Association of Type Traits Scored Linearly with Production and Herdlife of Holsteins[1]

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ABSTRACT

Linear type evaluations for 18 traits on 43,428 first lactation cows were used to determine relationships of type traits with herdmate deviation milk and herdmate deviation fat. Lifetime information on 17,288 of these cows was used to evaluate type traits with herdlife. Cows were scored (1 to 50 points) for 16 traits between September 1, 1979 and January 1, 1984 by evaluators of 21st Century Genetics Cooperative Mating Appraisal program. Disposition and milkout were scored by herd owners. Cows with extreme dairy character, excellent dispositions, and moderate rump width were associated with greatest production and herdlife. Tall first lactation cows with deep udders had highest herdmate deviations for milk and milk fat, but cows with average height and udder depth had longer herdlife. Variation among herds was more important in determining herdlife than production when linear and quadratic effects for all traits were considered in models. Dairyness and udder depth had largest differences associated with herdmate deviation milk (1276 and 1167 kg), herdmate deviation fat (39 kg each), and herdlife (90 and 59 d) at ± 2 SD from the mean score. For several traits, predicted response at extreme scores was different when cubic effects were added to models.

INTRODUCTION

A 50-point linear type evaluation program, Mating Appraisal for Profit (MAP), was implemented in September 1979 by Midwest Breeders Cooperative (now 21st Century Genetics). The objectives of linear evaluation programs are to obtain more accurate sire evaluations for type traits (11) and to use the evaluations as an aid in mating decisions. Advantages of using linearly scored traits in preference to descriptive traits for the purpose of evaluating animals were described by Thompson et al. (26).

Because of the time required to collect complete production and herdlife (HL) information on cows, early studies of linear programs concentrated on parameter estimation (10, 22, 25, 26), relationship of linear scores with descriptive type measures (23), and relationship of linear scores with various sire summary measures (5). Virtually all previous work involving the association of type evaluations with productive information on dairy cows has been done with descriptive type analyses (1, 2, 3, 4, 6, 7, 8 , 9, 12, 13, 14, 15, 17, 24, 27, 29). The MAP program has been evaluated on several occasions, ranging from an evaluation of the corrective mating aspects of MAP (4) to parameter estimation (1, 10, 24, 25) and factor analyses of type traits (20, 21). Parameter estimation has been done twice (10, 25) since the MAP program has been changed to linear evaluation of type traits.

Past research suggests only certain descriptive traits are associated with production or HL. Traits related to production are udder traits and dairy character (13, 14, 15, 16, 17, 18, 27, 28, 29). Herdlife has been associated with production (3, 9, 19, 28 29), profit (12), and type score (3, 13, 14, 16, 17, 19, 28, 29) of cows in several analyses. Berger et al. (3) found effects of type score and yield to be independent pre-

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TABLE 1. Description of linear traits used in the Mating Appraisal for Profit program with heritabilities.

Trait	Score = 1	Score = 50	Heritability[1]
Basic form	Angular	Thick	.42
Strength of body	Narrow and frail	Wide and strong	.23
Dairyness	Undesirable	Outstanding	.25
Stature	Short	Tall	.36
Body depth	Shallow body	Deep body	.30
Rump side-view	Pins higher than hips	Extreme slope	.25
Rear legs side-view	Posty	Sickle hocked	.17
Foot angle	Low angle	Steep angle	.09
Fore udder attachment	Broken	Tight	.18
Udder depth	Deep	Shallow	.24
Rump width	Narrow	Wide	.17
Rear legs rear-view	Severe toe out	No toe out	.08
Rear udder height	Low	High	.19
Rear udder width	Narrow	Wide	.15
Suspensory ligament	Negative cleft	Extreme cleft	.12
Fore and rear teat placement	Base of teats wide	Base of teats touching	.18
Disposition[2]	Extreme problem	Excellent	.08
Milkout[2]	Extremely slow	Extremely fast	.14

[1]Heritability reported by Foster et al. (10).

[2]Scored by the herd owner.

dictors of HL. Tigges et al. (27) found codes considered ideal for some nonudder descriptive traits were associated with average or below average profit. Honnette et al. (13) found that 6 of 11 traits affecting HL and 7 of 11 traits affecting lifetime milk yield had scores considered desirable associated with small or negative effects for HL or lifetime milk.

Thomas et al. (22) and Berger et al. (4) evaluated corrective mating programs in Jerseys and Holsteins, respectively, and found changes in scores resulting from corrective mating can be determined. Performance of the cow, whether in yield, HL, or other measures should define which traits are important and the optimum score for these traits, based on the magnitude of differences in performance as scores change

Objectives of this study were: 1) to identify traits and optimum scores that are related to herdmate deviations for milk, milk fat, and HL; 2) to quantify the magnitude of differences in production and HL as scores for a trait change, and 3) to identify combinations of traits associated with herdmate deviation milk, milk fat, and HL.

MATERIALS AND METHODS

Linear type scores (range 1 to 50 points) were available on 18 traits for 43,428 first parity Holstein cows to determine relationships of linear traits with first lactation herdmate deviations in kilograms for milk (HMDM) and fat (HMDF). Complete lifetime information in days (HL) was available on 17,288 of these individuals and these records were used to analyze the relationship between linear traits and HL in a preliminary analysis. Sixteen traits were scored from September 1, 1979 to January 1, 1984 by 11 evaluators of 21st Century Genetics Cooperative while disposition and milkout were evaluated by herd owners during the same time. A complete description of the traits is given by Thompson et al. (25). Table 1 lists traits evaluated in the MAP program, descriptions of extreme values for the traits, and heritability estimates for MAP traits. Scores were assigned over the entire range of 1 to 50 points for all traits. Current data were the same as those used for parameter estimation (10) and for factor analyses of type traits (20, 21).

Production data obtained from Wisconsin DHI, Minnesota DHI, and the Mid-States Regional Processing Center were used to calculate HMDM and HMDF and to determine HL. The HMDM and HMDF were calculated from 305-d lactation, twice daily milking (305-2X-ME) production records on all cows to account for environmental differences across herds and years. For the short time span of these data, time trends for production were considered unimportant and were not included in the statistical model used for analyses. The HMDM and HMDF were calculated for cattle from Wisconsin and Minnesota using a 5-mo rolling season to identify herdmates, requiring that animals have at least one herdmate in the season. All cows with type scores were in their first lactation; thus, HMDM and HMDF were first lactation measures. However, records of all herdmates were utilized in rolling season averages. For records processed at the Mid-States Regional Processing Center, HMDM and HMDF were calculated using a varying 3- to 9-mo rolling season that required at least five herdmates to obtain a valid deviation (30). Herdmate deviations were used instead of standardized records with absorption of herd-year-seasons because production records of unscored animals could be used in calculating HMDM and HMDF, which allowed for more information to be incorporated in estimation of HMDM and HMDF.

