Associations among patterns in daily body weight, body condition scoring, and reproductive performance in high-producing dairy cows

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ABSTRACT

The objective was to investigate the associations between body condition scores (BCS) and daily body weight (BW) in the first 150 d of lactation (DIM) and reproductive performance in high-producing dairy cows. Data included automated daily BW measurements and BCS of 2,020 Israeli Holstein cows from 7 commercial farms. Individual BW series were smoothed using penalized cubic splines, and variables representing BW patterns were generated. The presence of 7- and 21-d cycles in BW was determined using time-series analysis. Associations between BW and BCS and conception at first artificial insemination (AI) were analyzed using generalized estimating equations. Multivariate survival analysis was used for associations between BW and BCS and the calving-to-first AI interval, first AI-to-conception interval, and calving-to-conception interval. First-parity cows that lost $\geq 12\%$ and second-parity cows that lost $\geq 15\%$ of their BW from calving to nadir BW were less likely to conceive at first AI. Cows without 7-d cycles in BW were 1.48 times more likely to conceive at first AI relative to cows with 7-d cycles. The odds of conceiving at first AI increased by 53% for each additional unit in BCS from 40 to 60 DIM. In the multivariate survival analysis, a BCS of ≤ 2.5 between 40 and 60 DIM, the percentage of BW lost from calving to nadir BW, and a BW loss of $\geq 7\%$ from calving to 10 DIM were associated with reduced reproductive performance. The presence of 21-d cycles in BW was associated with high reproductive performance in first-parity [odds ratio (OR) = 1.18] and second-parity cows (OR = 1.22). The presence of 7-d cycles in BW was associated with low reproductive performance in first-parity cows (OR = 0.77), but not in older cows. Based on previous findings and on the associations found in this study, we postulate that 21-d cycles are probably related to the

sexual cycle and could be used as a proxy for assessing ovarian activity. Variables representing relative BW loss (%) were better predictors for impaired reproductive performance than those representing absolute BW loss (kg) and may be more suitable for estimating individual adaptation to negative energy balance in herds for which automated daily BW is available.

Key words: body weight, dairy cow, body condition scoring, reproduction

INTRODUCTION

Negative energy balance (NEB) is considered a physiological phenomenon in high-yielding dairy cows in early lactation (Goff and Horst, 1997), during which cattle undergo an energy deficit because maximum milk production is attained before maximum feed consumption. Because almost all cows undergo a state of NEB in early lactation from which they eventually recover, Jorritsma et al. (2003) suggested the use of the term "adaptation to NEB." They defined cows as less adapted when certain risk factors, such as a longer lasting or more deeply calculated NEB or certain biochemical, endocrinological, or (sub)clinical characteristics, were present. However, the degree of adaptation per cow is difficult to determine, and many risk factors have been investigated and proposed.

Changes in energy balance in early lactation are accompanied by body fat mobilization and changes in BW. Therefore, BCS and BW were proposed as managerial tools and as estimators for adaptation to NEB (Maltz, 1997; Coffey et al., 2001). Various studies have shown positive (Suriyasathaporn et al., 1998; Roche et al. 2007), negative (Heuer et al., 1999), or no (Markusfeld et al., 1997; Gillund et al., 2001) association between BCS at calving and the probability of conceiving at first AI. Markusfeld et al. (1997) found that cows with a higher BCS postpartum were less prone to anestrus. Losses in BCS between calving and first AI negatively affected the likelihood of conception (Gillund et al., 2001; Roche et al., 2007) and were associated with pro-

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longed calving-to-conception intervals (Suriyasathaporn et al., 1998; Gillund et al., 2001). Cows with low BCS between 45 d postpartum and first AI were less likely to conceive (Buckley et al., 2003; Patton et al., 2007; Roche et al., 2007). Low postpartum BCS was genetically correlated with a longer interval to commencement of luteal activity (Royal et al., 2002), a prolonged calving interval (Pryce et al., 2000), and more days to first service and days open (Dechow et al., 2004).

Buckley et al. (2003), using individual BW measured at 2.5- to 5-wk intervals, found that a higher BW gain in the 90 d after the beginning of breeding was associated with higher rates of submission for breeding and higher rates of pregnancy to first service. Roche et al. (2007) found significant relationships between reproductive performance and BW and BCS or changes in BW and BCS during early lactation. Reproductive performance was negatively affected when BW and BCS measurements indicated a postpartum NEB of increased severity and duration.

