Effects of Selection for Body Size on Feed Efficiency and Size of Holsteins[1,2]

R. P. YEREX,[3] C. W. YOUNG, J. D. DONKER, and G. D. MARX[4]
Department of Animal Science
University of Minnesota
St. Paul 55108

ABSTRACT

First lactation records from a herd of Holstein cows bred for either high production and large size or for high production and small size were examined to estimate effects of selection for size and feed efficiency. Selection was among progeny-tested bulls available from the artificial insemination industry. Three rations were fed that differed for ratios of concentrate to milk. After three generations, groups of cows bred for large or small size differed by 50.2 kg in weight, 5.6 cm in wither height, 6.4 cm in length, 2.1 cm in depth, and 5.9 cm in chest circumference; most differences were due to a decrease in the size of the small cows. On the basis of total lactations, cows bred for small size were 2.8% more feed efficient than cows bred for large size. During the first 90 d of lactation cows fed the low concentrate ration were more efficient than those fed the high concentrate ration. Season of calving had an effect on feed efficiency between d 30 and 120 of lactation. During this period cows calving between December and May were more efficient.

INTRODUCTION

Feed efficiency as a measure of profitability offers potential to aid dairy producers when making selection decisions. For milk, as for other agricultural products, profitability is dependent on product value and on costs of inputs to production. Estimating input costs is expensive and time-consuming. For feed efficiency, accurate measurement of feed offered and of feed not consumed is required. Costs of estimating feed efficiency often exceed benefits to the producer. Hence, relationships of feed efficiency and traits that are more easily measured become important.

Several studies investigated relationships of feed efficiency and other traits (6, 7, 8). It would be desirable if selection for feed efficiency could be accomplished indirectly by selection for related traits. However, related traits need to be easily measured, at least moderately heritable, and of economic importance. Traits that have been studied in this regard include both production and nonproduction traits.

Among nonproduction traits, some body measures have received attention for their relationships with feed efficiency. Mason et al. (8) measured phenotypic correlations of feed efficiency and body size for Danish Red cattle. Correlations of feed efficiency with body weight, wither height, and heart girth were −.12, −.04, and −.16. Dickinson et al. (2) found negative correlations of feed efficiency with several body measurements of Brown Swiss, Ayrshire, and Holstein cows. Pooled across breeds, these correlations ranged from −.21 for heart girth to −.29 for wither height. For Holsteins, the correlation of body weight and feed efficiency was −.41. It could then be hypothesized that smaller cows may be more feed efficient than larger cows.

This study examines changes of feed efficiency resulting from a breeding program that included selection for large or small body size.

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[2]Contribution to Regional Project NC-2.
[3]Department of Animal Science, Cornell University, Ithaca, NY 14853.
[4]Northwest Experiment Station, University of Minnesota, Crookston 55716.

The objective of the study was to determine effects of cow size, quantity of concentrate fed, and the interaction of these factors on cow profitability. This report, however, deals only with 1) response to selection for body size, and 2) the relationship of body size and feed efficiency.

MATERIALS AND METHODS

Data were records of 193 first lactation Holstein cows at the Northwest Experiment Station, University of Minnesota, Crookston, initiated between 1966 and 1980.

At inception of the project, cows and heifers were paired for size, sire, age, and, in the case of lactating cows, production, Members of each pair were assigned to two genetic groups. Group 1 was bred for high production and large body size, whereas Group 2 was bred for high production and small body size. All cows were housed in the same structure and managed similarly.

Sires for both groups were selected largely on transmitting ability for size, but production and functionality were considered. Numeric ratings for size of a sire's progeny were unavailable during the years spanned by this project. The Holstein Association rated sires by descriptive code, while most AI organizations rated them for stature and other traits with 0 to 4 stars. Those rating systems were used for initial screening, but were often supplemented by observations on the bull's own phenotype or by measurements taken on a sample of daughters. In most cases, the latter approach was impractical. Because of these problems, selection differentials for size could not be estimated.

Offspring of dams within each group were assigned to that same group regardless of actual body size. Voluntary culling was for production and size and was infrequent prior to completion of two lactations.