Fewer animals were eligible to be included in analyses of linear scores with HL because some individuals were still in the herds or it could not be determined whether other animals were still in the herds. A cow was considered to have a completed HL if she met one of the following criteria: 1) presence of a valid DHI code indicating the animal was culled for purposes other than dairy (HL was calculated as the number of days from first freshening to the date of removal from the herd); 2) failure to calve by 540 d after the date of her last calving (HL was calculated as the number of days between her first and last reported freshening dates plus 305 d, which would account for one additional normal lactation). Criterion 2 was included to account for cows that were not assigned a termination code but had the opportunity to refreshen within 540 d. There were relatively few cows in this category.

Raw scores of the 18 linear type traits were preadjusted for stage of lactation and age at first freshening (10) before inclusion in the following multiple regression model to analyze the association of the linear type traits with HMDM, HMDF, and HL:

$$Y_{ijk} = \alpha + H_i + \Sigma b_l T_{ikl} + \Sigma b'_l T^2_{ikl} + b_{19}(PDM_j - \overline{PDM}) + e_{ijk} \quad [1]$$

where:

Y_{ijk} = HMDM (kg) of the k^{th} cow by the j^{th} sire, in the i^{th} herd-year of evaluation;
α = the intercept;
H_i = effect of the i^{th} herd-year of evaluation, which was absorbed;
T_{ikl} = the adjusted linear score for the l^{th} trait on the k^{th} individual in the i^{th} herd year;
T^2_{ikl} = the adjusted linear score squared for the l^{th} trait on the k^{th} individual in the i^{th} herd-year;
b_l = coefficient of linear regression of the l^{th} trait, l = 1 to 18;
b'_l = coefficient of quadratic regression of the l^{th} trait squared, l = 1 to 18;
PDM = PD milk;
$(PDM_j - \overline{PDM})$ = the deviation of the j^{th} sire's PDM (kg) from the mean;
b_{19} = coefficient of linear regression on PDM deviation; and
e_{ijk} = random residual.

All effects in the model were fixed except e_{ijk}. A second model [2] evaluating the effect of type traits on HMDF was identical except PD fat (PDF) was the covariate. The model evaluating effect of type traits on HL [3] was identical except it included covariates for both PDM and PDF.

The method of fitting effects of type traits in these models assumes quadratic effects are fit after linear effects. Thus, if a type trait had a quadratic relationship ($P \leq .05$) with a dependent variable, the linear coefficient was retained for accuracy regardless of whether it was significant. Values of both coefficients were reported and used in predicting response of the dependent variable to changes in score of the type trait. These were second-order models. However, if the quadratic effect for a type trait was not significant ($P > .05$), a model containing only linear effects of type traits would be more appropriate. First-order models containing only linear effects of all type traits were also used. For traits where the quadratic effect was not significant, evaluation was from the first-order model. If the quadratic coefficient was not significant from the second-order model and the linear coefficient was not significant from the first-order model, the trait was assumed not related to the dependent variable.

The first- and second-order regression equations should be sufficient for describing the relationship between type traits and dependent variables near the central portion of linear scores, where most animals were scored. However, third-order models containing cubic effects of type traits may more clearly describe relationships at extreme scores. For this reason, a model containing cubic effects was analyzed for each dependent variable. Although the cubic model may help in predicting response at extreme scores, there are few cows with extreme scores. Approximately 5% of the cows scored for each trait had scores less than 10 points or greater than 40 points. Our major interest was in differences realized for cows having most frequent scores. Therefore, results will be reported from first- and second-order models. Results of the third-order models will be used for comparison with results obtained from first- and second-order models.

TABLE 2. Traits with significant linear and quadratic regression coefficients, and optimum scores for herdmate deviation milk derived from first- and second-order regression models.

Trait	Linear regression	Quadratic regression	Optimum score
	Second-order model[1]		
Basic form	.49	−.293**	2
Dairyness	18.44**	.457**	50
Udder depth	5.23	−1.008**	2
Rump width	25.22**	−.409**	29
Rear udder width	3.98	.195*	50
Fore and rear teat placement	12.46**	−.246**	25
Disposition	1.09	.148**	50
	First-order model[2]		
Stature	15.97**		50
Body depth	−9.78**		1
Rump side view	5.35**		50
Fore udder attachment	−6.40**		1
Rear legs rear view	1.54*		50
Rear udder height	6.93**		50
Suspensory ligament	9.87**		50

[1]Second-order models contained linear and quadratic effects for all type traits.

[2]First-order models contained linear effects for all type traits.

*Regression coefficient ($P \leq .05$).

**Regression coefficient ($P \leq .01$).

RESULTS

Association of Traits with Herdmate Deviation Milk

Multiple regression analysis [1] resulted in 14 traits with a significant ($P \leq .05$) association with HMDM. Table 2 lists these traits with significant regression coefficients and optimum scores for the traits. The optimum score for a trait was defined as the score associated with largest HMDM. Seven traits had statistically significant quadratic regression coefficients for HMDM from the second-order model and 7 additional traits had significant linear regression coefficients from the first-order model.

Regression equations resulted in identification of two types of optimum scores for traits: intermediate and extreme. Because the intercept was absorbed with herd-years, the intercept for these curves was always 0 at the imaginary trait score 0, and differences were relative to this point. Extreme optima could occur at either end of the scale, depending on trait definitions and the biological direction of the relationship. This occurred when linear relationships existed and could occur when linear and quadratic regressions were significant, depending on specific values of the coefficients. For practical purposes, optima were defined as extreme if the maximum point on the curve was ≤5 or ≥45 points.

Optimum scores were either 1 or 50 points when linear regressions were involved (i.e., results from first-order models). For traits with linear and quadratic relationships to HMDM, optimum scores were identified by setting the first derivative of the regression equation equal to 0, and solving for the trait score that maximized or minimized the curve. If the maximum or minimum was outside the range 1 to 50 points, or if it was ≤5 or ≥45 points, it was assumed an extreme optimum score existed for the trait. If the maximum point on the curve was between 5 and 45 points, it was assumed an intermediate optimum existed for the trait. Of the 14 traits significant for HMDM, 12 traits had extreme optima while two traits, rump

TABLE 3. Changes in herdmate deviation milk (HMDM) over the range ± 2 SD of scores from the mean.

