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Phenotypic variation in live weight and live-weight changes of lactating Holstein-Friesian cows

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Abstract

This study quantified individual phenotypic variation in live weight and live-weight changes during the first three lactations and estimated the effects of age, lactation week and pregnancy on live weight. Data comprised weekly averaged live weight (calculated from daily observations) during 452 lactations of 239 Holstein-Friesian cows. Unadjusted mean live weights were 553 (s.d. 50), 611 (s.d. 55) and 654 (s.d. 57) kg during first, second and third parity, respectively. Estimated effect of growth during parity was 46, 52 and 23 kg for the first three parities. Mean maximum weight loss was 26, 22 and 22 kg for first, second and third parity and variation was large among individuals. Week of lactation when cows had their maximum weight loss ranged from 7 weeks in first lactation to 13 weeks in third lactation. Estimated maximum effect of pregnancy on live weight during the lactation varied from 27 to 59 kg. Phenotypic variance in live weight increased with parity. Repeatabilities of live-weight observations within parity were 0·85. Across parities, high repeatabilities were found for calving weight and mean live weight but not for parameters associated with maximum weight loss. Correlations between weekly means and mean live weight during the whole of lactation were high. It was concluded that single live-weight observations of heifers are a good measurement of mean live weight during the first three parities.

Keywords: *dairy cattle, live weight, phenotypic variation, repeatability.*

Introduction

Maintenance requirements of dairy cattle largely depend on live weight (LW) (Agricultural Research Council, 1980). Proportionately about 0·55 of the food cost of a cow from calving until fourth parity is related to maintenance requirements (Korver, 1988). Negative economic values have been reported for LW (e.g. Groen, 1989; Visscher *et al.*, 1994) because costs associated with higher growth and maintenance exceed revenues from selling culled animals with higher LW.

Mean LW might be a good measurement of the maintenance requirements during lactation. When mean LW is in the breeding goal, the value of LW observations as selection traits has to be known. Field studies on LW (e.g. Ahlborn and Dempfle, 1992; Hietanen and Ojala, 1995; Koenen and Groen, 1998) found a large phenotypic variance for LW. This variance is partly caused by three systematic effects: age dependent growth, lactation stage and pregnancy. First, cows gain weight until they reach maturity at approximately 5 years of age (Touchberry and Batra, 1976). Secondly, cows lose LW in early lactation as a result of negative energy balance. Later in lactation, LW increases when new tissue reserves are built up (Bines, 1976). Van Elzakker and van Arendonk (1993) indicated that variation for LW changes during lactation was large among individuals. Thirdly, weight of the foetus, foetal membranes, uterus and uterus contents increase the LW of pregnant animals (Bereskin and Touchberry, 1967; Silvey and Haydock, 1978). When mean LW is predicted from field data of lactating cows adjustment for these systematic effects is needed.

Information on individual variation in LW changes during and across lactations and on adjustment factors for LW of lactating dairy cattle is limited. The correlation of single LW observations with mean LW and the repeatability of LW observations at different lactation stages and across parities determine the optimal moment and frequency of LW recording.

The aim of this study is to quantify phenotypic variation among individuals for LW and LW changes of Holstein-Friesian cows in the first three lactations.

Material and methods

Data

Lactating Holstein-Friesian cows were weighed twice daily (directly after leaving the milking parlour) from January 1989 through August 1995 at the Institute for Animal Nutrition 'Schothorst' (Lelystad, The Netherlands). When LW was recorded for at least 4 days, weekly mean of LW was calculated and stored. Lactations with less than 35 weekly means or with missing values in the first three weeks of lactation were deleted. Only the first three parities were included in the analyses as the number of cows in higher parities was limited. The data included 18 875 weekly means for 239 cows in 452 lactations. The mean number of weekly means per animal during the first 45 weeks in lactation was 41 ± 3. Missing values were replaced by estimated weekly means from fifth order polynomials, which were fitted for individual lactations. In the final data, 7% of the records were based on estimates.

