Relationships Between Transition Cow Nutrition and Management Strategies and Outcomes in Large Dairy Herds in the Northeastern US

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Introduction

Many management factors contribute to cow success during the transition period including minimizing management related stressors, ration formulation and feeding strategies, monitoring and treatment of health disorders, and facilitating cow comfort (Nydam et al., 2017). Nutritional strategy recommendations during the transition cow period are often driven by results from controlled research trials or anecdotal observations. Although research exists evaluating transition cow nutritional strategies, large-scale data availability is limited, particularly for the periparturient and fresh cow periods. In addition, controlled research trials are often completed in tiestall barns, removing many influences of environment and management, potentially resulting in varying outcomes in freestall herds.

The adoption of a controlled energy diet throughout the dry period has increased amongst the dairy industry and has been supported by controlled research trials for improving postpartum health (Janovick et al., 2011; Mann et al., 2015; Richards et al., 2020); however, some studies have demonstrated decreased milk production in animals fed a controlled energy prepartum diet (Vickers et al., 2013). It has been proposed that feeding a lower starch diet during the fresh period might result in cows having improved milk production compared to cows fed higher levels of fermentable starch during the fresh period (Allen et al., 2009); however, data are lacking or have not fully supported this theory (McCarthy et al., 2015; Rockwell and Allen, 2016).

Limited field data exist that describe different management strategies that contribute to cow success in commercial farm settings. Therefore, recommendations are often driven by field experience from concepts established through controlled research with comparatively small numbers of cows. Bach et al. (2008) reported a 13.2 kg/d range in the mean milk production across 47 herds that were fed the exact same TMR and determined that 50% of the observed variation was attributed towards non-nutritional management factors. Limited research and field observations have demonstrated that non-nutritional management factors, such as stocking density, pen moves, and commingling of primiparous and multiparous cows, can impact health and milk production (Cook and Nordlund, 2004; von Keyserlingk et al., 2008; Huzzey et al., 2012); however, besides heat abatement, little research has evaluated the impact of management factors on reproductive performance. Controlled research trials typically attempt to evaluate the change in one management factor while minimizing changes with additional management factors; therefore, the magnitude of the impact of management factors has not been fully elucidated. In addition, most studies evaluating management factors have not been conducted during the transition period. Evaluating management and nutritional factors with outcomes on commercial farms, such as health, blood biomarkers, milk production, and reproductive performance may provide an understanding of how these factors contribute to transition cow success across a range of farm practices.

Our first objective was to identify relationships between dry period and periparturient period nutritional strategies as characterized by ration contents of starch, forage NDF, or both, and biomarkers of energy metabolism [nonesterified fatty acids (**NEFA**) and β-hydroxybutyrate (**BHB**)] and inflammation [haptoglobin (**Hp**)], disease, milk production, and reproductive performance. Our second objective was to evaluate relationships between putative periparturient management factors at the pen- and herd-level with blood biomarkers, disease, milk production and reproductive performance.

Experimental Design

A prospective cohort study was conducted from a convenience sample of 72 farms located in New York and Vermont between November 2012 and August 2015. Inclusion criteria for herds were 1) Holstein herds, 2) ≥ 400 milking cows, 3) free-stall housing, 4) TMR-fed herds, and 5) enrolled in monthly DHI testing or have on-farm milk recording with record management by Dairy Comp 305 (DairyComp 305, Valley Ag Software, Tulare, CA) or PCDART (PCDART, Dairy Records Management System, Raleigh, NC). Farms that met these inclusion criteria were enrolled based upon their willingness to participate. Farms were visited 3 times for data collection focused on the same cohort of animals during the far-off dry (28 to 49 d prior to expected parturition), close-up dry (0 to 21 d prior to expected parturition; 4 wk after the first visit), and fresh (0 to 21 DIM; 16 to 21 d after the second visit) periods. Cows were observed for health disorders of interest in the first 30 DIM by farm personnel and case definitions for the health disorders were provided to the farm for recording and consistency purposes.

