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Changes in body condition score from calving to first insemination and milk yield, pregnancy per AI, and pregnancy loss in lactating dairy cows: A meta-analysis

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ABSTRACT

We determined the association of body condition score (BCS) at calving, at first postpartum artificial insemination (AI), and change in BCS between calving and first AI on pregnancy per AI (P/AI) at 30–45 d, pregnancy loss to 60–85 d, and milk yield in lactating dairy cows. Outcome data were included from 15 studies and 47 herd-year combinations. Additional variables included season of AI, herd, days in milk at first AI, parity, and of mean daily milk yield within 2 wk of first AI. The BCS scale employed was a standard 1–5 scale (1 = severe under conditioning or emaciated and 5 = severe over conditioning) with 0.25 cut points. Presynchronization treatments that included $PGF_{2\alpha}$ and GnRH increased ($P < 0.05$) the proportion of cows with luteal function before AI compared with $PGF_{2\alpha}$ alone. Compared with no presynchronization treatment those that included $PGF_{2\alpha}$ or $PGF_{2\alpha}$ and GnRH increased ($P < 0.05$) first P/AI. Cows having BCS ≥2.75 at AI had greater ($P < 0.01$) first P/AI than cows with BCS <2.75. As BCS at first AI increased, P/AI increased in a linear ($P = 0.04$) fashion and was greater in cows expressing estrus when BCS at AI was <2.50. Presynchronization had no association with P/AI for cows with BCS at calving <3.00 compared with those with BCS ≥3.00. In contrast, multiparous cows tended ($P = 0.06$) to have greater P/AI when they calved with BCS ≥3.00 compared with <3.00. Increasing BCS at AI was associated with decreased ($P = 0.01$) pregnancy loss. Pregnancy per AI did not differ among cows according to the magnitude of prebreeding BCS loss, but more multiparous cows losing more than 0.5 units of BCS tended to have greater pregnancy losses in second-parity cows ($P = 0.09$) and in cows of third or greater ($P < 0.001$) parity. Daily milk yields at first AI differed among parities as expected, but a parity by BCS at calving interaction was detected ($P = 0.008$). Daily milk yield at first AI decreased ($P < 0.001$) linearly as BCS at AI increased, with an exacerbated greater negative effect during summer. More prebreeding loss in BCS was associated with more ($P < 0.05$) milk yield in first- and second-parity cows. We concluded that greater BCS at first AI was associated with improved P/AI, but magnitude of prebreeding BCS loss was not associated with P/AI. In contrast, more pregnancy loss was associated with more prebreeding BCS loss in multiparous cows. Cow having lesser BCS at AI and greater prebreeding loss in BCS produced more milk than their herd mates of greater BCS and lesser prebreeding loss in BCS, respectively.

1. Introduction

Changes in body condition and body weight naturally occur during lactation and can influence future lactation and fertility outcomes depending on management during late lactation and during the dry period of the dairy cow. Body weight alone is not a good indicator of body reserves because body weight is affected by factors such as parity, stage of lactation, frame size, gestation, and breed [1]. Although scoring body condition measures the amount of adiposity, it is subjective in nature so determining both the inter-assessor reliability and intra-assessor consistency of BCS evaluation is important. Variation among three experienced and one less experienced assessor using a 5-point scale [2] was evaluated in Holsteins and the assessors either agreed or deviated by no more than 0.25 BCS units in more than 90% of the evaluations [3].

Assessing BCS is an important tool because of its relationship to

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milk yield, reproductive traits, health, and disease. Relationships between BCS (and its postpartum change) and metabolic disease and health have been addressed in individual studies [4–6] and in extensive reviews [1,7,8]. In general, over conditioned cows at calving and BCS loss thereafter increased risk for infectious, clinical, and subclinical metabolic disease, uterine disease, mastitis, and retained placenta. Primiparous Canadian Holstein and Ayrshire cows with a genetically high BCS conceived earlier in lactation with a greater chance to become pregnant [9]. In general, genetic selection for production traits resulted in greater postpartum loss of body condition and a failure to repartition significant amounts of energy toward body reserves until later in lactation or when lactation ceased [10]. Body condition scoring has its limitations because the relationship of BCS and body fat becomes weak at the bottom of the BCS scale in which sc fat content is limited and the decrease in BCS at these levels indicate muscle protein loss and not loss of internal fat depots [8,11].

Prepartum BCS and its changes during early lactation are associated with inactive ovaries, postpartum anestrus, greater likelihood of failure to conceive by 150 d in milk, greater incidences of retained placenta and metritis, and more culling [5,6,12,13]. Loss of BCS during the dry period was a predisposing factor associated with health disorders and reduced productive and reproductive performance in Holstein cows [14]. Postpartum loss in BCS was associated with increased milk and less BCS loss during the first month of lactation, whereas changes in BCS during the dry period, BCS at dry-off, duration of the dry period, and change in BCS during the first month of lactation were more strongly associated with milk yield than health problems [15]. In general, cows with more body fat reserves mobilized more fat for milk fat synthesis and under conditioned cows at calving produced lower-fat milk without affecting milk yields [6].

Previous meta-analyses [16,17] addressed the relationships between reproduction or milk yield and BCS in dairy cows. Body condition in those studies were scored on different scales and required transformations to a common scale of 0–5, different from that standard 1–5 scale used in North America. Traditional meta-analyses offer quantitative advantages to qualitative review articles because they attempt to analyze results (not the original experimental unit outcomes) from all available studies in the literature. Traditional meta-analyses present, however, their own challenges. Results are estimated using means and some measure of variation that are unbalanced and factor effects are far from being independent. “This leads to unique statistical estimation problems similar to those observed in observational studies, such as leverage points, near collinearity, and even complete factor disconnectedness, thus prohibiting the testing of the effects that are completely confounded with others” [18]. Moreover, from a statistical standpoint, individual studies are blocks and their effects must be considered random because the inference being sought is to future unknown studies [19].

Information in the literature regarding the effects of BCS on pregnancy per AI and pregnancy loss are limited to few analyses in dairy cows exposed to presynchronization of estrous cycles and inseminations after estrus or ovulation synchronization. The objective of this report was to examine the effect of BCS at calving, at first AI, and prebreeding change in BCS using the same defined scale (1–5) at 0.25-unit cut points on pregnancy outcome, pregnancy loss, and milk yield in cows inseminated at first service after detected estrus or ovulation synchronization.

2. Materials and methods

Original data for the present report were obtained from 15 published studies collected in 17 unique Holstein dairy herds spanning 16 years. Results originated from a cross section of university and commercial dairy herds located in one western (California; 6 herds) and six Midwestern (Indiana, Kansas, Missouri, Michigan, Minnesota, and Wisconsin) states and one other country (Republic of North Macedonia) in which cows were first inseminated after individual herd mean voluntary periods of 60–85 d (mean ± SD = 73 ± 8 d). Some characteristics of the 17 herds and published studies [20–34] are summarized in Table 1 including the numbers of cows studied, mean parity, mean days in milk at first AI, milking frequency, and mean daily milk yield assessed within 2 wk of first AI. One study included Holstein-Friesian cows (Republic of North Macedonia). Other specific herd details are available in the original reports cited in Table 1.