Trait	Score		Change in HMDM relative to the mean or optimum score[1]		
	Mean	Optimum	at –2 SD	at + 2 SD	Range
Basic form	25.4	2	131 (13.3)[2]	–218 (37.5)	349[3]
Dairyness	30.0	50	–510 (17.3)	657 (42.7)	1167
Stature	27.3	50	–171 (16.6)	171 (38.0)	342
Body depth	29.3	1	120 (17.1)	–120 (41.5)	240
Rump side view	27.0	50	–67 (14.5)	67 (39.5)	134
Fore udder attachment	27.9	1	89 (14.0)	–89 (41.8)	178
Udder depth	31.8	2	520 (21.0)	–756 (42.6)	1276
Rump width	26.8	29	–103 (14.8)	–24 (38.8)	103
Rear legs rear view	29.2	50	–25 (12.9)	25 (45.5)	50
Rear udder height	28.2	50	–81 (16.6)	81 (39.8)	162
Rear udder width	27.9	50	–163 (14.6)	232 (41.2)	395
Suspensory ligament	30.9	50	–119 (18.8)	119 (43.0)	238
Fore and rear teat placement	27.8	25	–38 (12.9)	–74 (42.7)	74
Disposition	27.8	50	–120 (9.7)	218 (45.9)	338

[1]If the optimum score is within the range ± 2 SD of the mean, HMDM (kg) change is relative to the optimum score rather than the mean score.

[2]Numbers in parentheses are the scores at ± 2 SD.

[3]The range (kg) is expressed as an absolute value.

width and fore and rear teat placement, had intermediate optima (Table 2).

Review of traits and their optimum scores indicated the following trait characteristics were associated with high HMDM: cows angular for basic form, with extreme dairyness, very tall, with shallow bodies, sloping rumps, broken fore udder attachments, deep udders, medium rump widths, legs with no toe out, high, wide rear udders, extreme udder cleft, moderately wide teat placement, and excellent dispositions. Tall, sharp, angular cows with shallow bodies and capacious udders that are well supported seem to be associated with high milk production in the first lactation as measured by HMDM. This result does not necessarily imply deep udders are preferred for all ages of cattle, nor does it imply that tall cattle are efficient producers of milk.

One way to rank the importance of traits is to observe the difference in HMDM as scores change from their trait mean. For example, for basic form, HMDM at the mean score of 25.4 is –176 kg HMDM. This value is relative to the intercept. At 2 SD below the mean (13.3 points), average HMDM is –45 kg, a difference of + 131 kg as cows are scored more angular. At 2 SD above the mean (37.5 points), average HMDM is –394 kg, or –218 kg relative to the mean score. Over the score range of ± 2 SD, which includes 95% of all cows evaluated for basic form, a change in score from 37.5 points to 13.3 points was associated with a 349-kg increase in HMDM (Table 3).

Under this type of ranking system, traits that have the largest change in HMDM over ± 2 SD change in score would be most important, because they represent the greatest potential gain in yield as scores change. For traits with intermediate optima where the optimum score is within ± 2 SD of the mean score, changes reported in Table 3 for HMDM are relative to the optimum score rather than the mean score. The range of scores is still relative to the mean, however. This gives a more accurate representation of the true difference in change of HMDM inasmuch as it compares a maximum value to values at other scores. Udder depth and dairyness at 1276 and 1167 kg, respectively, have a considerably larger change in HMDM over this range than the other 12 traits. Udder depth and dairyness are moderately heritable at .24 and .25, and because their genetic correlation is approximately .00 (10), selection could be practiced on each trait without a negative correlated response in the other. Deep udders and extreme dairyness are associated with highest HMDM. Within first-parity cows, deeper udders seem to be necessary for the capacity to have greater yield and, thus, higher HMDM than cows with less deep udders.

A second group of traits associated with moderate changes of HMDM over ± 2 SD are basic form (349 kg), stature (342 kg), body depth (240 kg), rear udder width (395 kg), suspensory ligament (238 kg), and disposition (338 kg). Several other traits with statistically significant relationships with HMDM are associated with changes of less than 200 kg HMDM over ± 2 SD and are considered unimportant when compared with the former traits. Traits such as foot angle, strength of body, rear legs side view, and milkout are not significantly related to HMDM of the cow. A graphical description of the relationship between HMDM and trait score for the four traits with largest changes of HMDM is presented in Figure 1. This figure illustrates that when the trait score 1 is optimum, all deviations are negative, as is true for udder depth. Likewise, all deviations are positive if the trait score 1 is least desirable, as with dairyness.

TABLE 4. Traits with significant linear and quadratic regression coefficients, and optimum scores for herdmate deviation fat derived from first- and second-order regression models.

Trait	Linear regression	Quadratic regression	Optimum score
	Second-order model[1]		
Basic form	.11	-.009*	5
Strength of body	.44	-.008*	27
Dairyness	.59**	.016**	50
Body depth	-.49*	.008*	1
Udder depth	.57*	-.037**	7
Rump width	.92**	-.016**	29
Disposition	-.02	.007**	50
Milkout	.45**	-.006**	38
	First-order model[2]		
Stature	.52**		50
Rump side view	.09*		50
Rear udder width	.46**		50
Suspensory ligament	.27**		50

[1]Second-order models contained linear and quadratic effects for all type traits.

[2]First-order models contained linear effects for all type traits.

*Regression coefficient ($P \leq .05$).

**Regression coefficient ($P \leq .01$).

Association of Traits with Herdmate Deviation Fat

Multiple regression analysis [2] resulted in 12 traits with a significant association ($P \leq .05$) with HMDF. Table 4 lists traits with significant regression coefficients and optimum scores for the traits. Eight traits had statistically significant quadratic regression coefficients from the second-order model [2], and four additional traits had significant linear regression coefficients from the first-order model.

Ten of the 12 traits significant for HMDF were also significant for HMDM. They are basic form, dairyness, stature, body depth, rump side view, udder depth, rump width, rear udder width, suspensory ligament, and disposition. Each of these 10 traits had optima within five points for both HMDM and HMDF. Table 5 lists changes in HMDF over ± 2 SD of changes in scores for traits significant for HMDF. Figure 2 graphically illustrates the 4 traits associated with the largest change in HMDF.

Generally, traits associated with large differences in HMDM were associated with large differences in HMDF. Udder depth and dairyness had largest changes of HMDF over ± 2 SD of scores at 39 kg each. Moderate changes of HMDF over ± 2 SD were found for stature (12 kg), rear udder width (12 kg), and disposition (13 kg). Smaller changes were found for the remaining traits. For udder depth, the optimum score of 7 points for HMDF indicates that, although deep udders are associated with higher HMDF, as the udder becomes excessively deep the equation predicts a slight decrease in HMDF that was not observed for HMDM.

