

## Influence of Holstein-Friesian Strain and Feed System on Body Weight and Body Condition Score Lactation Profiles

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### ABSTRACT

The objective of the present study was to determine effects of strain of Holstein-Friesian and feed system on body weight (BW) and body condition score (BCS; scale of 1 to 5) lactation profiles in seasonal-calving, grass-based milk production systems. The 3 strains of Holstein-Friesian compared differed in milk production potential and were high-production North American (HP), high-durability North American (HD), and New Zealand (NZ). The 3 feed systems compared were a high grass allowance feed system typical of spring-calving herds in Ireland (MP); an increased stocking rate system (HS); and an increased concentrate supplementation system (HC), each maintained within a separate farmlet. The data comprised 20,611 weekly BW and 7,920 BCS records assessed every 3 wk across 5 yr on 584 lactations. An exponential function was used to model BW and BCS lactation profiles across feed systems. Across feed systems, the NZ strain was significantly lighter (545 kg) but had greater average BCS (3.10 units) compared with the HP (579.3 kg and 2.76 units, respectively) and HD strains (583.2 kg and 2.87 units, respectively). Across feeding systems, the HD and HP strains exhibited a greater loss of BCS in early lactation (0.27 and 0.29 units, respectively) compared with the NZ strain (0.21 units). The HP strain failed to gain BCS over the entire lactation. Concentrate input did not affect the rate of BCS or BW loss in early lactation or BCS at 60 DIM. This study extends previous research outlining the greater suitability of the NZ strain to the low-cost grass-based system of milk production predominantly operated in Ireland.

**Key words:** Holstein-Friesian, body weight, body condition score, pasture

### INTRODUCTION

It is now widely accepted that, similar to most lactating mammals, dairy cows in early lactation do not con-

sume enough feed to meet the energetic requirements of lactation (Nielsen, 1999). The deficit in energy is generally bridged through catabolism of body energy reserves leading to a decline in BCS postpartum (Mao et al., 2004; Berry et al., 2006; Roche et al., 2006). Due to the moderate correlation between BCS and BW (Berry et al., 2002), a decline in BW postpartum is also generally observed over and above that accounted for through the expulsion of the fetus and associated membranes and fluids.

Body condition score and BCS change have been correlated with production (Dechow et al., 2001, 2002), metabolic disease incidence (Roche and Berry, 2006), health (Berry et al., 2007), and fertility (Buckley et al., 2003; Dechow et al., 2004; Roche et al., 2007). The influence of nutrition on BCS is inconsistent, with authors such as Mao et al. (2004), Berry et al. (2006), and Roche et al. (2006) reporting influences of management systems on BCS over lactation, whereas other studies showed no effect of alternative treatments (Veerkamp et al., 1995). Body weight and BW change have also been reported to be associated with health (Berry et al., 2007) and fertility (Buckley et al., 2003; Roche et al., 2007) as well as being directly related to energy maintenance requirement (NRC, 2001) and thus by definition, energy balance.

Internationally, genetic selection among cattle breeders for higher milk production within the Holstein-Friesian population has resulted in production gains of 1 to 2% per year (Dillon et al., 2006). Although selection has been based primarily on milk production, selection on type traits such as dairy character and body size and depth has further intensified the genetic gain toward increased angularity of the dairy cow population (Kelm et al., 2000). Because of strong antagonistic genetic correlation between BCS and angularity (Veerkamp and Brotherstone, 1997) and the insufficient increases in feed intake to meet requirements when selecting on yield alone (van Arendonk et al., 1991), selection on increased milk yield and angularity without cognizance of other functional traits will result in animals that rely on greater mobilization of body tissue in early lactation to support high milk yield.

Received August 2, 2006.

Accepted December 4, 2006.

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Previously reported heritability estimates for BW and BCS as well as changes in BW and BCS (Dechow et al., 2002; Berry et al., 2003) suggest the existence of genetic variation and thus the possible existence of strain differences in BW and BCS profiles. Previous studies using random regression models have also documented significantly different shapes of BCS and BW lactation profiles between animals (Berry et al., 2003; Coffey et al., 2003). An understanding of the BCS and BW profiles throughout lactation facilitates the assessment of the impact of genetic origin as well as nutrition and may subsequently be used to identify an optimum management system and germplasm that avoids long periods of negative energy balance postpartum.

On investigation of previously described lactation profiles for BCS and BW, Roche et al. (2006) proposed that BCS and BW curves closely resembled horizontally inverted milk yield lactation curves. Roche et al. (2006) subsequently proceeded to use the Wilmink function (1987) to describe the BCS and BW profiles for dairy cows of 2 genetic strains across 3 feed systems and reported median  $R^2$  of 0.70 and 0.80 for BCS and BW, respectively. Horan et al. (2005a) fitted the Wilmink function to describe the shape of lactation profiles for milk, fat, and protein yield in a subset of the current data set, achieving a range in mean  $R^2$  value of 0.66 to 0.89.

Significant effects of strain of Holstein-Friesian and feed system on milk production (Horan et al., 2005b), lactation curve characteristics (Horan et al., 2005a), grass DM intake (Horan et al., 2006), and reproductive performance (Horan et al., 2004) have been reported previously using a subset of the current data set. In summary, cows of New Zealand origin produced less milk than those of North American origin with important strain by environment interactions present (Horan et al., 2005b). Selection solely for milk yield resulted in higher grass DMI and an improved response to concentrate supplementation, with cows selected within pasture-based systems achieving the highest grass DMI per kilogram of BW (Horan et al., 2006). Reproductive performance was poorest for cows selected solely for milk production (Horan et al., 2004), whereas animals of New Zealand origin had significantly higher SCC than animals of North American origin (McCarthy et al., 2007). The objective of this study was to determine, using the Wilmink function, the effect of strain of Holstein-Friesian and feed system on BW and BCS profiles throughout lactation to better comprehend the above realized differences.

