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Associations of breed and feeding management with milk production curves at herd level using a random regression test-day model

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ABSTRACT

Earlier studies identified large between-herd variation in estimated lactation curve parameters from test-day milk yield and milk composition records collected in Ragusa province, Italy. The objective of this study was to identify sources of variation able to explain these between-herd differences in milk production curves, by estimating associations of animal breed (Holstein Friesian vs. Brown Swiss), feeding system [separate feeding (SF) vs. total mixed ration (TMR)], and TMR chemical composition on milk and milk components herd curves. Data recorded from 1992 through 2007 for test-day (TD) milk, fat, and protein yields from 1,287,019 records of 148,951 lactations of 51,489 cows in 427 herds were processed using a random regression TD model. Random herd curves (HCUR) for milk, fat, and protein yields were estimated from the model per herd, year, and parity (1, 2, and 3+) using 4-order Legendre polynomials. From March 2006 through December 2007, samples of TMR were collected every 3 mo from 37 farms in Ragusa province. Samples were analyzed for dry matter, ash, crude protein, soluble nitrogen, acid detergent lignin, neutral detergent fiber, acid detergent fiber, and starch. Traits used to describe milk production curves were peak, days in milk at peak, persistency, and mean. Association of feeding system and animal breed with HCUR traits was investigated using a general mixed model procedure. Association of TMR chemical composition with HCUR traits was investigated using multivariate analysis with regression and stepwise model selection. Results were consistent for all traits and parities. Feeding system was significantly associated with HCUR peak and mean, with higher values for TMR. Animal breed was significantly associated with HCUR persistency, with higher values for Brown Swiss herds. Furthermore, animal breed influenced HCUR peak and mean, with higher values for Holstein Friesian herds. Crude protein had the largest effect on HCUR peak and mean, whereas the interaction between crude protein and dry matter mainly affected persistency. When provided by a national evaluation system, HCUR can be used as an indicator of herd feeding management.
Key words: herd curve, feeding management, test-day model

INTRODUCTION

Test-day (**TD**) models are used in most countries to perform genetic evaluations of milk production for dairy cattle by using TD observations instead of aggregated 305-d yield observations (Ptak and Schaeffer, 1993; Reents et al., 1995; Jamrozik et al., 1997a; Schaeffer et al., 2000). Because a milk recording system is also an important source of information for management, clear advantages have been reported by several authors to use the same data and statistical procedures for management purposes and genetic evaluation. Everett et al. (1994) suggested using results of TD models for monitoring genetics and management in dairy cattle. Several management applications have been suggested. Mayeres et al. (2004) and Pool and Meuwissen (1999) investigated the ability of a TD model to predict yield from TD records, where information from national evaluation systems provided information for individual farmers. Herd curves were included in the TD model used for routine evaluation in the Netherlands to adjust abnormal additive genetic variance at the extremes of lactations (De Roos et al., 2004). Caccamo et al. (2008) investigated the possibility of using random regression TD model (**RRTDM**) outputs to give advice about farm management, and these authors found that random regression herd curves differed remarkably between herds. Their results showed that herd curve variance for dairy cattle in Ragusa and Vicenza provinces was extremely high for milk, fat, and protein yields, especially at the peak of the lactation, suggesting that

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Table 1. Distribution of 37 herds per feeding system (TMR vs. separate feeding) and breed

Group	Herds (n)	Cows (n)			
		Mean	SD	Minimum	Maximum
TMR					
Holstein Friesian	22	70.2	35.7	22	157
Brown Swiss	6	43.2	11.8	25	57
Subtotal	28	64.4	33.8	22	157
Separate feeding					
Holstein Friesian	6	28.5	10.6	20	48
Brown Swiss	3	24.7	8.1	19	34
Subtotal	9	27.2	9.5	19	48
Total	37	55.4	33.8	19	157

variation could be explained by differences in management practices across herds that mainly influence peak production.

The advantages of using TMR instead of separate feeding include eliminating choice among feeds, higher production, reduced digestive upsets early in lactation, NPN fed multiple times with other feed ingredients throughout the day, reduced labor, prevention of milk fat depression by providing a specific forage to concentrate ratio, quantitative formulation of the diet, and mechanization of the feeding procedure (Coppock, 1977). Several studies have investigated the effect of using different feeding strategies on milk production: some reported higher production when feeding TMR compared with separate feeding (Gordon et al., 1995; Bargo et al., 2002), whereas others found no (or very small) effects (Gordon et al., 1995; Yrjänen et al., 2003; Ferris et al., 2006).