Strength of body and milkout were the only traits significantly associated with HMDF that were not associated with HMDM. The optimum score for these traits was intermediate (27 and 38, respectively), and changes in HMDF over ± 2 SD from the mean score were small (2 and 4 kg). These traits, along with body depth, rump side view, and rump width are considered unimportant compared with other traits because of the relatively small change in HMDF associated with changes in scores for the traits, even though the regression coefficients were signifi-

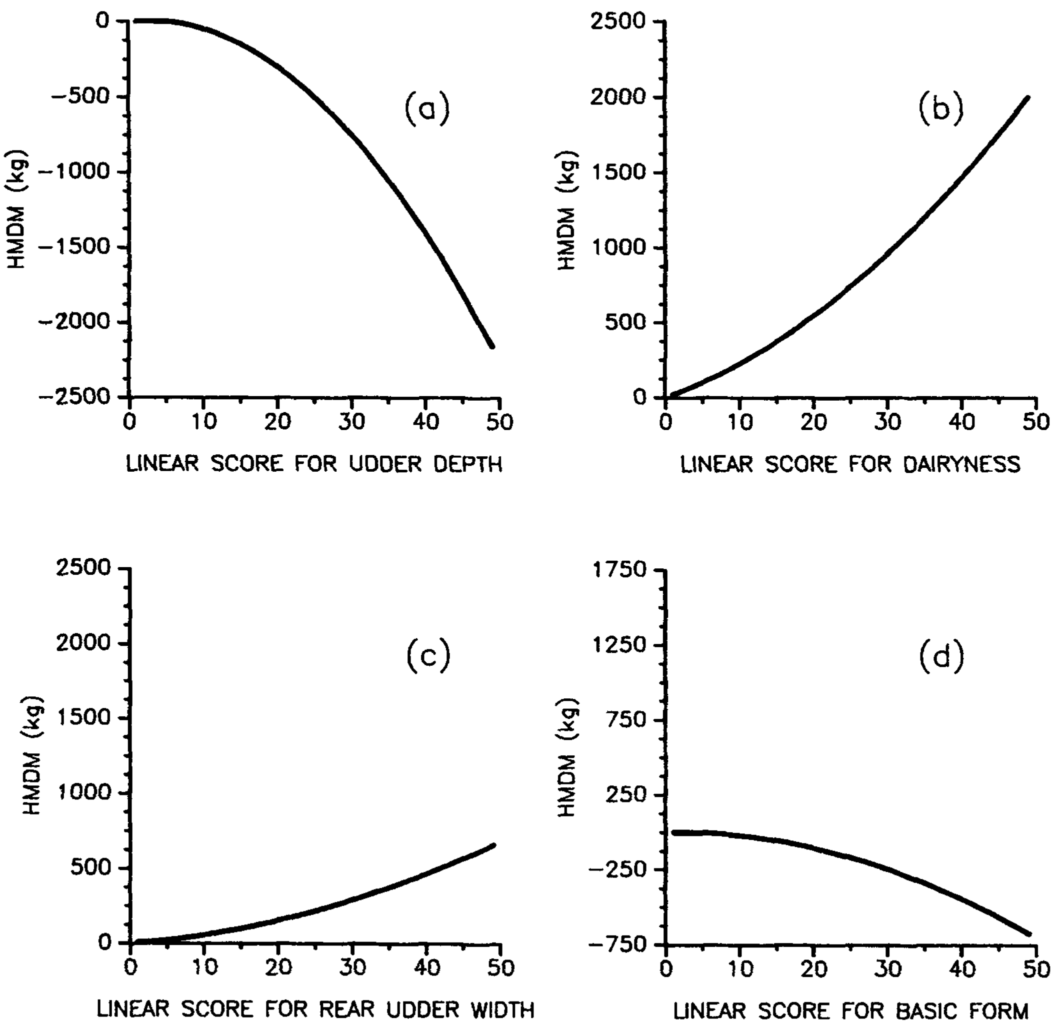

Figure 1. Quadratic regressions of herdmate deviation milk (HMDM) on udder depth (a), dairyness (b), rear udder width (c), and basic form (d).

cant. Dairyness and udder depth are considered most important because of the larger changes in HMDF associated with change in scores of these traits. This conclusion was the same as for HMDM.

Traits not significantly associated with HMDF that were significant for HMDM were fore udder attachment, rear legs rear view, rear udder height, and fore and rear teat placement. These traits were associated with small differences in HMDM and consequently are not as important as other traits.

Association of Traits with Herdlife

Multiple regression analysis [3] evaluating the relationship of linearly scored traits with HL resulted in 7 traits with an association ($P \leq .05$) with HL. Table 6 lists traits with significant linear and quadratic regression coefficients and the optimum scores for these traits. Stature, udder depth, rump width, and milkout had significant quadratic regression coefficients for HL from the second order model. Dairyness, rear legs side view, and disposition had

TABLE 5. Changes in herdmate deviation fat (HMDF) over the range ± 2 SD of scores from the mean.

Trait	Score		Change in HMDF relative to the mean or optimum score[1]		
	Mean	Optimum	at −2 SD	at + 2 SD	Range
Basic form	25.4	5	3 (13.3)[2]	−6 (37.5)	9[3]
Strength of body	25.1	27	−2 (12.3)	−1 (37.9)	2
Dairyness	30.0	50	−17 (17.3)	22 (42.7)	39
Stature	27.3	50	−6 (16.6)	6 (38.0)	12
Body depth	29.3	1	−1 (17.1)	1 (41.5)	2
Rump side view	27.0	50	−1 (14.5)	1 (39.5)	2
Udder depth	31.8	7	15 (21.0)	−24 (42.6)	39
Rump width	26.8	29	−3 (14.8)	−2 (38.8)	3
Rear udder width	27.9	50	−6 (14.6)	6 (41.2)	12
Suspensory ligament	30.9	50	−3 (18.8)	3 (43.0)	6
Disposition	27.8	50	−4 (9.7)	9 (45.9)	13
Milkout	29.9	38	−4 (12.8)	−1 (47.0)	4

[1]If the optimum score is within the range ± 2 SD of the mean, HMDF (kg) change is relative to the optimum score rather than the mean score.

[2]Numbers in parentheses are the scores at ± 2 SD.

[3]The range (kg) is expressed as an absolute value.

significant linear relationships with HL from the first-order model.