Blood samples were collected from a convenience sample of 11 to 24 cows within each herd at the close-up visit and from the same cohort of cows at the fresh period visit. To reflect herd demographics, approximately one-third of the cows sampled were primiparous cows. Postpartum whole blood was measured for BHB. Prepartum and postpartum plasma was analyzed for NEFA and postpartum plasma was analyzed for Hp on cows 0 to 12 DIM.

The formulated diets fed to the cows observed at the time of the visit were collected from the nutritionist or herd manager. The forages fed to the observed group of cows were sampled at each visit and analyzed by near-infrared spectroscopy at a commercial laboratory (Green Mountain Feed Testing Laboratory, Newport, VT) and evaluated for particle size with the 3-sieve Penn State Particle Separator (**PSPS**; Cumberland Valley Analytical Services, Maugansville, MD). Physically effective NDF (**peNDF**) was calculated by multiplying the proportion of TMR above the 4-mm sieve by the average analyzed ration NDF on a DM basis. Physically effective undigested NDF after 240 h of in vitro fermentation (**peuNDF240**) was calculated by multiplying the proportion of TMR above the 4-mm sieve by the average analyzed ration undigested NDF after 240 h of in vitro fermentation on a DM basis (**uNDF240**; Miller et al., 2020). The formulated diets with analyzed forage samples were inputted into the Cornell Net Carbohydrate and Protein System (CNCPS v. 6.1, Cornell University, Ithaca, NY). The ration CNCPS files were imported into the Nutritional Dynamic System Professional (NDS Professional version 3.8.10.06, RUM&N Sas, Reggio Emilia, Italy) for nutrient extraction.

For each visit, the farms were retrospectively dichotomized within parity group into different nutritional strategies as determined by starch, forage NDF, or both, based on the CNCPS-formulated diet. For the far-off period, farms were characterized as feeding a controlled energy diet (**CE**; <16.5% starch and ≥40% forage NDF) or not CE (**NCE**; ≥16.5% starch or <40% forage NDF or both). For the close-up period, farms were characterized as feeding a higher forage NDF (**HF**; ≥40% forage NDF) or lower forage NDF diet (**LF**; <40% forage NDF) and for the fresh period, farms were characterized as feeding a lower starch (**LS**; <25.5% starch) or higher starch diet (**HS**; ≥25.5% starch).

For the management pen-level analysis, we assessed management explanatory variables during the far-off, close-up, and fresh period visits. Stall stocking density was calculated as the number of cows in the pen at the time of the visit divided by the number of usable stalls in the pen. If the pen was a bedded pack, a stall was considered 11 m^2 of pack space (Nordlund, 2009). Bunk stocking density was calculated as the number of cows in the pen at the time of the visit divided by the number of headlocks. If a pen did not have headlocks, a headlock was considered 61 cm of rail space (NFACC, 2009). The feed pushup frequency within each day for a pen was dichotomized as < 5×/d or ≥ 5×/d (Miller-Cushon and DeVries, 2017). The feeding frequency within each day was not evaluated during the prepartum period due to few observations in which the pen was fed more than once per day. Commingling of primiparous and multiparous cows was also assessed at the pen-level.

For the management herd-level analysis, explanatory variables assessed included whether cows were routinely vaccinated in the calving pen and fresh pen, whether the herd utilized a maternity pen or a calving pen, the number of pen moves during the prepartum and postpartum period, time spent in the calving pen and fresh pen, and time spent locked up in the fresh pen. A maternity pen was classified as a pen cows moved into at least 0 to 3 d prior to expected calving while a calving pen was classified as a pen cows move into when exhibiting signs of labor. The prepartum pen moves were the number of pen moves from dry off or 60 d prior to expected calving to parturition for primiparous and multiparous cows, respectively (> 2 vs. ≤ 2). The move from the lactating pen to the far-off dry cow pen was included in this measure for multiparous cows. The postpartum pen moves were the number of pen moves from parturition to 90 DIM (> 2 vs. ≤ 2). The time spent in the calving pen before moving to the fresh pen after parturition was dichotomized as ≤ 8 h or > 8 h. The time spent in the first pen moved into after parturition was dichotomized as ≤ 10 d or > 10 d. Time spent locked up in fresh pen for health checks was categorized as: 1) locked up < 1×/d for < 1 h, 2) locked up daily for < 1 h, or 3) locked up daily for ≥ 1 h.