The objective of this study was to identify sources of variation able to explain differences between herds in milk and milk component production curves obtained from routine evaluation software. This variation was explained by associating animal breed, feeding system, and TMR chemical composition with herd curve traits estimated using a RRTDM.

MATERIALS AND METHODS

Data

To estimate random curves, a TD model on a full data set was run using a software developed initially for the Dutch national genetic evaluation. Data were supplied by the local milk-recording agency (APA, Ragusa, Italy) and included 1,287,019 TD records of milk (kg), fat (g), and protein (g) of 148,951 lactations and collected on 51,489 cows in 427 herds from January 1992 to April 2008.

For a subset of these farms and years, information on feeding practices was collected every 3 mo from 40 farms in Ragusa province in Southern Italy from March 2006 through December 2007. Selection of these farms was based on farmers' agreement to participate in the study and cooperate with data collection requirements and based on a convenience sample of feeding system [separate feeding (**SF**) vs. TMR], and breed of the animals (Holstein Friesian vs. Brown Swiss; Table 1). During data collection, 2 farms withdrew and 1 farm changed feeding system from SF to TMR. Therefore, those 3 farms were excluded from data analysis. Out of the remaining farms, 28 (6 Brown Swiss and 22 Holstein Friesian) fed their animals using a TMR system, whereas 9 farms (3 Brown Swiss and 6 Holstein Friesian) used a traditional SF system. Samples of TMR were analyzed for DM at 100°C (AOAC, 1994), ash (AOAC, 1994), CP (AOAC, 1994), soluble nitrogen (**SN**, Licitra et al., 1996), acid detergent lignin (**ADL**, Goering and Van Soest, 1970), NDF (Van Soest et al., 1991), ADF (Goering and Van Soest, 1970), and starch (AOAC 1998; method 996.11). All chemical analyses were expressed on a DM basis. For both feeding strategies, diets were evaluated using CPM Dairy (version 3.0.8, Cornell University, Ithaca, NY; University of Pennsylvania, Kennett Square, PA; and Miner Agricultural Research Institute, Chazy, NY).

Estimation of Herd Curve Traits

Production TD records for the full data set were processed using a multiple-lactation, single-trait RRTDM. The software and model were adapted to this study from the model used by NRS (Arnhem, the Netherlands) for the Dutch national genetic evaluation (NRS, 2009), as described by Caccamo et al. (2008):

$$y_{dijklmnoprs} = pd_i + pysd_j + pay_k + pcipr_l + yw_m + htd_n + \sum_{q=0}^{4} z_{oq}\left(hcur_{qr} + ag_{qrs} + pe_{qrs} + \begin{Bmatrix} 0, & \text{if } p < 3 \\ ls_{pq}, & \text{if } p \geq 3 \end{Bmatrix}\right) + e_{dijklmnoprs},$$

where $y_{dijklmnoprs}$ = yield record (milk, fat or protein yield, or SCS) of the cow s on DIM d of parity p within herd test-day (**HTD**) effect n and belonging to fixed effect class i, j, k, l, and m defined as follows; pd_i = ith class of parity (7 levels) × class of DIM (2,695 classes; 385 DIM classes); $pysd_j$ = jth class of parity × year of calving × season of calving × class of DIM (1,680 classes; 14 DIM classes); pay_k = kth class of parity × age at calving × year of calving (368 classes); $pcipr_l$ = lth class of parity × calving interval × stage of pregnancy (270 classes); yw_m = mth class of year of test × calendar week of test (260 classes); htd_n = random herd × test date n (42,481 classes); z_{oq} = order q Legendre polynomial for DIM o (Kirkpatrick et al., 1990), where o = min{d,365}. In this way, TD records with DIM >365 were modeled as DIM = 365 with regard to the regression effects; $hcur_{qr}$ = random herd curve (**HCUR**) effect of herd × year of test (4,094 classes) corresponding to polynomial q of parity r, where r = min{p,3}. In this manner, each herd gets a regression curve for parity 1, 2 and ≥3; ag_{qrs} = random additive genetic effect of cow s (59,977 classes) corresponding to polynomial q of parity r; pe_{qrs} = random permanent environmental effect of cow s (51,489 classes) corresponding to polynomial q of parity r; ls_{pq} = lactation-specific permanent environmental effect of lactation p corresponding to polynomial q (76,571 classes). Only TD records from lactations with parity ≥3 are assigned to a lactation specific permanent environmental effect. In this manner, lactations with parity ≥3 have one common permanent environmental curve and one specific curve for each lactation; $e_{dijklmnoprs}$ = residual belonging to observation $y_{dijklmnoprs}$.