Three traits had extreme optima and the remaining 4 had intermediate optima. A higher proportion of traits related to HL had intermediate optima compared with HMDM or HMDF. Optimum scores for traits significantly associated with HL indicate that cows with longest HL are those that are near average for stature, udder depth, rump width, and milkout and that have posty legs, extreme dairy character, and excellent dispositions. The desirability of posty legs could be described differently as extremely sickled legs being undesirable. Alternatively, posty legs may only be a problem in extreme cases when they are so straight the cow's movement is restricted, which may be an infrequent occurrence. It was not possible to determine this from the data. Changes in HL over the range ± 2 SD of scores were 90 d for dairyness, 59 d for udder depth, 44 d for disposition, 35 d for milkout, 32 d for rear legs side view, 27 d for rump width, and 17 d for stature (Table 7). Figure 3 presents a graphical description of traits associated with largest differences in HL. Dairyness and udder depth were most important, although other significant traits had relatively large differences for HL.

Several differences exist between HL and HMDM or HMDF when one considers significant traits and optimum scores for these traits. First, there are fewer significant traits for HL, although all traits significant for HL except rear legs side view were significant for HMDM or HMDF. Second, some traits with intermediate optima for HL had extreme optima for HMDM and HMDF. For example, cows with deep udders had higher HMDM and HMDF in their first lactation, but cows with moderate udder depth had longer HL. Thus, one could not maximize HMDM and HMDF without sacrificing gain in HL. The reverse is also true. A similar situation exists with stature. It is possible that different optima could exist for other dependent variables, such as different lactations, measures of efficiency, and other traits. Further investigation is warranted.

Variation due to Herds and Other Effects

The proportion of variation in models [1], [2], and [3] that could be attributed to herd variation and to type traits plus sire PD was of interest. Variation due to herds was measured by the R^2 by evaluating models [1], [2], and [3] with herds only. Variation due to herds plus other effects was estimated from the full second-order model. Table 8 lists R^2 values for these models.

Models [1] and [2], evaluating HMDM and HMDF, had R^2 of approximately 30% when the full model was used. These same models

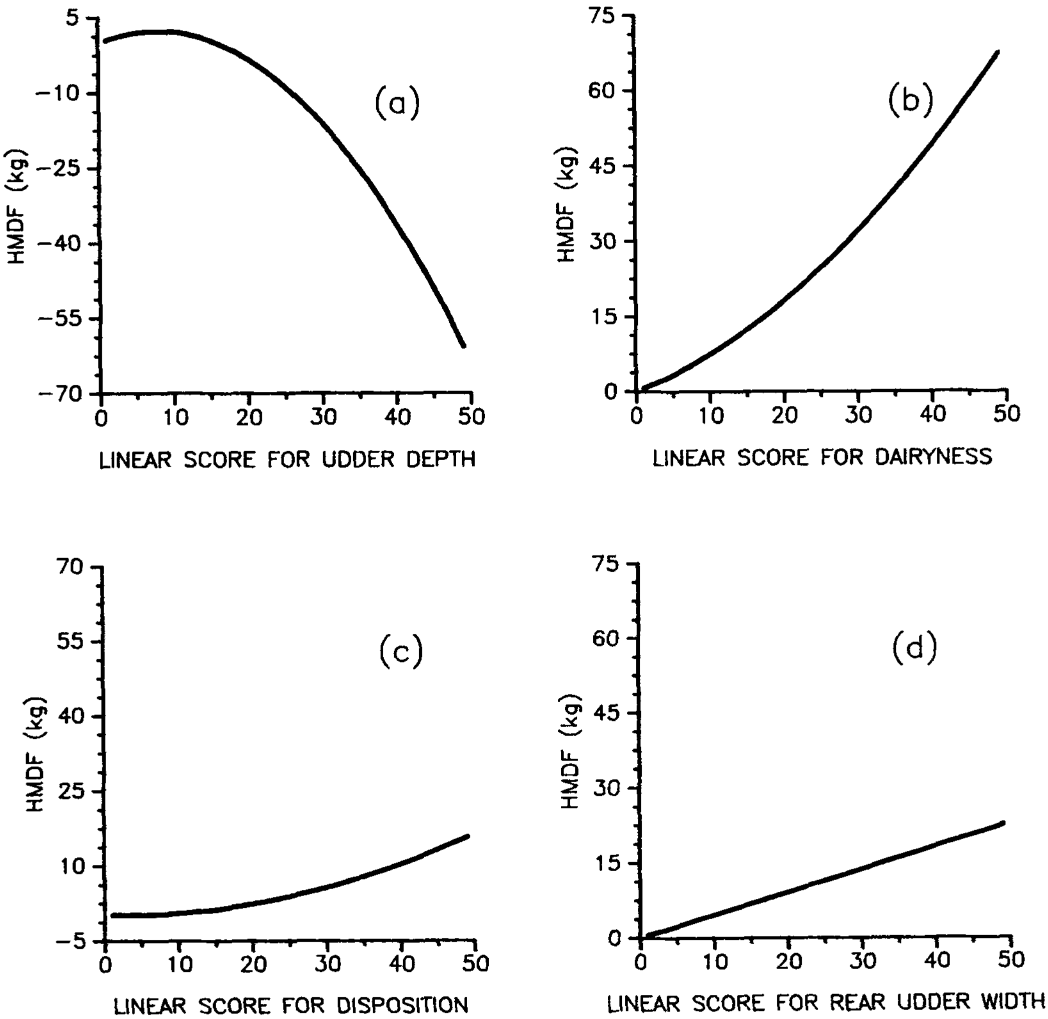

Figure 2. Quadratic and linear [for (d)] regressions of herdmate deviation fat (HMDF) on udder depth (a), dairyness (b), disposition (c), and rear udder width (d).

had R^2 of approximately 17% when herds were included but with other effects ignored. Thus, although herds were important in determining production of cattle, linear type traits and sire PD add information to knowledge about these productive traits when they were fit after herds. Model [3], evaluating HL, had an R^2 of 56% using the full model. This was considerably higher than the R^2 for production traits. Herd variation accounted for almost all (99%) of this variation in a model where other effects were ignored, indicating that although type traits were significantly associated with HL, the significantly large herd effects indicate herd management affects HL more than type traits or sire PD. Programs aimed at improving HL should be directed at improvement of herd management practices.