The outcomes of interest were: 1) prevalence of elevated prepartum circulating NEFA concentration in multiparous cows (≥0.17 mmol/L), 2) prevalence of elevated postpartum circulating NEFA (≥0.59 mmol/L), 3) prevalence of postpartum circulating BHB (≥1.2 mmol/L), 4) prevalence of elevated postpartum circulating Hp (≥0.45 g/L), 5) disorder incidence of one or more of displaced abomasum, clinical ketosis, or metritis within 30 DIM (**DI**), 6) herd average milk production at 4 wk of lactation (**WK4MP**), 7) herd average 305-d mature equivalent milk yield at approximately 120 DIM (**ME305**), 8) 21-d herd pregnancy rate (**PR**), 9) herd risk of conceiving as identified by pregnancy (**CR**), and 10) the pregnancy risk to first service (**PRFS**). Biomarker thresholds were chosen as they were the herd alarm levels associated with an increase in disorder incidence for primiparous and multiparous cows. The prevalence of elevated prepartum NEFA concentrations were only evaluated for multiparous cows since a herd-alarm level was not identified for primiparous cows. The 21-d PR was determined by averaging the two-21 d periods after the herd VWP for the group of cows that calved within the same time frame as the cows sampled. The CR was determined by averaging the conception risk, as identified by pregnancy, for the first 2 estrus cycles after the VWP for the group of cows that calved within the same time frame as the cows sampled. Cows that were never bred were removed from the PRFS analysis (n = 155). All outcomes were calculated by parity within a farm due to some farms feeding different diets to the multiparous and primiparous cows and multiparous and primiparous cows being housed separately.

All statistical analyses were calculated using SAS software (SAS 9.4, SAS Institute Inc., Cary, NC). For objective 1, mixed effects linear models were generated using PROC MIXED for all outcomes by parity group at the herd-level. Nutritional strategies were assessed during the dry period and the periparturient period using two models for each outcome: A) the main effects of the nutritional strategy during the far-off and close-up dry periods, and B) the main effects of the nutritional strategy during the close-up dry and fresh periods. Calving season [cool (October through April) vs. warm (May through September)] and the interaction between the nutritional strategy main effects were included in the full models. Multiparous and primiparous cows were initially analyzed separately. If the association between the nutritional strategies and outcome of interest were similar between parity groups, then multiparous and primiparous cows were combined and parity group was included as a covariate and herd was included as a random effect. A manual backwards stepwise elimination was used to remove the interaction term if $P \geq 0.15$ and season and parity group if $P \geq 0.10$. Comparisons to farms that fed NCE during the far-off period and HF in the close-up period were not assessed due to a limited number of observations, as this is not a common nutritional strategy amongst farms in the Northeastern United States.

For objective 2, a simple linear regression (PROC REG or PROC GLM) was conducted on all possible continuous explanatory variables and categorical explanatory variables that occurred before the outcome of interest to determine the univariable association for the pen level-management analysis. Explanatory variables with a $P < 0.2$ were offered to a multivariable general linear model (PROC GLM) for each outcome. Calving season was included as a covariate if $P < 0.10$ in a univariate analysis and a manual backwards stepwise elimination process ensued until all variables had a $P < 0.1$.

The far-off period was not assessed for primiparous cows due to too many missing observations. For the herd-level management analysis, a simple linear regression analysis (PROC GLM) was conducted on all possible explanatory variables and included parity, the interaction with parity, and the random effect of farm. Calving season was included in the simple linear regression analysis as a covariate if season was associated with the outcome. Explanatory variables with a $P < 0.2$ were offered to a multivariable general linear model (PROC MIXED) for each outcome with herd as a random effect and a manual backwards stepwise elimination process ensued until all variables had a $P < 0.1$.

