Livestock Science 150 (2012) 74–79

Contents lists available at SciVerse ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Evaluation of beef cow and calf separation systems to improve reproductive performance of first-calf cows

P.G.M.A. Martins [a,b], J.D. Arthington [a,*], R.F. Cooke [c], C.G. Lamb [d], D.B. Araújo [a], C.A.A. Torres [b], J.D. Guimarães [e], A.B. Mancio [b]

[a] University of Florida, IFAS, Range Cattle Research and Education Center, 3401 Experiment Station, Ona, FL 33865-9503, United States
[b] Universidade Federal de Viçosa, Departamento de Zootecnia, Av. Peter Henry Rolfs, s/n, 36570-000 Viçosa, MG, Brazil
[c] Oregon State University, Eastern Oregon Agricultural Research Center, 67826-A Highway 205, Burns, OR 97720-9394, United States
[d] University of Florida, IFAS, North Florida Research and Education Center, 3925 Highway 71, Marianna, FL 32446-8091, United States
[e] Universidade Federal de Viçosa, Departamento de Veterinária, Av. Peter Henry Rolfs, s/n, 36570-000 Viçosa, MG, Brazil

ARTICLE INFO

Article history:
Received 23 May 2012
Received in revised form
6 August 2012
Accepted 7 August 2012

Keywords:
Body condition score
Cow–calf operations
Progesterone
Reproduction
Weaning

ABSTRACT

A two-year study was conducted with the objective to compare the effects of a traditional 48-h calf withdrawal to early-weaning and repeated 48-h calf withdrawals on postpartum interval and measures of performance of first-calf cows. A total of 112 primiparous, Brahman × British cow–calf pairs were randomly allotted to three treatments over two consecutive years: early weaning (EW; permanent cow and calf separation); interval weaning (IW—48-h calf withdrawal; five times, 20 days apart); and control (CON; single 48-h calf withdrawal). Early-weaned calves were kept in an annual ryegrass (*Lolium multiflorum*) pasture and were fed supplemental concentrate (16% crude protein) daily at 1% of body weight. During the 48-h calf withdraw IW- and CON-calves were provided hay, water and free-choice access to the same concentrate supplement. Treatments were initiated at the start of a 90-day breeding season (average days postpartum = 97 ± 19). Blood samples were collected over 90 days on 10-day intervals for determination of progesterone concentrations. Resumption of cyclicity was defined as two consecutive samples with concentrations of progesterone ≥ 1.5 ng/mL. Cow body weight was determined at the start (day 0), middle (day 41), and end (day 90) of the study, and cow body condition score was estimated using a nine-point scale where 1 = emaciated and 9 = obese on same days, only on year 2. Calf body weight was determined at the start and end of the study. Pregnancy was diagnosed by transrectal ultrasonography at approximately 45 days after the end of the breeding season. Cow body weight and body condition score at the beginning of the breeding season did not differ (369 ± 38.2 kg and 4.5 ± 0.59, respectively); however, by day 90 body weight was greater ($P < 0.01$) and body condition score tended to be greater ($P = 0.08$) for EW versus IW and CON (385, 356, and 359 kg; SEM = 2.6; and 4.6, 4.1, and 3.9; SEM = 0.20 for EW, IW, and CON cows, respectively). Calf BW was also greater ($P < 0.01$) for EW calves versus IW and CON calves at the end of the study (170, 127, and 132 kg for EW, IW, and CON calves, respectively; SEM = 3.1). Cows in the EW and IW treatments had resumption of cyclicity earlier than CON cows (average days to resume cyclicity = 65, 67, and 75 for EW, IW, and CON cows, respectively; SEM = 0.2). By day 20 of the breeding season (corresponding to an average of 117 days postpartum), more ($P = 0.06$) EW cows were cycling than CON-cows with IW cows intermediate. Cows exposed to IW had a greater ($P = 0.05$) pregnancy rate than CON cows. Compared

* Corresponding author. Tel.: +1 863 735 1314; fax: +1 863 735 1930.
E-mail address: jarth@ufl.edu (J.D. Arthington).

1871-1413/$ - see front matter
http://dx.doi.org/10.1016/j.livsci.2012.08.003

to a traditional, single-time, 48-h calf withdrawal, repeated 48-h calf withdrawal resulted in greater cow pregnancy rate with a reduced period of postpartum anestrus.

1. Introduction

The main objective of a cow–calf production system is to yield a high calf crop each year, which is the primary factor impacting profitability. A high calf crop is dependent upon optimal reproduction, which is one of the most important factors affecting the financial viability of a cow–calf enterprise (Hess et al., 2005). In this scenario, a cow has to calve once a year; therefore, the resumption of estrus within a relatively short time-frame following parturition is recognized as a major milestone to achieving optimal reproductive performance (Hess et al., 2005). This is often limited by a prolonged postpartum anestrous interval (Ciccioli et al., 2003), which is most evident in primiparous compared with mature cows. Additionally, suckling, calf presence, and cow body condition are all known factors that impact and regulate the duration of the postpartum anestrous period.

