Relationships among milk yield, body weight, and reproduction in Holstein and Czech Fleckvieh cows

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ABSTRACT: The objective of this study was to determine the dynamics and relative body weight (BW) changes after parturition and their relationships to milk yield in Holstein (H) and Czech Fleckvieh (F) cows, and also the relationships between their BW changes in the first 8 weeks of lactation and reproductive performance. A retrospective, observational study comprised analyses of individual cow records from a computerised herd management system. Production, body weight, and reproduction data were collected between December 2004 and February 2009 from F and H cows kept in a single experimental station. A total of 475 calving interval records (F: N = 132; H: N = 343) were included in the analysis. The data were evaluated using the mixed linear model with repeated measures, and parameters were estimated by the REML method. Whereas BW changes in F first-parity cows significantly ($P < 0.01$) differed from those detected in greater-parity cows during the major part of lactation, no such differences were manifested for H first-parity animals. The average BW change in weeks 1 to 8 was closely correlated with the BW change in the lactation week, with the lowest BW (NADIR) ($r > 0.83$, $P < 0.0001$) in both breeds. In H cows, the average BW change in weeks 1 to 8 and in NADIR significantly ($P < 0.01$) negatively correlated with the length of postpartum anoestrus, days between parturition and conception, days between first service and conception, and calving interval ($P < 0.05$ and $P < 0.01$, respectively). In F cows, the only significant correlations were those with days between parturition and first service ($P < 0.05$ and $P < 0.01$, respectively). It was concluded that BW changes postpartum might indicate reproduction problems particularly in H cows.

Keywords: dairy cow; negative energy balance; body weight; milk yield; reproduction

Negative energy balance (NEB) usually occurs in high-yielding dairy cows in early lactation when their energy expenditure is greater than their energy intake. NEB affects a number of physiological functions and especially reproductive performance of dairy cows after parturition. In order to ensure proper herd management and cows' reproduction, it is essential to estimate the extent and duration of NEB. Because of the difficulty of routine measuring the energy balance status, an indirect indicator – the body condition score (BCS) – is used. Together with the BCS, the body weight (BW) of cows also changes during the period of NEB. It was concluded in earlier studies that the changes in BCS and those in BW are two different traits (Veerkamp and Brotherstone, 1997; Berry et al., 2002, 2007). A relationship exists between BCS, relative BW change in maximum NEB, and the reduced reproductive performance of cows (van Straten et al., 2009). The authors also concluded that the parameters characterising relative BW changes are better predictors of reduced reproductive performance than the measures of absolute BW changes and can be used to estimate the individual adaptation to NEB.

However, to take advantage of the change of BW for herd management and cow reproduction, it is necessary to define more precisely the associations between BW and other traits.

It was previously reported that cattle breeds specialised for milk production have a greater ability to mobilize body reserves than dual-purpose breeds (Berglund and Danell, 1987). Therefore, they lose more BW, and the resulting NEB is associated with fertility and health problems (Domecq et al., 1997; Pryce et al., 2004).

BW changes are also affected by the parity of cows. Higher-parity dairy cows lose more BW in early lactation (Korver et al., 1985; Berglund and Danell, 1987). Also, the period with minimum BW increased with parity in Holstein cows, whereas no systematic trend for the maximum weight loss was found (Koenen et al., 1999). Holstein cows usually do not reach mature size before the age of 4 to 5 years (Hietanen and Ojala, 1995). Thus, less BW loss and the shorter period of BW recovery can also be explained by the growth of young animals.

Banos et al. (2005, 2006) investigated the possibility of selecting cows according to the changes in total body energy estimated on the basis of weekly determined BCS and BW in first-parity cows. This approach provided reliable predictions of this trait for subsequent parities as well. BW changes in the first 120 days of lactation in high-yielding cows were examined in detail in a study by van Straten et al. (2008). Older cows in early lactation suffered a longer period in NEB and lost more BW. However, the authors mentioned a large individual variability existing in these traits within parity groups and the necessity for further research to elucidate the relationships between BW changes, milk production, and reproductive performance.