Although most cows in 14 studies were first inseminated after a fixed time, 26.7% of cows were detected in estrus before or at the scheduled fixed time of AI. In general, synchronization of ovulation included a basic Ovsynch fixed-time AI program (GnRH − 7 d − $PGF_{2\alpha}$ − 48–56 h − GnRH − 12 to 16 h − first postpartum AI) with or without an intravaginal progesterone impregnated controlled internal drug release insert (CIDR, Zoetis, Florham Park, NJ, USA). Presynchronization of estrous cycles was attempted by administering: (1) two doses of $PGF_{2\alpha}$ 14 d apart, which preceded Ovsynch by 10–14 d ($PGF_{2\alpha}$); or (2) Ovsynch (Double Ovsynch) or $PGF_{2\alpha}$ and GnRH 3 d apart, which preceded Ovsynch by 10 d ($PGF_{2\alpha}$ + GnRH). Some cows received no presynchronization before Ovsynch. The residual study [28] involved synchronization of estrus with similar programs without the final GnRH treatment of Ovsynch and inseminations were based on visual observation, heat-patch activation, rump-mounted pressure sensitive radio telemetric devices, or automated activity monitors that employed accelerometers for prediction of estrus.

Estrus expression before or at insemination in studies that employed timed AI was determined by either grease paint rubs, rump-mounted patches (Kamar Inc., Zionsville, IN, USA; Estrotect, Rockway Inc., Spring Valley, WI), pressure-sensitive electronic devices (HeatWatch, Cow Chips LLC, Manalapan, NJ), automated activity monitors (MooMonitor, DairyMaster, Inc., Kerney, Ireland; CowManager SensOor system, Agis Automatisering BV, Harmelen, Netherlands), or visual detection of standing behavior. Positive cycling status (luteal function) in response to presynchronization was determined by either progesterone concentrations (≥1 ng/mL in either of two samples collected 10 d apart), presence of luteal structures, or both, 10–14 d before estrus or ovulation synchronization was initiated.

In each study, pregnancy diagnosis occurred first between 30 and 45 d after AI by using either transrectal palpation or ultrasonography. A second confirming diagnosis was conducted 4–6 wk later (60–85 d after first AI) to assess pregnancy loss. Pregnancy loss was determined based on the absence of a viable fetus at the second diagnosis. Body condition scores were assigned at calving and within 10 d of first insemination using a traditional 5-point scale (1 = severe under conditioning and 5 = severe over conditioning) [2,3]. All data (parity, calving date, first AI date, milk yield, and pregnancy outcomes) were recorded originally by researchers or extracted from herd records.

2.1. Statistical analyses

Two binomial outcomes (pregnancy per first AI [P/AI] and subsequent pregnancy loss) and one continuous outcome (milk yield at AI) were analyzed in separate models. Separate models included each one of two continuous variables (BCS at calving or BCS at AI). In addition, three additional fixed variables were examined: change in BCS between calving and first insemination (BCS at AI *minus* BCS at calving), BCS at calving (<3.00 vs. ≥ 3.00) according to

Table 1
Source of data from 15 studies conducted between 2005 and 2021 and representing 17 unique dairy herds in seven U.S. states and one other country.

Location[a]	*n*	Parity[b]	Days in milk at AI[b]	Times milked	Daily milk[b], kg	BCS at calving[b]	BCS at first AI[b]	Change in BCS[b,c]	P/AI at 30–45 d	P/AI at 60–85 d	PL[d]	Reference
Kansas-1	430	2.2 ± 1.3	66 ± 5	3 ×	41 ± 12	…	2.3 ± 0.4	…	31.2	29.5	5.2	[20]
Indiana	80	2.0 ± 0.8	72 ± 3	3 ×	…	3.0 ± 0.7	…	…	37.5	37.5	0.0	[21]
Kansas-2	217	1.8 ± 1.0	79 ± 9	2 ×	…	2.6 ± 0.4	2.3 ± 0.3	−0.3 ± 0.4	42.9	37.3	12.9	[21]
Missouri	243	2.0 ± 1.0	74 ± 7	2 ×	…	2.9 ± 0.3	2.6 ± 0.3	−0.2 ± 0.4	32.9	29.6	10.0	[21]
Michigan	152	1.6 ± 0.5	81 ± 2	2 ×	…	2.6 ± 0.4	2.4 ± 0.4	−0.2 ± 0.4	35.5	32.9	7.4	[21]
Minnesota	194	1.7 ± 0.5	70 ± 2	3 ×	…	3.1 ± 0.4	2.8 ± 0.4	−0.3 ± 0.5	29.9	23.2	22.4	[21]
Wisconsin	182	2.2 ± 1.2	71 ± 3	3 ×	…	…	2.8 ± 0.5	…	36.3	35.2	3.0	[21]
Kansas-3	199	2.2 ± 1.4	70 ± 9	3 ×	45 ± 10	…	2.0 ± 0.4	…	32.2	29.6	7.8	[22]
Kansas-1	298	1.9 ± 1.0	65 ± 8	3 ×	43 ± 15	…	2.1 ± 0.4	…	33.6	30.9	8.0	[22]
Kansas-2	120	1.7 ± 0.9	76 ± 9	2 ×	44 ± 11	…	2.3 ± 0.4	…	31.7	29.2	7.9	[23]
California-2	104	2.3 ± 1.7	82 ± 2	3 ×	50 ± 10	…	2.7 ± 0.2	…	41.3	39.4	4.7	[23]
California-3	151	3.0 ± 1.8	82 ± 2	3 ×	53 ± 11	…	2.7 ± 0.3	…	29.1	28.5	2.3	[23]
California-4	96	2.5 ± 1.4	82 ± 2	3 ×	54 ± 10	…	2.7 ± 0.3	…	27.1	24.0	11.5	[23]
California-6	212	3.1 ± 1.7	82 ± 2	3 ×	56 ± 11	…	2.8 ± 0.4	…	38.2	34.9	8.6	[23]
California-7	207	2.4 ± 1.3	86 ± 2	3 ×	44 ± 10	…	2.7 ± 0.2	…	45.4	42.5	6.4	[23]
California-8	245	2.5 ± 1.7	86 ± 2	3 ×	43 ± 11	…	2.7 ± 0.2	…	40.8	38.0	7.0	[23]
Kansas-2	733	1.9 ± 1.2	77 ± 8	2 ×	54 ± 10	2.7 ± 0.5	2.3 ± 0.4	−0.4 ± 0.4	35.9	31.5	12.2	[24]
Kansas-2	464	2.0 ± 1.1	70 ± 4	3 ×	49 ± 12	3.1 ± 0.5	2.5 ± 0.5	−0.6 ± 0.5	39.2	34.7	11.5	[25]
Kansas-1	675	2.2 ± 1.2	66 ± 6	3 ×	33 ± 13	…	2.3 ± 0.4		35.7	33.9	5.0	[25]
Kansas-3	439	2.1 ± 1.3	74 ± 5	3 ×	34 ± 10	…	2.4 ± 0.4	…	31.7	29.4	7.2	[25]
Kansas-4	1154	2.2 ± 1.3	77 ± 2	3 ×	36 ± 11	…	2.5 ± 0.4	…	40.5	37.2	8.1	[25]
Kansas-2	134	1.9 ± 1.1	69 ± 4	3 ×	48 ± 13	2.8 ± 0.5	2.3 ± 0.4	−0.5 ± 0.5	34.3	29.1	15.2	[26]
Kansas-2	582	1.8 ± 1.0	73 ± 4	3 ×	50 ± 10	3.4 ± 0.5	2.7 ± 0.4	−0.6 ± 0.5	38.7	32.1	16.9	[27]
Kansas-2	144	1.8 ± 1.2	62 ± 7	3 ×	…	3.3 ± 0.5	2.7 ± 0.4	−0.6 ± 0.5	37.5	32.6	13.0	[28]
Kansas-2	201	1.8 ± 1.1	61 ± 5	3 ×	…	3.1 ± 0.5	2.7 ± 0.3	−0.5 ± 0.5	28.4	26.4	7.0	[28]
Kansas-4	475	2.1 ± 1.2	75 ± 8	3 ×	42 ± 8	…	2.9 ± 0.4	…	36.8	34.1	7.4	[29]
Kansas-1	474	1.8 ± 1.2	69 ± 5	3 ×	39 ± 10	…	2.7 ± 0.4	…	46.8	41.6	11.3	[29]
Kansas-2	397	2.0 ± 1.0	73 ± 2	3 ×	48 ± 10	2.8 ± 0.5	2.5 ± 0.3	−0.3 ± 0.4	37.3	31.7	14.9	[30]
Kansas-2	104	2.2 ± 1.0	79 ± 6	3 ×	55 ± 11	2.8 ± 0.6	2.6 ± 0.3	−0.2 ± 0.5	38.5	37.5	2.5	[31,32]
Kansas-2	160	1.8 ± 1.0	73 ± 2	3 ×	47 ± 11	2.9 ± 0.5	2.5 ± 0.3	−0.4 ± 0.4	31.9	30.6	5.94	[33]
Kansas-2	469	1.7 ± 0.7	73 ± 2	3 ×	…	2.9 ± 0.5	2.5 ± 0.4	−0.4 ± 0.5	40.3	37.3	7.4	[34]
No. Macedonia	346	1.9 ± 1.1	68 ± 6	2 ×	29.9 ± 4	…	2.7 ± 0.4	…	35.2	32.7	7.4	[34]
Overall mean	315	2.1 ± 1.2	73 ± 8	…	43.9 ± 13	3.0 ± 0.5	2.5 ± 0.4	−0.44 ± 0.47	36.7	33.3	9.1	
n	10337	10337	10337	…	5653	4218	10246	4127	10337	10337	3784	