Nutritional Strategy Results

Prevalence of Elevated Biomarkers

We found no evidence that there was a difference in the prevalence of elevated prepartum NEFA concentration between the far-off ($P = 0.97$) or close-up ($P = 0.25$) nutritional strategies for multiparous cows.

We found no evidence that there was a difference in the prevalence of elevated postpartum NEFA concentration for the dry period nutritional strategies for multiparous and primiparous cows nor for the periparturient period nutritional strategies for multiparous cows. We observed an interaction between the close-up and fresh period nutritional strategies for primiparous cows ($P = 0.05$) such that herds that were fed HF × HS had a higher prevalence of elevated NEFA (28.7 ± 6.5%) than herds that were fed LF × HS (11.7 ± 4.3%; $P = 0.14$), but not different than herds fed HF × LS (16.1 ± 6.7%; $P = 0.54$) or LF × LS (21.9 ± 5.1%; $P = 0.84$).

For the prevalence of elevated BHB concentration analysis, multiparous and primiparous cows were separated for the dry period nutritional strategy analysis due to dissimilar results. We observed an interaction between the far-off and close-up nutritional strategy for primiparous cows ($P = 0.10$); however, we found no evidence that there was a difference in the prevalence of elevated postpartum BHB concentration for the typical nutritional strategies observed in the Northeastern US based on the Bonferonni test. For the dry period model for multiparous cows, we observed a lower prevalence of elevated BHB concentration for HF fed herds during the close-up period than LF fed herds (13.0 ± 3.6 vs. 21.1 ± 2.6%; $P = 0.07$) and there was no evidence for a difference in the prevalence of elevated BHB concentration for the far-off nutritional strategies ($P = 0.59$). Primiparous and multiparous cows were combined for the periparturient model due to similar results. We observed a lower prevalence of elevated BHB concentration on HF fed herds versus LF fed herds (11.1 ± 2.8 vs. 16.6 ± 2.0%; $P = 0.11$) during the far-off period and HS fed herds versus LS fed herds (10.0 ± 2.3 vs. 17.8 ± 2.5%; $P = 0.02$) during the close-up period.

For the prevalence of elevated Hp concentration analysis, we found no evidence that there was a difference in the prevalence of elevated postpartum Hp concentration for the periparturient period nutritional strategies for multiparous cows. For the dry period nutritional strategy, we found no evidence that there was a difference in the prevalence of elevated Hp concentration for the far-off nutritional strategy (*P* = 0.77); however, we observed a difference in the prevalence of elevated Hp concentration for the close-up nutritional strategy for primiparous and multiparous cows such that HF fed herds had a higher prevalence of elevated Hp concentration that LF fed herds (*P* = 0.14). We observed a difference in the prevalence of elevated Hp concentration for the fresh nutritional strategy for primiparous cows such that LS fed herds had a lower prevalence of elevated Hp concentration that HS fed herds (*P* = 0.06).

Postpartum Health, Milk Yield, and Reproductive Performance Outcomes

We found no evidence that there was a difference in DI for the dry period nutritional strategies for multiparous and primiparous cows. We observed an interaction between the close-up and fresh nutritional strategies for multiparous and primiparous cows (*P* = 0.009) such that cows fed HF close-up followed by a LS fresh diet or LF close-up followed by a HS fresh diet had the highest DI (18.9 ± 4.0%)I; however, we found no evidence that the DI differed between any of the nutritional strategies based on the Tukey honest significance difference test *(P* > 0.19).

We found no evidence that there was an association between different nutritional strategies and either WK4MP or ME305.

For the 21-d PR analysis, multiparous and primiparous cows were separated for the dry period nutritional strategy analysis due to dissimilar results. For multiparous cows, there was no evidence that the 21-d PR differed between far-off nutritional strategies (P = 0.69); however, the 21-d PR was slightly higher in LF fed herds during the close-up period compared to HF fed herds (24.7 ± 1.0 vs. 22.2 ± 1.4%; *P* = 0.14). We observed an interaction between the far-off and close-up period nutritional strategies for primiparous cows (*P* = 0.07); however, we found no evidence that there was a difference in the 21-d PR for the typical nutritional strategies observed in the Northeastern United States, based on the Bonferroni test (*P* > 0.26). Multiparous and primiparous cows were also separated for the periparturient period nutritional strategy analysis due to dissimilar results. Similar to the dry period nutritional strategy model for multiparous cows, the 21-d PR was slightly higher in LF fed herds during the close-up period compared to HF fed herds (24.7 ± 1.0 vs. 22.1 ± 1.3%; *P* = 0.14); however, there was no evidence that the 21-d PR differed between the fresh period nutritional strategies. We found no evidence that the 21-d PR differed between the close-up (*P* = 0.49) or fresh period (*P* = 0.22) nutritional strategies for primiparous cows.