## MATERIALS AND METHODS

### Animals

Three strains of Holstein-Friesian cows were compared and are outlined in more detail by Horan et al.

(2005b) and McCarthy et al. (2007). In brief, the 3 strains compared were high-production North American (HP), high-durability North American (HD), and New Zealand (NZ). To initially create the HP strain, the top 50% of Holstein-Friesian cows in the Moorepark herd (based on pedigree index for milk production) were inseminated with semen from 5 North American Holstein-Friesian sires chosen as the 5 highest sires available in Ireland at the time based on the production-based relative breeding index. Therefore, the HP strain was selected to illustrate what would happen if Irish dairy farmers continued to select animals aggressively for increased milk production.

To initially create the HD strain, the bottom 50% of Holstein-Friesian cows in the Moorepark herd (based on pedigree index for milk production) were inseminated with semen from 5 North American Holstein-Friesian sires, chosen on a combination of their pedigree indices for milk production, fertility, and linear (muscularity) traits. Therefore, the HD strain was generated to represent a more balanced breeding policy including some fertility indicator traits as well as milk production traits.

The NZ animals were imported as embryos from New Zealand. The NZ embryos were generated by mating high genetic merit New Zealand Holstein-Friesian cows with 5 high genetic merit New Zealand Holstein-Friesian sires. On average, 87.5% of the NZ strain genes were of New Zealand Holstein-Friesian ancestry.

The data consisted of 99, 117, 125, and 126 cows in the years 2001 to 2005, respectively. In 2001 all animals were primiparous; in 2002, 45 were parity 1 and 72 were parity 2; in 2003, 9 animals were parity 1, 45 were parity 2, and 63 were parity 3; in 2004, 27 animals were parity 1, 12 were parity 2, and 86 were parity 3 and above; and in 2005, 27 animals were parity 1, 18 were parity 2, and 81 were of parity 3 and above. In the present study, parity was recoded as 1, 2, 3, and 4+. Primiparous animals entering the herd from the spring of 2003 onward were bred from within each strain using sires concurrent with the different breeding objectives as outlined above relative to that strain. Each strain represents on average, 13 sires over the 5 yr of the study. The maximum, minimum, and median number of daughters from respective sires for the HD, HP, and NZ strains was 16, 1, and 6; 26, 1, and 6; and 21, 1, and 5, respectively.

### Feed Systems

There was a separate farmlet for each of the 3 feed systems, which are described in more detail by Horan et al. (2005b). The 3 systems compared were a high grass allowance feed system typical of spring-calving

herds in Ireland (**MP**, control); an increased concentrate feed system (**HC**), and an increased stocking rate system (**HS**). The MP system had an overall stocking rate of 2.47 cows/ha, N fertilizer input of 290 kg of N/ha (from early January to late September), and received 325 kg of concentrate/cow in early lactation with the remainder of the lactation diet comprising grazed grass. The HC feed system had a similar overall stocking rate and N input as the MP feed system but a concentrate input of 1,445 kg/cow. The ingredient composition of the concentrate feed (kg/t as fed) was as follows: 250 kg of barley, 260 kg of corn gluten, 350 kg of beet pulp, 110 kg of soybean meal, and 30 kg of minerals plus vitamins. The HS group had similar concentrate (327 kg/cow) and N inputs as the MP system but had an overall stocking rate of 2.74 cows/ha. The MP and HC systems were designed to allow each strain to express its potential within each feed system largely unrestricted by limitations in feed supply. The differential in stocking rate between the MP and HS systems was imposed by reducing the area of each paddock in the HS system by 10% relative to the control MP system and then maintaining the same residency time in the HS and MP paddocks. This stocking rate was imposed daily throughout the grazing period and therefore had a cumulative effect through lower regrowth rates and consequently lower pregrazing yields in subsequent rotations.

All primiparous animals were treated similarly for the first 4 wk of lactation. Animals were blocked within strain into groups of 3, based on calving date, preexperimental milk production, live weight, and BCS and then randomly assigned to 1 of 3 feed systems. Once allocated to a feed system, animals were retained on the same feed system in subsequent lactations. The concentrate supplementation pattern for each feed system was previously reported by Horan et al. (2005a). Animals in the MP and HS feed systems received their total concentrate allocation in early lactation, receiving no further concentrate supplementation after late April. From late April until the end of lactation, animals in the HC system continued to receive 3.5 kg (DM) of concentrates.

The feed systems were applied immediately postpartum to all multiparous animals. In all 5 years, animals were turned out to grass during the day in early February. Animals were bred over a 13-wk breeding season from late April until late July each year. Animals were outdoors day and night until mid November, when they were housed only at night. After December 1, they were housed day and night. During the housed period, animals were fed grass silage ad libitum, with excessively low BCS cows receiving some concentrate supplementation.

### Data Editing and Analysis

Body weight was recorded weekly on exit from the milking parlor using an electronic scale calibrated weekly against known weights. Body condition score was recorded every 3 wk during the lactation (4 wk in late lactation in some years) on a 1-to-5 scale (1 = emaciated, 5 = extremely fat) in increments of 0.25 as outlined by Lowman et al. (1976). Body condition scores were assigned by one individual throughout the study.

The data set comprised 20,611 BW and 7,920 BCS measurements from 584 lactations on 240 cows between the years 2001 to 2005. The BW record in the week immediately before calving and the last BCS record before calving were retained and allocated a negative value determined by days precalving. This was necessary to facilitate accurate predictions of BW and BCS at calving using the mathematical function applied. Preliminary graphical examination of the raw data revealed a BCS and BW profile similar to the inverted milk lactation profiles reported by Horan et al. (2005a) using a subset of the current data set. Hence, the Wilink (1987) exponential model curve was fitted to each lactation to BW and BCS separately.