Association of Traits with Dependent Variables Using Third-Order Models

Third-order models were used for each dependent variable to determine if response at

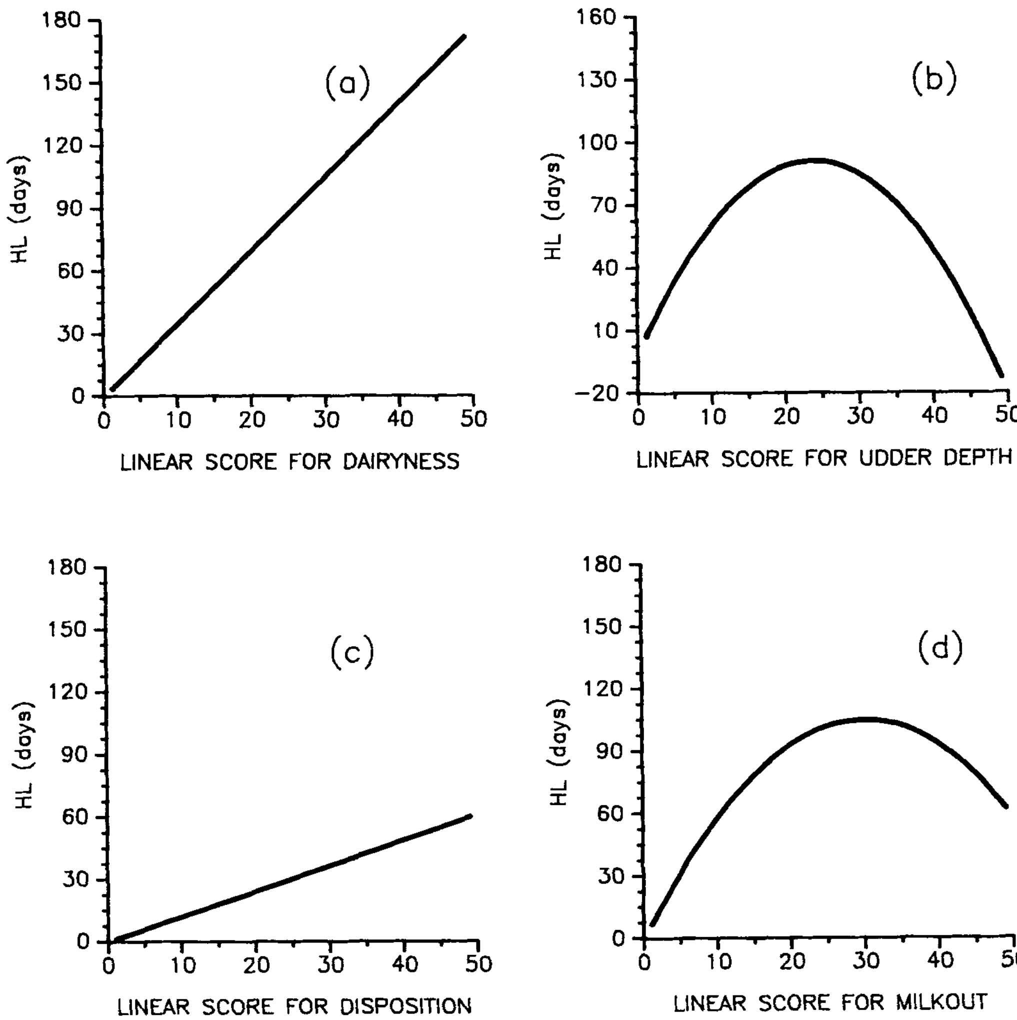

Figure 3. Quadratic (b,d) and linear (a,c) regressions of herdlife (HL) on dairyness (a), udder depth (b), disposition (c), and milkout (d).

extreme scores differed from predictions using first and second order models. Using the third-order model, 6 traits had significant ($P \leq .05$) cubic regression coefficients for HMDM (Table 9). They were stature, body depth, fore udder attachment, udder depth, rear udder height, and fore and rear teat placement. All 6 traits were significantly associated with HMDM from the first- or second-order model.

Predicted response in HMDM at ± 2 SD from the mean score for each trait using the third-order model was virtually identical to response predicted from the first- or second-order model. Predictions at extreme scores varied when third-order models were used for analyses, and each trait will be discussed as it differed from the model previously reported. Optimum score for stature was 45 points, indicating tall cows were associated with highest HMDM but with a downward trend of 150 kg HMDM as score increased from 45 to 50 points. There was also a slight upward trend of 39 kg HMDM as score decreased from 7 points to 1 point. The rate of decrease in HMDM as body

TABLE 6. Traits with significant linear and quadratic regression coefficients and optimum scores for herdlife derived from first- and second-order regression models.

Trait	Linear regression	Quadratic regression	Optimum score
	Second-order model[1]		
Stature	7.56*	−.141*	28
Udder depth	7.72*	−.163*	24
Rump width	8.26**	−.141*	25
Milkout	7.04**	−.118**	30
	First-order model[2]		
Dairyness	3.51**		50
Rear legs side view	−1.32*		1
Disposition	1.23**		50

[1]Second-order models contained linear and quadratic effects for all type traits.

[2]First-order models contained linear effects for all type traits.

*Regression coefficient ($P \leq .05$).

**Regression coefficient ($P \leq .01$).

depth score increased from 1 to 10 points and 40 to 50 points was faster than through the middle range of scores, although the direction of decrease was the same as for the first-order model. This indicated an increased advantage of shallow bodied cows over deep bodied cows than was predicted from the first-order model. The HMDM increased 417 kg as body depth score changed from 10 points to 1 point.

The relationship of HMDM with increasing score of fore udder attachment was negative using the first-order model. The third-order model predicted the relationship was positive as score changed from 1 to 14 points (+ 136 kg) and from 40 to 50 points (+ 87 kg). The score associated with highest HMDM was 14, indicating a fore udder attachment that tends to be broken was associated with greatest yield. The shape of the curve describing the relationship of HMDM with udder depth predicted from the third-order model was similar to that predicted from the second-order model, with the optimum score shifted from 2 to 13 points. The third-order model predicted a decrease of 405 kg HMDM as udder depth score decreased from 13 points to 1 point.

For rear udder height, HMDM increased 161 kg as score increased from 18 to 40 points and

TABLE 7. Changes in herdlife (HL) over the range ± 2 SD of scores from the mean.

Trait	Score		Change in HL relative to the mean or optimum score[1]		
	Mean	Optimum	at −2 SD	at + 2 SD	Range
Dairyness	30.0	50	−45 (17.3)[2]	45 (42.7)	90[3]
Stature	27.3	28	−14 (16.6)	−17 (38.0)	17
Rear legs side view	29.3	1	16 (17.1)	−16 (41.5)	32
Udder depth	31.8	24	−1 (21.0)	−59 (42.6)	59
Rump width	26.8	25	−27 (14.8)	−10 (38.8)	27
Disposition	27.8	50	−22 (9.7)	22 (45.9)	44
Milkout	29.9	30	−34 (12.8)	−35 (47.0)	35

[1]If the optimum score is within the range ± 2 SD of the mean, HL (d) change is relative to the optimum score rather than the mean score.