For the CR analysis, multiparous and primiparous cows were separated for the dry period nutritional strategy analysis because the results were dissimilar; however, we found no evidence that there was an association between different dry period nutritional strategies and CR for multiparous and primiparous cows. For multiparous cows, there was no evidence that the CR differed between the periparturient nutritional strategies. For primiparous cows, we observed an interaction (*P* = 0.14) between the close-up and fresh period nutritional strategies such that HF × HS fed herds (50.1 ± 2.7%) had a higher CR than HF × LS fed herds (40.6 ± 2.8%; $P = 0.08$), LF × LS fed herds (40.2 ± 2.3%; $P = 0.03$), and LF × HS fed herds (42.5 ± 1.9%; $P = 0.11$).

For the PRFS analysis, multiparous and primiparous cows were combined in the dry period and periparturient period models due to similar results. We found no evidence that there was an association between different nutritional strategies and PRFS.

Management Strategy Results

Prevalence of Elevated Biomarkers

Only multiparous cows were evaluated for the prevalence of elevated prepartum NEFA concentrations since we only identified a herd-alarm level for multiparous cows. For the herd-level analysis, we found no evidence that prepartum pen moves was associated with the prevalence of elevated prepartum NEFA concentrations. For the pen-level analysis, no explanatory variables remained in the far-off model. For the close-up period, a 1-percentage unit increase in the proportion of particles on the 4-mm sieve of the PSPS for the close-up period pens resulted in a 1.2-percentage unit increase in the proportion of multiparous cows with elevated prepartum NEFA concentration ($R^2 = 0.06$; $P = 0.03$).

For the prevalence of elevated postpartum NEFA concentrations, no explanatory variables remained in the models for primiparous cows nor in the far-off period model for multiparous cows. For the pen-level analysis, a 1-percentage unit increase in the proportion of particles in the PSPS pan during the close-up and fresh periods resulted in a 1.0-percentage unit decrease ($P = 0.04$) and 0.7-percentage unit increase ($P = 0.09$) in the proportion of multiparous cows with elevated postpartum NEFA concentration, respectively. A 1-percentage unit increase in bunk stocking density for multiparous cows during the fresh period resulted in a 0.15-percentage unit increase in the proportion of multiparous cows with elevated postpartum NEFA concentration ($P = 0.06$). For the herd-level analysis, herds that kept cows in the calving pen for > 8 h after parturition had a greater proportion of cows with elevated postpartum NEFA concentration compared to herds that kept cows in the calving pen for ≤ 8 h (43.6 ± 6.0 vs. 21.0 ± 2.3%; $P < 0.001$).