[a] Location and coded herd number within state.
[b] Mean ± SD.
[c] Change in body condition from calving to first AI (BCS at AI *minus* BCS at calving).
[d] Pregnancy loss between first and second pregnancy diagnoses.

recommended dry-off BCS of 3.00–3.25 [14], and either increase or no increase in BCS between calving and first insemination. Prebreeding change in BCS between calving and first AI was categorized into three categories of BCS loss: loss of <0.50 unit, loss of 0.50–1.00 unit, or loss of ≥1.00 unit as in Refs. [17,35]. Simple Pearson correlations were assessed between BCS at calving, BCS at AI, and prebreeding change in BCS using procedure CORR in SAS v. 9.4 (SAS Institute Inc., Cary, NC, USA).

Models were constructed according to recommended guidelines outlined by Refs. [18,19] in which herd-year served as the random surrogate for study. The random statement included the intercept and continuous BCS variable (BCS at calving or BCS at AI) with an unstructured covariance matrix and SUBJECT = herd-year. Herd-year was chosen because using study as the random effect in the model produced zeroes for estimates and standard errors.

Analyses of the outcome variables were conducted in SAS by applying a generalized linear mixed model using the GLIMMIX procedure with LINK = logit, DISTRIBUTION = binomial solution, with the ILINK option to produce back-transformed least squares means and standard errors. Models to analyze the binomial dependent variables of P/AI and pregnancy loss included each of the five BCS measures in separate ANOVA plus the fixed effect of presynchronization (none, $PGF_{2\alpha}$, or $PGF_{2\alpha}$ + GnRH), occurrence of estrus at first insemination, parity (1, 2, or ≥3), season of insemination (winter = December, January, and February; spring = March, April, and May; summer = June, July, and August; and autumn = September, October, and November), the random effect of herd-year (n = 47), and the covariate of days in milk at insemination.

Luteal status after presynchronization was analyzed using the previous binomial model, excluding the estrus-expression factor. Analyses of the continuous measure of daily milk yield at AI were conducted similarly but also excluding the estrus-expression factor. In initial models, all two-way interactions were included but only main effects (presynchronization, parity, season, estrus occurrence, and BCS variable) were retained in final models in addition to all two-way interaction effects that produced P values ≤ 0.10 in the initial models. When interactions ($P < 0.10$) of any fixed BCS category was detected with another variable, only differences within that variable were separated using the LSD option in SAS. In all cases, statistical significance of effects was set as $P \leq 0.05$, with tendencies as $0.05 < P \leq 0.10$.

3. Results

3.1. Descriptive statistics

Individual study means of BCS at calving, BCS at AI, mean change in BCS between calving and first AI, P/AI at first AI, subsequent pregnancy loss, and milk yield of cows enrolled in each of the 15 studies are summarized (Table 1). Overall BCS at calving averaged 2.9 ± 0.5 (mean ± SD) and decreased by 0.44 ± 0.47 units between calving and first AI. First P/AI averaged 37% with 9.2% of the conceptuses lost by the second pregnancy diagnosis. Milk yield at AI averaged 43.9 ± 13 kg/d (mean ± SD).

3.2. Estrous cyclicity

Treatments that included both $PGF_{2\alpha}$ and GnRH increased ($P < 0.05$) the proportion of cows with luteal function after presynchronization treatments compared with no presynchronization or with only $PGF_{2\alpha}$ treatments (Table 2). In addition, effects of parity, season, and BCS loss, but not BCS at calving, influenced proportion of cows with established luteal function after presynchronization treatments (Table 2).

3.3. Presynchronization and estrus expression

Presynchronization treatments with $PGF_{2\alpha}$ + GnRH or $PGF_{2\alpha}$ increased ($P < 0.01$) P/AI in cows regardless of BCS variable analyzed. In addition, P/AI was greater in all seasons compared with summer and greater in primiparous cows compared with multiparous cows regardless of presynchronization treatment (Table 3). Cows having BCS ≥2.75 at AI had greater ($P < 0.01$) P/AI than cows with BCS <2.75 (35.6 vs. 31.5%), respectively. No interactions ($P > 0.10$) of BCS with presynchronization treatments were detected.