The numbers of cows in first, second and third parity, were 185, 164 and 103 respectively. Mean, standard deviation and range of unadjusted LW records for each parity are in Table 1. Out of the 185 heifers, 125 and 64 had also observations in second and third parity, respectively. Of the 103 third parity cows, 54 had also an observation at fourth calving.

Cows were given roughage *ad libitum* and a fixed amount of concentrates. Roughage consisted of fresh grass, grass silage, maize silage or a mixture of these roughages. Out of the 452 lactations, 217 were subject to four nutritional experiments. The amount of concentrates differed for each experiment. Every year in October a new experiment started with a different concentrate level and composition. Within each experiment, four to 10 different levels of concentrates were included. All animals were in the same herd and were, apart from nutritional differences, subject to the same management.

Mean proportion of Holstein-Friesian genes of the animals was 0·93 (s.d. 0·09). Mean 305-day lactation milk yields were 7501, 9094 and 9663 kg in the first, second and third parities.

To estimate the relationships between single observations and weekly means, bidaily LW observations from the experimental farm 'Ossenkampen' (Wageningen, The Netherlands) were used in addition to the main data. At this herd, 5795 weights were collected on 70 Holstein-Friesian cows during 79 days. Weekly means were calculated in a similar procedure as in the first data collection period. After adjustment for parity, the correlation between single weighing and weekly means was estimated on decomposition of the intra-week variance.

Adjustment for fixed effects

Live-weight records from animal l calving in experimental group i and pregnancy group k were analysed by the following model:

$$y_{ijklm} = \mu + \exp_i + w_j + a_1 \times (age - \overline{age}) + a_2 \times (age - \overline{age})^2 + p_k + e_{ijklm}$$

where: y_{ijklm} = live weight (kg); μ = intercept; $\exp_i$ = fixed effect of the experimental group (27 levels); w_j = fixed effect of lactation week (45 levels); a_1, a_2 = regression coefficients; age = age at calving (days); p_k = fixed effect of pregnancy group (6 levels) and e_{ijklm} = random error.

An experimental group was defined as a combination of experiment and treatment. All animals that were not included in an experiment were assigned to the same experimental group. Six classes for the effect of pregnancy were defined: ≤3, 4, 5, 6, 7 and 8 or more months pregnant. Stage of pregnancy was based on date of next calving, assuming a mean gestation length of 279 days. When date of next calving was not available, pregnancy stage was based on time since last insemination. Adjusted LW records were defined as $\mu + w_j + e_{ijklm}$.

Within each parity, the relative contribution of each fixed effect to the total variation in LW was calculated as the relative difference in mean square residual between the full model and models where

Table 1 *Number of cows, number of observations, means, s.d., CV and range of unadjusted weekly averaged live weight in first, second and third parity*

	No. of cows	No. of observations	Mean (kg)	s.d. (kg)	CV	Min. to Max.
First parity	185	8325	553	50	0·09	410-711
Second parity	164	7380	611	55	0·09	455-852
Third parity	103	4635	654	57	0·09	496-869

Table 2 *Relative contribution of the fixed effects to the total phenotypic variance in live weight in first, second and third parity and the proportion of explained variance* (R^2_{adj})

	First parity	Second parity	Third parity
Effect of			
Experiment	0·14	0·13	0·22
Week	0·04	0·12	0·03
Age	0·09	0·06	†
Pregnancy	†	0·00	0·00
R^2_{adj}	0·34	0·36	0·29

† Not significant.