As mentioned above, the changes in BW are influenced by a number of factors. However, to be able to exploit BW dynamics in herd management, it is necessary to determine its relationship to other traits. The first objective of this study was to determine the dynamics (kg) and relative (%) BW changes after parturition and their associations with milk yield in Holstein (dairy) and Czech Fleckvieh (dual-purpose) cows.

Knowledge of the relationships between BW changes and reproductive performance provides the insight essential for successful reproduction management. Cows losing more BW in early lactation conceived with greater likelihood than those with a greater BW loss (Westwood et al., 2002).

Heavier cows required more inseminations to conceive and had higher first service to conception intervals in several studies (Hansen et al., 1999; Veerkamp et al., 2000; Berry et al., 2002). These results were, however, not confirmed by other authors (Spiekers et al., 1991) and, to our knowledge, no studies evaluating the influence of BW changes during the entire calving interval on reproductive performance have been performed.

Relationships between milk yield, BCS, BW changes in early lactation, and reproduction can be used as important tools to identify cows at risk of poor reproductive performance (Buckley et al., 2003). Thus, the quantification of these relationships together with the use of modern milking parlours equipped with automated walk-through scales may provide the opportunity to reduce reproduction problems in high-yielding dairy herds. Increased severity and duration of NEB indicated by BCS and BW changes had a detrimental effect on all the reproduction parameters observed in a study with seasonal-calving Holstein cows (Roche et al., 2007). Positive effects of BCS at NADIR and BW changes following the first insemination as well as the deleterious effect of marked BCS loss after parturition on most reproductive performance parameters have been suggested. High negative correlations between the first luteal activity and the BW measured 100 days after parturition, and BW changes in the first 100 days of lactation were observed as well (Veerkamp et al., 2000).

The reports mentioned above provide evidence that the magnitude and pattern of BW changes in the first weeks of lactation are of utmost importance for the subsequent reproductive performance of cows. The mean BW change obtained on the basis of weekly BW changes might be a better predictor of NEB than the BW change measured at a specific time point. However, no analysis of the relationships between the BW changes in the first 8 weeks of lactation and reproductive performance has yet been performed, and, therefore, such an analysis was the objective of the second part of this study.

MATERIAL AND METHODS

Animals and feeding

Production, BW, and reproduction data were collected between December 2004 and February 2009

from Czech Fleckvieh (F) and Holstein (H) cows kept in the experimental station of the Institute of Animal Science in Prague. A total of 475 calving interval records (F: N = 132; H: N = 343) were included in the analysis. The animals were loose-housed in four interconnected straw-bedded barns and fed total mixed rations (TMR) designed according to the stage of lactation and reproduction cycle (four groups). The TMRs for early lactation first-parity and multiparous cows were formulated to allow milk yields of 30 and 40 kg, respectively.

Milk yield

Milk yields of individual cows were recorded twice a day at each milking and archived as daily milk yields (kg). Average daily milk yields were calculated for each of the weeks 1 to 43. Only cows with known milk yields for at least 25 weeks of lactation and those with at least five records of daily milk yield in any lactation week were selected for further analysis.

Body weight

BWs were recorded electronically twice a day using automatic walk-through scales located in the 2 × 5 tandem milking parlour, and the values were archived as average daily BWs. The average BWs in given lactation weeks (henceforth BW) were calculated for each cow. The BW in lactation week 1 (henceforth BW after parturition) was used as a reference value to determine the change of BWs during lactation (henceforth BW change) calculated as follows:

BW change (%) = (BW − BW after parturition) × 100/BW after parturition

As the predicted point of the lowest NEB, the lactation week with the lowest BW (henceforth NADIR) was determined, as well as the BW change during this week (henceforth BW change in NADIR). Similarly to milk yields, the average BW change in weeks 1 to 8 after parturition (henceforth BW change in weeks 1 to 8) was calculated. Only cows with known BWs for at least 25 weeks of lactation and those with at least four records of average daily BWs in any lactation week were selected for further analysis.

