Relationships Between Body Measurements, Body Weight, and Productivity in Holstein Dairy Cows[1]

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ABSTRACT

Body measurements, milk production, and body weight data were collected on 1898 lactations of 771 Holstein dairy cows from 1968 to 1986. Body weight and the body measurements of heart girth, paunch girth, wither height, chest depth, pelvic length, pelvic width, and body length were used. Milk production variables were milk yield, fat yield, 4% FCM, fat percentage, and SNF percentage. Estimated feed efficiency was expressed as ratio of milk energy content to net energy feed intake. Phenotypic correlations indicated a high positive relation between estimated feed efficiency and milk (.61), fat (.62), and 4% FCM (.63) yields. Uniformly negative correlations were found between estimated feed efficiency and all seven body measurements and body weight; range was from −.18 for wither height to −.33 for body weight. Multiple regression analyses were conducted on a first, second, and overall parity basis, showing that cows with smaller heart girth and larger paunch girth had significantly higher yields. Taller cows produced more milk than shorter cows. Cows lighter in body weight yielded greater FCM as first-calf heifers and through all lactations.

INTRODUCTION

Importance of body size and weight in dairy cattle has been investigated by many authors. Most investigators agree that larger cows have higher milk yields (5, 7, 13, 15, 17, 23). Phenotypic and genetic relationships between body measurements, body weight, and milk production have been investigated by a number of workers (4, 14, 21, 25, 27), but the results have been inconsistent. In addition, much of the body size and body weight data have been obtained shortly before or after first calving and mostly from university experiment stations.

Wilk et al. (28) used data from 1949 to 1961 from University of Minnesota Experiment Station herds to study genetic and phenotypic relationships between body measurements at various ages and milk production. Phenotypic correlations between milk production and body measurements fell between −.1 and +.1 and were not significantly different from 0. Estimates of genetic correlations were mostly positive, but correlation between 12 mo weight and milk production of .43 was the only significant correlation obtained. Wilk et al. concluded that body measurements were of little value in predicting milk production, but no basis was found for the often encountered claim of a genetic antagonism between measures of body size and milk production.

Ability of dairy cows to convert feed into milk products has generally been termed "feed efficiency". Freeman (8, 9) contributed a review and evaluation of the genetic aspects of feed efficiency. He stated that genetic correlation between efficiency of milk production and lactation yield is high. Selection for increased feed efficiency (gross energetic efficiency) was nearly as effective as selection on milk production.

Increase in yield associated with increases in weight as reported by several authors (1, 5, 17, 22) showed that heavier cows possess little, if any, superiority in feed efficiency over smaller cows. Hooven et al. (18) presented genetic correlations of .28 between body weight and production but −.17 between body weight and efficiency. They concluded that although

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increased body weight was associated with more milk production, it also resulted in decreased efficiency. Cows were fed (18) on the basis of milk produced. Whether these relationships would change if cows were fed ad libitum is not known.

Dickinson et al. (6) reported a high positive phenotypic relationship between efficiency and various measures of production and income and uniformly negative relationships between efficiency and mean body weight, gain in weight, and body size. In that study, Holsteins were more efficient than Brown Swiss with Ayrshires intermediate. If compared within breeds, however, cows of smaller size or weight and cows that gained less weight in first lactation were significantly more efficient than cows of larger size or greater weight or weight gain.

The objectives of this study were 1) to determine relationships of body weights and measurements during first and later lactations with production variables and 2) to determine relationships of body measurements and body weights with estimated feed efficiency.

MATERIALS AND METHODS

Data

Body weight and seven body measurements were taken during each parity between 30 and 55 d postpartum. The seven body measurements were 1) heart girth, smallest circumference just behind the forelegs with the cow standing square on her legs and holding her head up; 2) paunch girth, largest circumference about the barrel; 3) wither height, distance from ground to the highest point of the withers; 4) chest depth, vertical distance from the back to the floor of the chest at the shallowest part of the chest; 5) pelvic length, distance from in front of the hook bone to the back of the pinbone; 6) pelvic width, distance from outside of the left hook bone to outside of the right hook bone; and 7) body length, horizontal distance from the front point of the shoulder to the end of the pinbones. At each measurement, care was taken to have the animal standing in a natural position on a level surface. Two observers recorded each body measurement, and the two measurements were then averaged. Only one measurement of body weight was taken.