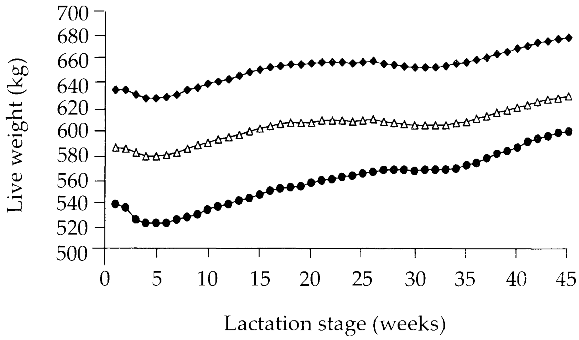

Figure 1 Fixed effect of lactation stage on live weight in first parity (●), second parity (△) and third parity (◆).

one effect at a time was ignored. Fixed effects that were not significant were removed from the model.

Curve parameters

After adjusting the LW records, four new variables were defined to illustrate individual variation for LW during the lactation. Calving weight (CLW) was defined as LW at the 1st week of lactation. Mean live weight (MLW) was defined as mean LW during the first 45 weeks of lactation. Maximum weight loss (LOSS) was defined as CLW minus minimal LW during lactation. Week in lactation when LW was minimal was defined as MIN. Pearson correlations between estimates for these variables were estimated within and across parities as a measure of the repeatability of LW and LW changes. Moreover, correlations between LW at different lactation weeks and MLW were estimated within and across parity.

Results

Fixed effects

The proportion of variance explained by simultaneously considering experimental group, age at calving, week of lactation and pregnancy group ranged from 0·29 to 0·36 (Table 2). The relative contribution of the individual fixed effects of the total phenotypic variance is in Table 2. The largest proportion was explained by the effect of experimental group. The effect of age at calving decreased with parity and was no longer significant in third parity ($P > 0{\cdot}05$). Estimates for the effect of lactation week on LW during the first three lactations are in Figure 1. LW decreased after calving, was minimal at about 5 weeks and increased thereafter. LW clearly increased with parity. No significant effect was found for the effect of pregnancy in first lactation, whereas it was significant and small in the second and third parities. The estimated contrast between the first pregnancy group (≤3 months pregnant) and the sixth group (8 or more months pregnant) was 22 and 37 kg for second and third parity, respectively.

Variance components and repeatabilities

Phenotypic variance in adjusted LW tended to be highest in the period 20 to 30 weeks of lactation and increased with parity (Table 3). Within all parities,

Table 3 *Phenotypic standard deviation (kg) of live weight in different weeks in the first three parities and correlations among repeated live weight observations in first parity after adjustment for fixed effects*

Week of lactation	Parity			Week of lactation									
	1	2	3	1	5	10	15	20	25	30	35	40	45
1	35·0	43·5	45·8	1	0·86	0·73	0·65	0·59	0·56	0·59	0·69	0·69	0·70
5	34·1	41·0	43·0		1	0·92	0·85	0·79	0·76	0·75	0·81	0·78	0·77
10	37·5	42·2	45·0			1	0·95	0·90	0·85	0·84	0·85	0·81	0·79
15	39·3	44·0	46·0				1	0·95	0·91	0·88	0·87	0·82	0·79
20	41·4	46·3	51·5					1	0·94	0·90	0·87	0·81	0·76
25	45·2	47·7	53·2						1	0·92	0·85	0·79	0·74
30	44·9	48·2	51·6							1	0·90	0·83	0·78
35	40·5	43·1	46·4								1	0·94	0·89
40	39·7	43·5	49·9									1	0·92
45	41·1	44·3	50·8										1

Table 4 *Mean ± s.e., minimum, maximum and median of estimated calving weight (CLW), maximum weight loss (LOSS), lactation week with minimum live weight (MIN), and mean live weight (MLW) during lactation in first, second, and third parity*

	Mean	s.e.	Min. to Max.	Median
First parity				
CLW (kg)	537	35	458-636	536
LOSS (kg)	26	20	0-94	23
MIN (week)	7	5	1-28	5
MLW (kg)	557	37	456-661	554
Second parity				
CLW (kg)	585	43	487-763	581
LOSS (kg)	22	23	0-137	16
MIN (week)	11	12	1-40	6
MLW (kg)	603	40	503-729	603
Third parity				
CLW (kg)	633	46	532-781	636
LOSS (kg)	22	25	0-107	13
MIN (week)	13	11	1-39	9
MLW (kg)	655	45	561-751	655

correlations between LW were high and generally decreased with increasing time interval between repeated observations. This is illustrated for the first parity by the correlation matrix of LW (Table 3). The mean correlation between any pair of weekly means was 0·85, 0·84 and 0·85 in first, second and third lactation respectively. These means were estimated by averaging all possible combinations among the 45 weekly records and are a measurement of the repeatability.

