PHYSIOLOGY AND MANAGEMENT

Estimation of Body Weight from Body Size Measurements and Body Condition Scores in Dairy Cows

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ABSTRACT

The objective of this study was to evaluate the use of hip height and width, body condition score, and relevant demographic information to predict body weight (BW) of dairy cows. Seven regression models were developed from data from 972 observations of 554 cows. Parity, hip height, hip width, and body condition score were consistently associated with BW. The coefficients of multiple determination varied from 80 to 89%. The number of significant terms and the parameter estimates of the models differed markedly among groups of cows. Apparently, these differences were due to breed and feeding regimen. Results from this study indicate that a reliable model for estimating BW of very different dairy cows maintained in a wide range of environments can be developed using body condition score, demographic information, and measurements of hip height and hip width. However, for management purposes, substantial improvements can be obtained by developing models that are specific to a given site.
(**Key words**: body weight estimation, body condition score, body size measurements, feeding regimen)

Abbreviation key: **BCS** = body condition score, **ECM** = energy-corrected milk.

INTRODUCTION

The BW of dairy cows is important for several management purposes, including assessment of feed efficiency, the value of culled cows, and the efficiency of rearing replacement heifers. However, BW measurements are complicated to interpret because statistically, they are multidimensional (mass per unit of volume) (2), but biologically, they are composites. For example, size (skeletal development), fatness, and gut fill are major determinants of BW. For several management and research applications, these components of BW should be separated. For instance, fluctuations in gut fill are usually irrelevant for monitoring production and for research purposes. For practical reasons, BW is difficult to obtain regularly in typical dairy herds. Heart girth measurement, a widely used proxy for BW, are easier to obtain but has the same interpretation problems as BW. In addition, heart girth measurements can be difficult to perform uniformly because the positioning of the cow during measurement can easily affect the results.

For management and research purposes, there is a growing interest in scoring body condition regularly (10), and research (4, 5, 8, 9, 12) has shown that a body size measurement such as height is a potentially important determinant of the gross production, production efficiency, and health of dairy cows. Such measurements are routinely collected in some intensively managed herds (9, 10), and more widespread use is strongly recommended (5). Consequently, body size measurements and body condition scores (**BCS**) may be available from ongoing production and health management programs in the future. The value of such measurements can be evaluated in terms of BW, and these measurements may provide a convenient option to assess BW.

Wither height, hip height, and hip width are indicators of skeletal development (body size) that are relatively easy to obtain precisely because the anatomical locations for measurement are easy to identify. These measurements can also be made from behind the cow, which is practical in most housing systems. Another advantage is that height and width measurements represent two extremes with respect to skeletal development. Mature height is developed first (91% at 21 mo of age), and mature hip width is developed last (84% at 21 mo of age) (1). Because skeletal development is progressive and relatively slow, few measurements are needed to determine precisely a valid growth curve for the individual animal through interpolation and extrapolation. In theory, most additional variability in BW should be determined by BCS.

To our knowledge, the ability of these three measurements to predict BW in cattle has not been studied previously. Several studies (2, 8) of genetic aspects of size and production traits have yielded correlation matrices or type scores based on multivariate an-

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alyses, such as factor analysis, but BCS has not been included. Several studies (5, 10) of physiology and management have examined relationships among BCS, some type measurements, production, and health. Those studies have not included hip width or a similar indicator of skeletal development and have not specifically addressed relationships with BW. Wither height and hip width (BCS not included) have been found to predict BW very precisely (R^2 ~100%) in heifers (4). The precision of those estimates might have been overestimated because the occurrence of multiple measurements per heifer was not efficiently considered. Predictions from body size measurements of cows must be expected to explain less variability than those of heifers because growth rate of cows is much slower. Inclusion of demographic variables and interactions among predictor variables may improve predictions.

The objective of this study was to evaluate the use of hip height, hip width, and BCS to predict BW in dairy cows. Parity, DIM, age at first calving, and current milk production were included in the analyses as covariates.