Unknown parents were assigned to 259 phantom pedigree groups based on their selection path (sires to breed sons, sires to breed daughters, dams to breed sons, and dams to breed daughters), breed, country of origin, and birth year. Random effects were HTD and HCUR, animal additive genetic effect, and permanent environmental effect modeled using fourth-order Legendre polynomials. The random and permanent environmental regression curves were modeled using fourth-order Legendre polynomials.

Fixed and random effects included in the model run by NRS for the national genetic evaluation were adapted to the data and the aim of this study. In particular, differences occur in the inclusion of 2 fixed effects (parity × age at calving × year × season of calving and parity × age at calving × year × season of calving × lactation stage), that were replaced by pay and $pysd$, respectively. The fixed effect number of days dry × lactation stage was removed from the NRS model and yw was added in this study, whereas HTD was included as a random effect. Parities used in this study were 7, whereas in NRS model only the first 3 parities are used. The decision to include all parities in the model implementation described in this study was primarily dictated by the need to use TD estimates coming out from the model for all the cows for management purposes.

The traits used to describe HCUR were peak, DIM at peak (**DIMP**), persistency, and mean. Depending on the shape of the lactation curve (convex or concave), the peak was estimated as the maximum or the minimum of the curve respectively when it does not occur at the beginning or at the end of the lactation. Persistency (P) was defined as

$$P = \frac{1}{245}\sum_{i=61}^{305} y_i - y_{60},$$

(Kistemaker, 2003), where y_i = yield at DIM i. Herd curve traits were estimated per year during the study for parities 1, 2, and 3+ for each of the 37 farms involved in data collection.

Statistical Analysis

To identify the variation sources, HCUR traits were associated with breed and feeding system variables and TMR chemical components. The first analysis included the traits of the curves estimated for each herd, parity, and year when management information was collected (2006 and 2007), the feeding system (TMR vs. SF), and the breed (Holstein Friesian vs. Brown Swiss). Using the data set with 37 herds, association of feeding system and breed with HCUR traits was investigated using SAS MIXED procedure (version 9.1.3, SAS Institute Inc., Cary, NC) applied to a linear mixed model having each curve trait (peak, DIMP, persistency, and mean) per herd, parity (1, 2, or 3), and year (2006, 2007) as dependent variables. Breed, feeding system, year, and their interactions were included in the model as fixed effects, whereas farm within breed was treated as a repeated observation. Means for breed and feeding system were tested using pairwise lsmeans coupled with Bonferroni's adjustment.

The second analysis included the traits of the curves estimated for the 28 herds with TMR for each year (2006 and 2007) and the yearly average of the detailed chemical composition of the TMR. Association of composition of the TMR composition with the shape of lactation curve was investigated using the following linear regression model:

$$t_{ijk} = \mu + DM_{ijk} + Ash_{ijk} + CP_{ijk} + SN_{ijk} + ADL_{ijk} + NDF_{ijk} + ADF_{ijk} + Starch_{ijk} + e_{ijk},$$

where t_{ijk} is the curve trait (peak, DIMP, persistency, and mean) of the ith herd for the jth parity in the kth year (2006, 2007); DM_{ijk}, Ash_{ijk}, CP_{ijk}, SN_{ijk}, ADL_{ijk}, NDF_{ijk}, ADF_{ijk}, and $Starch_{ijk}$ are the average chemical composition of TMR sampled for the ith herd and jth parity within kth year. Interactions were also included in the model but only reported when significant.

To select the subset of independent variables that best explain each dependent variable and to avoid inclusion of regressors correlated to one another, the backward-forward elimination, stepwise selection option was used in PROC REG, multi-regression procedure using SAS statistical software (SAS Institute Inc.). The default significance level of 0.15 was used for the variables to enter in and remain in the model as other variables entered the model.

RESULTS

Least squares means values for peak, DIMP, persistency, and mean for milk, fat, and protein HCUR, grouped by feeding system and by breed are presented in Table 2. Feeding system had the largest effect ($P < 0.05$) on peak and mean for fat and protein yields for all parities. Herds using a TMR had higher peak values compared with those using SF for fat HCUR (0.23, 0.25, and 0.28 vs. 0.03, 0.11, and 0.12 g for parities 1, 2, and 3+, respectively) and protein HCUR (0.18, 0.22, and 0.22 vs. 0.08, 0.11, and 0.11 g for parities 1, 2, and 3+, respectively).