Cows within each genetic group were assigned at random to one of three rations differing by the amount of concentrate fed. Concentrate to milk ratios for milk above 9.1 kg were 1:1.5, 1:3, and 1:5 for the high, medium, and low concentrate rations, respectively. Concentrate was ground corn, oats, barley, and dried beet pulp in equal amounts. Forages were corn silage and alfalfa haylage. Details of the feeding schedules, use of feedstuffs, feed sampling, feed analyses, and ration composition are a study by Donker et al. (3). Feed efficiency was gross efficiency, measured as kilograms of TDN consumed per kilogram of 4% FCM produced. Milk weights were recorded daily, and milk was tested monthly for protein and fat.

Weight and body measurements were taken 1 mo postpartum. Two models were used to evaluate the effect of selection on these. Model 1, used to examine measures of size across groups, was:

$$Y_{ijklmno} = \mu + G_i + S_{ij} + D_k + A_l + R_m + N_n + E_{ijklmno} \qquad [1]$$

where $Y_{ijklmno}$ is a size observation of the o^{th} cow in the i^{th} genetic group, of the j^{th} sire within that group, calving in the k^{th} season, in the l^{th} age group at calving, assigned to the m^{th} ration, in the n^{th} generation.

Model 2 was used to examine within-group changes in size over generations. It differed from Model 1 in that genetic group was excluded and sires were no longer nested within genetic group. Data from the two genetic groups were analyzed independently.

Gross feed efficiency was calculated for each cow on a total lactation basis and for 10 periods of lactation, each 30 d in length. Data were analyzed using a modified form of Model 1, which included interactions for genetic group with season, genetic group with ration, genetic group with generation, and season with ration.

Statistical analysis utilized the General Linear Model procedure of SAS (5). All models were first fit in complete form and then were reduced to only significant effects ($P<.05$). A reverse stepwise procedure was performed on the basis of reduction sums of squares. Least squares means were obtained from reduced models.

RESULTS AND DISCUSSION

Weight and Body Measurements

Table 1 has least squares means and standard errors (from Model 1) for weight and body measurements by group and generation. Table 2 has least squares means from Model 2 where data from the two groups were analyzed separately. Generation 1 cows were progeny of

TABLE 1. Least squares means for size measurements obtained from across-group analysis within generations.

Trait	Generation	Group 1[1]		Group 2[1]	
		X̄	SE	X̄	SE
Wither height, cm	1	132.8	.5	130.0	.5
	2	133.0	.5	127.7	.6
	3	132.8	.8	127.2	1.0
Weight, kg	1	506.9	6.2	485.3	6.3
	2	505.6	6.7	464.0	7.7
	3	504.7	7.7	454.5	10.3
Body length, cm	1	136.8	.8	133.6	.7
	2	134.7	.7	130.3	.8
	3	135.4	1.0	129.0	1.3
Chest depth, cm	1	68.8	.3	67.0	.3
	2	68.2	.4	65.1	.5
	3	68.0	.5	65.9	.7
Chest circumference, cm	1	184.3	.9	181.9	.9
	2	183.9	1.3	178.6	1.5
	3	184.9	1.2	179.0	1.6

[1] Group 1 was bred for large size, group 2 for small size.

TABLE 2. Least squares means for size measurements obtained from within-group analysis across generations.

Trait	Group[1]	Generation 1		Generation 2		Generation 3	
		X̄	SE	X̄	SE	X̄	SE
Wither height, cm	1	135.6	1.1	134.6	.8	134.1	1.1
	2	130.0	.5	127.7	.6	127.2	.9
Weight, kg	1	526.3	9.8	529.2	9.7	526.8	11.2
	2	497.8	7.5	478.1	8.6	470.4	10.4
Body length, cm	1	136.5	.9	136.9	.9	137.7	1.1
	2	134.0	.9	131.8	.9	130.8	1.1
Chest depth, cm	1	70.2	.5	69.9	.5	69.4	.6
	2	67.4	.5	65.8	.5	66.7	.6
Chest circumference, cm	1	187.6	1.8	188.1	1.8	188.8	2.1
	2	182.6	1.2	179.4	1.4	180.5	1.7

[1] Group 1 was bred for large size, group 2 for small size.

base animals. First lactation weights and body measurements were not available on many base cows as they had been purchased following termination of a line development project with the herd. Consequently, data from base cows were not analyzed. Results are described by trait.