MATERIALS AND METHODS

Data were collected from April 1995 until May 1996 from seven commercial Danish dairy herds. Four research technicians from the Danish Institute of Animal Science (Tjele, Denmark) obtained the following measurements: 1) BW (kilograms), 2) BCS [five-point scale where 1 = very thin to 5 = extremely fat measured in increments of 0.5; (7)], 3) height at the highest point of the hip (measured in centimeters using a vertical standard equipped with a crossbar and level), and 4) width of the hip (measured in centimeters using a standard equipped with two crossbars). Information about parity, age at first calving, and actual production of energy-corrected milk (**ECM**) was obtained from the national milk recording scheme. The milk production record (one test day record only) that was closest to the date of BW measurement (±20 d) was used. Only lactating cows were included in the data file. In three herds, data were collected on one occasion; in the other four herds, data were collected on three to four occasions. All BW and body size measurements in a herd were obtained by the same technician on a single day. Days in milk were calculated as the number of days postpartum when BW and body measurements were obtained. After data verification, the final data file comprised 830 observations of 431 Danish Holstein-Friesian cows, 81 observations of Danish Jersey cows, and 61 observations of a mixed group comprising crossbreds, such as Jersey × Red Danish, and purebred Red Danish, which are similar to Danish Friesian cows in size and type. This final data file, which contained 972 observations of 554 cows, was subdivided into seven subsets; each subset contained one observation per cow as follows.

Data File 1

Measurements were taken in April or early May (spring) from Friesian cows (n = 386) in five herds (one recording in each herd). All cows had been fed preserved forages and concentrates at least 4 mo prior to recording (barn fed).

Data File 2

Measurements were taken in spring from Friesian cows (n = 175, including 165 from data file 1) in three herds (one recording per herd). All cows had been allowed to graze pasture between 7 and 16 d prior to recording (grazed).

Data File 3

Measurements were taken in late July and in August (summer) from Friesian cows (n = 139, including 107 cows from data file number 1) in three herds (one recording per herd). All cows had been allowed to graze pasture between 88 and 110 d prior to recording.

Data File 4

Measurements were taken in October or November (fall) from Friesian cows (n = 130, including 86 cows from data file number 1) in three herds (one recording in each herd). All cows had been barn fed between 35 and 14 d prior to recording and had been grazed at least 6 h daily the last 5 mo prior to being turned in.

Data File 5

Measurements taken from Jersey cows (n = 81) in two herds on several occasions during the entire year. Cows were both barn fed and grazed.

Data File 6

Measurements were taken from crossbred or Red Danish cows (n = 61) from one herd on several occasions during the entire year. Cows were both barn fed and grazed.

Data File 7

The first measurements were taken from Friesian, Red Danish, Jersey, or crossbred cows (n = 498; all) during the barn feeding period in April (winter) in seven herds (all cows in this file were included in one or more of data files 1 to 6).

The data were analyzed using multiple regression according to the GLM procedure of SAS (11). The main effects in the analyses were herd, parity (1 to ≥5), age at first calving, DIM, current milk production (ECM), hip height, hip width, and BCS. Categorical variables (herd and parity) were recorded as dummy variables (0 or 1). The main reason herd was included as a fixed effect in the analysis was to adjust for possible effects of technician (especially the technique used to determine BCS) and factors that were specific to the herd (e.g., scale condition, although all possible efforts were made to calibrate scales). The applied design did not allow separation of the effects of herd and technician.

A statistical model that used a backward elimination strategy was applied as follows. First, complex models were specified for each of the seven data files (full models). The full models for each of data files 1 to 5 contained eight main effects [herd, parity (1 to ≥5), age at first calving, DIM, current milk production, hip height, hip width, and BCS] and quadratic and cubic effects for age at first calving, DIM, hip height, hip width, and BCS. Finally, all possible two-factor interaction terms were included (categorical as well as continuous main effects). Significance of interactions that involved herd were tested in the full models by fitting these terms last. Model 6 did not include herd because all cows were in the same herd, and Model 7 only included parity, stage of lactation,

TABLE 1. Description of body measurements and demographic data in Danish Friesian (n = 431) and Jersey cows (n = 62).