[2]Numbers in parentheses are the scores at ± 2 SD.

[3]The range (d) is expressed as an absolute value.

TABLE 8. Multiple squared correlation values (R^2) for models containing herds only and models containing herds plus other effects.[1]

Model dependent variable[2]	R^2 herds only	R^2 with herds and other effects	Percentage of variation due to herds
HMDM	.168	.306	55
HMDF	.175	.292	60
HL	.553	.559	99

[1]Other effects include linear and quadratic for type traits plus sire predicted differences.

[2]Dependent variables were herdmate deviation milk (HMDM), herdmate deviation fat (HMDF), and herdlife (HL).

then decreased 114 kg as score changed from 40 to 50 points. The HMDM increased 455 kg as score decreased from 18 points to 1 point. The third-order model predicted the score of 1 to be optimum for rear udder height, whereas the first-order model predicted the score of 50 to be optimum. Optimum scores were simply the highest point on each curve. The optimum score 50 was from the first-order model, and was due to the positive relationship observed through the middle range of scores, which was similar between the two models. For fore and rear teat placement, HMDM decreased 61 kg as score increased from 22 to 42 points, but HMDM decreased 345 kg as score decreased from 22 points to 1 point. Extremely wide teat placement was least desirable, whereas scores above 22 points were associated with small differences in HMDM.

Using the third-order model to predict HMDF; dairyness, body depth, fore udder attachment, udder depth, and fore and rear teat placement had cubic regression coefficients ($P \leq .05$) for HMDF (Table 9). Dairyness, body depth, and udder depth were significantly associated with HMDF from the second-order model. Fore udder attachment and fore and rear teat placement were not associated with HMDF using either the first- or second-order model, although these traits were associated with HMDM. The relationship of HMDF with dairyness was essentially unchanged from prediction using the second-order model, except HMDF changed little as dairyness score increased from 1 to 10 points. Cows with shallow bodies had highest levels of HMDF with the largest change in HMDF (+ 12 kg) realized as score decreased from 11 points to 1 point. the HMDF decreased 3 kg as fore udder attachment score decreased

TABLE 9. Traits with significant third-order regression coefficients and optimum scores for herdmate deviation milk (HMDM) and fat (HMDF) and herdlife (HL).

Trait	Linear regression	Quadratic regression	Cubic regression	Optimum score
			HMDM	
Stature	−16.72	1.424	−.0185*	45
Body depth	−65.91**	2.006**	−.0228**	1
Fore udder attachment	26.85*	−1.321**	.0165**	14
Udder depth	80.99**	−3.795**	.0323**	13
Rear udder height	−66.54**	2.632**	−.0298**	1
Fore and rear teat placement	43.33**	−1.527**	.0162**	22
			HMDF	
Dairyness	−.37	.057**	−.00052*	50
Body depth	−1.95**	.067**	−.00074*	1
Fore udder attachment	.74	−.033	.00044*	50
Udder depth	3.69**	−.151**	.00132**	16
Fore and rear teat placement	1.12*	−.04*	.00044*	50
			HL	
Rump side view	29.26**	−1.091**	.0128**	50
Foot angle	11.21*	−.555*	.0085**	50

*Regression coefficient ($P \leq .05$).

**Regression coefficient ($P \leq .01$).

from 7 points to 1 point, and increased 5 kg as score increased from 42 to 50 points but changed less than 2 kg for scores between 7 and 42 points. The optimum score for udder depth was 16 points, and the shape of the curve was similar to that for HMDM. Scores greater than 13 points for fore and rear teat placement were associated with small changes in HMDF (<3 kg), while scores decreasing from 13 points to 1 point were associated with a −8-kg change in HMDF.

Using the third-order model to predict HL, rump side view and foot angle had significant cubic regression coefficients for HL (Table 9). Neither trait had a significant association with HL when the first- or second-order model was used. The equation essentially predicted no change in HL as score for rump side view changed from 15 to 40 points. As score decreased from 15 points to 1 point, which indicated pins progressively higher than hips, HL decreased 209 d. As score changed from 40 to 50 points, i.e., pins much lower than hips, HL increased 92 d. Although these values are large, the error of prediction is larger at extreme scores because of the relatively small number of cows with extreme scores. The relationship of HL with foot angle was similar to that of rump side view. There was no change in HL as score for foot angle changed from 10 to 34 points. As score changed from 34 to 50 points, or as foot angle became very steep, HL increased 162 d. As score for foot angle decreased from 10 points to 1 point HL decreased 54 d.

DISCUSSION

Dairyness and udder depth, because of their association with all three dependent variables, and because of large differences in responses associated with changes in them, seem to be the most important traits in the MAP program. Optimum scores indicated that cows with extreme dairyness had higher HMDM and HMDF and longest HL. First-parity cows with deep udders had highest HMDM and HMDF, but cows with average udder depth in the first lactation had longest HL.

Other traits important because of moderate differences associated with dependent variables are basic form, stature, rear udder width, rear legs side view, disposition, and milkout. Cows that are average to tall for stature, having wide rear udders, and excellent dispositions were associated with highest dependent variables for these traits. Cows angular for basic form had highest HMDM and HMDF, and cows with moderate milkout had highest HMDF and HL. The HL was longest for cows with straight legs. Although important, selection for linearly evaluated type traits should not replace direct selection for traits of proven economic importance (i.e., milk and milk components).

Biases could exist in scores assigned for disposition and milkout because herd owners assign scores for these traits while having prior knowledge of the individual's production. A problem that exists with the analyses of HL is there are fewer individuals with calculated HL than with calculated HMDM or HMDF, because many younger animals have not had time to express complete HL, and many of the presumably better older animals still remain in the herds. A reasonable approach would be to reanalyze the data for HL when all individuals have completed HL, as this was a preliminary study. A possible explanation of why there are fewer traits significant for HL is the incompleteness of the HL data set. Another could be that there are actually fewer traits related to HL than to HMDM or HMDF.

Utilizing third-order models to predict response at extreme scores can have value in describing relationships that exist between type traits and dependent variables. However, large errors of prediction at extreme scores, a result of the small number of animals scored at extremes, would limit inferences from this information. The most important results from third-order models suggest the desirability of steep foot angle and sloping rumps. Although some differences exist in predictions when third-order models were used, conclusions remain the same for the middle range of scores of these traits.