Reproduction

Records on insemination, conception, and calving of cows were used to determine the following basic reproduction parameters: days between parturition and first service (PFS), days between first service and conception (FSC), days open (days between parturition and conception, DO), calving interval (CI), and gestation length (GL). The length of post-partum anoestrus (LPA) was estimated on the basis of the pedometric activity of cows measured using pedometers attached to their hind legs. The number of steps was transmitted to a receiver located in the milking parlour and archived as the average number of steps per hour. The end of anoestrus and thus the onset of oestrus were proclaimed when the average number of steps per h in a given day was equal to or exceeded 190% of the average number of steps per h in the previous ten days (Berka et al., 2004).

Data handling and statistical analyses

Management, production, and reproduction data obtained were processed and archived using the modular computerised herd management system AFIFARM, version 3.02 (S.A.E., Afikim, Israel). The database was continually updated with animal and pedigree information (dates of birth, calving, culling, and breed, sire, dam) and reproduction records (date of the first and following services, date of conception).

All data were subjected to the exploration analysis aimed at testing the normality of distribution of different dependent variables and at identifying outliers. Basic descriptive statistics was calculated for each of the parameters observed.

Milk yield, BW and its changes in different cows as dependent variables were analysed using the mixed linear model with repeated measurements. Parameters were estimated using the REML method of the MIXED procedure in SAS (SAS Institute, 2006) in accordance with the following model:

$$Y_{ijklm} = \mu + S_i + B_j + L_k + W_l + LW_{kl} + BL_{jk} + BLW_{jkl} + e_{ijklm}$$

where:
Y_{ijklm} = dependent variable, alternatively milk yield (average milk yield in a given lactation week), BW (average BW in a given lactation week), or BW change (average difference between BW in a given lactation week and BW after parturition)

μ   = mean value
S_i = season (i = 1 to 17), trimestral periods from December 2004 to February 2009 (December to February; March to May; June to August; September to November)
B_j = breed (j = 1, 2), breeds F and H
L_k = number of lactation (k = 1 to 4)
W_l = week of lactation (l = 1 to 43)
LW_{kl} = interaction between number and week of lactation
BL_{jk} = interaction between breed and number of lactation
BLW_{jkl} = three-factorial interaction between breed, number of lactation, and week of lactation
e_{ijklm} = random error, $e_{ijklm} \sim \mathrm{N}(0, \sigma_e^2)$

In the model, random (co)variances between weeks in milk within lactation were summarized by residual **R** matrix, which was assumed to be a block diagonal with identical 43 × 43 submatrices, each corresponding to an individual lactation:

$$\mathbf{R} = \begin{bmatrix} \mathbf{R}_1 & & & \\ & \mathbf{R}_2 & & \\ & & \ldots & \\ & & & \mathbf{R}_n \end{bmatrix}$$

where: $\mathbf{R}_1 = \mathbf{R}_2 = \ldots = \mathbf{R}_n$

As alternatives, the compound symmetry, unstructured, autoregressive of order 1 and the Toeplitz covariance structures were compared. The Toeplitz covariance structure was found to be the most appropriate in accordance with Akaike's Information Criterion (AIC) and the Schwartz Bayesian Criterion (SBC) (Littell et al., 2000). The least square means were calculated and multiple comparisons were made with *P*-values adjusted using Tukey's procedure.

Pearson's correlation coefficients between milk yield, BW change, and reproduction parameters were determined using the CORR procedure in SAS (SAS Institute, 2006).

RESULTS AND DISCUSSION

Milk yield, BW, and reproduction parameters of Czech Fleckvieh and Holstein cows

Basic statistics of milk yield, BW, and reproduction parameters calculated separately for F and H cows from the experimental population are given in Table 1.