An interaction of estrus expression and BCS at AI was detected ($P = 0.007$). Predicted probabilities illustrating that interaction showed that cows detected in estrus at AI with BCS < 2.50 compared with no estrus had greater P/AI, whereas little differences occurred for cows with greater BCS (Fig. 1). Furthermore, second-parity cows that expressed estrus had greater P/AI than their contemporaries that did not show estrus (44.9 vs. 30.4%), whereas little differences were detected in cows of first (41.6 vs. 40.5%) or third or greater parity cows (28.9 vs. 32.6%, interaction between parity and estrus, $P < 0.001$), respectively.

No difference ($P > 0.12$) in pregnancy loss was detected between cows presynchronized with $PGF_{2\alpha}$ (8.6%) compared with $PGF_{2\alpha}$ + GnRH (10.7%). Cows detected in estrus, however, had fewer ($P < 0.05$) pregnancy losses than cows not expressing estrus (9.6 vs. 15.2%).

3.4. Body condition score at calving

Mean (±SD) body condition score at calving ranged from 2.6 ± 0.4 to 3.4 ± 0.5 in the 15 studies representing 4178 cows (Table 1). Of the 3446 observations analyzed having observations for all variables in the final model, BCS at calving ranged from 1.75 to 4.50 with 98.1% in the 2.00–4.00 range. Illustrated in Fig. 2 are the predicted probabilities of P/AI based on BCS at calving. Although no effect of BCS at calving was detected ($P = 0.25$), a parity by BCS interaction trend ($P = 0.09$) was detected for P/AI (Fig. 2). Primiparous cows with BCS at calving <3.25 had greater P/AI than older cows. Cows inseminated during summer (13.7%) had greater ($P < 0.001$) pregnancy losses than cows inseminated during winter (8.1%) but did not differ from autumn (10.0%) or spring (11.5%).

3.5. Body condition score at first AI

Mean (±SD) body condition score at first AI ranged from 2.0 ± 0.4 to 2.9 ± 0.4 in 31 herd replications representing 10081 cows (Table 1). Of the 8454 observations analyzed with complete data, BCS at AI ranged from 1.25 to 4.00 with 93.8% in the 2.00–4.00 range. Pregnancy per AI increased ($P = 0.04$) linearly as BCS increased from 1.25 to 4.00 (Fig. 1). As BCS at AI increased, it was also associated with less ($P = 0.02$) pregnancy loss as indicated by the predicted probabilities of pregnancy loss (Fig. 3).

3.6. Change in prebreeding body condition score between calving and insemination

Mean (±SD) change in prebreeding BCS ranged from −0.6 ± 0.5 to −0.2 ± 0.4 in 14 herd replications representing 4072 cows (Table 1). Of the 3438 observations analyzed with complete data, changes in prebreeding BCS produced a distribution curve that was slightly skewed to the left, ranging from a loss of 2.25 units to a gain of 1.50 units (not shown). Nearly 18% of the cows lost more than 1.0 BCS unit and 53.3% lost more than 0.5 units during the prebreeding period. Few cows (9.6%) had either no change or a slight positive change in BCS between calving and first AI. Prebreeding BCS loss

Table 2
Factors associated with established luteal function (% cycling) after presynchronization of estrous cycles before first insemination.

Item	*n*	%cycling[a]
Presynchronization[b]		
None	222	85.1^{x}
PGF2α	1399	79.0^{x}
PGF2α + GnRH	1363	91.5^{y}
Parity		
1	1349	87.9^{x}
2	979	86.5^{x}
≥3	656	83.3^{y}
Season		
Autumn	810	88.4^{xy}
Winter	897	84.3^{xy}
Spring	738	80.9^{x}
Summer	539	89.1^{y}
BCS at calving		
<3.00	1557	86.3^{x}
≥3.00	1427	85.6^{x}
Prebreeding BCS loss		
<0.5	634	88.7^{x}
0.5–1.0	513	84.8^{y}
≥1.0	253	83.7^{y}

x,y Means within item with different superscript letters differ ($P < 0.05$).
a Determined by progesterone concentrations (≥1 ng/mL in either of two samples collected 10 d apart), presence of luteal structures, or both, 10–14 d before AI.
b Presynchronization of estrous cycles: (1) no presynchronization (none); (2) two doses of $PGF_{2\alpha}$ 14 d apart, which preceded Ovsynch by 10–14 d (PGF2α); (3) treatment with Ovsynch (Double Ovsynch) or PGF2α and GnRH 3 d apart, which preceded Ovsynch by 10 d (PGF2α + GnRH).

Table 3
Pregnancy per AI based on interactions of presynchronization of estrous cycles with season and parity.

Factor	Presynchronization[a]			
	None	PGF2α	PGF2α + GnRH	
	% pregnancy per AI			
Season				Season means
Autumn	31.5	38.1	37.2	35.6x
Winter	30.0	39.3	44.0	37.5x
Spring	30.4	36.3	40.1	35.5x
Summer	23.5	27.8	27.3	26.1y
Parity				Parity means
1	33.4	29.0	24.1	38.9x
2	40.9	34.1	30.9	32.3y
≥3	42.6	34.1	34.2	29.6y
Presynch means	28.7x	35.2y	36.9y	

x,y Means within factor with different superscript letters differ ($P < 0.05$).
a Presynchronization of estrous cycles: (1) no presynchronization (none); (2) two doses of $PGF_{2\alpha}$ 14 d apart, which preceded Ovsynch by 10–14 d (PGF2α); (3) treatment with Ovsynch (Double Ovsynch) or $PGF_{2\alpha}$ and GnRH 3 d apart, which preceded Ovsynch by 10 d (PGF2α + GnRH).

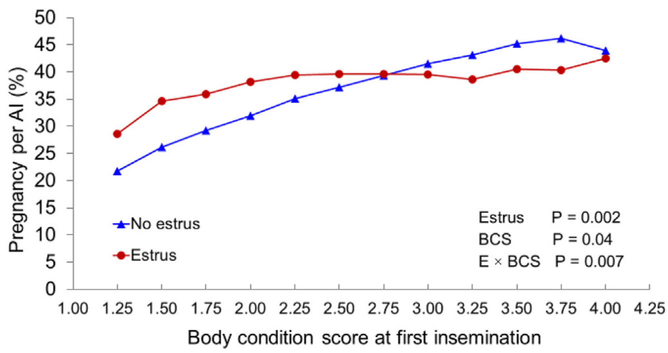

Fig. 1. Predicted probabilities of pregnancy per first insemination at Days 30–45 and body condition score (BCS) at first insemination. The interaction (P = 0.007) between estrus expression and BCS is illustrated.

was not associated (P = 0.33) with P/AI.

Pregnancy loss ranged from 0 to 22.4% in the 32 herd replications (Table 1) and was associated (P = 0.003) with prebreeding loss in BCS as characterized by an interaction between parity and the amount of BCS loss (Fig. 4A). Although no differences in loss were observed among primiparous cows, second-parity cows that lost 0.5–1.0 unit of BCS tended (P < 0.10) to have increased risk of pregnancy loss compared with cows with <0.5 BCS loss but did not differ from the losses in cows that lost ≥1.0 unit. On the other hand, cows in their third or greater parity losing >0.5 BCS units had greater (P < 0.05) pregnancy loss than those losing <0.50 BCS units.