The results obtained from this study are dependent on how these dependent variables are measured. Production variables are first lactation HMDM and first lactation HMDF. The HL is measured only on individuals having the opportunity to complete HL. Other variables such as later lactation yield, alternative measures of HL, and measures of efficiency could be evaluated. Continued investigation into the relationships of linear type traits with many dependent variables will aid in developing accurate definitions of important traits and in assigning appropriate weights to these traits for selection index applications. These analyses are some of the first of the effects of linear type traits for which performance information is available on large numbers of cattle. Future analyses should evaluate applications of linear type trait analyses with other dependent variables.

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REFERENCES

1 Aitchison, T. E., A. E. Freeman, and G. M. Thompson. 1972. Evaluation of a type appraisal program in Holsteins. J. Dairy Sci. 55:840.
2 Andrus, D. F., and L. D. McGilliard. 1975. Selection of dairy cattle for overall excellence. J. Dairy Sci. 58:1876.
3 Berger, P. J., W. R. Harvey, and E. A. Rader. 1973. Selection for type and production and influence on herdlife of Holstein cows. J. Dairy Sci. 56:805.
4 Berger, P. J., W. A. Dishman, and A. E. Freeman. 1986. Evaluation of merit of a corrective mating program for Holstein cattle. J. Dairy Sci. 69:1403.
5 Boldman, K. G., and T. R. Famula. 1985. Association of sire dystocia transmitting ability with progeny linear type traits in Holsteins. J. Dairy Sci. 68:2052.
6 Burnside, E. B., A. E. McClintock, and K. Hammond. 1985. Type, production, and longevity in dairy cattle: a review. Anim. Breed. Abstr. 52:711.
7 Dadati, E., B. W.. Kennedy, and E. B. Burnside. 1985. Relationship between conformation and reproduction in Holstein cows: type and calving performance. J. Dairy Sci. 68:2639.
8 Dadati, E., B. W. Kennedy, and E. B. Burnside. 1986. Relationships between conformation and calving interval in Holstein cows. J. Dairy Sci. 69:3112.
9 Everett, R. W., J. F. Keown, and E. E. Clapp. 1976. Relationships among type, production, and stayability in Holstein cattle. J. Dairy Sci. 59:1505.
10 Foster, W. W., A. E. Freeman, P. J. Berger, and A. Kuck. 1988. Linear type trait analysis with genetic parameter estimation. J. Dairy Sci. 71:223.
11 Freeman, A. E. 1982. Linear scoring of type conformation in dairy cattle in the U.S.A. Proc. Winter Conference, Digest No. 37. British Cattle Breeders Club, Cambridge, Engl.
12 Gill, G. S., and F. R. Allaire. 1976. Relationship of age at first calving, days open, days dry, and herdlife to a profit function for dairy cattle. J. Dairy Sci. 59:1131.
13 Honnette, J. E., W. E. Vinson, J. M. White, and R. H. Kliewer. 1980. Contributions of descriptively coded type traits to longevity of Holstein cows. J. Dairy Sci. 63:807.
14 Honnette, J. E., W. E. Vinson, J. M. White, and R. H. Kliewer. 1980. Prediction of herdlife and lifetime production from first lactation production and individual type traits in Holstein cows. J. Dairy Sci. 63:816.
15 Miller, R. H., N. W. Hooven, Jr., and J. W. Smith. 1971. Relationships between type and performance of daughters of artificial insemination sires. J. Dairy Sci. 54:1096.
16 Norman, H. D., and L. D. Van Vleck. 1972. Type appraisal III. Relationships of first lactation production and type traits with lifetime performance. J. Dairy Sci. 55:1726.
17 Norman, H. D., B. G. Cassell, R. E. Pearson, and G. R. Wiggans. 1981. Relation of first lactation production and conformation to lifetime performance and profitability in Jerseys. J. Dairy Sci. 64:104.
18 Petersen, M. L., L. B. Hanson, C. W. Young, and K. P. Miller. 1986. Conformation resulting from selection for milk yield of Holsteins. J. Dairy Sci. 69:1884.
19 Schaeffer, L. R., and E. B. Burnside. 1974. Survival rates of tested daughters of sires in artificial insemination. J. Dairy Sci. 57:1394.
20 Sieber, M., A. E. Freeman, and P. N. Hintz. 1987. Factor analysis for evaluating relationships between first lactation type scores and production data of Holstein dairy cows. J. Dairy Sci. 70:1018.
21 Sieber, M., A. E. Freeman, and P. N. Hintz. 1988. Comparison between factor analysis from a phenotypic and genetic correlation matrix using linear type traits of Holstein dairy cows. J. Dairy Sci. 71:477.
22 Thomas, C. L., W. E. Vinson, R. E. Pearson, B G. Cassell, H. D. Norman, and E. P. Barton. 1984. Relationships between linearly scored components of type and final score of Jersey cows. J. Dairy Sci. 67:372.
23 Thomas, C. L., W. E. Vinson, R. E. Pearson, H. D. Norman, and E. P. Barton. 1986. Evaluation of corrective mating for type traits in Jersey cattle. J. Dairy Sci. 69: 1618.
24 Thompson, J. R., A. E. Freeman, and P. J. Berger. 1980. Variation of traits in mating appraisal. J. Dairy Sci. 63: 133.
25 Thompson, J. R., A. E. Freeman, D. J. Wilson, C. A. Chapin, P. J. Berger, and A. Kuck. 1981. Evaluation of a linear type program in Holsteins. J. Dairy Sci. 64:1610.
26 Thompson, J. R., K. L. Lee, A. E. Freeman, and L. P. Johnson. 1983. Evaluation of a linear type appraisal system for Holstein cattle. J. Dairy Sci. 66:325.
27 Tigges, R. J., R. E.. Pearson, and W. E. Vinson. 1986. Prediction of lifetime relative net income from first lactation production and individual type traits in Holstein cows. J. Dairy Sci. 69:204.
28 Van Doormaal, B. J., E. B. Burnside, and L. R. Schaeffer. 1986. An analysis of the relationships among stayability, production, and type in Canadian milk-recording programs. J. Dairy Sci. 69:510.
29 Van Vleck, L. D., D. B. Filkins, H. W. Carter, and C. L. Hart. 1969. Relationships between type traits and longevity of daughters of New York Holstein sires. J. Dairy Sci. 52:1823.
30 What cows are the herdmates? 1980. Iowa Coop. Ext. Serv. (Publ.)DyS-2330.