The Wilink function is described as

$$y_t = a + b \times e^{-0.05 \times t} + c \times t.$$

In this model, the  $a$ ,  $b$ , and  $c$  parameters relate to the height of the curve, the initial lactation phase, and the final lactation phase, respectively, and  $y_t$  represents BW or BCS at day  $t$  of lactation. A positive  $b$  parameter is indicative of a declining initial phase following calving, whereas a negative  $b$  value is indicative of an inclining initial phase. An inclining phase postnadir results in a positive  $c$  parameter, whereas a negative  $c$  parameter is indicative of a declining phase. Regression parameters were estimated separately for each cow-parity using PROC NLIN (SAS Institute, 2006).

Residuals were calculated as the difference between the actual and predicted values at each DIM. The mean square prediction error was calculated as the variance of the residuals. The median  $R^2$  for the fit of the Wilink function was also calculated for BW and BCS separately.

Average BW and BCS throughout the 305-d lactation were also extracted from the daily predictors of the curve. Body condition score and BW at calving were predicted from the function curve by setting DIM to zero. Body weight and BCS at 305 DIM were considered as dry-off BW and BCS. To determine nadir BW, the first derivative of the Wilink function with respect to time for each cow-parity was set equal to zero and solved for DIM. Days in milk to nadir BW, loss of BW to nadir,



**Table 1.** Effect of strain of Holstein-Friesian and feed system (MP, HS, and HC)<sup>1</sup> on BW parameters

Variable <sup>2</sup>	Holstein-Friesian strain and feed system									SE	Significance <sup>3</sup>		
	High production			High durability			New Zealand				S	F	S × F
	MP	HS	HC	MP	HS	HC	MP	HS	HC				
<i>a</i>	514.5	491.1	492.9	496.6	502.1	500.0	473.3	479.1	467.1	6.23	0.001	0.26	0.05
<i>b</i>	107.1	119.1	111.3	106.3	99.2	110.1	107.2	109.9	111.8	4.61	0.14	0.50	0.18
<i>c</i>	0.33	0.39	0.42	0.40	0.36	0.46	0.41	0.35	0.46	0.018	0.15	0.001	0.05
Calving (kg)	615.7	616.8	607.6	597.6	597.8	606.6	583.4	573.4	579.2	7.43	0.001	0.77	0.56
Dry off (kg)	606.4	607.8	633.1	621.6	614.2	641.6	592.7	581.5	608.2	6.95	0.001	0.001	0.79
Average (kg)	563.0	552.6	569.4	566.8	565.6	573.5	529.6	534.3	539.1	5.58	0.001	0.01	0.35
Nadir (kg)	537.1	519.6	522.6	519.6	525.1	525.2	506.8	497.1	497.9	5.67	0.001	0.78	0.05
DIM to nadir	58.6	55.7	52.1	53.0	53.1	51.3	51.8	56.8	52.3	1.78	0.16	0.05	0.13
Loss to nadir (kg)	83.3	91.3	81.5	79.0	72.2	78.1	84.0	78.0	80.0	3.91	0.05	0.64	0.18
Gain postnadir (kg)	77.3	89.6	99.8	92.9	85.3	108.1	96.8	81.9	108.3	4.37	0.10	0.001	0.05
Gain during breeding (kg)	24.1	28.0	32.1	29.8	27.2	34.5	31.4	25.7	34.8	1.58	0.07	0.001	0.02

<sup>1</sup>MP = Moorepark feed system; HS = high stocking rate feed system; HC = high concentrate feed system.

<sup>2</sup>*a*, *b*, and *c* parameters are estimated parameters relating to the height of the curve, the initial phase, and the final phase, respectively.

<sup>3</sup>S = effect of strain of Holstein-Friesian; F = effect of feed system; S × F = effect of interaction between strain of Holstein-Friesian and feed system.

and amount gained postnadir to 305 d were also calculated. A large proportion of cows displayed a negative final (*c*) phase for BCS, and thus nadir BCS did not exist. Berry et al. (2006) found that animals enter positive energy balance close to 60 DIM, and strong correlations between BCS change to 60 DIM and subsequent changes in BCS over lactation have been reported previously (Berry et al., 2002). Sixty DIM also corresponded with average DIM at commencement of the breeding season in this study. Therefore, BCS at 60 DIM, loss from calving to this point, and the amount subsequently gained were determined. Body condition score and BW change during the breeding season were also calculated as the change between 60 and 151 DIM.

Mixed model analysis using PROC MIXED (SAS Institute, 2006) was performed separately on the 3 parameters of the function as well as the various BCS and BW variables derived from the function. Cow was included as a repeated effect with an unstructured covariance matrix assumed among records within cow. All dependent variables were normally distributed. Class variables tested in the model included strain, feed system, and parity. Continuous covariates considered for inclusion in the model were PTA for milk yield, fat yield, protein yield, fat concentration, protein concentration, calving day of year, and calving to conception interval all centered within strain by parity. The relationship between dependent variables and the continuous covariates were visually assessed to identify the appropriate order of the polynomial, which was also tested for significance in the model using the *F*-test. Only factors significantly ( $P < 0.05$ ) affecting dependent variables were retained in the model with the exception of strain and feed system, which were forced into the model.