For the prevalence of elevated postpartum BHB concentrations, no explanatory variables remained in the BHB models for the far-off period for primiparous cows or the close-up period for primiparous and multiparous cows. For the pen-level analysis, a 1-percentage unit increase in the proportion of particles on the 8-mm PSPS sieve during the fresh period resulted in a 1.2-percentage unit decrease in the proportion of primiparous cows with elevated postpartum BHB concentrations ($P < 0.001$). Commingled fresh period pens had a greater proportion of primiparous cows with elevated BHB concentrations compared to non-commingled fresh period pens (16.2 ± 2.6 vs. 6.2 ± 3.6%; $P = 0.03$). Fresh period pens that were fed >1×/d had a lower proportion of primiparous cows (7.1 ± 3.7 vs. 15.3 ± 2.5%; $P = 0.08$) and multiparous cows (21.7 ± 4.9 vs. 40.1 ± 3.2%; $P = 0.08$) with elevated BHB concentrations compared to pens that were fed ≤1×/d. A 1-cm per cow increase in water space during the far-off period resulted in a 3.7-percentage unit decrease in the proportion of multiparous cows with elevated postpartum BHB concentration (*P* = 0.04). For the herd-level analysis, we observed an interaction between parity group and the time spent in the calving pen after parturition such that herds that kept multiparous cows in the calving pen for more than 8 h had a lower proportion of multiparous cows with elevated postpartum BHB concentration (4.7 ± 7.0 vs. 17.7 ± 2.0%; *P* = 0.08) and herds that kept primiparous cows in the calving pen for more than 8 h had a higher proportion of primiparous cows with elevated postpartum BHB concentration (26.6 ± 5.4 vs. 7.2 ± 2.1%; *P* = 0.001) compared to herds that kept primiparous or multiparous cows in the calving pen for ≤ 8 h after parturition.

For the prevalence of elevated postpartum Hp concentrations, no explanatory variables remained in the model for the close-up period for multiparous cows. For the pen-level analysis, pushing up feed ≥ 5×/d during the close-up and fresh periods resulted in a 22.9% (R^2 = 0.08; *P* = 0.07) and 22.7% (R^2 = 0.08; *P* = 0.06) increase in the proportion of primiparous cows with elevated Hp concentration, respectively. A 1-percentage unit increase in the proportion of particles on the 19-mm PSPS sieve during the far-off period resulted in a 0.4-percentage unit decrease in the proportion of multiparous cows with elevated Hp concentration (R^2 = 0.04; *P* = 0.10). Commingled fresh period pens had a lower proportion of multiparous cows with elevated Hp concentration compared to non-commingled fresh period pens (36.0 ± 2.5 vs. 48.8 ± 4.3%; *P* = 0.01). For the herd-level analysis, we observed an interaction between the number of prepartum pen moves and parity (*P* = 0.07). Herds that moved primiparous cows ≤ 2× from 60 d prior to expected calving to parturition had a lower proportion of primiparous cows with elevated Hp concentrations compared to herds that moved primiparous cows > 2× (57.1 ± 5.2 vs. 69.0 ± 5.6%; *P* = 0.04). There was no evidence that the proportion of multiparous cows with elevated Hp concentration in herds that moved cows ≤2× from dry-off to parturition versus herds that moved multiparous cows > 2 times differed (*P* = 0.50). We also observed an interaction between parity group and the time in the calving pen after parturition (*P* = 0.002). Herds that kept primiparous cows in the calving pen for >8 h had a greater proportion of primiparous cows with elevated Hp concentrations compared to herds that kept primiparous cows in the calving pen for ≤ 8 h (79.4 ± 8.3 vs. 46.7 ± 3.5; *P* < 0.001). There was no evidence that the proportion of multiparous cows with elevated Hp concentrations differed between herds that kept cows in the calving pen for >8 h versus ≤ 8 h (*P* = 0.57). We also observed an interaction between parity group and the time locked in the fresh pen (*P* = 0.09). There was no evidence that the proportion of multiparous cows with elevated Hp concentrations differed between herds that had multiparous cows locked up for different periods of time (*P* = 0.56). Herds that had primiparous cows locked up daily for ≥ 1 h had the lowest proportion of primiparous cows with elevated Hp concentration (53.3 ± 7.9%) though there was no evidence that it differed from herds that had primiparous cows locked up daily for < 1 h (72.3 ± 5.7%; *P* = 0.11) or herds that had primiparous cows locked up for < 1×/d for < 1 h (63.6 ± 5.6%; *P* = 0.72).