Animal breed affected peak and mean for milk yield and persistency for all traits and parities 2 and 3+. Holstein Friesian herds had higher values compared with Brown Swiss herds for milk HCUR peak (5.32, 6.69, and 6.96 vs. 2.83, 3.26, and 3.62 kg for parities 1, 2, and 3+, respectively) and milk HCUR mean (4.63, 5.41, and 5.41 vs. 2.50, 2.96, and 3.00 kg for parities 1, 2, and 3+, respectively). Brown Swiss herds had higher persistency values compared with Holstein Friesian herds for milk HCUR (−0.17 and −0.23 vs. −1.21 and −1.21 kg for parities 2 and 3+, respectively), fat HCUR (0.02, −0.01, and −0.02 vs. 0.00, −0.05, and −0.05 g for parities 1, 2, and 3+, respectively), and protein HCUR (0.00 vs. −0.02 g for both parities 2 and 3+). A significant effect of the interaction between animal breed and feeding system was found only for DIMP in first lactation milk HCUR.

Descriptive statistics for each chemical parameter of TMR samples collected from the 28 farms involved in the project are shown in Table 3. Correlations among chemical components are shown in Table 4. A negative correlation between DM and SN was observed. This was possibly because of wet forages (silages) in the TMR, which often have higher SN content than dry forages. However, some farms also added water to their TMR, which also may have reduced DM and increased SN. The significantly high ($P = 0.001$) positive correlation between SN and ADF suggested the possible use of wet citrus products. Positive correlations among ADL, ADF, and NDF, and negative correlations between starch and ADL, ADF, and NDF were consistent: higher ADL content means higher content of both NDF and ADF, but lower content of starch.

Results of multiple regression analysis performed to estimate association of average TMR chemical composition with HCUR traits are shown in Table 5. The CP content of the TMR had the greatest effect of composition of TMR for all effects (Table 5). Crude protein had a significant effect ($P < 0.05$) on peak and mean HCUR for all traits and for all parities. An interaction between CP and DM was significantly associated with persistency for milk HCUR for all parities, but for fat and protein HCUR for parities 2 and 3+ only. A significant effect was found for DM on fat and protein HCUR persistency for parity 1. Mean values for each curve trait were estimated for farms using a TMR with all the extreme values of CP (13.25 ± 0.76 − 16.01 ± 0.45) and DM (91.13 ± 0.37 − 94.49 ± 0.56). Figures 1 and 2 show average (n = 3) HCUR of second-parity protein and fat yields for the combination of extreme values of CP and DM; low CP-high DM farms had the lowest peak and mean values for milk production HCUR (1.8 and 1.6 respectively) compared with high CP-high DM farms (9.9 and 8.6, respectively).

DISCUSSION

Animal Breed

Previous research has reported differences in milk and milk component yields due to breed (McDowell and McDaniel, 1968; Brandt et al., 1974; Dechow et al., 2007; Walsh et al., 2008). In this study, the major differences were found between Holstein Friesian and Brown Swiss farms in HCUR peak for milk yield and persistency for milk, fat, and protein yields. In general, herd curves of Holstein Friesian farms had higher milk peak but were less persistent for all traits compared with Brown Swiss farms. Holstein Friesian cows have been chosen by farmers for their greater milk productivity compared with other breeds. However, to some extent the observation was surprising because breed effect is already accounted for by the pedigree structure in the TD model and assigning unknown parents to phantom groups that differed by breed. The effect observed here suggests that there are more effects with breed than can be explained by the genetic makeup of the individual animals alone. These are likely management

Table 2. Least squares means values of peak, DIM at peak, persistency, and mean of herd curves for milk (kg), fat (g), and protein (g)[1]