Body Weight. Group 1 cows were significantly heavier than group 2 cows in all three generations. By the third generation this difference was 50.2 kg. Model 2 confirmed that group 2 cows decreased significantly for body weight from one generation to the next. Analysis within group 1 showed no significant change for body weight over generations.

Wither Height. Group 1 cows were significantly taller than group 2 cows for all three generations. By the third generation this difference was 5.6 cm. Response to selection for size was rapid and significant. However, within-group analysis revealed that the difference between the two groups was due to a reduction in wither height in group 2 cows; group 1 cows did not change significantly.

Body Length. Group 1 cows were significantly longer than group 2 cows for all three generations. This was due to a significant reduction in length of group 2 cows across generations. By third generation, group 2 cows were 6.4-cm shorter than group 1 cows. Within group 1 body length did not change significantly over generations.

Chest Depth. Model 1 revealed that group 1 cows were significantly larger in depth of chest for all generations. Third generation cows differed by 2.1 cm. Model 2 indicated group 2 cows had significantly less depth of chest over generations. Group 1 showed no significant change over generations.

Chest Circumference. After three generations, genetic groups differed by 5.9 cm for chest circumference. This was attributable to the significant decrease for cows in group 2. Group 1 cows did not show any significant change.

The two groups diverged significantly for weight and all body measurements; however, response to selection was not equal for the two groups. Group 2 cows became smaller, whereas group 1 cows did not change for size. Much of the asymmetry in response to selection for size was likely because of fewer errors made when evaluating AI sires for small size versus large size. Furthermore, during early years of the project, many bulls with exceptional phenotypes for size were not acceptable because of low transmitting abilities for production. Consequently, selection for large size was not as intense as may have been desirable. Over the long-term, selection for size will probably be equally effective in both directions. Considering the positive emphasis placed on size by AI units, it seems unlikely that the early success in reducing size can be sustained.

Feed Efficiency

Analysis of gross feed efficiency involved the use of one primary model, applied to total lactation efficiency as well as to 10 separate periods of lactation, each 30 d in length. The model was identical to Model 1 except that some interactions were included. Those were group × season $(GD)_{ik}$, group × ration $(GR)_{im}$, group × generation $(GN)_{in}$, and season × ration $(DR)_{km}$. However, these interactions were insignificant, and none appeared in models from which least squares means were estimated. Significant effects of independent variables examined on gross feed efficiency over the total lactation and for each 30-d period of lactation are in Table 3.

Genetic group affected feed efficiency during periods 3 through 6 and for the total lactation. Sire, season, and ration also significantly affected feed efficiency during a majority of the first 5 periods, but not during the last 5 (the latter half of lactation). Independent variables found to be significant accounted for 33% of variation in total lactation gross feed efficiency, for from 33 to 45% of total variation in this measure during periods 3 to 5 but for less than 20% of total variation during other periods.

A reduced form of the model containing only significant effects was obtained for each period before least square means were derived. Results that follow are organized by period within significant effect.

Group. Group effect was significant during periods 3, 4, 5, and 6 as well as for lactation treated as a whole. Least squares means are presented in Table 4. Due to the way feed efficiency was measured and calculated, a smaller number indicates greater efficiency. Group 2

TABLE 3. Summary of tests of significance for independent variables on gross feed efficiency over the total lactation and during consecutive 30-d periods.

Independent variable	Period of lactation[1]										Total
	1	2	3	4	5	6	7	8	9	10	
Group			*	*	*	*					*
Sire			*	*	*						*
Season		*	*	*							
Age											
Ration	*	*	*								
Generation											
R^2	.12	.19	.45	.38	.33	.03					.33

[1] Periods are consecutive 30-d periods starting at parturition.