Body weight of cows after parturition

The least square means (LSM) of cow BWs in the first 43 weeks of lactation are shown in Figure 1. The pattern of BW changes was similar for both breeds. A relatively sharp decline of BW after parturition was followed by a moderate BW increase. At the end of the experimental period, the cows of both breeds had markedly higher BW compared to their BW after parturition. F cows had higher BW after parturition (*P* < 0.001) than H cows. The

Table 1. Descriptive statistics of milk yield, body weight, and reproduction parameters

Variable	Czech Fleckvieh cows			Holstein cows		
	N	mean	STD	*N*	mean	STD
Milk yield (kg/day)	132	26.7	5.28	343	32.8	5.97
BW after parturition (kg)	132	622	80.2	343	599	67.9
BW change week 1 to 8 (kg)	132	−18.4	22.02	343	−26.0	22.92
BW change in NADIR (kg)	132	−38.0	33.14	343	−47.6	30.42
Days of postpartum anoestrus	132	24.4	17.29	343	42.3	27.93
Days between parturition and first service	132	66.1	23.92	343	83.1	39.51
Days open	121	96	52.1	306	125	66.6
Calving interval (days)	101	382	53.4	236	403	64.4
Gestation length (days)	101	288	5.2	236	280	9.2

BW = body weight, NADIR = lactation week with the lowest BW

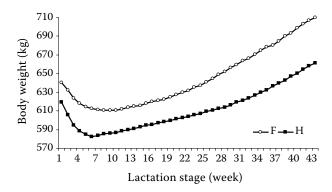Figure 1. Least square means of body weight in Czech Fleckvieh (F) and Holstein (H) cows

Figure 2. Relative body weight change in Czech Fleckvieh (F) and Holstein (H) cows

initial difference in BW (21 kg) between the breeds continually increased after week 20 until it reached 49 kg at the end of the period. Figure 1 also demonstrates that H cows reduced their BW more rapidly and reached NADIR in week 6 postpartum, whereas F cows reached NADIR in week 8 postpartum.

Relative BW changes (%) in both breeds are shown in Figure 2. The lowest LSM of BW change for F and H cows was determined in week 6 (–4.0 ± 0.54%) and in week 8 (–5.5 ± 0.35%), respectively. At the end of the analysed period, F and H cows had 9.6 ± 0.61 and 6.5 ± 0.39%, respectively, higher BW compared to their BW after parturition. It is apparent that the entire range of relative BW change during the 43 weeks postpartum was 13.6 and 12.0% for F and H cows, respectively. The most distinctive breed differences in BW were observed at the end of the period analysed.

Large variation in BW between herds has been previously reported (Hietanen and Ojala, 1995; Koenen and Groen, 1998). The development of BW of H cows during lactation observed in our study was widely in agreement with previous reports
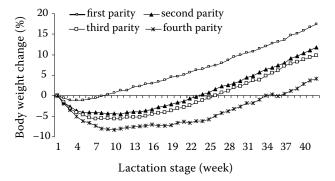
(Koenen et al., 1999; van Straten et al., 2008). To our knowledge, no similar study involving F or any other dual-purpose breed has yet been published. The more rapid BW loss observed in H cows indicates a greater ability to mobilize body reserves in high-producing dairy breeds compared to those with combined milk and beef production (Berglund and Danell, 1987).

As a significant ($P < 0.001$) interaction between breed, number of lactation and lactation week on relative BW change was detected, a more detailed analysis became necessary, and its results are demonstrated in Figures 3 and 4.

In the F breed, the most distinct development of BW changes was observed in first-parity cows. Whereas the BW changes in F first-parity cows significantly ($P < 0.01$) differed from those detected in greater-parity cows during the major part of lactation, no such differences were manifested for H first-parity animals. Marked BW changes were also found for fourth-parity F cows, but these estimates might be biased by a relatively high standard error due to the low number of animals in the group.