Previously, daily BW changes during the first 120 d of lactation were quantified in high-producing dairy cows (van Straten et al., 2008), demonstrating the presence of 7- and 21-d cycles. Furthermore, the presence of 21-d cycles in individual BW was associated with decreased odds of being diagnosed with inactive ovaries. The objective was to determine associations between BCS and individual daily BW characteristics and reproductive performance. More specifically, BCS and variables generated from multiple time series of automated daily BW measurements in the first 150 d of lactation were used to investigate their associations with the odds of conception at first AI and with the intervals of calving to first AI, first AI to conception, and calving to conception in high-producing dairy cows on commercial dairy farms.

MATERIALS AND METHODS

Study Design and Population

The study was designed as an observational, prospective cohort study and was conducted in a convenience sample of 7 typical Israeli commercial dairy farms from different geographical regions in Israel. The study population consisted of high-producing Israeli Holstein cows kept under zero grazing in open sheds. All farms fed a TMR ad libitum. Breeding was by AI. The farms included BW measured daily, using automated walk-through scales (S.A.E., Kibbutz Afikim, Israel) connected to the farm computer (Afifarm computerized milking and management software, Kibbutz Afikim, Israel), and were willing to participate. Herd size ranged from 251 to 824 cows.

The farms were members of the Israel Cattle Breeders Association, performed monthly milk recordings, and participated in the Herd Health Program of "Hachak-lait," the Mutual Society for Veterinary Services (Caesarea Industrial Park, Israel). Within this program, each farm was assigned an attending veterinarian who performed all diagnostic, routine, and emergency clinical work. All cows were examined 5 to 14 d postpartum for uterine disease. Sick cows and cows with an average daily milk production <25 kg were checked for ketosis. Pregnancy was detected by rectal palpation between 40 and 45 d after AI. These data, in parallel with management, health, production, and reproduction data, were recorded by and stored on the farm computer using either NOA (acronym derived from Hebrew for "Management of Cattle Herds," Israel Cattle Breeders Association) or Afifarm management software. Geographical location, herd size, and milk production were described previously (van Straten et al., 2008).

During the months of March and June 2006, scales on all farms were calibrated. In addition, scales were calibrated approximately every 4 mo. For each farm, the study period began after initial calibration, included 1 yr of calvings, and ended 180 d after the last cow calved.

Data Management and Statistical Analyses

All data management and analyses were performed using SAS version 9.1 (SAS Institute, 2006). Results were considered statistically significant if P was <0.05.

Calving, Management, Daily Milk Production, and Reproduction. Data for calving, management, daily milk production (kg), and reproduction were retrieved from the farm computer. Definitions of the variables used are summarized in Table 1. Body condition score (5-point scale, where 1 = emaciated and 5 = obese) was assigned by the attending veterinarian at 5 to 14 d after calving (**BCS1**) and 40 to 60 d postpartum (**BCS50**). Changes in BCS during the first 50 d of lactation were obtained by subtracting BCS50 from BCS1. Although it is highly likely that some variation existed between the 6 attending veterinarians performing the BCS, this variation was neither estimated nor taken into account. The average voluntary waiting periods (**VWP**) implemented by the farms participating were representative of Israeli dairy farms in general, and ranged from 94 to 118, 79 to 112, and 76 to 121 DIM for cows of first, second, and third parity and greater, respectively, with the exception of 1 farm that implemented an average VWP of 133 DIM for cows of second parity and greater. Data regarding AI and their outcomes were available only for the first AI and for the AI that resulted in conception. Daily milk produc-

Table 1. Definitions of variables used in the analysis for determining patterns in daily BW, BCS, and reproductive performance in high-producing dairy cows

Variable	Definition
Milk fever	Periparturient recumbency, treated with calcium
Stillborn calf	Calf dead within 24 h of calving
Retained placenta	Placental membranes visible in vulva at least 24 h after calving
Metritis	Abnormal vaginal discharge with or without systemic disease at routine inspection 5 to 14 d postpartum
Displaced abomasum	Clinically diagnosed by attending veterinarian
Ketosis	Urine acetoacetic acid concentration ≥ 1.5 mmol/L ¹
Unobserved heat	Cows presented to the attending veterinarian after the voluntary waiting period with the complaint of not being observed in heat
Inactive ovaries	Cows with unobserved heat rectally examined twice by the attending veterinarian (1-wk interval) with no corpus luteum
Summer calving	Calving in the months June to September
Summer insemination	First AI occurring in the months June to September
90-d milk production	Cumulative daily milk production (kg) from calving to 90 d in lactation

¹Ketostix, Bayer (Dublin, Ireland).

tion (kg), which was available from 1 to 90 DIM, was summed and used as cumulative 90-d milk production.