*$P<.05$.

cows were significantly more efficient than group 1 cows during these periods. On a complete lactation basis this difference was 2.8%. Group 2 cows had the greatest advantage in efficiency during period 3 when they were 4.1% more efficient than group 1 cows.

Sire. The nested effect of sire within group was significant during periods 3, 4, and 5 on a total lactation basis (Table 3). Least squares means for sires were obtained from a modified form of the model that contained no confounding effect of groups. Least squares means for 40 progeny groups ranged from a best of .486 ± .056 for a bull used to sire small cows to a worst of .653 ± .026 for a bull used to sire large cows. Large differences existed among sires of both groups.

TABLE 4. Least squares means for gross feed efficiency from across groups analysis by periods where significant differences were found.

Period[1]	Group[2]	$\bar{X}$	SE
Total lactation	1	.585	.006
	2	.557	.008
3	1	.539	.007
	2	.498	.009
4	1	.570	.007
	2	.537	.009
5	1	.601	.008
	2	.558	.010
6	1	.614	.008
	2	.586	.009

[1] Periods consisted of 30 d and were numbered starting at parturition.

[2] Group 1 was bred for large size, group 2 for small size.

Season of Calving. Four seasons of calving were defined as follows: Season 1, December to February; Season 2, March to May; Season 3, June to August; Season 4, September to November. The effect of season of calving was significant during periods 2, 3, and 4. Table 5 shows the resulting least squares means for seasons by period. Cows calving between the months of December and May were generally most efficient. These results agree with those reported by Hooven et al. (6).

Ration. During the first three periods of lactation, ration had a significant effect on feed efficiency. Table 6 shows the least squares means for these periods. During these periods, cows fed the low concentrate ration were significantly more efficient than those fed the high concentrate ration. When adjusted to the high production of early lactation the high concentrate ration apparently overfed the animals. These results are similar to those found by Brody (1).

CONCLUSIONS

Due to the difficulties involved with gathering data on feed efficiency on the farm, direct selection for feed efficiency is often impractical. An indirect selection scheme would appear most appropriate. Others (4, 6, 8) have sug-

TABLE 5. Least squares means for gross feed efficiency from across groups analysis for season of calving effects by periods where significant differences were found.

Period[1]	Season of calving[2]	$\bar{X}$	SE
2	1	.449	.008
	2	.431	.011
	3	.490	.012
	4	.503	.011
3	1	.507	.009
	2	.499	.011
	3	.533	.012
	4	.541	.012
4	1	.543	.009
	2	.533	.011
	3	.575	.013
	4	.567	.012

[1] Periods are as defined in Table 3.

[2] Season 1 was December to February, season 2 was March to May, season 3 was June to August, season 4 was September to November.

TABLE 6. Least squares means for gross feed efficiency from across-groups analysis for ration effects by periods where significant differences were found.

Period[1]	Ration[2]	$\bar{X}$	SE
1	1	.440	.010
	2	.394	.010
	3	.366	.010
2	1	.495	.009
	2	.461	.009
	3	.448	.009
3	1	.537	.009
	2	.519	.008
	3	.503	.009

[1] Periods are as defined in Table 3.

[2] Ration 1 was 1:1.5 concentrate to milk, ration 2 was 1:3 concentrate to milk, and ration 3 was 1:5 concentrate to milk, all based on milk above 9.1 kg/d.

gested that selection for production, highly correlated to feed efficiency, would result in worthwhile increases in feed efficiency. Of these, only the study of Mason et al. (8) sought to include size in an index for indirect selection for feed efficiency.

This study has shown that selection for reduced body size results in significant changes in various body parameters. Feed efficiency data collected on the two breeding groups indicated that smaller cows are more efficient than larger cows. Production has been shown to be highly correlated to feed efficiency (2, 6, 8, 9). From these studies and the results of the present study it would seem that a selection scheme emphasizing production, and reversing, or at least eliminating, the past emphasis on larger body size would result in highly productive, efficient animals. Dairy producers of the future will in all likelihood place greater emphasis on efficiency of production, while gross production may receive less attention. Consequently present emphasis on body size cannot be justified.

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