Figure 3. Relative body weight change in Czech Fleckvieh cows of different parity

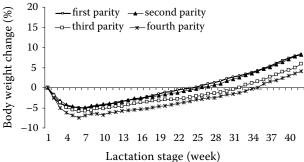Figure 4. Relative body weight change in Holstein cows of different parity

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In agreement with our results, similar development of BW changes postpartum in H first- and greater-parity cows was reported by Roche et al. (2007). In another study, however, significant differences in relative BW changes in NADIR between H first- and greater-parity cows (6.5 and 8.5%, respectively) and also in time space to NADIR (29 and 34 days, respectively) were reported (van Straten et al., 2008).

Only a slight loss of BW postpartum in F cows compared to H cows (Figures 2 and 3) seems to be due to marked differences between breeds in the milk yield of first-parity cows (Figures 5 and 6). Holstein cows were exposed to a more severe NEB accompanied by a more extensive loss of BW postpartum due to higher milk production. However, this line of reasoning does not provide an explanation as to why there was no difference in BW change postpartum between H first-parity and second- or third-parity cows when the differences in peak milk yields were 12.3 and 12.4 kg, respectively. This may have been influenced by specific herd conditions, higher energy requirements, and increased susceptibility to energy depletion in young animals.

It is also necessary to take into consideration that an increase in BW postpartum does not always indicate that a cow is in a state of positive energy balance (Butler and Smith, 1989). This is mainly due to the effect of an increasing gut fill (Roche et al., 2007). In addition, older cows reach maximum feed intake (Bossen et al., 2009). Nevertheless, rapid gain in BW, though due to increased gut fill, could be considered a beneficial property with respect to adaptation to NEB (van Straten et al., 2008).

In agreement with other studies (Koenen et al., 1999; Roche et al., 2007; van Straten et al., 2008), greater-parity cows tended toward higher BW loss in the first months of lactation, a longer time needed to reach the original BW, and less excess of the original BW by the end of the lactation period observed. This tendency was more pronounced in F than in H cows.

Milk yield and its relationship to BW changes

As expected, the differences in daily milk yields between breeds were highly significant ($P < 0.001$) throughout the period analysed. Detailed milk yields of F and H cows of different parities are shown in Figures 5 and 6. First-parity cows of both breeds clearly exhibited lower milk yields in the first 30 weeks of lactation than greater-parity cows. Although H cows produced more milk than F cows regardless of parity, the differences between greater parity cows were reduced in size.

The peak milk yields of F and H first-parity cows were recorded in weeks 7 and 6, respectively, and the difference was 7 kg of milk ($P < 0.001$). In agreement with our results, the peak milk yield was reached on the average 37 days after parturition in 166 000 first-parity H cows (Dědková and Němcová, 2003).

Relationships between BW changes and reproduction parameters

The ability of cows to adapt to the stress of the organism in the first weeks of lactation is the main factor influencing their health status and reproduction parameters. Thus, the period of the first two months postpartum is clearly decisive for the development of BW during the entire calving interval.

The results of correlation analysis determining the relationships between the BW change in weeks 1 to 8, BW change in NADIR and basic repro-
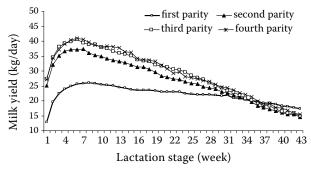

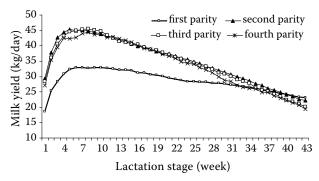Figure 5. Milk yield of different parity Czech Fleckvieh cows

Figure 6. Milk yield of different parity Holstein cows

Table 2. Pearson's correlation coefficients between the average body weight change in weeks 1 to 8 postpartum, BW change in NADIR, and reproduction parameters

Variable	Czech Fleckvieh cows			Holstein cows		
	N	BW change in weeks 1–8	BW change in NADIR	N	BW change in weeks 1–8	BW change in NADIR
Days of postpartum anoestrus	132	–0.078	–0.062	343	–0.175**	–0.244***
Days between parturition and first service	132	–0.194*	–0.237**	343	–0.062	–0.110*
Days open	121	–0.145	–0.116	306	–0.171**	–0.197**
Calving interval (days)	101	–0.118	–0.123	236	–0.155*	–0.162*
Gestation length (days)	101	0.072	0.084	236	0.060	0.051
Days between first service and conception	121	–0.052	0.004	306	–0.159**	–0.163**
BW change in NADIR (kg)	132	0.877***		343	0.839***	