Daily BW Data Editing. Cows were automatically weighed on their return from the milking parlor 3 times daily, and the 3 measurements were arithmetically averaged for further analysis. Daily BW measurements from the first 150 DIM were included in the analysis. Each subject (a cow within a given lactation) was assigned a unique identification number based on its herd book, farm, and parity numbers. Variables representing BW changes in early lactation were generated by smoothing individual BW measurements using penalized cubic splines. This procedure used a nonparametric model with penalized least squares estimates for each subject. The time unit DIM was included in the model as a single smoothing variable. As many unique design points as BW measurements were used for each time series, and the trade-off between goodness of fit and smoothness was determined by minimizing the generalized cross-validation function (PROC TPSPLINE; SAS Institute, 2006). A detailed description of the model can be found elsewhere (van Straten et al., 2008).

BW-Related Variables. Variables representing absolute or relative BW and change in BW were used in the different models. Body weight at calving was defined as the smoothed value for BW (kg) at calving, and BW at nadir was defined as the smoothed value for BW (kg) at the nadir BW. Absolute BW changes were calculated by subtracting the smoothed BW of any given day from the smoothed BW at calving. Relative BW change was calculated as

$$\text{Relative BW change} = \frac{BW_C - BW_T}{BW_C},$$

where BW_T is the smoothed BW on any given day in lactation and BW_C is BW at calving. Analyses used

the absolute and relative BW change from calving to d 10 in lactation (**BWL10** and **RBWL10**, respectively), to d 20 in lactation (**BWL20** and **RBWL20**, respectively), and at nadir BW (**BWLCN** and **RBWLCN**, respectively). Losses in BW were indicated by positive numbers for absolute and relative BW changes, whereas gains in BW were indicated by negative numbers.

For each cow, the number of days from calving to nadir BW was determined. The variables BW at nadir, number of days from calving to nadir BW, **BWL10**, **RBWL10**, **BWL20**, **RBWL20**, **BWLCN**, and **RBWLCN** were dichotomized. If any of the values of these variables for a certain cow belonged to the upper quartile, indicating greater absolute or relative BW loss or loss of BW for a greater number of days, the value of the corresponding dichotomous variable was set to 1. Otherwise, the value was set to 0. Upper quartiles were determined for first-parity cows (**PAR1**), second-parity cows (**PAR2**), and cows of third parity and greater (**PAR3**) separately, because significant differences were found in these variables across the different parity groups. If, during model building, a certain variable showed a significant relationship with the outcome of interest in both its continuous and dichotomous forms, the form that gave the smallest Akaike's information criterion was chosen.

A dichotomous variable indicating whether a cow was inseminated for the first time before nadir BW was reached (**BWLAI**) was created. If the number of days from calving to nadir BW was greater than or equal to the number of days from calving to first AI, the value of the variable **BWLAI** was set to 1. If this was not the case, the value of **BWLAI** was set to 0.

Time-Series Analysis. To determine whether 7- or 21-d cycles were present in individual BW measurements (i.e., BW measurements from 1 cow), BW measurements were analyzed from each cow separately. As such, classical time-series techniques were used in

Table 2. Number of valid observations (n), mean $\pm$ SD, and minimum and maximum values for BCS, BW-related variables, and cumulative 90-d milk production, stratified by parity group

Variable	First parity					Second parity					Third parity and greater				
	n	Mean	SD	Minimum	Maximum	n	Mean	SD	Minimum	Maximum	n	Mean	SD	Minimum	Maximum
BCS at calving	787	3.0	0.4	2.00	4.50	684	3.0	0.4	1.75	4.25	925	3.2	0.4	2.00	4.75
BCS 40 to 60 d postpartum	686	2.7	0.4	1.50	4.25	529	2.6	0.4	1.50	4.00	695	2.6	0.4	1.25	3.75
BW (kg) at calving	814	535.0	54.2	275.6	715.7	686	633.8	57.9	446.6	873.8	931	692.8	64.8	344.8	971.3
BW (kg) at nadir	781	484.2	49.2	361.6	656.0	589	559.5	56.8	405.9	750.1	743	608.1	58.6	317.0	798.5
BW loss (kg) within 10 d of calving	806	25.6	22.6	-94.0	136.4	666	31.9	23.1	-164.4	130.4	910	32.4	24.9	-123.0	150.7
BW loss (%) within 10 d of calving	806	4.7	4.2	-21.3	25.1	666	5.0	3.8	-17.4	34.4	910	4.6	3.6	-21.4	22.0
BW loss (kg) within 20 d of calving	798	36.4	26.7	-107.0	134.5	667	49.0	28.7	-105.4	169.5	914	51.8	31.3	-82.5	178.9
BW loss (%) within 20 d of calving	798	6.7	4.9	-22.3	28.6	667	7.6	4.5	-22.7	22.1	914	7.3	4.3	-22.7	14.8
BW loss (kg) from calving to nadir	781	51.8	35.0	0	236.8	589	75.1	41.2	0	269.5	743	86.1	48.7	0	383.0
BW loss (%) from calving to nadir	781	9.5	6.0	0	38.5	589	11.7	6.1	0	35.9	743	12.2	6.5	0	54.7
Days to nadir BW	781	41.6	35.1	1	150	589	65.3	42.8	1	150	743	74.0	45.0	1	150
Cumulative 90-d milk production (kg)	798	2,904.4	403.0	1,212.9	4,347.6	676	4,013.7	515.9	2,203.9	5,648.6	915	4,271.2	572.8	1,390.2	6,458.1