Further analyses of the prebreeding changes (no increase or increase) in BCS or comparing cows with BCS <3.00 vs. BCS ≥3.00 at calving were not associated with P/AI. Overall, for cows in which BCS increased between calving and first AI, pregnancy losses were less (P < 0.05) than in cows whose BCS did not increase (10.0 vs. 13.5%), respectively. For cows with increased post-calving BCS, however, only those inseminated during winter had fewer pregnancy losses, whereas no differences were observed during other seasons (Fig, 4B, interaction [P = 0.06] between season and prebreeding change in BCS).

3.7. Body condition score and milk yield at AI

Analysis of daily milk yield differed (P < 0.001) among parities and produced an interaction (P = 0.008) between parity and BCS at calving (Fig. 5A). In addition, an interaction (P = 0.03) of BCS at AI and season was detected. Predicted probabilities of that interaction are shown in Fig. 5B. The relationship between milk yield at AI and BCS at AI was linear (P < 0.001) with milk yield decreasing as BCS at AI increased, particularly exacerbated during summer.

Cows with an increasing BCS after calving compared with those with no increase produced less (P < 0.001) milk (52.7 ± 0.7 vs. 50.9 ± 0.7 kg/d), respectively. Those cows that lost <0.5 BCS units (51.0 ± 0.7 kg/d) produced less (P < 0.001) milk than cows that lost 0.5–1.0 BCS unit (52.8 ± 0.7 kg/d) and cows that lost more than 1.0 BCS unit (52.7 ± 0.7 kg/d).

Prebreeding change in BCS and milk yield differed (P < 0.001) among parities as expected. In addition, an interaction (P < 0.05) was detected between change in BCS between calving and AI and parity (Fig. 6). In general, milk yield in cows in their first two lactations was greater (P < 0.05) when more than 0.5 units of prebreeding BCS was lost. In contrast, similar increases in milk were observed in third or greater parity cows losing >0.5 units of BCS, but not in the largest loss category (Fig. 6).

3.8. Simple correlations among measures

Simple Pearson correlations among continuous measures (n = 1802) all differed (P < 0.05) from zero. Body condition score at calving was positively associated (r = 0.56) with the BCS at AI, but negatively correlated (−0.62) with the change in BCS from calving to AI. In other words, greater BCS at calving was associated with greater prebreeding loss in BCS. Body condition score at AI was positively correlated (r = 0.30) with prebreeding change in BCS.

4. Discussion

Our objective was to examine the effect of body condition scores at calving, at first AI, and prebreeding changes in BCS using the same defined scale (1–5) at 0.25-unit cut points on pregnancy outcome, pregnancy loss, and milk yield in cows whose estrous cycles were presynchronized before estrus or ovulation synchronization for first postpartum insemination. The BCS measures examined are consistent with suggested indices that are associated with fertility (BCS at calving and at AI, prebreeding change in BCS) [8,16,17] and with milk yield [6,7,16,17].

Onset of estrous cycles after parturition is influenced by BCS at calving, BCS at AI, prebreeding change in BCS, season, and milk yield [36,37]. Although our presynchronization treatments that included both $PGF_{2\alpha}$ and GnRH increased the proportion of cows with luteal function by 7.5–15.8% before AI, no effect of BCS at calving or BCS at AI was associated with this measure (Table 2). In contrast, more cows losing <0.5 units of BCS before AI had established luteal function by 10–14 d before estrus or ovulation synchronization. Inclusion of GnRH in presynchronization induces

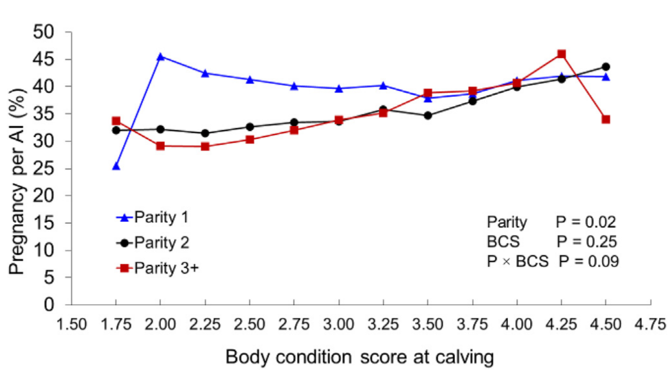

Fig. 2. Predicted probabilities of pregnancy per first insemination at Days 30–45 and body condition score at calving score (BCS) at calving. The tendency (P = 0.09) for an interaction between parity and BCS is illustrated with their associated P values.

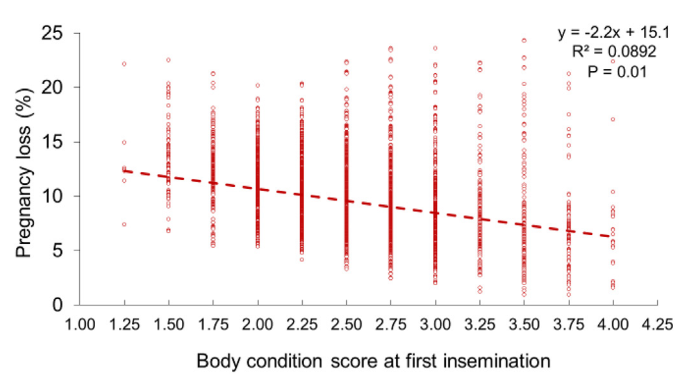

Fig. 3. Predicted probabilities of pregnancy loss after first insemination and BCS at first insemination. The dashed line represents the best-fit linear regression (equation shown) with its multiple coefficient of variation (R2) and P value.