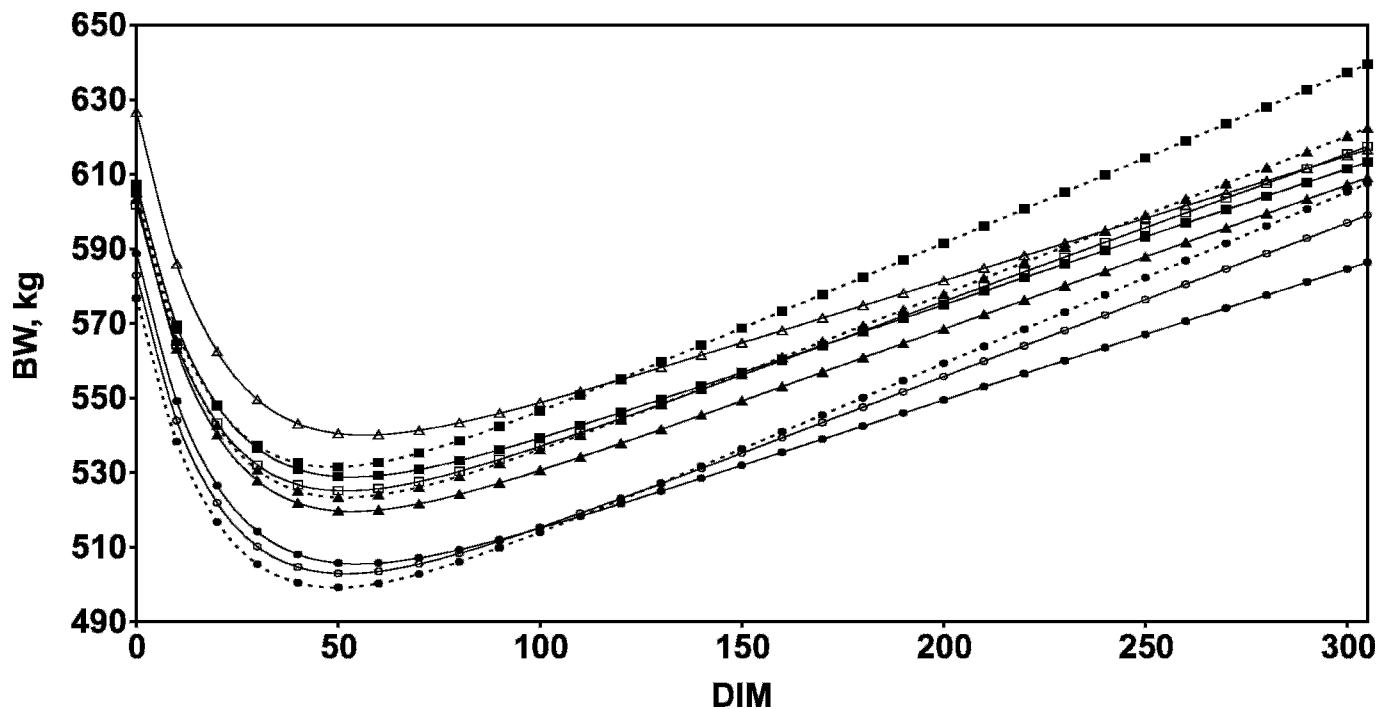
Biologically plausible interactions were also tested for significance in the model. Differences between least squares means were tested using the *t*-test.

## RESULTS

The median  $R^2$  values of the Wilmlink function to BW and BCS were 0.86 and 0.59, respectively. Average BW and BCS across the entire data set were 544 kg and 2.91 BCS units, respectively. Nadir BW was 504 kg and occurred at 54 DIM. A BW loss of 82 kg occurred from calving to nadir, whereas animals gained 93.6 kg from nadir to 305 DIM. Body condition score at 60 DIM was 2.91 units, whereas animals lost 0.28 BCS units from calving to 60 DIM.

## BW

The effect of strain of Holstein-Friesian on the 3 parameters of the Wilmlink function fitted to BW is presented in Table 1. Irrespective of feed system, average BW of the NZ strain was significantly lower than that of both the HD and HP strains. A significant interaction between strain and feed system was evident for the *a* and *c* parameters (Figure 1) relating to the height of the curve and the incline phase, respectively. In the MP system the height (i.e., *a* parameter) was significantly different between all strains; however, within both the HS and HC systems, the NZ strain had the lowest *a* parameter, the HD the highest, and the HP strain was not significantly different from either. Within the HS and HC feed systems, the *c* parameter was not significantly different between strains, whereas in the MP system, the HP strain had a significantly lower *c* param-

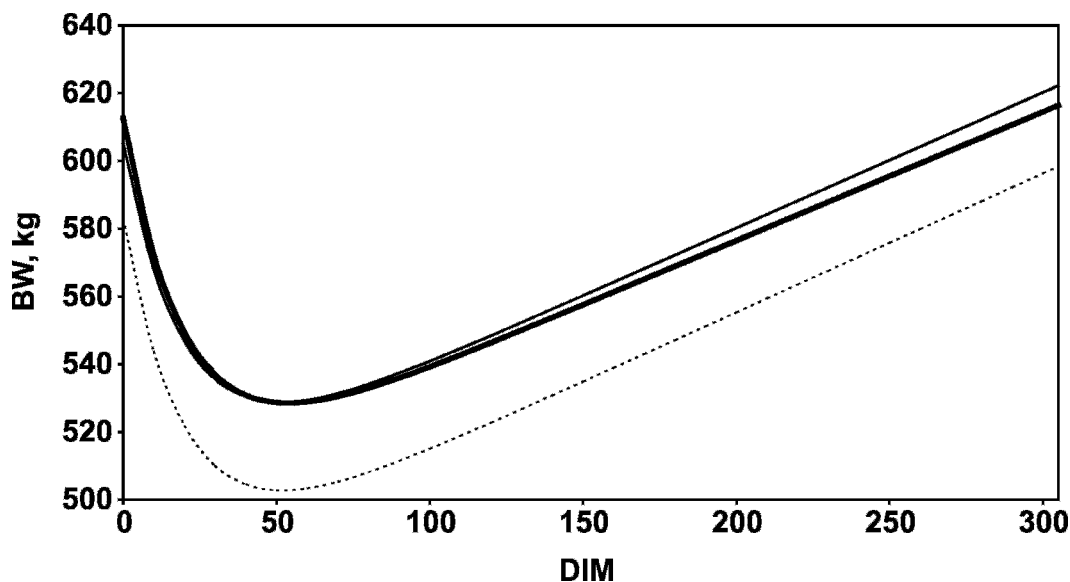


**Figure 1.** Lactation profile of strain  $\times$  feed system interaction for BW. Strains:  $\triangle$ ,  $\blacktriangle$  = high production;  $\square$ ,  $\blacksquare$  = high durability;  $\circ$ ,  $\bullet$  = New Zealand. Feed systems: open symbols + solid line = Moorepark; solid symbols + solid line = high stocking rate; solid symbols + dashed line = high concentrate.

eter than both other strains with no significant difference between the HD and NZ strains.