which the time series were represented additively as the sum of the trend component, the periodic component, and the “white noise” or random error component (van Straten et al., 2008). Briefly, the trend of the time series was represented by polynomial functions of the variable DIM up to the eighth order, and the periodic component of the time series was represented by pairs of sine and cosine functions chosen a priori to represent 7- and 21-d cycles, respectively. The polynomial-harmonic regression was performed using the SAS procedure PROC REG (SAS Institute, 2006). Two dichotomous variables were constructed: the first for the presence of a 7-d cycle that was set to “1” if a significant 7-d cycle was found, and the second for the presence of a 21-d cycle that was set to “1” if a significant 21-d cycle was found in the model.

Inclusion Criteria and Handling of Missing Data. The criteria for the inclusion of data in the different analyses and the methodology used for handling missing BW measurements are described in the Appendix. The number of observations available for analysis and the values for BCS, BW-related variables, and 90-d milk production are shown in Table 2.

Data Imputation. The BCS50 was missing from the data of 2 farms. Because this variable was associated with the outcomes of interest, and because it was necessary to include the data from these farms in the analyses, the missing values of BCS50 from these 2 farms were predicted using a linear regression model. The methodology is presented and discussed in the Appendix.

Relationship Between Conception at First AI and Other Covariates. A generalized estimating equations regression model was used to adjust for clustering of the data at the farm level. The logit link function was chosen, and the covariance structure used for the working matrix **M** was compound symmetry. Thus, the underlying assumption was that any 2 observations from the same farm showed the same correlation, but that observations from different farms were uncorrelated. The level of significance associated with the independent variables was based on the generalized estimating equations score statistic (PROC GENMOD; SAS Institute, 2006).

Before inclusion in the model, the associations between the dependent variable and potential independent variables were tested using either the chi-square test for independence, in the case of categorical variables, or the *t*-test for independent samples, in the case of continuous variables. Independent variables significantly associated with the dependent variable were then investigated for the presence of collinearity using the same tests. Finally, the significant independent variables were consecutively entered into the model using the Wald test as the test

for significance. Odds ratios (**OR**) were obtained by exponentiation of model (PROC GENMOD; SAS Institute, 2006) regression coefficients.

Analysis of Time to Event Data. Time from calving to first AI, time from first AI to conception, and time from calving to conception were analyzed by multivariable survival analysis using Cox regression (PROC PHREG; SAS Institute, 2006). Although a Cox regression models the time to event, the output is expressed either as a hazard ratio (the conditional, instantaneous relative probability of an event between groups) in the case of a continuous time measurement or, in the case of a discrete time measurement, as an OR or discrete-time hazard (the conditional relative probability of an event between groups in a time interval). Variables that decrease or increase the hazard ratio (OR) lengthen or shorten, respectively, the time to event. In the analysis of time to event data, the treatment of ties (2 or more events occurring at the same time) should receive considerable attention. The data were heavily tied, making Breslow's approximation (the default of PROC PHREG) for the formula of the partial likelihood less suitable (Allison, 1995). The ties in our data were assumed the result of discrete time measurement (i.e., time units of days) rather than the grouping of continuous, untied data. Consequently, the DISCRETE option in PROC PHREG was used, and the resulting model was not a proportional hazard model, but a proportional odds model, as proposed by Cox:

$$\log\left(\frac{P_{it}}{1 - P_{it}}\right) = \alpha_t + \beta_1 x_{i1} + \dots + \beta_k x_{ik},$$

where P_{it} is the conditional probability that individual i experienced an event at time t given that an event had not already been experienced by that individual, α_t is a constant, and x is a set of k fixed covariates with corresponding coefficients β . The interpretation of the OR obtained from a proportional odds model is analogous to the interpretation of one obtained from a logistic regression model: OR >1 or <1 indicates the increased or decreased probability, respectively, of an event occurring.