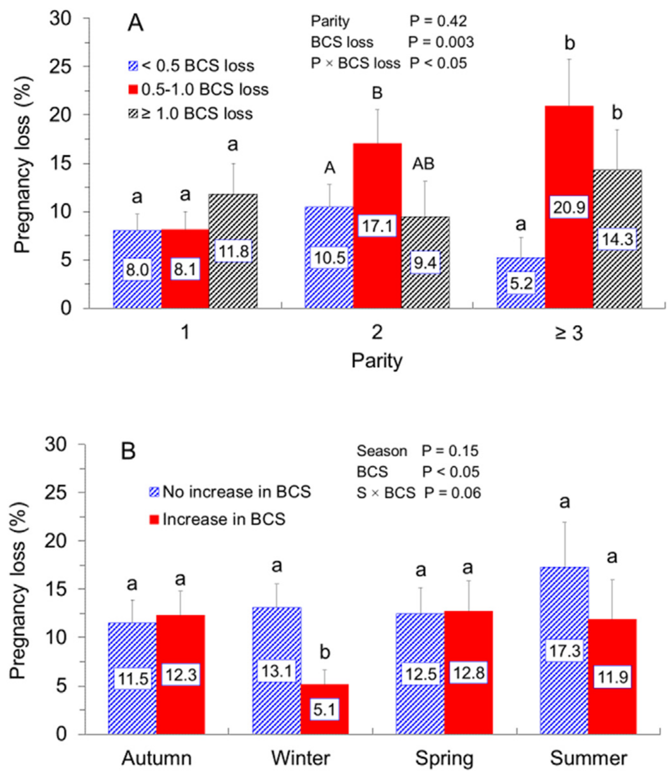

Fig. 4. (A)Pregnancy loss after first insemination at Days 30–45 based on parity and the magnitude of body condition score (BCS) loss between calving and first AI. (B) Pregnancy loss after first insemination based on season of insemination and whether BCS either increased or did not increase during the prebreeding period. The bars represent the least squares means ± SEM (mean value is inset within each bar). Probability values are based on the illustrated interactions. Lower case letters denote differences ($P < 0.05$) among means within parity or season. Upper case letters denote trends ($P = 0.08$) for differences among means within second-parity cows.

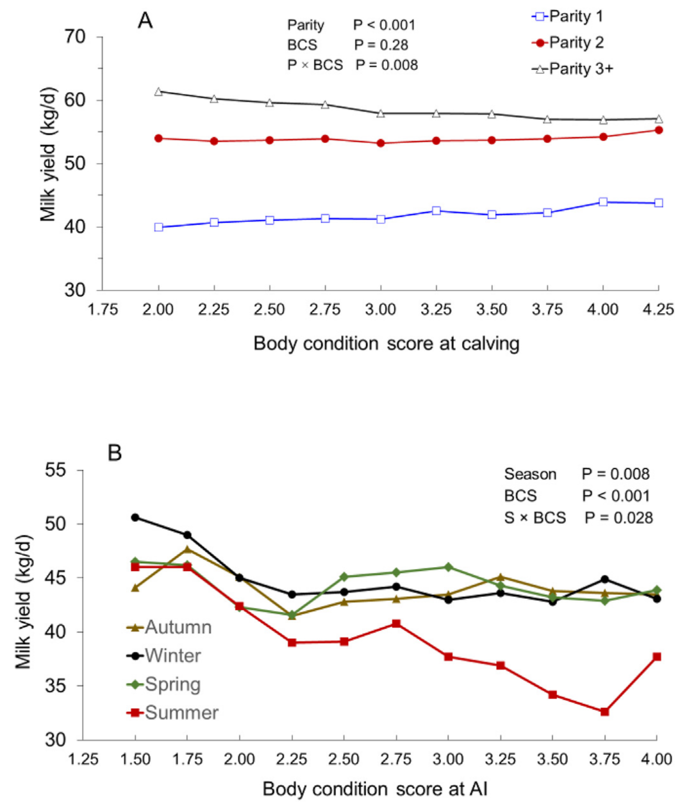

Fig. 5. (A) Predicted probabilities of daily milk yield at first insemination illustrate the interaction ($P = 0.008$) of BCS at calving with parity. (B) Predicted probabilities of daily milk yield as affected by its interaction ($P = 0.028$) with season of insemination.

ovulation in those cows that have not first ovulated before presynchronization [25,26,30].

Results from a meta-analysis demonstrated that including GnRH as part of a presynchronization treatment (Double Ovsynch) improved P/AI compared traditional $PGF_{2\alpha}$ presynchronization treatments for primiparous cows [38]. Also consistent with the latter study was the lack of presynchronization treatment effect on pregnancy loss reported herein. Lack of a detected difference in P/AI for cows receiving $PGF_{2\alpha}$ with $PGF_{2\alpha}$ + GnRH presynchronization treatments in the present study is likely related to a greater proportion of older cows studied, which is consistent with [38] in which only primiparous cows had significantly greater P/AI, whereas P/AI in multiparous cows did not differ between $PGF_{2\alpha}$ with $PGF_{2\alpha}$ + GnRH presynchronization treatments. Consistent with the present results, both presynchronization systems improved P/AI in dairy cows compared with no presynchronization treatment.

In another meta-analysis [39] in which cows were inseminated upon detected estrus after the traditional $PGF_{2\alpha}$ presynchronization with two doses of $PGF_{2\alpha}$ administered 14 d apart compared with cows similarly treated but completing both the presynchronization and ovulation synchronization program with a fixed-time AI, no differences in pregnancy loss were detected. Although we detected fewer pregnancy losses in cows detected in estrus as in one large study using progesterone and estradiol-based fixed time AI [40], most studies have reported that risks of pregnancy loss are similar in cows inseminated following synchronization of estrus or ovulation or following detection of spontaneous estrus [36,39,41].

Because no interactions were detected between BCS variables and presynchronization treatments, body condition is not likely influencing pregnancy outcomes differently in cows after presynchronization before insemination after estrus or ovulation synchronization. First postpartum reestablishment of luteal function in dairy cows is associated with BCS at calving, whereas estrus expression was associated with milk yield and fertility [16]. Although the interval from calving to first observed estrus is a function of when first postpartum ovulation occurs, first observed estrus was not associated with BCS [17].

Although scoring body condition is subjective, it is strongly

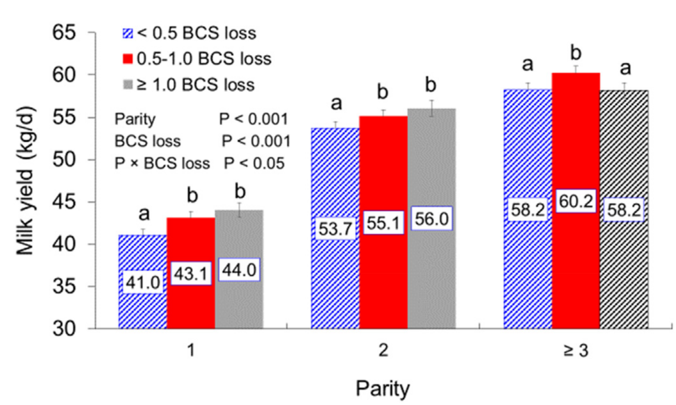

Fig. 6. Daily milk yield at AI (least squares means ± SEM) based on the interaction ($P < 0.05$) between parity and category of prebreeding loss in body condition score (BCS). Numbers inset within individual bars represent mean yields. Lower case letters denote differences ($P < 0.05$) among means within parity.

associated with available energy reserves as evidenced by a positive relationship (r = 0.75 to 0.93) between BCS and the proportion of physically dissected fat in Friesian cows [42]. The correlation between body condition and body fat, however, seems to become weak at the bottom of the BCS scale when sc fat content is limited and the decrease in BCS at these levels indicate muscle protein loss and not loss of internal fat depots [7,11].