Postpartum Health, Milk Yield, and Reproductive Performance Outcomes

For the DI pen-level analysis, a 1-percentage unit increase in bunk stocking density during the close-up period resulted in a 0.13-percentage unit increase in DI for primiparous cows ($R^2 = 0.09$; $P = 0.03$). Fresh period pens that had feed pushed-up ≥ 5×/d had a higher DI for primiparous cows than pens that had feed pushed-up < 5×/d (14.0 ± 2.5 vs. 0.0 ± 7.5%; $P = 0.08$). Caution should be used when interpreting the fresh period model for primiparous cows as only 6 observations remained in the <5×/d feed pushup frequency category. A 1-percentage unit increase in the proportion of particles on the PSPS 19-mm sieve during the far-off period and particles on the 8-mm sieve during the close-up period resulted in a 0.3-percentage unit decrease ($P = 0.08$) and 0.5-percentage unit increase ($P = 0.02$) in DI for multiparous cows, respectively. Fresh period pens that were fed >1×/d had a lower DI for multiparous cows than pens that were fed ≤1×/d (7.5 ± 2.9 vs. 14.8 ± 1.8%; $P = 0.04$). For the herd-level model, herds that had cows vaccinated in the calving pen had a higher DI than herds that did not (26.1 ± 5.0 vs. 13.5 ± 2.0%; $P = 0.02$). Herds that did not lock up cows daily had a lower DI (14.4 ± 3.2%) compared to herds that had cows locked up daily for < 1 h (22.7 ± 3.5%; $P = 0.06$); however, there was no evidence that herds that had cows locked up < 1×/d for < 1 h differed from herds that had cows locked up daily for ≥ 1 h (22.2 ± 4.5%; $P = 0.25$).

For the WK4MP analysis, no explanatory variables remained in the far-off model for multiparous cows. A 1-percentage unit increase in the proportion of particles on the PSPS 19-mm sieve for the close-up pen rations resulted in a 0.1-kg/d increase in WK4MP for primiparous cows ($R^2 = 0.06$; $P = 0.07$). A 1-percentage unit increase in the fresh pen stall stocking density resulted in a 0.03-kg/d increase in WK4MP for primiparous cows ($P = 0.07$). Primiparous and multiparous cows in fresh period pens and multiparous cows in close-up pens that had feed pushed up ≥ 5×/d produced less WK4MP than pens that had feed pushed up < 5×/d (fresh pen for primiparous: 33.4 ± 0.4 vs. 35.2 ± 1.0 kg/d; $P = 0.09$; close-up pen for multiparous: 46.5 ± 0.5 vs. 48.6 ± 1.1 kg/d; $P = 0.08$; fresh pen for multiparous: 46.6 ± 0.4 vs. 49.1 ± 1.0 kg/d; $P = 0.03$). Primiparous cows commingled with multiparous cows in the fresh period pens produced less WK4MP than primiparous cows in non-commingled pens (33.4 ± 0.4 vs. 35.2 ± 1.0 kg/d; $P = 0.03$). A 1-percentage unit increase in uNDF240 (%DM) in the fresh period pen TMR resulted in a 0.9-kg/d decrease in WK4MP for multiparous cows (P = 0.01). For the herd-level analysis, we observed a calving pen vaccination by parity group interaction (P = 0.05). Herds that had multiparous cows vaccinated in the calving pen produced less WK4MP than herds that did not have multiparous cows vaccinated in the calving pen (42.7 ± 1.8 vs. 46.8 ± 0.4 kg/d; $P = 0.04$); however, we found no evidence that there was a difference in WK4MP for primiparous cows that were vaccinated in the calving pen versus not vaccinated ($P = 0.80$).

For the ME305 analysis, no explanatory variables remained in the close-up period model for primiparous cows nor for the far-off period model for multiparous cows. For the pen-level analysis, a 1-percentage unit increase in peuNDF240 during the fresh period resulted in a 468-kg ($R^2 = 0.15$; $P = 0.002$) and 278-kg ($R^2 = 0.07$; $P = 0.02$) decrease in ME305 for primiparous and multiparous cows, respectively. A 1-percentage unit increase in stall stocking density during the close-up period resulted in an 8-kg increase in ME305 for multiparous cows (*P* = 0.06). A 1-percentage unit increase in the proportion of particles on the PSPS 4-mm sieve for the close-up period TMR resulted in an 86-kg increase in ME305 for multiparous cows (*P* = 0.01). Multiparous cows that were commingled with primiparous cows in the close-up period pens produced less ME305 than multiparous cows that were not commingled (12,414 ± 166 vs. 13,129 ± 253 kg; *P* = 0.02). For the herd-level analysis, there was an interaction between postpartum pen moves and parity (*P* = 0.06) such that herds that had primiparous cows moved ≤ 2× within the first 90 DIM produced more ME305 milk than herds that moved primiparous cows > 2× (12,950 ± 199 vs. 12,231 ± 214 kg; *P* = 0.01). We found no evidence for a difference in ME305 for herds that moved multiparous cows ≤ 2× versus > 2× within the first 90 DIM (*P* = 0.32).