Before its inclusion in the model, the association between time to event and potential independent variables was tested using either the Kaplan-Meier method (PROC LIFETEST; SAS Institute, 2006) for categorical variables or a Cox regression model with the single covariate in the case of a continuous variable. Subsequently, the significant independent variables were entered consecutively into the model using the Wald

chi-square as a test for significance. For these Wald tests, the robust sandwich estimate of Lin and Wei (1989) for the covariance matrix was used to account for clustering at the farm level (COVSANDWICH option in PROC PHREG).

Finally, to test whether the model needed extension to allow for nonproportional odds, the presence of time-dependent variables was tested for, when this seemed biologically plausible, by including interactions between the logarithm of time to event and a covariate. Because the effects of the different independent variables on the odds of an event occurring varied considerably by parity group, the analysis was stratified according to this variable.

RESULTS

Conception at First AI

Data from 2,020 cows were used for the models. Overall, 664 cows (32.9%) conceived at first AI. Univariate and multivariate associations are shown in Table 3. Coefficients estimated using predicted BCS50 values were within the 95% confidence intervals of those estimated using actual BCS50 values, and statistically significant variables were identical in both models. A cow belonged to the upper quartile in relative BW loss from calving to nadir BW (**UQLCN**) if it lost ≥ 12.3 , ≥ 15.0 , and $\geq 15.7\%$ of its BW from calving to nadir for PAR1, PAR2, and PAR3, respectively.

The odds of conceiving at first AI were significantly decreased for cows that belonged to the UQLCN and that exhibited 7-d cycles in BW, whereas the odds were increased with each additional unit of BCS50 (Table 3). However, in an expanded model, interaction terms between UQLCN, BCS50, and the 3 parity groups were significant, whereas the independent effects of UQLCN and BCS50 lost significance, indicating that the effects for BCS50 and UQLCN were parity-group dependent.

Time to Event Data

Calving to First AI. The odds of AI on a given day after calving for PAR1 ($n = 744$) decreased by 21% if the cow lost $\geq 7\%$ of its BW from calving to 10 DIM (i.e., belonged to the upper quartile) and by 26% if diagnosed with ketosis (Table 4). Similarly, the odds of AI increased by 18% for cows with 21-d cycles in BW and by 1% for each additional 10 kg of BW at nadir.

For PAR2 ($n = 673$), the odds of AI on a given day after calving decreased by 33% for cows with a BCS1 of <2.50 compared with those with a BCS1 between 2.50 and 3.50 and by 21% for those with a BCS50 of <2.50 compared with those with a BCS50 between 2.50 and

Table 3. Univariate and multivariate analysis (using a generalized estimating equations model) of variables associated with the odds of conceiving at first AI¹

Variable	Univariate: OR ² (95% CI ³)	Multivariate: OR (95% CI)	Multivariate with interactions: OR (95% CI)
Parity			
1	1.31 (1.07, 1.61)	1.48 (1.28, 1.70)	0.22 (0.04, 1.14)
2	1.43 (1.24, 1.65)	1.45 (1.29, 1.63)	0.17 (0.02, 1.55)
3 and above	1	1	1.00
BCS50 ⁴	1.68 (1.37, 2.06)	1.53 (1.15, 2.02)	1.04 (0.65, 1.67)
Summer insemination			
No	1.60 (1.15, 2.10)	1.68 (1.18, 2.38)	1.69 (1.18, 2.42)
Yes	1	1	1
Ketosis			
No	1.48 (1.16, 1.88)		
Yes	1		
Change in BCS from calving to BCS50	0.71 (0.59, 0.87)		
BW (kg) at calving	0.999 (0.997, 1.000)		
Days to nadir BW	0.997 (0.995, 0.997)		
BW loss (kg) first 20 DIM	0.997 (0.995, 0.999)		
UQLCN ⁵			
No	1.25 (1.04, 1.52)	1.24 (1.04, 1.49)	1.01 (0.74, 1.39)
Yes	1	1	1
Inseminated before nadir BW			
No	1.27 (1.03, 1.55)		
Yes	1		
7-d cycle in BW			
Absent	1.31 (0.97, 1.77)	1.46 (1.02, 2.08)	1.48 (1.03, 2.12)
Present	1	1	1
BCS50 × parity			
BCS50 × parity 1			1.91 (1.03, 3.56)
BCS50 × parity 2			2.04 (0.89, 4.63)
BCS50 × parity ≥3			1
Parity × UQLCN			
Parity 1 × UQLCN no			1.29 (0.89, 1.87)
Parity 1 × UQLCN yes			1
Parity 2 × UQLCN no			1.49 (1.13, 1.95)
Parity 2 × UQLCN yes			1
Parity 3 × UQLCN no			1
Parity 3 × UQLCN yes			1

¹Blank cells were not significant.²OR = odds ratio, adjusted for farm.³CI = confidence interval.⁴BCS50 = BCS between 40 and 60 DIM.⁵UQLCN = upper quartile in BW loss (%) from calving to nadir BW.