	Lactation number									
	1		2		3		4		≥5	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
	Danish Friesians									
Observations, no.	304		213		136		70		107	
BW, kg	536	63	579	63	598	56	618	72	636	69
	(445, 650)[1]		(496, 700)		(521, 705)		(535, 750)		(536, 784)	
Age at first calving, d	840	114	834	82	832	85	812	54	803	68
	(734, 1073)		(740, 1025)		(728, 1017)		(733, 904)		(730, 940)	
DIM, d	190	116	199	112	164	106	194	126	167	102
	(27, 373)		(30, 380)		(23, 356)		(12, 409)		(16, 351)	
ECM,[2] kg	23	5	26	7	28	8	27	8	27	9
	(14, 31)		(14, 37)		(13, 40)		(10, 38)		(11, 39)	
Hip height, cm	141	3	142	4	141	3	140	4	140	4
	(135, 147)		(136, 148)		(134, 146)		(134, 148)		(134, 146)	
Hip width, cm	54	3	56	3	57	2	58	3	59	3
	(49, 59)		(51, 60)		(53, 61)		(54, 64)		(54, 63)	
Body condition score[3]	2.4	0.5	2.4	0.6	2.3	0.6	2.4	0.8	2.6	0.7
	(1.5, 3.0)		(1.5, 3.5)		(1.5, 3.0)		(1.0, 3.5)		(1.5, 3.5)	
	Danish Jerseys									
Observations, no.	10		14		20		24		13	
BW, kg	357	40	380	51	407	36	406	42	440	39
	(300, 405)		(309, 503)		(370, 485)		(348, 481)		(356, 509)	
Age at first calving, d	731	49	729	66	760	79	741		680	28
	(656, 815)		(639, 917)		(642, 929)		(694, 817)		(652, 714)	
DIM, d	213	135	100	116	186	143	152	90	151	132
	(11, 364)		(7, 369)		(13, 443)		(16, 284)		(5, 331)	
ECM, kg	16	5	19	5	24	5	23	5	20	6
	(9, 26)		(9, 29)		(17, 33)		(16, 30)		(11, 30)	
Hip height, cm	127	7	127	3	125	3	123	3	124	3
	(122, 140)		(122, 134)		(121, 132)		(118, 128)		(120, 130)	
Hip width, cm	45	2	47	2	48	3	48	2	50	4
	(41, 47)		(44, 51)		(43, 53)		(46, 49)		(45, 59)	
Body condition score	3.5	0.7	3.1	0.9	2.8	0.7	2.5	0.7	2.5	0.6
	(1.5, 4.0)		(1.5, 4.5)		(1.5, 4.0)		(1.5, 4.0)		(2.0, 4.5)	

[1]The 5th and 95th percentiles are presented in parentheses.

[2]Energy-corrected milk.

[3]Five-point scale (1 = very thin to 5 = extremely fat, measured in 0.5 increments) (7).

TABLE 2. Correlation among BW, body size measurements, and demographic variables in Danish dairy cows (n = 554).

	Variable						
	1	2	3	4	5	6	7
	Danish Friesians (830 observations, 431 cows)						
BW, kg	1.00	0.10	0.41	–0.08	0.25	0.72	0.53
Age at first calving, d		1.00	0.12	–0.07	0.10	0.20	0.01
DIM, d			1.00	–0.40	0.04	0.24	0.43
ECM,[1] kg				1.00	0.08	–0.00	–0.34
Hip height, cm					1.00	0.21	–0.09
Hip width, cm						1.00	0.29
Body condition score[2]							1.00
	Danish Jerseys (81 observations, 62 cows)						
BW, kg	1.00	–0.30	0.36	–0.04	0.09	0.66	0.34
Age at first calving, d		1.00	0.03	–0.18	0.01	–0.21	–0.11
DIM, d			1.00	–0.53	0.06	0.12	0.21
ECM, kg				1.00	–0.01	0.09	–0.34
Hip height, cm					1.00	–0.02	0.29
Hip width, cm						1.00	0.03
Body condition score							1.00
	Crossbred Jersey × Red Danish (61 observations, 61 cows)						
BW, kg	1.00	0.02	0.10	0.08	0.69	0.83	0.57
Age at first calving, d		1.00	–0.11	0.23	0.06	0.10	0.18
DIM, d			1.00	–0.38	0.02	0.11	0.17
ECM, kg				1.00	0.05	0.20	–0.21
Hip height, cm					1.00	0.55	0.23
Hip width, cm						1.00	0.38
Body condition score							1.00

[1]Energy-corrected milk.