		Feeding system		Breed	
Curve trait	Parity	Traditional	TMR	Brown Swiss	Holstein Friesian
Peak					
Milk	1	2.57[b]	5.25[a]	2.42[b]	5.41[a]
	2	2.57[b]	6.75[a]	2.56[b]	6.76[a]
	3+	3.18[b]	7.01[a]	3.15[b]	7.04[a]
Fat	1	0.02[b]	0.24[a]	0.09	0.17
	2	0.07[b]	0.26[a]	0.14	0.19
	3+	0.08[b]	0.28[a]	0.15	0.21
Protein	1	0.05[b]	0.19[a]	0.08	0.16
	2	0.09[b]	0.23[a]	0.11	0.20
	3+	0.09[b]	0.23[a]	0.12	0.21
DIM at peak					
Milk	1	137.92	131.81	124.02	145.70[2]
	2	89.67	93.19	98.93	83.93
	3+	93.25	106.63	105.00	94.88
Fat	1	141.25	157.25	174.50	124.00
	2	131.13	112.45	95.33	148.25
	3+	114.96	96.14	89.88	121.22
Protein	1	173.21	188.64	212.71[a]	149.14[b]
	2	124.64	102.42	126.00	101.06
	3+	102.03	107.50	106.50	103.03
Persistency[3]					
Milk	1	0.02	−0.19	−0.10	−0.07
	2	−0.51	−0.89	−0.16[a]	−1.24[b]
	3+	−0.50	−0.97	−0.22[a]	−1.25[b]
Fat	1	0.00[b]	0.02[a]	0.02	0.00
	2	−0.02	−0.04	−0.01[a]	−0.05[b]
	3+	−0.02	−0.05	−0.02[a]	−0.05[b]
Protein	1	0.01[b]	0.03[a]	0.02	0.01
	2	−0.01	−0.02	0.00[a]	−0.02[b]
	3+	−0.01	−0.02	0.00[a]	−0.02[b]
Mean					
Milk	1	2.20[b]	4.60[a]	2.14[b]	4.66[a]
	2	2.55[b]	5.42[a]	2.53[b]	5.45[a]
	3+	2.58[b]	5.44[a]	2.57[b]	5.45[a]
Fat	1	0.07[b]	0.19[a]	0.11	0.14
	2	0.08[b]	0.23[a]	0.14	0.17
	3+	0.08[b]	0.23[a]	0.14	0.17
Protein	1	0.07[b]	0.17[a]	0.09	0.15
	2	0.08[b]	0.19[a]	0.11	0.17
	3+	0.08[b]	0.19[a]	0.10	0.16

[a,b]Means per parity within a trait for feeding system or breed not sharing the same superscript differ significantly ($P < 0.05$).

[1]Means were estimated for feeding system and animal breed groups

[2]The effect of the interaction between animal breed and feeding system was significant.

[3]Persistency was estimated as $P = \frac{1}{245}\sum_{i=61}^{305} y_i - y_{60}$ (Kistemaker, 2003), where y_i = yield at DIM i.

Table 3. Mean chemical composition of TMR samples collected from 28 farms in Ragusa province

Item	Mean	SD	Minimum	Maximum
DM (%)	93.40	1.24	90.74	95.30
Ash (% of DM)	7.83	0.69	6.67	9.54
CP (% of DM)	15.44	1.78	11.95	24.40
Soluble N (% of DM)	32.43	5.58	21.64	48.63
ADL[1] (% of DM)	4.13	0.78	2.39	6.46
NDF (% of DM)	40.47	4.00	25.97	48.60
ADF (% of DM)	22.57	2.39	17.00	29.97
Starch (% of DM)	20.93	2.88	14.18	28.46

[1]ADL = acid detergent lignin.

Table 4. Pearson correlations among chemical properties of TMR samples collected from 28 farms in Ragusa province

Item	Ash	Soluble N	ADL[1]	ADF	NDF	CP	Starch
DM	0.19	−0.29*	0.10	−0.35**	−0.01	0.07	0.11
Ash	1	−0.34*	0.21	0.25	0.25	−0.23	−0.31*
Soluble N		1	0.18	0.45***	0.19	0.15	−0.35**
ADL			1	0.39**	0.52***	−0.15	−0.32*
ADF				1	0.53***	−0.31*	−0.63***
NDF					1	−0.39***	−0.40***
CP						1	0.03

[1]ADL = acid detergent lignin.

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 5. Values of R^2 and estimates (SE) for the regression parameters after using multiregression with backward and forward elimination[1]

Trait	Parity	R^2	DM	CP	DM × CP	NDF × starch
Peak						
Milk	1	0.24		0.277***		
	2	0.18		0.242**		
	3+	0.14			0.002**	
Fat	1	0.14			0.002**	
	2	0.22		0.270***		
	3+	0.15		0.232**		
Protein	1	0.17		0.243**		
	2	0.14		0.218**		
	3+	0.12			0.002*	
DIM at peak						
Milk	1	0.2			−0.002*	
	2	0.13				0.003**
	3+	NS				
Fat	1	0.27				
	2	0.12		−0.201**		
	3+	0.22		−0.164*		
Protein	1	0.14	−0.236*			
	2	NS				
	3+	0.06				
Persistency[2]						
Milk	1	0.18		1.526*	−0.019**	
	2	0.33			−0.003***	0.002
	3+	0.30			−0.003***	0.002
Fat	1	0.14	−0.005*			
	2	0.39		1.133*	−0.015*	
	3+	0.29			−0.003***	
Protein	1	0.06	−0.226*			
	2	0.32		1.575**	−0.019**	0.002
	3+	0.27		1.312*	−0.016*	0.002*
Mean						
Milk	1	0.18		0.246**		
	2	0.14		0.220**		
	3+	0.14		0.216**		
Fat	1	0.16		0.241***		
	2	0.13		0.217**		
	3+	0.12		0.211**		
Protein	1	0.16		0.228**		
	2	0.12		0.204**		
	3+	0.11		0.196**		