3.50. The odds of AI were 4.6 times greater for PAR2 cows with a BCS50 >3.50 compared with those with a BCS50 between 2.50 and 3.50. The odds of AI on a given day after calving in PAR3 (n = 863) decreased by 26% for cows with a BCS50 of <2.50 compared with those with a BCS50 between 2.50 and 3.50 and by 17% for cows with 21-d cycles in BW.

First AI to Conception. For PAR1 (n = 743), the odds of conceiving on a given day after AI decreased by 28% if the cow lost >12.3% of its BW from calving to nadir and by 21% if a 7-d cycle was present in BW (Table 4). The odds of conceiving increased by 47% for each increase in BCS50.

The odds of conceiving on a given day after first AI in PAR2 (n = 675) increased by 99% for each unit increase in BCS50. In PAR3 (n = 726), the odds of

conceiving on a given day after first AI decreased by 2% for each 1% loss in BW from calving to nadir and increased by 71% if a 7-d cycle was present in BW.

Calving to Conception. The odds of conceiving on a given day after calving in PAR1 (n = 759) decreased by 24% if the cow lost ≥7% of its BW from calving to 10 DIM and by 23% if 7-d cycles in BW were present (Table 4). The odds of conceiving increased by 57% for each unit increase in BCS50.

The odds of conceiving on a given day after calving in PAR2 (n = 647) decreased by 24% for cows with a BCS1 <2.50 compared with cows with a BCS1 between 2.50 and 3.50. The odds of conceiving were 2.14 times greater for each extra BCS50 unit and increased by 22% if 21-d cycles in individual BW measurements were present.

Table 4. Odds ratios (OR)¹ and 95% confidence intervals (CI) for the effect of variables that affected ($P < 0.05$) the intervals of calving to AI, AI to conception, and calving to conception for cows of first, second, and third parity and greater, estimated by proportional odds models

Parity group	Variable	Calving to insemination: OR (95% CI)	Insemination to conception: OR (95% CI)	Calving to conception: OR (95% CI)
Parity 1, n		744	743	759
	UQL10 ²	0.79 (0.67, 0.94)		0.76 (0.64, 0.89)
	Ketosis	0.74 (0.62, 0.88)		
	21-d cycle BW	1.18 (1.02, 1.37)		
	BW at nadir (kg)	1.01 (1.00, 1.03)		
	Summer AI		0.66 (0.51, 0.84)	0.75 (0.58, 0.96)
	UQLCN ³		0.72 (0.61, 0.85)	
	BCS50 ⁴		1.47 (1.11, 1.93)	1.57 (1.13, 2.17)
	7-d cycle BW		0.79 (0.63, 1.00)	0.77 (0.61, 0.96)
Parity 2, n		673	675	647
	BCS1 ⁵ <2.50	0.67 (0.54, 0.82)		0.76 (0.60, 0.95)
	BCS1 >3.50	1.12 (0.65, 1.94)		0.89 (0.51, 1.56)
	2.50 ≤ BCS1 ≤ 3.50	1		1
	BCS50 <2.50	0.79 (0.66, 0.94)		
	BCS50 >3.50	4.56 (2.49, 8.36)		
	2.50 ≤ BCS50 ≤ 3.50	1		
	Summer calving	1.43 (1.07, 1.91)		
	BCS50		1.99 (1.59, 2.48)	2.14 (1.74, 2.62)
	Summer AI		0.69 (0.55, 0.86)	0.70 (0.53, 0.92)
	Metritis		0.67 (0.57, 0.78)	0.76 (0.62, 0.94)
	21-d cycle BW			1.22 (1.02, 1.45)
	90-d milk production (kg)	0.97 ⁶ (0.96, 0.99)		
		863	726	907
Parity 3, n	BCS50 <2.50	0.74 (0.67, 0.82)		0.79 (0.66, 0.93)
	BCS50 >3.50	1.96 (0.90, 4.25)		3.1 (1.41, 6.86)
	2.50 ≤ BCS50 ≤ 3.50	1		1
	Summer calving	1.28 (1.05, 1.56)		
	21-d cycle BW	0.83 (0.69, 0.99)		
	7-d cycle		1.71 (1.31, 2.24)	
	Metritis		0.76 (0.63, 0.92)	
	Summer AI		0.77 (0.63, 0.92)	0.72 (0.60, 0.87)
	RBWLCN ⁷		0.98 (0.97, 1.00)	
	Ketosis			0.80 (0.65, 0.99)
	Each 10 kg of BW at calving			0.98 (0.97, 0.99)

¹Blank cells were not significant.²UQL10 = upper quartile in BW (%) loss in the first 10 DIM.³UQLCN = upper quartile in BW (%) loss from calving to nadir BW.⁴BCS50 = BCS between 40 and 60 DIM.⁵BCS1 = BCS at calving.⁶Calculated per 100 kg of milk.⁷RBWLCN = BW (%) lost from calving to nadir.