Figure 2 shows that although the height of the BW profile (i.e.,  $a$  parameter) was significantly lower for

the NZ strain, the shape of the lactation profiles was relatively similar across strains as indicated by the lack of a significant difference in the  $b$  parameter. However, strain did significantly affect some other variables de-



**Figure 2.** Body weight lactation profile for the New Zealand (-----), high durability (—), and high production (—) strains across all feed systems ignoring the strain  $\times$  feed system interaction.

**Table 2.** Effect of strain of Holstein-Friesian and feed system (MP, HS, and HC)<sup>1</sup> on BCS parameters (BCS units)

Variable <sup>2</sup>	Holstein-Friesian strain and feed system									SE	Significance <sup>3</sup>		
	High production			High durability			New Zealand				S	F	S × F
	MP	HS	HC	MP	HS	HC	MP	HS	HC				
<i>a</i>	2.76	2.74	2.74	2.82	2.82	2.83	3.00	3.03	3.00	0.046	0.001	0.99	0.97
<i>b</i>	0.31	0.31	0.27	0.32	0.27	0.26	0.22	0.28	0.23	0.035	0.19	0.52	0.62
<i>c</i> (× 10 <sup>-3</sup> )	-0.29	-0.10	0.17	-0.13	-0.02	0.57	0.30	0.18	0.71	0.145	0.001	0.001	0.66
Calving	3.07	3.05	3.01	3.16	3.11	3.14	3.22	3.29	3.26	0.033	0.001	0.85	0.40
Dry off	2.64	2.70	2.78	2.74	2.82	3.05	3.08	3.08	3.24	0.042	0.001	0.001	0.15
Average	2.75	2.76	2.78	2.80	2.86	2.94	3.06	3.09	3.15	0.032	0.001	0.001	0.38
BCS at 60 DIM	2.78	2.77	2.76	2.81	2.84	2.88	3.03	3.06	3.07	0.036	0.001	0.46	0.69
Loss to 60 DIM	0.31	0.30	0.24	0.31	0.26	0.22	0.19	0.25	0.17	0.031	0.01	0.02	0.51
Gain post 60 DIM	-0.09	-0.04	0.03	-0.05	-0.02	0.13	0.06	0.03	0.16	0.034	0.001	0.001	0.63
BCS during breeding	2.75	2.75	2.76	2.79	2.84	2.90	3.04	3.06	3.10	0.034	0.001	0.07	0.67
Gain during breeding	-0.04	-0.03	0.00	-0.03	-0.02	0.04	0.02	0.00	0.05	0.013	0.001	0.001	0.58

<sup>1</sup>MP = Moorepark feed system; HS = high stocking rate feed system; HC = high concentrate feed system.

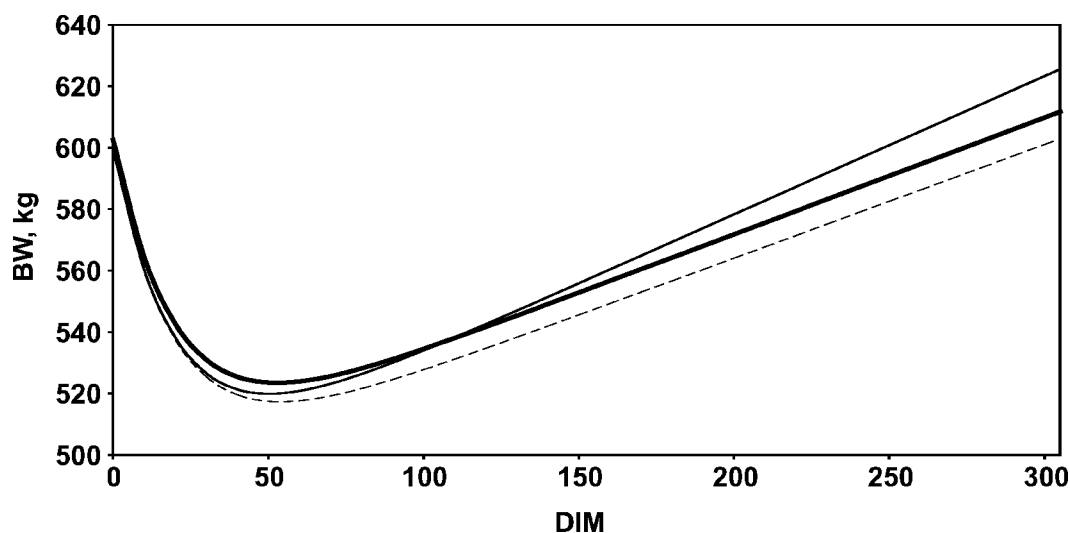
<sup>2</sup>*a*, *b*, and *c* parameters are estimated parameters relating to the height of the curve, the initial phase, and the final phase, respectively.

<sup>3</sup>S = effect of strain of Holstein-Friesian; F = effect of feed system; S × F = effect of interaction between strain of Holstein-Friesian and feed system.