[2]Five-point scale (1 = very thin and 5 = extremely fat, measured in 0.5 increments) (7).

hip height, hip width, and BCS as main effects. Squared and cubic terms and interactions were the same as those that were described previously.

Second, the full models were simplified by removing the least significant terms one by one. This strategy could not be used for the data file 5 because the file contained few observations and because distribution of the data was unbalanced with respect to parity and DIM. Instead, most interaction terms were tested using a forward inclusion strategy. Herd was maintained as a main effect in the models, regardless of significance. Models were reduced until all terms (except herd) were significant at $P = 0.01$ (Type III sums of squares F test).

The intercepts and regression coefficients from the model fitted to data files 1 and 7 were finally used to calculate predicted BW (or expected BW based on observed values of body measurements and BCS) for all seven data files. Therefore, the model fitted to Friesian cows that had been barn fed was used to calculate expected BW for cows of all breeds that were allowed to graze (the parameter estimate for herd was set to 0). The relationships among these predictions and the measured BW were assessed through calculation of simple product moment correlation coefficients, which were squared to allow comparison with the R^2 values obtained from the multiple regression analyses.

Model 1 was chosen for prediction because data represented cows that were exposed to relatively stable housing and feeding conditions. Application of that model to the same type of cows that were switched to very different feeding and management conditions (i.e., grazing) should allow an assessment of the difference in BW caused by that switch (primarily because of changes in gut fill).

Model 7 was chosen for prediction because data represented extremes related to body size and a broad spectrum of housing and management conditions. Such a model should be valid for a wide range of herds. Comparison with models that were specific to each data file allowed evaluation of the precision of model 7.

RESULTS

Table 1 shows the data stratified by parity (1 to ≥5) and breed (Friesian and Jersey). The data presented for Friesian cows contained more than one observation per cow. The means, standard deviations, and 5th and 95th percentiles (90% of observations were included in this interval) are given for each variable for each stratum. Most of the differences among lactations appeared to be unimportant. However, values for BW, ECM, and hip width appeared to be smallest for first and second parity cows. Age at first calving, DIM, and BCS were similar for different parities. Hip height appeared to be smallest for cows of parities 4 to ≥5. The DIM was quite different for lactation groups in data file 5. There were 34 BCS >3.5 (3%). Data for crossbred cows are not shown, but values were intermediate with respect to body size measurements.

Table 2 shows separate correlation coefficients for Friesians, Jerseys, and the mixed group (crossbred and Red Danish) to indicate the magnitude of associations among all of the included variables. Numerically, coefficients were quite different among breeds. Characteristics that had the largest association with BW included hip width, BCS, and DIM (across parities). The largest and most consistent correlations between predictor variables were for DIM and ECM (negative between 0.38 and 0.53), DIM and BCS, and ECM and BCS.

Table 3 shows the seven final models for the estimation of BW. The coefficients of variation for the models (residual standard deviation of the model/mean of the dependent variable) were 4 to 7%, and the R^2 were 80 to 89%. Parity, DIM, hip height, hip width, and BCS consistently were important predictors for BW in all data files. The number and combinations of polynomial and interaction terms differed among models. No interaction or higher order terms were important for the model describing the BW of data file 6. Interactions existed between DIM and hip height and between parity and hip width in Model 2. In Model 3, there was an interaction between age at first calving and hip width. In Model 4, age at first calving was included in interactions with both parity and hip width. In Model 5, there was also an interaction between age at first calving and parity.

TABLE 3. Data characteristics, regression coefficients,[1] and predictive ability of the final models for the estimation of BW of dairy cows.