[1]The regressions are in SD units for y per unit x, where y = herd curve traits for milk, fat, and protein and x = average TMR chemical properties. Ash, soluble nitrogen, acid detergent lignin, NDF, ADF, and all their interactions with all other variables were included in the set of regressors, but no significant effect was found.

[2]Persistency was estimated as $P = \frac{1}{245}\sum_{i=61}^{305} y_i - y_{60}$ (Kistemaker, 2003), where y_i = yield at DIM i.

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

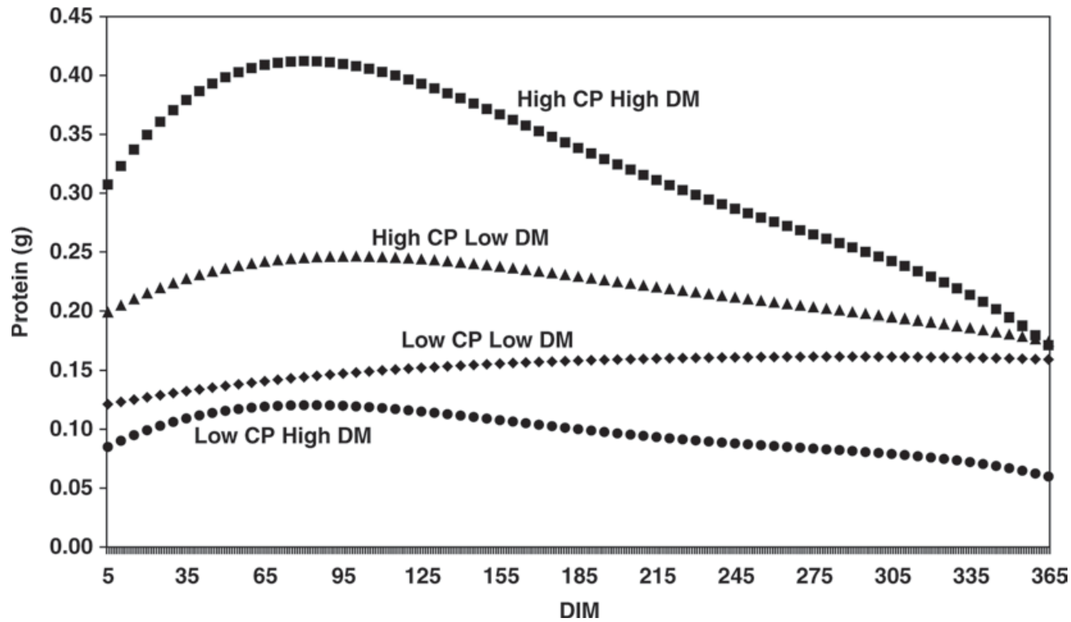

Figure 1. Average (n = 3) herd curve of second-parity protein yield for combination of extreme values of CP and DM (♦ = low content of both CP and DM, ● = low content of CP and high content of DM, ▲ = high content of CP and low content of DM, and ■ = high content of both CP and DM).

effects that are confounded with breed and were picked up in the random herd curves analyzed in this study. Another reason could be that breed effect is adjusted at the TD level and not as a random effect on overall herd production. One solution to adjust for these effects in the RRTDM would be to include a random curve for breed. This would remove breed differences, allowing advisors to give management advice independent of breed. Walsh et al. (2008) explored the influence of breed and feeding system on milk production,