Measures of production were 1) milk yield, 2) fat yield, 3) 4% FCM, 4) fat percentage (% fat), and 5) SNF percentage (% SNF). Milk records were up to 305 d in length. Actual milk yield rather than mature equivalent milk yield was used to show more nearly the biological relationships with actual body measurements and weights.

Body measurement data were combined with production data and consisted of 1898 lactation records from 771 cows by 131 sires. Data were collected between 1968 and 1986.

The research farm, which has been described in detail (2, 3, 9, 16, 19, 26), is operated under reasonably typical Iowa conditions and is used primarily for long-term dairy cattle breeding research. For this project, foundation females were selected as heifers for high and low milk production on the basis of their pedigree estimates. At the time of purchase, the foundation females were assigned alternatingly to be bred to high PD milk (PDM) sires or breed average PDM sires to form a 2 × 2 factorial design. Female offspring (generation 1) resulting from these matings were then bred to sires of the same genetic merit (high or breed average) as were their dams. This system has been continued for all succeeding generations, thereby accumulating the differences that resulted from continued selection for milk production (10). A repeat mating design was used separately to produce progeny from high and average sires. A group of three bulls was introduced each year and used for 2 yr. Therefore, groups of sires always overlapped by 1 yr (16).

All cows in milk are housed in freestall barns and milked in one parlor. The progeny of high and breed average sires are intermixed within each lot where they are fed the same ration free choice. All animals are managed alike. All female offspring born are kept and raised to be herd replacements. The ration fed to lactating cows consisted of about 1.5 parts silage to 1 part herd ration and 3.6 kg of alfalfa hay. These figures are based on as-fed weights and have remained reasonably constant through the years.

Definition of Efficiency

Total actual yields were converted according to Gaines and Davidson (12) to a 4% FCM basis by .4 (milk) + 15 (fat). The milk energy content (MEC) then was calculated by Gaines' (11) formula as .75 FCM. Therefore, FCM and MEC are correlated perfectly.

Definitions of efficiency differ among studies, but all attempt to measure a ratio of energy output to energy input. In this study, energy input was not measured on each cow; therefore, estimated feed efficiency (EFE) was estimated as MEC/net energy (NE) consumed. The MEC and the different feed requirements were calculated on a lactation basis for each cow in megacalories. The NE were estimated using the 1978 NRC nutrient requirements (24) for each lactation.

This EFE fromula is similar to formulas used by other authors (6, 15, 16, 20) and often expressed as gross efficiency. Inasmuch as feed consumption for each cow was not recorded, the calculated ratio of output energy to input energy is an estimated value, and the highest values indicate those animals with the greatest EFE for milk production. These computed values are not accurate for individual cows but should give meaningful average values.

The following linear regression equations were computed from table values (24) for lactating and dry cows.

Milk Production. The NE for milk production was calculated as:

$$NE_{milk} = [.59167 + .09619\ (\text{fat}\ \% - 2.5\%)]\ \text{milk}$$

Maintenance and Growth. If the lactation involved was a third or later lactation, the regression equation used was:

$$NE_{\geqslant 3} = 6.56564 + [.01233\ (BW - 350)]\ (DIM + DD - 60)$$

where BW = body weight, 30 to 55 d postpartum; DIM = day in milk; and DD = days dry.

If the lactation was a second lactation, maintenance requirements were increased by 10% to allow for growth of young lactating cows, and the equation used was:

$$NE_2 = 7.2222 + [.01356\ (BW - 350)]\ (DIM + DD - 60)$$

If the lactation was a first lactation, maintenance requirements were increased by 20% to allow for growth, and the equation used was:

$$NE_1 = 7.87876 + [.01479\ (BW - 350)]\ (DIM + DD - 60)$$

The total maintenance requirements of mature dry cows, including allowance for the last 2 mo of gestation, were calculated as:

$$NE_{dry} = 8.53527 + [.0160\ (BW - 350)]\ 60$$

Statistical Analysis

The model used in the analyses of the data was:

$$y_{ijkl} = \mu + s_i + g_j + \sum_{l=1}^{n} b_l(m_{ijkl} - \bar{m}_l) + e_{ijkl}$$

where:

y_{ijkl} = milk yield, fat yield, 4% FCM, % fat, % SNF, or EFE for the set of measurements or body weights for which l = 1 to n for cow k with sires in group j, and in year-season i;