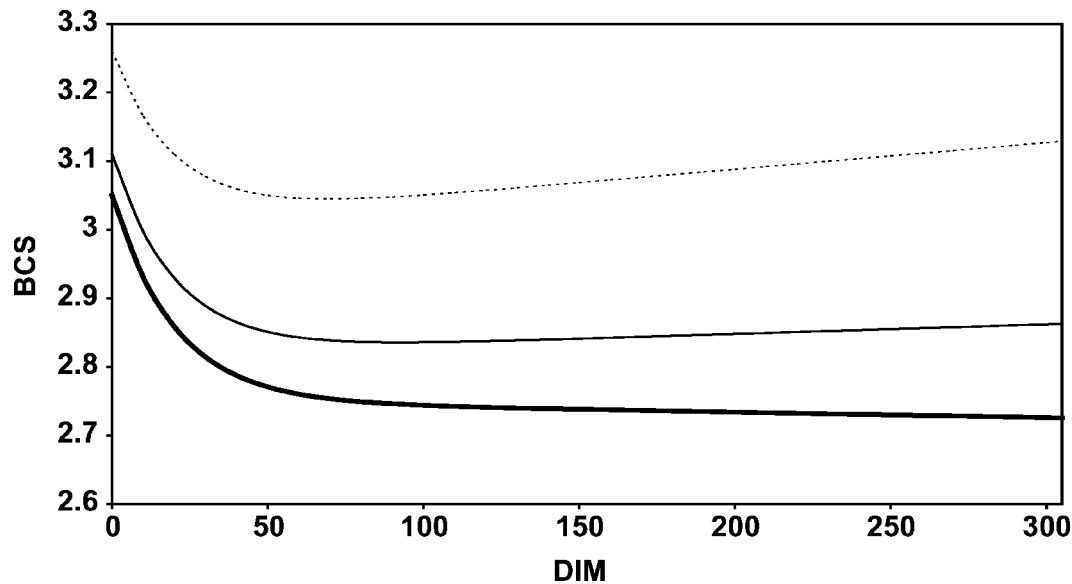
rived from the profiles (Table 1). Across all feed systems the HD strain lost significantly less BW to nadir than the HP strain because of the numerical difference in number of DIM to nadir. Significant interactions were found for nadir BW, BW gain postnadir, and BW gain during breeding. The HP strain had a significantly greater nadir BW compared with both the HD and NZ strains in the MP feed system, whereas in the HS and HC systems, nadir BW was not significantly different between the HD and HP strains but the NZ strain was significantly lower than both other strains. No significant difference in BW gain postnadir existed between strains in the HC and HS systems; however, in the

MP system the HD and NZ strains gained significantly more than the HP strain. The NZ strain exhibited the greatest BW gain postnadir in both the HS and HC feed systems, whereas the HD strain was highest in the MP feed system. Body weight change during the breeding season was significantly greater for the HD and NZ strains compared with the HP strain in the MP and HC feed systems; however, no significant difference occurred between strains in the HS system.

Figure 3 graphically illustrates the effect of feed system on the BW lactation profile. No significant effect of feed system on the *b* parameter for BW (Table 1) was found. Feed system had no significant effect on BW at



**Figure 3.** Body weight lactation profile for the high stocking rate (-----), Moorepark (—), and high concentrate (—) feed systems across all strains ignoring the strain × feed system interaction.



**Figure 4.** Body condition score lactation profile for the New Zealand (-----), high durability (—), and high production (—) strains.

calving, whereas at dry-off, animals on the HC feed system had the highest BW, with no significant difference between those in the MP and HS feed systems.

### BCS

No significant strain by environment interaction was found for any of the BCS traits; therefore, only the main effects of strain and feed system are discussed. However, strain by feed system estimates are presented in Table 2. The height (i.e., the  $a$  parameter) of the BCS lactation profile was significantly greater for the NZ strain compared with both the HD and HP strains. There was no significant effect of strain of Holstein Friesian on the rate of BCS loss postpartum (i.e., the  $b$  parameter); however, across all feed systems, the NZ strain gained BCS in the second phase of the lactation profile at a significantly higher rate than the other strains as indicated by the  $c$  parameter. Figure 4 graphically illustrates the higher BCS profile and greater rate of BCS gain in the latter phase of lactation in the NZ strain. The least squares mean for the  $c$  parameter of the HP strain across feed systems was negative ( $-0.08 \times 10^{-3}$  BCS units/d) indicating that, on average, HP animals were not gaining BCS by 305 DIM. Although Table 2 indicates a gain in BCS in the HC system ( $c$  parameter) for this strain, there was no significant strain by environment interaction; therefore, this gain is not applicable.

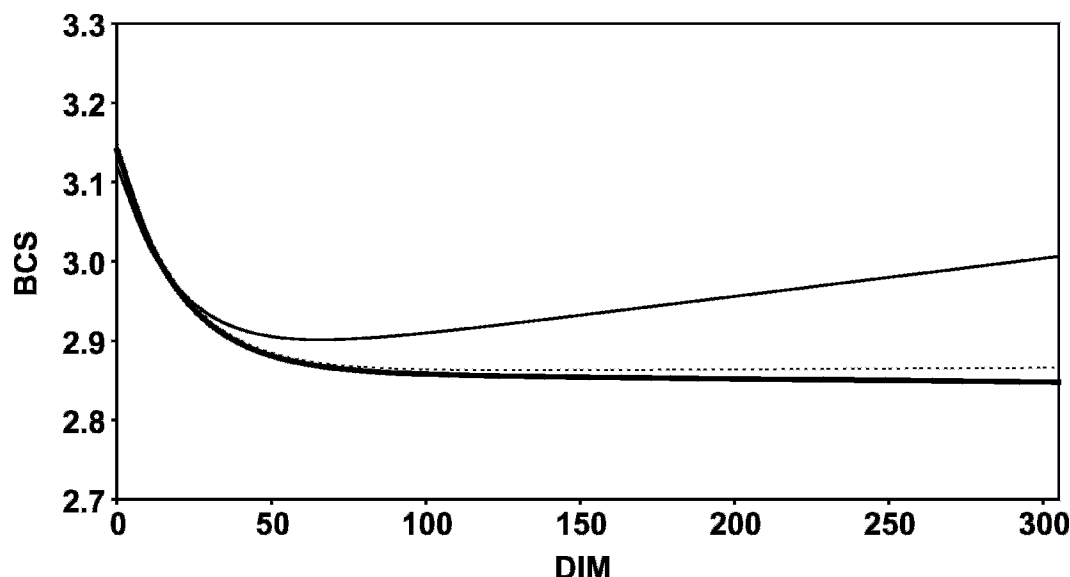
At both calving and drying off, BCS of all strains were significantly different from each other, with the NZ strain greatest, the HP lowest, and the HD strain

intermediate. The NZ strain lost less BCS to 60 DIM or commencement of the breeding season than the other strains irrespective of feed system. Irrespective of feed system, the NZ strain had the highest ( $P < 0.001$ ) BCS, the HP strain the lowest, and the HD strain was intermediate throughout the breeding season. No significant difference in BCS change over the breeding season existed between the HP and HD strains.