In PAR3 ($n = 907$) on a given day after calving, the odds of conceiving decreased by 21% for cows with a BCS50 <2.50 compared with cows with a BCS50 between 2.50 and 3.50 and by 2% for each additional 10 kg of BW at calving. The odds of conceiving were 3.1 times greater for cows with a BCS50 >3.50 compared with cows with a BCS50 between 2.50 and 3.50. A schematic representation of factors significantly associated with prolonged times to event in the 3 parity groups used in the analysis is given in Figure 1.

DISCUSSION

Cyclic changes in BW in high-producing dairy cows and their association with reproductive performance

have, to our knowledge, not been reported. Previously, an association was found between the presence of 21-d cycles in BW in dairy cows and a reduced probability of being diagnosed with inactive ovaries (van Straten et al., 2008). This finding, and our present finding of an association between the presence of these cycles and reduced calving-to-first AI and calving-to-conception intervals, supports our postulation that the presence of these cycles was associated with functioning ovaries. However, PAR3 cows with 21-d cycles in BW had longer calving-to-AI intervals. This discrepancy may be due to the bias introduced when calving-to-AI intervals are used as an outcome in studies aimed to investigate the associations that exist between reproductive performance and selected variables. This bias results from the

First-parity cows

Second-parity cows

Third and greater parity cows

Figure 1. Schematic representation of factors associated with an increase in days from calving to first AI, days from first AI to conception, and days from calving to conception in first-parity cows, second-parity cows, and cows of third and greater parity.

calving-to-AI interval being determined not only by the ability of cows to begin cycling postpartum, but also by the length of the VWP, which is a management decision. The VWP may be set at different values within a herd (e.g., high-producing cows, first-parity cows, and cows with low BCS may have longer VWP), thereby significantly influencing the length of the calving-to-AI interval in certain subpopulations in a herd.

van Straten et al. (2008) reported the presence of 7-d cycles in BW in high-producing dairy cows, although no association between cycle presence and calving diseases or milk production could be demonstrated. In the current study, an association (OR = 1.31; P = 0.033) was found between the presence of 7-d cycles and a reduced probability of conceiving at first AI. In PAR1, the presence of these cycles was associated with prolonged first AI-to-conception (OR = 0.79; P = 0.049) and calving-to-conception (OR = 0.77; P = 0.021) intervals. However, in PAR3 the presence of these cycles was associated (OR = 1.71; P = 0.001) with reduced first AI-to-conception intervals. A plausible explanation for this inconsistency is not readily available, suggesting that the relationship between 7-d cycles and reproductive performance may be modified by some other confounding variable.

Although the underlying cause of 7-d cycles in BW could be the weekly feeding practices under typical Israeli dairy management, the mechanism behind the cycles remains unclear. Only some associations could be demonstrated with some reproductive performance outcomes, but not with other health outcomes or milk production with respect to 7-d cycles, making their importance dubious.

Variables indicating relative BW or relative BW loss had greater associations with impaired reproductive performance than did their corresponding absolute values. For example, the amount of BW (kg) lost from calving to nadir BW in PAR3 was not associated with the first AI-to-conception interval, whereas the relative amount of BW (%) lost in this period was (OR = 0.98). Correspondingly, Roche et al. (2007) did not find that the amount of BW (kg) lost from calving to nadir had a significant effect on the odds of conceiving at first AI in a multivariate analysis. Apparently, the relative amount of BW lost by a cow in early lactation is a better estimator of the magnitude of NEB experienced than the absolute amount of BW lost. Therefore, relative BW values may be preferable when BW is used as a managerial tool for assessing adaptation to NEB.