μ = overall mean;

s_i = fixed effect of year-season i (i = 1 or 2 where season 1 = May to October and season 2 = November to April);

g_j = fixed effect of sires with genetic merit j (j = high or breed average PDM);

m_{ijkl} = measurement or body weight l (l = 1,. . .,8) of cow k with sire in group j and in year-season i;

$\bar{m}_l$ = mean measurement or body weight for measurement;

b_l = partial linear regression coefficient for measurement or body weight; and

e_{ijkl} = random residual.

This analysis was calculated by parity to determine if substantial changes in the relation of production to body measurements occurred as parity progressed. On an overall parity basis, parity was included in the above model as an independent variable. The fifth parity group included all lactations following the fourth lactation. Another model included linear and quadratic effects of body measurements and weights. Because no quadratic effects were significant, the linear model was used in the regression analysis.

RESULTS AND DISCUSSION

Means and CV of body measurements and body weights are in Table 1 by parity. Cows gained more than 140 kg (28%) in weight from first to fifth parities. In general, all body measurements and weight increased as parity increased. Skeletal measurements of body length, especially height at withers, had the lowest CV over time. Although chest depth, heart girth, and pelvic length were intermediate among the traits in their overall rank of CV, paunch girth and pelvic width had the largest CV. More flesh at the pinbones and hooks could have accounted for some of the increased variation in pelvic length. Progeny means of body measurements, body weight, and CV differed little between high and average merit sires. All body measurements and body weights were different ($P \leqslant .001$) among parities (Table 1).

Table 2 contains means and CV for production variables and EFE by parity. Coefficients of variation for yield traits are greater than those for % fat and % SNF. The EFE varied less than did yield; this result was similar to that of earlier studies by Hooven et al. (17). In contrast to the study of Hooven et al. (17), EFE decreased slightly from first to second parity, whereas milk yield increased. For second and greater lactations, average gross efficiency was .58 and similar to results of Hooven et al. (17, 18). Differences among means for production variables (Table 2) were different ($P \leqslant .001$) with the exception of % fat. The highest production was in the fourth parity.

Phenotypic correlations between recorded body measurements, body weight, production variables, and EFE from all lactation records are in Table 3. In general, there was a positive correlation ($P \leqslant .001$) in the range from .18 to .29 between milk yield, fat yield, and FCM and all body measurements and body weights. Correlation coefficients for % fat and body measurements were small (.04 to .09) and not significant for skeletal traits: wither height, chest depth, and body length. A negative (−.14 to −.20) association was found for % SNF and all measurements and body weights. The EFE showed highly significant negative correlations for all measurements and ranged from −.18 for wither height to −.33 for body weight. These results were similar to those of (6, 17). In general, taller, longer, deeper, and especially heavier cows tended not to be as efficient as smaller cows.

This method of calculating EFE always included a fraction of body weight in the denominator. For cows of the same weight, this fraction was 20% greater for first lactation than for third or later lactations. For cows with the same lactation, an automatic negative contribution to covariance would be expected between EFE and body weight; thus, part of the correlation between EFE and body weight is automatic. One way to account for this is to consider body weight change during lactations, but these data were not recorded.

Table 4 contains phenotypic correlation coefficients among production variables and EFE. Correlations with EFE were .61 for milk yield, .62 for fat yield, and .63 for FCM ($P \leqslant .001$). These results were slightly lower than those reported by others (17, 18, 21) but generally indicated the same tendency: higher production is positively correlated with EFE. The milk components % fat and % SNF had smaller associations (.05 and .07) with EFE and lower significance. Correlations among yields were high and negative between milk yield and percentages of fat and SNF as expected.

Linear regression coefficients for milk yield, fat yield, and FCM on body measurements and body weight for first, second, and all lactations are shown in Table 5. Regression coefficients for % fat, % SNF, and EFE were all extremely small, (essentially 0) and, therefore, not given in Table 5. Coefficients for heart girth were negative and highly significant with production variables in first and all lactations. The opposite could be seen with the measurement paunch girth. This was the only trait that had consistently highly significant positive regression coefficients with all three production variables in first, second, and all lactations. Difference between heart girth and paunch girth could be that cows with a wider, larger barrel were able

TABLE 1. Means and CV of body measurements and body weight by parity (number of records = 1898).