The linear increase in P/AI at first postpartum insemination as BCS at AI increased in the present study (Fig. 1) is consistent with observations from earlier meta-analyses [16,17]. In the former meta-analysis, however, the effects of body condition on first P/AI were highly heterogeneous so that a clear association between BCS categories and P/AI was only detected when BCS at calving was low (<2.50) when the correlation between BCS and body fat becomes weaker at low BCS [7,11]. Cows with high BCS (>3.50) at calving conceived 6–12 d sooner than cows with intermediate (2.50–3.50) and low BCS, whereas in cows with high BCS at first AI, conception occurred 12–24 d earlier [17]. Although in the latter meta-analysis, the relationship between P/AI and BCS at calving, at AI, and at its postpartum nadir, were linear and positive, our results did not corroborate that positive relationship between P/AI and BCS at calving (Fig. 2), but rather P/AI was related to parity.

Our analyses included one uniform 5-point BCS scale [2,3] in which 98.1 and 93.8% of the BCS observations at calving and at AI were in the 2.00–4.00 range. Furthermore, we treated BCS as a continuous variable. Previous reports of associations between BCS and P/AI [13,36,43–47] in confined or grazing dairy cows grouped into two or three categories of BCS at AI were conducted in a limited number of one-herd studies with few exceptions. These reports treated BCS as a fixed effect, but nevertheless demonstrated various percentage decreases in P/AI at first AI from the highest to the lowest BCS by 22.8% (four categories from ≤2.25 = 40.4% to ≥ 3.25 = 54.8%) [13]; 25.3% (two categories from 2.00 = 32.0% to ≥ 3.00 = 51.2%) [43]; 45.7% (two categories from <2.50 = 11.1% to ≥ 2.50 = 25.6%) [44]; 33.1% (three categories from <2.75 = 34.3% to > 3.00 = 55.9%) [45]; 38.6% (three categories from <2.50 = 21.7% to ≥ 3.25 = 63.3%) [46]; 15.2% (three categories from <3.00 = 33.6% to ≥ 3.75 = 46.3%) [36]; and 41.4% (two categories from <2.75 = 28.3% to ≥ 2.75 = 48.3% [47].

A significant linear negative relationship between BCS at calving and its postpartum nadir loss was reported for losses between −1.50 and −0.50 with a 33.9% loss for each additional unit of BCS loss [16]. Although no difference in the magnitude of BCS loss was associated with P/AI in the present study, 53% of our cows lost more than 0.5 BCS points during the prebreeding period compared with 83.7% of cows losing BCS during the first 40 d in milk [37], but only 7.3% of cows losing BCS during the first 3 wk after calving [13]. In the latter study, a loss in body weight was associated with reduced embryo quality and increased number of degenerated embryos by Day 7 after AI in cows that lost more body weight from the first to third week after calving.

When BCS increased after calving during winter but not during other seasons, pregnancy losses were reduced by 61% in the present study (Fig. 4B). We observed that pregnancy loss trended significantly downward as BCS at AI increased (Fig. 3). Greater pregnancy losses were observed in older cows in their third or greater parity when they lost more than 0.5 units of BCS between calving and AI (Fig. 4A). Our results are consistent with recent reports demonstrating that cows with excessive loss in BCS during the first 40 d in milk had greater pregnancy loss, decreased P/AI at first service, but increased milk yield [17,44].

Pivotal periods for pregnancy loss during the first trimester of gestation in dairy cows indicated losses of approximately 12% are observed during the second month of pregnancy [48], which is consistent with the magnitude of loss reported herein (Table 1). Early pregnancy losses that occurred before pregnancy assessments in the present study (Days 30–45) are also affected by body condition as fertilization failure or early embryo mortality (before 25 d of life) is associated with BCS at its postpartum nadir [49]. Consistent with our observations, BCS assessed at pregnancy diagnoses demonstrated that cows with BCS ≥3.25 (to 4.00) had fewer pregnancy losses than cows with lesser BCS (2.00–3.00) [49]. Furthermore, a 1-unit reduction in BCS between calving and 30 d in milk resulted in a 2.4-fold increase in pregnancy loss [17] and pregnancy loss was greatest for cows with low BCS at calving or excessive prebreeding loss in BCS [37]. Extent of pregnancy loss did not differ among cows regardless of BCS at Day 28 of gestation but losses were greater when cows lost body condition between Days 28 and 56 of gestation [50]. Because the heritability for embryo survival is 0.49 and for maternal effects is 0.17, genetic improvement of reproductive performance could be enhanced by selecting against pregnancy loss [51].

Further contributors to poorer P/AI in cows that lose body condition after calving relate to health issues [1] but changes in BCS during the dry period, BCS at dry-off, duration of the dry period, and change in BCS during the first month of lactation seem to be more strongly associated with milk yield than with health [15]. Cows that lost >1 BCS unit during the dry period had greater incidences of metritis, retained placenta, and metabolic disorders (displaced abomasum, milk fever, ketosis) and longer intervals to first breeding than cows that lost <1 BCS unit [14,52]. Cows that lost body condition during the first 40 d in milk and experienced reproductive-related or other health issues had poorer reproductive performance and decreased herd survival [53]. Furthermore, cows affected with clinical mastitis before first AI and BCS ≤2.75 at AI were more likely to experience pregnancy loss compared with cows with no clinical mastitis and BCS >2.75 [53].

Most studies have concluded that cows should only lose limited body condition after calving regardless of BCS at calving to maintain maximal milk yield and acceptable P/AI with limited pregnancy loss. For cows in a seasonal pasture-based system of milk production it is necessary to maintain BCS at 2.75 or greater during the breeding season [12]. Furthermore, losses should be restricted to 0.5 BCS unit to avoid pregnancy loss (Fig. 4A) and detrimental effects on fertility regardless of management [12,35,54]. A severe loss in BCS during early lactation was associated with an 11-d increase in the calving to conception interval [17].

Improvements in BCS during the first 3 wk after calving were associated with increased P/AI at first AI [13], but this was observed in only one of two farms studied. Compared with cows that either maintained or lost BCS after calving until the time of first AI, days to conception [46] averaged 9 d less and cows achieved greater P/AI [36] as observed in the present study (Fig. 1). The top three ranking variables that explained the variation in P/AI in 720 cows in one herd were parity, milk yield at 120 d of lactation, and change in BCS between parturition and wk 4 of lactation [55]. Furthermore, increased milk yield at 120 d of lactation was associated with an increased likelihood of conception, and decreased body condition during the first month of lactation was associated with decreased likelihood of conception [15]. An attempt to model reproduction in Holstein cows predicted consistent overall reproductive performance that was sensitive to milk yield and body reserves (represented by BCS) [56].