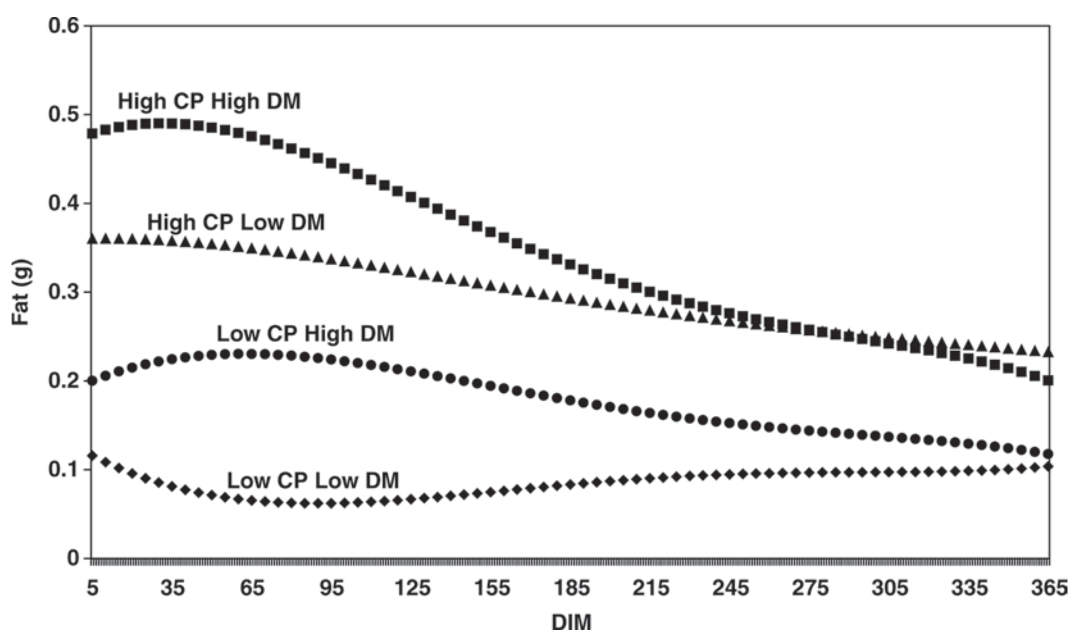

Figure 2. Average (n = 3) herd curve of second-parity fat yield for combination of extreme values of CP and DM (♦ = low content of both CP and DM, ● = low content of CP and high content of DM, ▲ = high content of CP and low content of DM, and ■ = high content of both CP and DM).

BW, BCS, reproductive performance, and postpartum ovarian function. Holstein Friesian animals produced the greatest yield of solids-corrected milk. As observed by Walsh et al. (2008), differences observed between the different breeds were a likely consequence of the selection criteria adopted for each breed. Similarly, McDowell and McDaniel (1968), Brandt et al. (1974), and Dechow et al. (2007) found that pure Holstein Friesian had the highest milk yield production compared with Brown Swiss.

Milk HCUR persistencies presented in this research are consistent with those of McDowell and McDaniel (1968). However, Brandt et al. (1974) found higher persistency for milk produced by Holstein Friesian cows compared with Brown Swiss. Although the definition of persistency was the same as in the McDowell and McDaniel work, the difference in results could be due to the selection of animals in the experiment.

Feeding Systems

Significant differences ($P < 0.001$) for peak and mean HCUR for all production traits were found between feeding systems (SF vs. TMR) in this study. The TMR-fed cows produced, on average, more milk, fat, and protein, and their curves had a higher peak compared with animals fed with SF. The effect was consistent for all parities in all traits except for milk in parities 2 and 3+. Several studies have compared TMR feeding systems (often referred to as complete feed or complete diet) with SF systems, where the forage and concentrate components of the diet are offered to cows separately.

Bargo et al. (2002) compared 3 feeding systems combining pasture and TMR (pasture plus concentrate, pasture plus partial TMR, and TMR) and found that the TMR feeding system resulted in the highest total DMI and milk production: cows on the TMR treatment produced 6.1 kg/d more milk compared with cows on a partial TMR treatment. Gordon et al. (1995) found that feeding a complete diet resulted in 3.04 kg/d more milk than feeding concentrate separately from silage without altering milk concentrations of fat and protein. In our study, herds fed the TMR had 1.88, 2.17, and 2.17 kg/d greater HCUR mean for parities 1, 2, and 3+, respectively. Similarly for milk composition, Bargo et al. (2002) found that the use of TMR increased milk fat percentage and true protein (0.35 and 0.34 more, respectively, than partial TMR). In our study we found that TMR herds produced more mean HCUR fat (0.10, 0.13, and 0.12 g/d, for parities 1, 2, and 3+, respectively) and protein (0.07, 0.09, and 0.09 g/d, for parities 1, 2, and 3+ respectively).