Parity	n	Heart girth	Paunch girth	Wither height	Chest depth	Pelvic length	Pelvic width	Body length	Body weight
		Means							
		(cm)							
1	765	187.5	219.9	131.2	71.8	51.9	51.1	153.2	489.8
2	484	195.7	232.1	135.5	74.8	54.2	54.9	159.4	553.3
3	313	201.2	238.7	137.0	76.8	55.3	56.9	163.1	595.6
4	177	202.8	241.7	137.3	77.4	55.5	57.4	163.7	609.8
⩾5	159	205.3	245.5	138.3	78.2	55.6	58.1	164.1	630.3
All	1898	194.8	230.3	134.4	74.4	53.7	54.2	158.3	546.4
		CV (%)							
1	765	3.91	4.55	2.85	3.57	4.14	4.76	3.67	10.04
2	484	3.41	4.34	2.68	3.21	3.92	4.13	3.66	9.59
3	313	3.88	4.64	2.71	3.38	4.22	4.36	3.62	10.35
4	177	3.76	4.46	2.77	3.21	4.52	4.20	3.73	9.82
⩾5	159	3.55	4.29	2.92	3.20	4.16	4.25	3.34	9.64
All	1898	5.04	6.04	3.46	4.68	5.05	6.70	4.61	13.73

to consume more feed and produce more milk and that by the time measurements were taken body fat had been catabolized resulting in smaller heart girth. Wither height was positively correlated ($P \leq .05$) with yield traits in first parity, was not significant in second parities, and was higher in significance ($P \leq .01$) in all lactations. Analyses of chest depth measurements showed a similar pattern to those for wither height, indicating that cows with deeper chests had higher milk yields. Skeletal measurements of pelvic length and body length were not significantly related to any of the three production variables. Pelvic width had positive correlation coefficients ($P \leq .05$) with milk in first parity, with fat yield, and with FCM in all parities. Regressions of the production traits on body weight were only significant for FCM in first parity, for fat yield and FCM in second parity, and for all three production variables in all parities. Over all parities, FCM decreased by 7.8 kg for each kg increase in body weight for cows with equal body measurements. This indicates that cows of equal size that lose weight produce more milk and cows that gain weight produce less milk.

In addition to linear regression analyses, a stepwise regression analysis for FCM on all lactations was conducted to reflect the variable's contribution to the model. Comparison of the F-statistics showed that pelvic width, paunch girth, and heart girth were ranked highest, followed by chest depth, body weight, and wither height. The two measurements that contributed the least to the model were pelvic length and body length. However, body length did not meet the .5 significance level for entry into the model. This indicated that length of cows contributed least in explaining FCM production. Results of the stepwise analysis compared well with those of the linear regression analyses. The R^2 for the model with year-seasons, high and average merit sire groups, linear effects of body measurements, and body weight ranged from 16% of total variation for fat yield to 34% for milk yield.

CONCLUSIONS

Results from regression analyses showed that cows with smaller heart girth and larger paunch girth had significantly higher yields of milk than cows with opposite circumferences. Wither height was positively associated with production traits in first parity cows but not significantly in second parity. Over all lactations, however, taller cows tended to produce significantly more milk than shorter cows.

TABLE 2. Means and CV of production variables and estimated feed efficiency (EFE) by parity (number of records = 1898).

Parity	n	Milk	Fat	FCM	Fat	SNF	EFE[1]
		Means					
		(kg)			(%)		
1	765	5531	202	5242	3.66	9.25	.587
2	484	6871	252	6527	3.71	9.12	.570
3	313	7137	263	6800	3.71	9.08	.578
4	177	7247	265	6880	3.68	9.01	.577
≥5	159	7153	263	6809	3.68	9.04	.573
All	1898	6433	236	6111	3.68	9.15	.579
		CV (%)					
1	765	32.52	32.24	31.92	11.48	3.90	10.34
2	484	27.02	25.42	25.55	11.08	4.12	10.10
3	313	26.23	25.76	25.40	10.95	4.45	12.00
4	177	28.07	27.81	27.41	10.73	4.28	12.20
≥5	159	28.31	28.00	27.68	10.41	3.45	10.62
All	1898	31.27	30.75	30.50	11.14	4.16	10.83

[1] Expressed as megacalories of milk energy content divided by megacalories of net energy.