	Model						
	1	2	3	4	5	6	7
Cows, no.	386	175	139	130	81	61	498
Breed	Friesian	Friesian	Friesian	Friesian	Jersey	Several[2]	Several[3]
Season of recording	Spring	Spring	Summer	Fall	All year	All year	Spring
Feeding regimen	Barn[4]	Grazing	Grazing	Barn	Various[5]	Various[5]	Barn
Mean BW (observed), kg	586	565	568	577	401	470	552
Model residual SD (MSE), kg	34	26	30	26	18	25	38
CV (MSE/Mean BW), %	6	5	5	4	5	5	7
R^2, %	80	89	84	85	89	86	85
	Regression coefficients						
Intercept	492	2571	–1642	622	–111	–814	–479
Herd[6]	0	0	0	0	0	. . .	. . .
Age at calving, d							
Linear	NS	NS	6.4	–1.0	–0.4	NS	. . .
Quadratic	NS	NS	–0.009	–0.001	NS	NS	. . .
Cubic	NS	NS	0.000003	NS	NS	NS	. . .
Lactation number							
1	–53	–912	–75	–420	–452	–37	–43
2	–35	–702	–48	–314	–367	–22	–36
3	–13	–606	–17	–301	–316	0	–20
4	–17	–704	–3	–381	–33	. . .	–11
5	0	0	0	0	0	. . .	0
DIM, d							
Linear	0.2	–2.2	0.2	0.1	–0.5	NS	0.1
Quadratic	NS	NS	NS	NS	0.003	NS	NS
Cubic	NS	NS	NS	NS	–0.00001	NS	NS
ECM[7] Production, kg/d	NS	–15	NS	NS	NS	NS	. . .
Hip height, cm	4.2	2.0	4.8	4.7	4.2	5.7	5.9
Hip width, cm							
Linear	–29.2	–76.2	–19.7	–15.0	4.5	8.0	2.8
Quadratic	0.3	0.6	NS	NS	NS	NS	NS
Body condition score[8]	33.5	47.3	37.3	31.7	21.6	57.0	–14.3

(continued)

TABLE 3 (continued). Data characteristics, regression coefficients,[1] and predictive ability of the final models for the estimation of BW of dairy cows.

	Model						
	1	2	3	4	5	6	7
Interactions between age at first calving and parity							
1	NS	NS	NS	0.4	0.5	NS	. . .
2	NS	NS	NS	0.3	0.5	NS	. . .
3	NS	NS	NS	0.4	0.4	NS	. . .
4	NS	NS	NS	0.5	0.1	NS	. . .
5	NS	NS	NS	0.0	0.0	NS	. . .
Interaction between age at first calving and hip width	NS	NS	0.03	0.03	NS	NS	NS
Interaction between stage of lactation and hip height	NS	0.02	NS	NS	NS	NS	NS
Interactions between hip width and parity							
1	NS	15	NS	NS	NS	NS	NS
2	NS	11	NS	NS	NS	NS	NS
3	NS	10	NS	NS	NS	NS	NS
4	NS	12	NS	NS	NS	NS	NS
5	NS	0	NS	NS	NS	NS	NS
Interaction between hip width and body condition	NS	NS	NS	NS	NS	NS	0.3
	Model predictions of BW[9] and correlation with observed BW						
Predicted BW using model 1							
Mean	590	608	600	586	500	517	573
r^2 (versus observed, ×100)	81	76	76	77	53	81	79
Predicted BW using model 7							
Mean	581	592	590	572	409	477	550
r^2 (versus observed, ×100)	74	79	77	77	62	81	85

[1]Models include only variables or terms significant at $P < 0.01$. NS = $P \geq 0.01$. Ellipses indicate the absence of a particular term in the analysis.

[2]Crossbred or Red Danish cows.

[3]Friesian, Red Danish, Jersey, and crossbred cows.

[4]Cows were fed preserved forages and concentrates.

[5]Cows were barn fed and grazed.

[6]Herd included as class variable (fixed effect). Reference herd = 0.

[7]Energy-corrected milk.

[8]Five-point scale (1 = very thin and 5 = extremely fat, measured in 0.5 increments) (7).

[9]Regression coefficients from Models 1 and 7 applied to predict BW in each of the seven data files. Agreement between predicted and observed BW was assessed with the squared correlation coefficient.

Important estimates in data file 1 included herd, parity, DIM, hip height, hip width (linear and quadratic), and BCS. For these data, the difference between first parity cows and cows in fifth or greater lactation for BW was 53 kg, and, for each additional 100 DIM, there was a corresponding increase of 15 kg of BW. A 1-cm increase in hip height was associated with a 4.2-kg increase in BW, and a one-unit increase in BCS was associated with a 34-kg increase in BW. The relationship between hip width and BW was curvilinear.

ECM was significant in model 2 only. The P values of interactions that involved herd (data not shown) only approached significance for the interaction between hip width and herd in Model 4 ($P = 0.02$) and for the interaction between ECM and herd in Model 1 ($P = 0.05$).