On the contrary, several studies have reported different results. In Gordon et al. (1995), a review of 13 comparisons of TMR versus SF showed that in most of the studies, feeding system had no or only a small effect on milk composition. Ferris et al. (2006) conducted 2 experiments to examine performance of dairy cows associated with 2 winter feeding systems (daily complete diet feeding vs. separate feeding of the forage and concentrate components). Feeding system had no significant effect on any aspect of performance of the dairy cows measured or on nutrient utilization. Animal performance was measured as total milk output throughout the experiments, milk per day, and milk composition (g/kg of milk). Bargo et al. (2002) concluded that milk yield responses to TMR were most likely to occur when studies involved high-yielding cows (>28 kg of milk per day) in early lactation. Yrjänen et al. (2003) found that feeding concentrate with 2 different strategies (SF vs. TMR) had no effect ($P > 0.05$) on milk production and milk composition. However, differences over the lactation curve were found: cows fed with SF produced more milk in early lactation, whereas cows fed TMR produced more milk later in the lactation period. As suggested by Yrjänen et al. (2003), the lack of difference in milk production and better response to SF in early lactation could be explained by the fact that cows were fed using a computerized self-feeder that allowed them to consume moderate levels of concentrate as frequent meals during the day. In classical SF strategies, feeding concentrates 2 or 3 times a day can have detrimental effects on rumen environment because the amount of concentrate is a major factor influencing rumen pH. All of these studies are based on experiments where individual animals were fed somewhat constant nutritive components, differing only in the strategies used to feed the animals. In the current study, herds using different feeding strategies were selected randomly to assess whether feeding management represents one source of variation in herd mean milk rather than individual cow milk responses.

Nutritional Composition

In this study, a significant effect ($P < 0.05$) of CP on peak and mean HCUR for all production traits was found. The interaction CP $\times$ DM had a significant effect ($P < 0.01$) on persistency for all traits and parities, except for fat and protein for first-parity cows, whereas NDF $\times$ starch marginally affected ($P < 0.1$) persistency for milk and protein HCUR in parities 2 and 3. These results confirmed those from other studies. Wu and Satter (2000) investigated milk production response in high-producing dairy cows to dietary supplementation with different amounts of protein. Cows fed diets with greater CP content (18%) achieved greater peak production, but had a decrease in milk production later in lactation almost identical to that in cows fed lower protein, suggesting that the highest protein did not affect the latter part of the lactation. Law et al. (2009) found that an increase in dietary CP concentration significantly increased milk, fat, and protein yields in early lactation (d 1 to 150), arguing that thereafter, protein concentration can be reduced with no detrimental effects on animal performance. Holter et al. (1997) found high correlations of dietary CP with milk and milk protein yield (r = 42 and 38%, respectively). However, Broderick (2003) reported that increasing dietary protein concentration above 167 g/kg of DM had only small positive effects on DMI and milk and protein yields. Similarly, Cunningham et al. (1996) found that increasing the amount of CP in diets had only small effects on the pattern of AA in duodenal digesta. Consequently, when diets contained higher amounts of CP, the yields of milk and milk components improved, probably because of higher flows of N and essential AA to the intestine. In the same study, when DMI of cows was higher, there appeared to be little advantage in increasing the percentage of dietary CP, underscoring how DMI can affect the response of lactating dairy cows to dietary concentrations of CP. Hristov et al. (2002) performed a meta-analysis based on nutritional studies published in the *Journal of Dairy Science* (volumes 73 through 82) to determine dietary factors affecting milk yield and milk protein yield in dairy cows. Correlations between milk yield and milk protein yield and dietary composition variables were poor.

Based on the meta-analysis performed by Hristov et al. (2002), higher effects of energy (starch) and forage quality (ADL, ADF, and NDF) were expected on herd curve traits. One reason could be that the association between yearly average diet composition on the average herd curve for production was investigated. The average chemical composition may have reduced the variability between TMR within herd, some of the explored effects, in particular energy and forage quality, might become more evident when combining the nutrition information with HCUR at the corresponding stage of lactation (beginning, peak, or end). For example, the TMR fed prior or during peak lactation might affect the shape of the curve more than the TMR fed on average across the lactation. This requires further investigations. It is also necessary to assess whether energy in the diet affects milk production at the cow level by examining individual animal curves or deviations of real from expected production estimated from the model.

CONCLUSIONS

Results from this analysis demonstrated that CP and DM content in the diet and their interaction significantly influence HCUR traits, especially peak, mean, and persistency. Herd curves therefore are useful to warn farmers about inappropriate feeding. However, this advice cannot be given without correcting properly for breed and feeding system, which are shown to be important sources of variation in herd milk and milk component yield curves. When feeding a TMR it is important to pay particular attention to DM and CP content in the diet. As a tool for farm managers, HCUR can be considered a good indicator of herd management related to feeding management by examining abnormal shapes or negative values of HCUR traits.

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