For the 21-d PR herd-level analysis, we observed an interaction between parity and the use of a maternity pen, such that herds that moved primiparous cows into a maternity pen where they were expected to calve in the next 0 to 3 d had a lower 21-d PR compared to herds that move primiparous cows into a calving pen when the primiparous cow was showing signs of labor (26.4 ± 1.8 vs. 29.7 ± 1.3%; *P* = 0.10). We did not observe a difference between multiparous cows (*P* = 0.32).

For the herd-level results for the CR analysis, herds that had cows stay in the calving pen for > 8 h after parturition had a lower CR than herds that had cows in the calving pen for ≤ 8 h (35.8 ± 2.4 vs. 40.3 ± 0.9; P = 0.09).

For the PRFS pen-level analysis, a 1-percentage unit increase in stall stocking density during the close-up period for primiparous cows and far-off period for multiparous cows resulted in a 0.15- (*P* = 0.06) and 0.19-percentage unit (*P* = 0.03) increase in PRFS, respectively. A 1-percentage unit increase in the proportion of particles on the PSPS 8-mm sieve during the close-up period for primiparous cows and close-up period for multiparous cows resulted in a 0.9- (P = 0.002) and 0.5-percentage unit (P = 0.007) increase in PRFS, respectively. Multiparous cows in the far-off and close-up period pens that had feed pushed up ≥ 5×/d had a higher PRFS than for pens that had feed pushed up < 5×/d (far-off: 35.2 ± 1.9 vs. 27.9 ± 3.1%; *P* = 0.05; close-up: 34.5 ± 2.0 vs. 23.3 ± 4.4%; *P* = 0.02). For the herd-level analysis, we observed an interaction between the amount of time locked in the fresh pen for fresh cow health checks and parity group (*P* = 0.08); however, we found no evidence that PRFS differed within each parity group (multiparous: *P* = 0.25; primiparous: *P* = 0.16). Herds that kept cows in the calving pen for > 8 h after parturition had a lower PRFS than herds that kept cows in the calving pen for ≤ 8 h (24.5 ± 4.2 vs. 38.2 ± 1.8%; *P* = 0.003).

Conclusions and Implications

This study provides further epidemiological evidence that nutritional and management factors both influence transition cow outcomes. In general, the nutritional strategy results of our study support feeding cows a high forage NDF close-up and high starch fresh diet to minimize excessive prevalence of elevated BHB concentration and reduce disease incidence in the early postpartum period. Similarly to the multiparous cows, the results of our study support feeding primiparous cows a controlled energy far-off, high forage NDF close-up, and high starch fresh diet to maximize reproductive performance, minimize excessive prevalence of elevated BHB, and to reduce disease incidence in the early postpartum period. From a management perspective, our results support maximizing bunk space and adequate water space per cow, avoiding commingling and increasing the feeding frequency during the fresh period, increasing the proportion of particles on the PSPS 19-mm sieve for the prepartum rations, not increasing the peuNDF240 of the fresh ration too much, avoiding vaccination in the calving pen, move cows to the calving pen when showing signs of labor versus 0 to 3 days prior to expected calving, reducing the number of prepartum and postpartum pen moves, and reducing the amount of time spent in the calving pen after parturition. Due to limited data and contradicting results, further research should evaluate short- and long-term effects of the amount of time locked up in the fresh pen, peuNDF240 during the transition period, particle size, feed pushup frequency, the use of a calving pen versus a maternity pen, and time spent in the calving pen.

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