Table 3 also provides mean BW predictions as determined by Models 1 and 7 for each of the seven data files. Agreements between predicted and observed BW were assessed by means of squared correlation coefficients. Predictions from Model 7 were more valid and precise than predictions from Model 1 (means of predicted and observed BW were more similar, and correlation was higher in general). However, Model 7 did not fit the data file 5 as well as it did the other data files. The interaction between hip width and BCS in Model 7 indicated that there was no association between BCS and BW among cows that were similar in size to Jerseys, but a one-unit increase in BCS among cows that were similar in size to Friesians was associated with approximately 50 kg of BW increase.

DISCUSSION

The goal of this observational study was to develop tools that could provide more precise and meaningful descriptions of dairy cows to support management decisions. Consequently, the associations that were revealed cannot and should not directly be regarded as causal (3). The number of observations was relatively limited in this study compared with the number of observations in other studies but was relatively large compared with those of most experimental studies. Compared with many other observational studies, measurements in this study were relatively exact, and the applied statistical significance values were low. Consequently, spurious associations were unlikely to occur.

No tests were performed to evaluate systematically breed differences in this study for two main reasons. First, relatively few data from Jersey cows were available. Second, the effects of breed were not of interest per se. Separate analyses were conducted under the a priori assumption that breeds were different.

The data in Table 1 show that the Danish Friesian cows included in this study were approximately the recommended size and weight at first calving (5), but these measurements were attained at approximately 27 mo of age in contrast to the recommended 24 mo of age. Although recommendations for size and BCS are somewhat arbitrary, the 95th percentiles for BCS at 3.0 to 3.5 indicated that the body condition of cows in this study was inadequate for maximum milk production (5). Whether body conditions were inadequate to obtain optimal economic results at the farm level cannot be judged from analysis of these data.

Mean height was numerically lower for cows in their third or greater lactation than for younger cows. Data from bulls showed that the mature height (and also other size measurements) is attained at approximately 52 wk of age (1). The pattern of greater mean height for younger cows in the current data files might have been due to an increased emphasis by the artificial insemination industry on increasing the size and stature of bulls. However, such a policy has not been applied in Danish Jersey, which have the same size pattern. Because several studies (6, 12) have shown that smaller cows are more efficient, smaller cows might be less likely to be culled (culling rate in these herds was approximately 40%).

The unadjusted correlation indicated that hip width was the strongest single predictor for the estimation of BW, which should have been expected because hip width is the body dimension that is developed last (1) and thus exhibits the most variation. However, the regression analyses showed that the relationships between body measurements and BCS were very important predictors of BW, and, together with demographic data, these three factors allowed a relatively precise estimation of BW (model coefficients of variation decreased to less than half that of unadjusted means).

In this study, herd was included as a covariate (data files 1 to 5), which allowed evaluation of the consistency of the effects of body measurements across different herd conditions (test for significance of interaction terms). Such interactions with herd were not significant ($P > 0.02$), but the main effect was significant. Therefore, measurements from different herds cannot be compared directly because of the effects of technician and other herd factors. The ranking of BW for cows based on a set of covariate values is unlikely to differ, however. If the results of this study were to be applied across herds (e.g., for selection purposes), this herd effect would pose no problems. If, in contrast, the results were to be applied within a specific herd (e.g., as an aid to establishing targets for size and BCS), some knowledge about that particular herd must be obtained (a validation study within the herd), or wider confidence intervals of target recommendations must be presented. A validation study is obviously inconvenient for extension purposes, but the same problem applies to the application of almost all results of research. Omission of the herd effect or inclusion of herd as a random effect in this analysis would not have solved this fundamental problem.

Results thus indicated that different models may be needed to predict BW in different environmental conditions and breeds. The BW estimation model for data file 5 was especially different from the other models. Further development of this model is needed in other herds with considerably more cows. However, Model 7 provided predictions that correlated well with the predictions that were specific to a particular group of cows, although BW clearly was overestimated for cows that were grazing. A biologically plausible explanation could be that gut fill is substantially reduced during grazing. Therefore, application of Model 1 to data file 2 probably provides a reliable estimate of the change in gut fill caused by the switch to grass feeding (43 kg = 608 kg – 565 kg). The current approach to the estimation of BW may more appropriately reflect the net BW because the approach is less influenced by random fluctuations in gut fill.