Severe postpartum negative energy balance affects fertility by a variety of mechanisms. A recent review highlighted that formulation and delivery of appropriate diets to limit total energy intake to requirements but also provide proper intakes of all other nutrients, including the most limiting amino acids (methionine and lysine) before calving, can lessen the extent of negative energy balance [57] and excessive loss in body condition after calving. Negative energy balance reduces the ability of the uterus to recover after calving and may result in persistent inflammatory mediated damage [58]. Inflammatory disease before AI decreases fertility of oocytes and their development to morula and impairs early conceptus development to elongation and secretion of interferon tau [58]. Metabolic changes associated with tissue mobilization may cause damage to oocytes either directly or via alterations in the follicular environment. Body condition score and days in milk influence carbohydrate metabolism in the follicle environment more so than alterations in the amount of fat such as triglycerides and total free fatty acids [59], thus influencing oocyte developmental competence. Oocyte competence is supported by the fact that changes in postpartum energy balance are related to dominant follicle function and bioavailability of circulating IGF-I [55,59]. Increasing body weight or body condition positively affect fertility outcomes when recipient heifers receiving in vitro-produced embryos were gaining weight during the first month of pregnancy [60]. Furthermore, super-ovulated heifers with BCS <3.50 had better embryo production [61].

In the present study, milk yield at AI was associated with BCS at calving and prebreeding loss in BCS, which both interacted with parity, in addition to BCS at AI, which interacted with season of AI (Figs. 5 and 6). Not only was milk yield greater in cows at the lower end of the BCS scale (Fig. 5B), but first- and second-parity cows produced more milk when they lost more than 0.5-units of BCS during the prebreeding period (Fig. 6). In the remaining cows in their third or greater lactation, the effect of BCS at AI was similar but minimal. Unlike the present study in which parity interacted with BCS at calving, ten of eleven earlier pre-1997 reports found no relationship of calving body condition and milk yield [6]. Furthermore, effects of calving BCS on milk solids was less consistent, but in general, cows with more body fat reserves mobilized more fat for milk fat synthesis and under conditioned cows at calving produced lower-fat milk without affecting milk yields [6]. Roche et al. [7] later concluded in their review that the associations among BCS variables and milk production imply a nonlinear effect of calving and nadir BCS. In addition, the relationship between post calving BCS change and milk yield indicated the existence of an optimum BCS to maximize milk yield, suggesting that should be in the range of 3.00–3.50 at calving [7].

Differences observed among studies also may be related to the genotypes studied because North American Holsteins produced more solids-corrected milk, whereas New Zealand Holstein-Friesians replenished more body condition when both genotypes were managed in a grass-based New Zealand system [62]. Furthermore, a genotype-environmental interaction was demonstrated by feeding levels, which had opposite effects on milk yield and body condition and had opposing effects on reproductive stages that led to similar final reproductive performance of Holstein and Normande cows in a grass-based compact calving system [63]. A genetically high BCS in early- and mid-lactation primiparous cows housed in confinement was associated with earlier conception during lactation and greater chance to become pregnant [9].

Loss in body condition during the dry period is not recommended because these cows are prone to have inactive ovaries after calving, delayed commencement of estrous cycles, greater likelihood of failure to conceive by 150 d in milk, and greater incidences of retained placenta and metritis [6,16]. In addition, BCS loss during the dry period is a predisposing factor associated with health disorders and reduced productive and reproductive performance in Holstein cows [14]. More under conditioned multiparous cows at calving were culled early and exhibited more postpartum uterine diseases [6]. Over-conditioned cows at calving had increased risk for ketosis [6], retained placenta and hypocalcemia [1,7], poorer feed intake [10,55], and greater body condition loss resulting in poorer P/AI and longer intervals from parturition to conception [6,55]. Body condition during the dry period and during the first 30 d in milk is predictive of cows at risk for failure to conceive at first AI [14,55]. Gain in body condition during the dry period resulted in more milk during the first 120 d of lactation and accelerated the rate of increase in milk yield [15]. Therefore, most have concluded that BCS at dry off or at calving should be between 3.00 and 3.25 [1,14,16].

Across the range of recorded BCS in the present report, the correlations were quite large ($r > 0.57$) between BCS at calving, BCS at AI, and the amount of prebreeding change in BCS, which is consistent with one review [7]. The interrelationships of these BCS assessments and their associations with dairy cow performance indicate that managing body condition is only one of many tools that can be used to monitor nutrition, reproduction, and health of dairy cows. Because of the strong relationship of body condition to pregnancy outcomes and milk yield, body condition score assessment is a management tool that should be applied more effectively on dairy farms, particularly in predicting reproductive outcomes. It is known that economic gain increases as the reproductive efficiency improves and these increments follow the law of diminishing returns but are still positive even at high levels of reproductive performance [64]. Furthermore, improved pregnancy outcomes result in greater milk yields, and therefore, higher milk income over feed cost, more calf sales, and lesser culling and breeding expenses [64]. In addition, pregnancy per AI after Ovsynch was reduced by 46% in cows with BCS <2.50 compared with cows of greater BCS at Days 63 ± 3 in milk, which also reduced net revenues per cow with poor BCS [42].

Roche et al. [65] concluded that BCS provides a gross but reasonably accurate measure of a cow's energy reserves. Although calving BCS affects early lactation dry matter intake, post calving BCS loss, milk yield, and cow immunity, calving BCS did not directly affect P/AI (consistent with our results in Fig. 2), but may influence reproduction through its effect on BCS nadir and postpartum BCS loss, which is consistent with [16,17]. Delay in detecting changes in BCS may be after the metabolic effects on reproduction have been initiated [8]. An alternative measure of the state of body composition and tissue metabolism may be required, one that accounts for changes in protein reserves and internal fat reserves, as well as sc fat [66] because the body, under the stress of negative energy balance, mobilizes all these tissues to maintain normal physiological functions [8].

Monitoring and adjusting nutrient needs of cows during late lactation and during the dry period to ensure adequate body condition at calving without over conditioning cows seems to be a reasonable step to maximize post-calving pregnancy and milk outcomes. It is now recommended that cows achieve a BCS of 3.0–3.25 by 1 month before calving or by dry off [14] and then consume 80%–100% of their energy requirements in the month before calving [57] because feeding energy-rich postpartum diets do not successfully reduce body lipid metabolism and or change early postcalving BCS [7].

Some technologies to assess body condition have been reviewed [7]. More recent reports of frequently collected body weight measurements by exit-parlor scales [67] or BCS assessments determined by an automated camera system at multiple time points such as dry-off, calving, and other points between calving and first AI [68,69] demonstrate potential tools to monitor body condition, energy balance, and health status. The latter report of 11393 lactations in 7928 Holstein cows in a commercial dairy demonstrated that poor BCS and more pronounced reductions in BCS occurring closer to first AI resulted in reduced odds of P/AI [68].

5. Conclusions

Pregnancy per AI increased linearly as BCS at first AI increased, but magnitude of prebreeding BCS loss was not associated with P/AI at first service. Less pregnancy loss was associated with greater BCS at AI. In contrast, more pregnancy loss was associated with more prebreeding BCS loss in multiparous cows. Cow having less body condition at AI and greater prebreeding loss in body condition produced more milk than their herd mates of greater BCS and less prebreeding loss in BCS, respectively. First- and second-parity cows produced more milk when they lost more than 0.5 units of BCS during the prebreeding period.

CRediT authorship contribution statement

Jeffrey S. Stevenson: Conceptualization, Methodology, Funding acquisition, Formal analysis, Project administration, Writing – review & editing. **Branko Atanasov:** Conceptualization; Project conductance; Review and editing.

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