The BCS assigned between 40 and 60 DIM was an important predictor for many of the reproductive performance outcomes used. Other studies have demonstrated relationships between BCS in early lactation and reproductive performance (Buckley et al., 2003; Patton et

al., 2007; Roche et al., 2007). Surprisingly, BCS50 was a better predictor for reproductive performance than the amount of BCS lost between calving and 40 to 60 DIM. Presumably, as an indicator for the extent of adaptation to NEB, the amount of body fat available for mobilization at 40 to 60 DIM is more informative than the amount of body fat lost from calving to this period. An association was found between low BCS50 and an extended first AI-to-conception interval (OR = 1.47 and 1.99 in first- and second-parity cows, respectively). This indicated that the relationship between low BCS during the interval from calving to first AI and the prolonged calving-to-conception intervals found here and in other studies were not only the result of prolonged VWP for cows with low BCS, but also were due to a true negative effect of reduced adaptation to NEB on the ability to conceive, maintain pregnancy, or both. There were no substantial associations between the duration of BW loss from calving to nadir BW or cumulative 90-d milk production and reproductive performance.

CONCLUSIONS

The relationship between the presence of 7- or 21-d cycles in BW and reproductive performance remains somewhat unclear, although previous work and this study both indicate that 21-d cycles were probably physiological and related to estrous cyclicity. The results of monitoring the 21-d cycles may constitute a useful proxy for assessing ovarian activity. Further research, including in-depth analyses of metabolic and endocrine measures, is necessary to elucidate the nature and mechanisms of these cycles.

Relative BW and relative BW loss were more highly associated with reproductive performance than the corresponding absolute values. Therefore, the use of relative values, such as the relative loss in BW in the first 10 DIM and the relative amount of BW lost from calving to nadir BW, should be considered if automated daily BW is to be used as a managerial tool. Low BCS between 40 and 60 DIM was an important predictor for reduced reproductive performance and could be monitored during routine farm work for this purpose.

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APPENDIX

Inclusion Criteria and Handling of Missing Data

For inclusion in the analysis of the relationships between the odds of conceiving at first AI and other covariates, a cow had to be inseminated at least once and remain in the herd until the outcome of the pregnancy

diagnosis was known. For inclusion in the analysis of time to conception, a cow had to have a follow-up period of 180 d postpartum. Additionally, the cow had to be inseminated at least once or presented to the attending veterinarian for unobserved estrus (i.e., the farm manager intended to artificially inseminate the cow). A cow coded for noninsemination (i.e., a cow that the farm manager decided not to artificially inseminate a priori) was not included in the analysis. Data from a cow included in the study, but that left the herd without conceiving before the end of the follow-up period, were considered right censored and contributed to the analysis until the day the cow left the herd.

During the study periods, technical failures in the walk-through scales occurred on 3 farms, resulting in periods with inaccurate BW measurements. To work efficiently with the available data, inclusion criteria for different BW variables were determined. Generally, daily BW measurements taken during the periods of technical failure were set to missing values. To have a valid, nonmissing value for BWL10, RBWL10, BWL20, and RBWL20, a cow had to have valid BW measurements for the first 20 DIM. To have a nonmissing value for BWLCN and RBWLCN, a cow had to have a nonmissing BW measurement for 1 of the first 3 DIM and have valid BW measurements for 54, 92, and 107 d postpartum for PAR1, PAR2, and PAR3 cows, respectively. These values were obtained by determining the upper quartile of days from calving to nadir BW on the farms that did not experience a technical failure in the walk-through scales. If a cow did not reach a distinct nadir during that period, then the value for BW at nadir was set to the BW measured 54, 92, or 107 d postpartum for PAR1, PAR2, or PAR3 cows, respectively. Finally, to have a nonmissing value for the presence of a 7- or 21-d cycle, cows had to have at least 70 d of valid, nonmissing BW measurements.

Data Imputation

The missing values of BCS50 were predicted on 2 farms by using a linear formula with coefficients obtained from a linear regression model applied to the data from the other farms. Initially, univariate relationships between BCS50 and possible covariates were established. Significant covariates were sequentially entered in a linear regression model. The adjusted R^2 of the final model was 0.41. The final model predictors and their coefficients were used to calculate the predicted BCS50 using the following linear formula:

$$\text{BCS50}_p = 0.205 + (0.567 \times \text{BCS1}) + (0.284 \times \text{first parity}) + (0.147 \times \text{second parity})$$

$$- (0.002 \times \text{BWLCN}) + (0.001 \times \text{NBW}) + (0.065 \\ \times \text{summer calving}) - (0.088 \times \text{ketosis}),$$

where BCS50_p was the predicted value for BCS50, BWLCN was BW loss (kg) from calving to nadir, and NBW was BW (kg) at nadir. The variable BCS50_p was used only for cows from farms on which BCS50 was not determined. The effect of using BCS50_p instead of

BCS50 was evaluated by comparing the final models including BCS50_p with identical models in which BCS50_p was replaced by BCS50. The effect was considered insubstantial if the coefficients for variables in the former model were within the 95% confidence intervals of the corresponding variables in the latter model or if variables significant in the former model retained the direction of effect but lost significance in the latter model.