Across all strains, feed system had no significant effect on the  $a$  and  $b$  parameters for BCS, whereas animals in the HC feed system had a significantly greater  $c$  parameter ( $0.48 \times 10^{-3}$  BCS units/d, respectively) than those in both the MP and HS feed systems ( $-0.04$  and  $0.02 \times 10^{-3}$  BCS units/d). No significant difference in BCS at 60 DIM was realized between the 3 feed systems; however, loss of BCS to this point was significantly lower for animals in the HC feed system. Body condition score change over the breeding season was significantly different ( $P < 0.001$ ) between feed systems, with animals in both the MP and HS feed systems losing BCS ( $-0.01$  and  $-0.02$  BCS units, respectively), whereas those in the HC gained BCS ( $0.03$  units) over this period. Animals in the HC feed system incurred significantly greater BCS gain post-60 DIM (Table 2) than those in the MP and HS feed systems, as illustrated in Figure 5.

### DISCUSSION

This study provides an insight into BW and BCS lactation profiles of animals of divergent genetic merit across alternative grass-based feeding systems. Fur-



**Figure 5.** Body condition score lactation profile for the high stocking rate (-----), Moorepark (—●—), and high concentrate (——) feed systems.

thermore, it permits an enhanced understanding of previously reported differences from a subset of the current data set with regard to DMI, milk production, and reproductive performance (Horan et al., 2004; 2005a,b; 2006). Median  $R^2$  values reported herein are similar to values reported in New Zealand dairy cattle when the Wilmink function was also fitted to BW and BCS (Roche et al., 2006) and suggests good modeling of the data using the exponential function. The goodness of fit to BW and BCS reported in the present study are also within the ranges reported by Horan et al. (2005a) for milk production using the Wilmink function on a subset of the current data set.

#### **Effect of Strain of Holstein-Friesian**

The lower average BW of the NZ strain is consistent with the findings of Berry et al. (2005) that dairy females of North American origin were heavier at maturity than those of NZ origin. Berry et al. (2005) attributed this difference to conscious selection by New Zealand farmers for lighter, more efficient cows and also the large negative weighting for BW in the New Zealand national breeding objective. Additionally, Roche et al. (2006) also showed that in New Zealand, North American-derived Holstein-Friesian cows were heavier throughout lactation, although significant differences in the shape of the BW profile were evident among strains corresponding to the current analysis.

The decline in BW immediately postpartum coincides with the expulsion of the fetus and uterine contents as well as the catabolism of body reserves (reflected in loss

of BCS postpartum) to supply energy for milk production (Koenen et al., 1999). In agreement with findings of Coffey et al. (2004) using a TMR diet, cows selected for greater production within country of ancestry (i.e., HP vs. HD), exhibited greater BW loss to nadir. However, despite the moderate correlations between BCS and BW (Berry et al., 2002), this was not reflected as a significant difference in BCS loss to 60 DIM.

The BCS profiles reported in the present study relate closely to the inverted milk production profiles of the same 3 strains (Horan et al., 2005a), with the HP strain having the greatest peak milk yield and the lowest persistency, and the NZ strain having the lowest peak milk yield and greatest persistency over lactation. Therefore, the greater postcalving loss of BCS and lower BCS at 60 DIM of the HD and HP strains relative to the NZ strain indicate that much of the additional milk produced by the 2 North American strains from within a pasture-based system is derived from body tissue mobilization.

Similar to findings of Roche et al. (2006) no significant differences in the rate of BCS change postpartum existed across strains in this study; however, contrary to findings of Roche et al. (2006) no significant difference in the rate of BW change postpartum was found in the present study. In that study however, greater BCS loss was observed in all strains postpartum reflecting the greater intensity of production and lower feed allocation of animals in the New Zealand system. Although previous studies have shown a positive association between level of BCS at calving and subsequent loss of BCS in early lactation (Ruegg and Milton, 1995; Berry et al.,



2002), the significantly greater BCS of the NZ strain at calving in the present study did not manifest in increased loss of BCS to 60 DIM, indicating that such a relationship does not hold across strains.

Differences in reproductive performance, including conception rate and overall pregnancy rate, has been reported previously for these strains (Horan et al., 2004) and illustrates poorest reproductive performance for the HP strain and greatest for the NZ strain. As the breeding season in the present study commenced at approximately 60 DIM, results suggest a superior energy balance for the NZ strain at this stage as indicated by their greater BCS at 60 DIM and lower BCS loss to 60 DIM. This may be a large contributing factor to the superior reproductive performance reported for the NZ strain (Horan et al., 2004), given the strong association observed between BCS postpartum and reproduction (Dechow et al., 2002; Buckley et al., 2003). Importantly, the HP strain failed to gain BCS up to 305 DIM necessitating the anabolism of body reserves in the dry period using more expensive concentrates or conserved forage compared with the NZ strain that, on average, anabolized body reserves in mid to late lactation. This suggests a greater suitability of the NZ strain to low-cost, grass-based systems of milk production. Furthermore, the superior BCS of the NZ strain throughout lactation suggests that these animals could be managed to a higher stocking rate and a lower feed allocation than both other strains without detriment to animal performance.

