especially Alan Napper and Bruce Sugar, as well as Barbara Dow for statistical analysis. This research was funded by New Zealand dairy farmers through DairyNZ Inc.

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