Individual LW curves

Mean ± s.e., range and median of CLW, LOSS, MIN and MLW are in Table 4. The variables CLW and MLW increased with parity and reflected the effect of growth during first and second parity. The increase of MLW indicated a growth of 46 kg during first and 52 kg during second parity. Growth during third lactation was approximated as 23 kg by considering the mean LW of 656 kg at fourth calving of the 53 cows from the third parity group that had also an observation in the fourth parity. Mean values

Table 5 *Correlations between calving weight (CLW), maximum weight loss (LOSS), lactation week with minimum live weight (MIN), and mean live weight (MLW) during lactation in first, second, and third parity*

Parameter	First parity	Second parity	Third parity
CLW-LOSS	0·37***	0·46***	0·34***
CLW-MIN	0·19*	0·17*	0·29**
CLW-MLW	0·74***	0·75***	0·78***
LOSS-MIN	0·34***	0·44***	0·56***
LOSS-MLW	−0·23**	−0·12	−0·19
MIN-MLW	−0·16*	−0·24**	−0·19

Table 6 *Correlations across parities for calving weight (CLW), maximum weight loss (LOSS), lactation stage with minimum live weight (MIN), and mean live weight (MLW) (number of animals within brackets)*

	First-second (no. = 125)	First-third (no. = 64)	Second-third (no. = 87)
CLW	0·53***	0·56***	0·61***
LOSS	0·12	0·10	0·52***
MIN	0·18	0·16	0·14
MLW	0·76***	0·76***	0·82***

for LOSS and MIN characterized the shape of the LW curve. Mean LOSS in first, second, and third parity was 26, 22 and 22 kg, respectively. Mean lactation week with minimum LW increased with parity: 7, 11 and 13 weeks in first, second, and third parity, respectively. Variables derived from the LW curves had a large individual variation. Moreover, estimates for LOSS and MIN had a skewed distribution.

Correlations between CLW, LOSS, MIN and MLW within each parity are in Table 5. Calving weight was highly correlated with MLW (0·74 to 0·78). Calving weight had a moderate positive correlation (0·34 to 0·46) with LOSS and with MIN (0·17 to 0·29). Correlations of the same trait across parities were high for CLW and MLW, whereas they were low for MIN and MWL (Table 6). Based on the within and between animal variation, the repeatability for CLW, LOSS, MIN, and MLW were 0·54, 0·22, 0·12 and 0·75, respectively. Weekly means for LW across the lactation were highly correlated with MLW (Table 7): correlations were highest between 10 and 35 weeks in lactation. The correlations between weekly LW in first parity and MLW in first, second and third parity depended on lactation week and were on average 0·92, 0·70, and 0·71, respectively. Correlation between single weighings and weekly means, based on the records of the additional data, was 0·95.

Table 7 *Correlation between live weight at different lactation stages and mean live-weight during the first 305 days of lactation*

Lactation week	First parity	Second parity	Third parity
1	0·74	0·75	0·78
5	0·89	0·88	0·87
10	0·95	0·94	0·93
15	0·96	0·95	0·94
20	0·95	0·94	0·94
25	0·93	0·92	0·94
30	0·93	0·93	0·95
35	0·95	0·94	0·94
40	0·92	0·90	0·91
45	0·88	0·89	0·89

Discussion

Statistical analysis
The aim of this study was to quantify individual variation for LW and LW changes. Parameters were derived from adjusted phenotypic records on LW.