BW = body weight, NADIR = lactation week with the lowest BW
$*P < 0.05$, $**P < 0.01$, $***P < 0.001$

duction parameters are given in Table 2. In H cows, the average BW change in weeks 1 to 8 significantly negatively correlated with LPA ($P = 0.001$), DO ($P = 0.003$), CI ($P = 0.017$), and FSC ($P = 0.005$). In F cows, the only significant correlation was with PFS ($P = 0.026$). The average BW change in weeks 1 to 8 was closely correlated with BW change in NADIR ($r > 0.83$; $P < 0.0001$) in both breeds.

Body weight change in NADIR observed in H cows was significantly correlated ($P < 0.001$) with LPA and DO as well as with FSC ($P = 0.004$), PFS ($P = 0.042$), and CI ($P = 0.013$). In F cows, correlation coefficients lacked statistical significance ($P > 0.05$) with the exception of PFS ($P = 0.006$). However, the PFS parameter is largely dependent on herd management. It seems likely that it was rather a herd management decision to extend PFS, particularly in F cows with a marked BW change, than the result of this change. The NEB in F cows probably did not reach the level which would have negatively affected LPA and other reproduction parameters. The results of BW changes postpartum obtained in the present study might indicate reproduction problems particularly in H cows.

The investigation of the relationships between BW change postpartum and reproduction revealed that the conception rate was significantly higher in the cows gaining BW compared to those losing BW (Youdan and King, 1977). Furthermore, a positive effect of BW gain 4 weeks prior to insemination on the conception rate was determined (Fulkerson et al., 2001). Westwood et al. (2002) concluded that cows with a lower BW loss during the first 42 days postpartum were more likely to conceive than cows

losing more BW in early lactation. On the contrary, it has been reported in several studies (Hansen et al., 1999; Veerkamp et al., 2000; Berry et al., 2002) that heavy cows need more services to conceive and have a higher FSC. Generally, the most suitable indicator with respect to the energy balance is not an absolute BW but its changes.

These conclusions are also supported by the results of studies in which BC and its changes were used as an indicator of NEB (Gillund et al., 2001; Pryce et al., 2001; Stockdale, 2001; Jílek et al., 2008). Cows of dual-purpose breeds exhibited less severe change of BC (NEB) with respect to reproduction. Thus, the severity and duration of NEB is usually within physiologically tolerated limits in these breeds (Jílek et al., 2006). The relationship existing between BW, BC, and reproduction efficiency of cows has been confirmed (Koenen et al., 1999; Fulkerson et al., 2001; Buckley et al., 2003; Jílek et al., 2008), and, therefore, new possibilities for the technical equipment of milking parlours, information technologies, and sophisticated analytical methods are emerging (van Straten et al., 2008; Bossen and Weisbjerg, 2009; Bossen et al., 2009) as efficient tools for the management of health and reproduction disorders in high-yielding dairy herds.

CONCLUSION

Overall dynamics and evolution of BW after parturition was similar for F and H cows. A relatively rapid decrease of BW in early lactation weeks was followed by a rather slow weight increase and the

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cows of both breeds were heavier at the end of the monitored part of their calving intervals than after parturition. The BW reduction was lower and occurred for a longer time in F compared to H cows. The F cows regained the same weight as that after parturition faster compared to the H cows.

The BW change in weeks 1 to 8 of lactation and BW change in NADIR were negatively correlated with all the reproduction parameters observed (except for gestation length) in both F and H cows. However, the correlations found for the F breed were mostly lower in magnitude and lacked statistical significance. It can be concluded that the monitoring of BW after parturition can be used as a management tool to prevent reproduction problems especially in top production dairy herds.

Acknowledgement

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