TABLE 3. Phenotypic correlation coefficients between body measurements, production variables, and estimated feed efficiency (EFE) (number of records = 1898).

Variable	Heart girth	Paunch girth	Wither height	Chest depth	Pelvic length	Pelvic width	Body length	Body weight
	(cm)							(kg)
Milk, kg	.18[a]	.26	.22	.22	.19	.27	.21	.20
Fat, kg	.21	.29	.24	.25	.22	.29	.23	.24
FCM, kg	.20	.28	.23	.24	.21	.28	.22	.22
Fat, %	.06**	.09	.04NS	.04NS	.08	.06**	.04NS	.09
SNF, %	−.14	−.14	−.14	−.12	−.14	−.20	−.14	−.20
EFE[1]	−.31	−.23	−.18	−.23	−.22	−.23	−.20	−.33

[a]All values are significant ($P \leqslant .001$) unless otherwise indicated.

[1] Expressed as megacalories of milk energy content divided by megacalories of net energy.

**$P \leqslant .01$.

Chest depth showed that first parity cows and cows over all parities with deeper chest measurements produced more milk than shallower cows. The only two measurements that did not have any significant regression coefficients with all production variables were pelvic length and body length. Regression coefficients for pelvic width were significant only for milk yield in first parity but were significant for all three production variables over all parities. This indicated that cows with wider pelvic measurements tended to produce larger yields. In first and second lactations, only regression coefficients for FCM were significant for body weight. Over all lactations, however, all three production variables were highly significant and negatively associated with body weight. In general, lighter cows tended to have larger milk and fat yields than did heavier cows. Regression coefficients were essentially 0 for EFE and body measurements and extremely small for body weight.

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TABLE 4. Phenotypic correlation coefficients between production variables and estimated feed efficiency (EFE) (number of records = 1898).

Variable	Fat	FCM	Fat	SNF	EFE[1]
	(kg)		(%)		
Milk, kg	.94***	.98***	−.13***	−.17***	.61***
Fat, kg		.99***	.18***	−.08***	.62***
FCM, kg			.05*	−.11***	.63***
Fat, %				.30***	.05*
SNF, %					.07**

[1] Expressed as megacalories of milk energy content divided by megacalories of net energy.

*$P \leqslant .05$.

**$P \leqslant .01$.

***$P \leqslant .001$.

TABLE 5. Partial linear regression coefficients of production variables on body measurements and body weight for first parity (n = 765), second parity (n = 484), and all lactations (n = 1898).

Dependent variables	Heart girth	Paunch girth	Wither height	Chest depth	Pelvic length	Pelvic width	Body length	Body weight	R^2[1]
	(cm)							(kg)	
				First parity					
Milk, kg	−71.5***	45.1***	54.9*	98.2*	−14.1	80.0*	.6	−6.7	.18
Fat, kg	−2.6**	1.7***	1.8*	4.2*	.0	2.6	−.3	−.2	.16
FCM, kg	−66.9***	43.4***	48.7*	102.5*	−5.6	70.8	−3.6	−6.3*	.17
				Second parity					
Milk, kg	−44.8*	64.8***	49.9	−63.7	50.7	48.0	−.1	−6.4	.34
Fat, kg	−1.2	2.9***	1.2	−2.6	1.9	1.2	.4	−.3**	.22
FCM, kg	−37.5	69.3***	37.6	−64.9	48.4	37.2	5.9	−7.7*	.28
				All lactations					
Milk, kg	−75.4***	58.1***	44.3**	58.4*	21.1	59.9*	9.4	−7.7***	.30
Fat, kg	−2.6***	2.4***	1.5**	1.6	1.6	1.8*	.3	−.3***	.26
FCM, kg	−68.7***	59.5***	39.9**	48.1	32.1	51.5*	7.7	−7.8***	.28

[1] Fraction of the variance accounted for by the model.

*$P \leq .05$.

**$P \leq .01$.

***$P \leq .001$.

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