In other studies, models with biologically interpretable parameters such as the Wood function (Wood, 1967) were used. The Wood function explained only a small part of the variation for LW (Wood *et al.*, 1980; Berglund and Danell, 1987). Moreover, problems with systematic bias, especially in early lactation, might be expected (Cobby and Le Du, 1978).

Random regression models (RRM) and covariance functions can also be used for the analysis of repeated observations. These models describe individual variation in the shape of a LW curve, and are also able to account for heterogeneity of variance across the LW curve during lactation (e.g. Schaeffer and Dekkers, 1994; Andersen and Pedersen, 1996). When RRM using orthogonal polynomials was used in the present study and the log likelihood ratio test was used to test the significance of higher order polynomials, a high order polynomial was needed to describe LW data (results not shown). These techniques would have been more valuable if observations were only available at a low frequency and interest was in describing variance for lactation stages without observations (Kirkpatrick and Heckman, 1989).

Fixed effects
Adjustment factors were estimated from the data. Experimental group explained a large proportion of variance. This might be due to variation in nutrition but also due to variation caused by season of calving as the start of an experiment was largely confounded with season of calving. Results from field data (Hietanen and Ojala, 1995; Koenen and Groen, 1998) show a large variation between herds for LW.

In this study, the mean lactation stage with minimum weight increased with parity, whereas no systematic trend for the maximum weight loss was found. Berglund and Danell (1987) found an increased weight loss with increased parity: weight loss increased from 13 kg at 45 days in first parity to 17 kg at 60 days in third parity. Hohenbroken *et al.* (1995) found a negative relationship between rearing intensity and lactation stage with MLW and MIN. Korver *et al.* (1985) found for higher parity Holstein-Friesian cows on a concentrate diet a mean weight loss of over 50 kg at 88 days in lactation.

Estimated effects of parity on LW are in line with results of Touchberry and Batra (1976) and Miller *et al.* (1969) on Holstein-Friesian cows. The parity effects in this study could have been biased upwards as a result of selection for milk yield since positive correlations between LW and yield have been reported (Ahlborn and Dempfle, 1992). This hypothesis was tested by selecting those 124 heifers that had the opportunity to complete three lactations. Out of this group, 63 had records during all three lactations. When MLW means during lactation of these latter 63 cows were compared with heifers that were culled before third lactation no significant difference for unadjusted LW was found, indicating that the bias in this study is minimal.

Estimates for the effect of pregnancy varied widely between parities and were hard to predict. One of the problems in estimating the effect of parity could have been a confounding of days in lactation and days pregnant, especially in first parity cows. However, when age at calving was removed from the model for first parity cows, a contrast of around 50 kg was estimated. Based on field data, Koenen and Groen (1998) found an estimated effect of 28 kg when 8 months pregnant. Results from Bereskin and Touchberry (1967) indicated a weight of around 40 kg. Silvey and Haydock (1978) suggested that adjustment of LW data of lactating cattle for pregnancy stage is only needed in late lactation and in the dry period.

Variance components and correlations
Observations of weekly means in different weeks had a high repeatability. Repeatabilities of single weighings are expected to be lower than repeatabilities of weekly means. But as the estimated correlation between single weighings and weekly means were high (0·95) this implied that the correlation between single weighings and MLW is also high.

The high phenotypic correlations for MLW across parities are in agreement with results of Oldenbroek (1984) and Persuad *et al.* (1991). These correlations and the high repeatabilities within and across parities for most lactation weeks indicate that LW observations on heifers are suitable to predict MLW, not only during the first but also during the second and third lactation.

Conclusion
After adjustment for age at calving, experimental group, and pregnancy stage, LW observations are highly repeatable within and across parities. LW observations during lactation were highly correlated with estimated lactation MLW. It was concluded that single LW observations of heifers are a good measurement of LW during the first three parities.

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