Horan et al. (2006) reported the greatest milk yield response to concentrate for the HP strain, lowest for the NZ strain, and intermediate for the HD strain at 3 stages during lactation. Large milk production responses to concentrate are indicative of genetic groups that are capable of consuming insufficient quantities of herbage to meet their nutritional requirements (Coulon and Rémond, 1991); therefore, indicative of a more negative energy balance, which is reflected here in BCS differences. No significant strain by feed system interaction occurred for BCS gain post-60 DIM in this study, whereas significant strain by feed system interactions have been reported previously, using a subset of the current data set, with regard to milk yield (Horan et al., 2005b) and grass DMI (Horan et al., 2006). This result may be a consequence of the differing substitution rates reported between these strains (Horan et al., 2006).

### ***Effect of Feed System***

The effect of feed system on average BCS and BW was mainly mediated through differences in late lactation, with the greatest difference being evident in animals

on the HC feed system. Feed system had no significant effect on BW or BCS at calving due the management practices during the dry period. In this study first parity animals received a 12-wk dry period whereas higher parity animals received an 8-wk dry period.

Similar to previous studies examining various herbage allowances and concentrate supplementation levels (Delaby and Peyraud, 2003), average BW was significantly greater for animals in the MP system than for those in the HS system, whereas BCS was not different between these animals. Because BW in dairy cows is affected by animal size (skeletal development), degree of fatness, and gut fill (Enevoldsen and Kristensen, 1997), the underlying reason for the BW difference between animals on the MP and HS feed systems must relate to the greater gut fill of animals in the MP feed systems due to their greater grass DMI (Horan et al., 2006). This increased grass DMI was therefore partitioned to milk production in agreement with the increased milk yield in the MP system compared with the HS system as reported by Horan et al. (2005b). Increased stocking rate (i.e., HS vs. MP) did not however lead to significant differences in BCS at 60 DIM or loss of BCS to 60 DIM. Although the effect of differences in stocking rates on herbage allowance for animals in the HS and MP systems does become progressively more pronounced as the grazing season advances because of the grazing management outlined, differences in BCS gain post-60 DIM were not present between animals in the MP and HS system. Consistent with these findings, Berry et al. (2005) reported no significant effect of either feed system on the length, girth, or height of a subset of animals from the current data set.

Animals in the HC system received higher concentrate supplementation levels than those in the other feed systems in early lactation (Horan et al., 2005a) and, unlike animals in the MP and HS systems, received concentrates from late April until the end of lactation. By 60 DIM and at the end of the breeding season (late July), cows in the HC feed system had received 190 and 550 kg of concentrate, respectively, above that received by animals in the other feed systems. The lack of an influence of this additional concentrate input on the rate of loss of both BCS and BW postcalving has been attributed to homeorhetic regulation (Bauman and Currie, 1980) in support of milk synthesis. Also, the correlated genetic response in feed intake in early lactation because of genetic selection for milk production alone is expected to cover only 40 to 48% of the corresponding energy requirements for milk production (van Arendonk et al., 1991). Therefore, energy intake and the rate of body tissue catabolism are

likely restricting factors to increased milk production in high genetic merit cows.

Although Horan et al. (2006) reported increases in total DMI for animals in the HC system (increases differing between strains), at greater intake or with increased diet energy density (HC vs. MP), additional energy intake is partitioned toward milk production in early lactation as the animal seeks to realize its genetic potential. Consequently, this additional concentrate confers no effect on the rate of BCS or BW loss postcalving. Supporting this, Horan et al. (2005a) reported significantly greater peak milk production and significantly greater rate of increase in milk production to peak for animals in the HC system, whereas Bargo et al. (2003) reported a linear increase in milk yield in early lactation with level of concentrate fed.

Similar to the present study, no influence of concentrate feeding on the amount of BW and BCS change postcalving was observed in New Zealand (Roche et al., 2006), also within grass-based systems of milk production. This has important implications for the effect of concentrate feeding level on energy balance and subsequent reproductive performance. Berry et al. (2006) reported no significant effect of concentrate feeding level on the height of energy balance lactation profiles. Furthermore, in the studies of both Kennedy et al. (2003) and Horan et al. (2004), supplementation levels ranging from 364 to 1,540 kg of concentrate/cow conveyed no significant effect on reproductive performance.

The occurrence of significant strain by feed system interactions for BW relates mainly to the increased BW for the HP strain in the MP feed system. This may relate to gut fill and is likely a consequence of the larger differential in grass DMI achieved between strains in the MP system compared with both other feed systems (Horan et al., 2006). Horan et al. (2006) also showed greater DMI for the HP strain compared with both other strains in the HC feed system; however, the diet within the HC system was of greater digestibility and greater DM content, and the resulting BW differences would thus be lesser. The significantly greater nadir BW for the HP strain compared with both the HD and NZ strains in the MP feed system resulted in a significantly reduced rate of BW gain postnadir (*c* parameter), compared with that achieved for this strain within the HS and HC systems, and a reduction in BW gain during the breeding season and for the entire period from nadir until drying.

## CONCLUSIONS

The Wilmink exponential function explained 90 and 60% of the variation in BW and BCS, respectively, and can therefore be considered effective in modeling the

change in profile of both BW and BCS through lactation. Significant differences were observed in grass-based systems of milk production, illustrating the influence of alternative breeding goals on BW and BCS. Holstein-Friesian cows selected exclusively on pedigree index for milk production (HP strain) were unable to gain BCS during lactation even when concentrate was incorporated into the diet; this was reflected by inferior reproductive performance for these animals (Horan et al., 2004) irrespective of feed system. By comparison, the study demonstrates that strains of Holstein-Friesian of lower milk production potential are capable of maintaining higher BCS at pasture and gaining significant BW and BCS during mid to late lactation. Results corroborate other studies documenting the ineffectiveness of concentrate inclusion as a mechanism to reduce the rate of BCS loss postcalving.

## ACKNOWLEDGMENTS

This study is part of a joint project between Dexcel (New Zealand), Massey University (New Zealand), and Teagasc (Moorepark). We would like to acknowledge the support of Colin Holmes (Massey University). We thank the staff of Curtins farm for their co-operation, care and management of the experimental animals.

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