Precision was poorer for Jerseys. These Jerseys might have been atypical. The measurement of BCS might also differ from Holsteins because Jersey cows are smaller or because the skin of Jerseys is thinner. Also, DIM likely explains more variability in BW in Jerseys (the simple correlation between BW and DIM was relatively high in Jerseys).

The high correlation indicated that the simple Model 7 ranked the cows satisfactorily compared with predictions from the models that were specific to a particular group of cows. For use in the field by dairy managers, a simple model, such as Model 7, might be preferred because few input data are needed and the validity of the model is acceptable for a relatively broad spectrum of feeding and management conditions and a wide range of cow types.

However, the results of this study should be validated by other studies representing greater extremes, particularly for BCS. Ideally, similar data would be collected and parameters specific to each herd would be estimated for each herd to which the proposed model would be applied.

The point estimates of the relationships between BCS and BW were 22 to 57 kg per unit of increase in BCS. A 50-kg increase in BW with each unit of increase in the applied (Danish) BCS is a generally accepted rule of thumb (7).

Systematic assessments of these body measurements may also provide valuable information for the analyses of production and health (e.g., potential interactions among cow type, housing dimensions, and health).

CONCLUSIONS

Measurements of hip height, hip width, BCS, and readily available information about age at first calving, parity, DIM, and current milk production were used in several models to predict the BW of individual cows. Agreement between actual and predicted BW showed that body size measurements can be used to provide valid and precise estimates of BW for use in field studies and management of the dairy herd.

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REFERENCES

1 Andersen, B. B. 1977. Genetic investigations on growth, body development and feed utilization in dual purpose cattle. Rep. No. 448, Natl. Inst. Anim. Sci., Copenhagen, Denmark. (In Danish with English subtitles and summary.)

2 Bonczek, R. R., D. O. Richardson, E. D. Moore, R. H. Miller, J. R. Owen, H. H. Dowlen, and B. R. Bell. 1992. Correlated response in growth and body measurements accompanying selection for milk yield in Jerseys. J. Dairy Sci. 75:307.

3 Enevoldsen, C., T. Kristensen, and J. Hindhede. 1996. Dairy herd management types assessed from indicators of health, reproduction, replacement, and milk production. J. Dairy Sci. 79:1221.

4 Heinrichs, A. J., G. W. Rogers, and J. B. Cooper. 1992. Predicting body weight and wither height in Holstein heifers using body measurements. J. Dairy Sci 75:3576.

5 Hoffman, P. C. 1996. Optimum growth rates for Holstein replacement heifers. Page 25 *in* Proc. Calves, Heifers, and Dairy Profitability Natl. Conf., Harrisburg, PA. Northeast Reg. Agric. Eng. Serv. (NRAES-74), Ithaca, NY.

6 Koenen, E.P.C., and A. F. Groen. 1996. Genetic analysis of growth patterns of Black and White dairy heifers. J. Dairy Sci. 79:495.

7 Kristensen, T. 1986. Method for estimation of body condition in dairy cows. Page 59 *in* Rep. No. 615., Natl. Inst. Anim. Sci., Copenhagen, Denmark. (In Danish with English subtitles and summary.)

8 Lin, C. W., A. J. McAllister, T. R. Betra, A. J. Lee, G. L. Roy, J. A. Vesely, J. M. Wauthy, and K. A. Winter. 1988. Effects of early and late breeding of heifers on multiple lactation performance of dairy cows. J. Dairy Sci. 71:2735.

9 Markusfeld, O., and E. Ezra. 1993. Body measurements, metritis, and postpartum performance of first lactation cows. J. Dairy Sci. 76:3771.

10 Markusfeld-Nir, O. 1996. Integrated dairy herd health programs—the Israeli experience. 1996. Page 126 *in* Proc. Soc. Vet. Epidemiol. Prev. Med., Univ. Glasgow, Glasgow, Scotland.

11 SAS® User's Guide: Statistics, Version 6.03 Edition. 1988. SAS Inst., Inc., Cary, NC.

12 Yerex, R. P., C. W. Young, and J. D. Donker. 1988. Effects of selection for body size on feed efficiency and size of Holsteins. J. Dairy Sci. 71: 1355.