Early weaning management programs can be practical and profitable for cow–calf operations. Compared to weaning at a normal time, early weaned (EW) cows experience improved body condition and greater body weight (BW) gain during the breeding season (Waterman et al., 2012). Additionally, EW primiparous cows have a shorter calving interval, increased pregnancy rate, and require fewer nutrients to support BW gain (Arthington and Kalmbacher, 2003; Arthington and Minton, 2004; Galindo–Gonzalez et al., 2007; Houghton et al., 1990; Schultz et al., 2005). Further, EW calves may have better feedlot performance, increased carcass quality, and experience less stress as indicated by lesser acute-phase protein concentrations during the feed yard receiving period (Arthington et al., 2005; Myers et al., 1999a, 1999b). However, several factors may discourage the implementation of early weaning by producers, such as limited information about the management of EW calves (Vendramini et al., 2006), and also greater feed and total costs than normal weaned (NW) calves (Blanco et al., 2009; Story et al., 2000).

The control of calf presence and, or suckling frequency is a low cost management practice used to shorten the postpartum anestrous period and to induce ovulation in suckling beef cows, under grazing conditions (Quintans et al., 2004). Calf removal for 48 h decreased the postpartum interval in beef cows (Smith et al., 1979) and increased serum luteinizing hormone (LH) concentrations (Edwards, 1985), necessary to stimulate ovarian follicular growth. We hypothesized that cows subjected to multiple 48-h calf withdrawals would have similar reproductive performance compared to EW cows, but greater reproductive performance than a single 48-h calf withdraw. Therefore, our objectives were to compare the effects of a traditional 48-h calf withdrawal to early-weaning and repeated 48-h calf withdrawals on post-partum interval and measures of performance of first-calf beef cows.

2. Materials and methods

This study was conducted over two consecutive years (beginning January 2009) at the University of Florida, Institute of Food and Agricultural Sciences, Range Cattle Research and Education Center, Ona, southwest Florida, United States. The animals utilized in this trial were cared for by acceptable practices as summarized in the Guide for the Care and Use of Agricultural Animals Research and Teaching (FASS, 2010), and the protocol was reviewed and approved by the University of Florida, IFAS, Animal Research Committee (approval number 002-10ONA).

2.1. Animals, care and diet

A total of 112 fall-calving, 2-year-old, Brahman × British cow–calf pairs ($n=64$ and 48 for years 1 and 2, respectively) were randomly assigned to one of three treatments: (1) early weaning (*EW*; calves early weaned in January); (2) interval weaning (*IW*; 48-h calf removal at the beginning of breeding season and then four additional times during the breeding season, 20 days apart); and (3) control (*CON*; single 48-h calf withdrawal at the beginning of the breeding season). Calves did not differ in age at the beginning of the breeding season (average age $=97 \pm 19.1$ and 91 ± 22.6 days for years 1 and 2, respectively). Within years, initial calf BW did not differ among treatments, but did differ between years (average BW $=96 \pm 16.5$ and 83 ± 13.7 kg for years 1 and 2, respectively; $P<0.01$). Dates for early weaning were chose to correspond with the start of the breeding season. Early weaned calves ($n=22$ and 16 for years 1 and 2, respectively; average age $=95 \pm 22.5$ days) were kept in a dry lot pen for 10 days for acclimatization. During this time, a commercial calf started feed (Pre-Conditioning/Receiving Chow; Purina Mills, St. Louis, MO), hay, and water were provided *ad libitum*. After this acclimatization period, calves were transferred to annual ryegrass (*Lolium multiflorum*) pasture and were fed a supplemental concentrate (from 14% to 16% crude protein) daily at 1% BW and provided free-choice access to a trace mineral/vitamin mix (Cattle Select Essentials Range, Lakeland Animal Nutrition, Lakeland, FL, USA). During the 48-h withdraw, IW ($n=21$ and 16 for years 1 and 2, respectively) and CON calves ($n=21$ and 16 for years 1 and 2, respectively) were kept enclosed within a pen located in the pasture. Calves had tactile contact with their dam, but they were not allowed to suckle. Water, hay and commercial concentrate supplement were provided during the 48 h. Following the 48-h withdrawal, calves from both treatments were returned to their dams.

All cows, and CON and IW calves were kept in two bahiagrass (*Paspalum notatum*) pastures and were provided free-choice access to stargrass (*Cynodon* spp.) hay. Treatments were equally represented among cows in both pastures. In addition, a free-choice commercial mineral/vitamin mix (Cattle Select Essentials Range) and water were provided. During the 90-day breeding season (from early January to early April, both years), all cows were exposed to Angus bulls, and the bull:cow ratio was approximately 1:30. Pregnancy was diagnosed by transrectal ultrasonography (7.5-MHz transrectal transducer; Aloka SSD-500V; Wallingford, CT, United States) at approximately 45 days after the end of the breeding season in both years. Individual cow BW was measured at the start of the breeding season (time of EW: January; day 0), middle (day 41) and at the end of the breeding season (early April; day 90) of both years. Individual cow body condition score (BCS) was collected at the same time of BW assessment only on the second year. Cow BCS was estimated by visual appraisal by two technicians using a nine-point scale where 1=emaciated and 9=obese (Kunkle et al., 1999), and the final value was derived from the mean of both measurements. Calf BW was measured at the start and end of the breeding season, and weights were adjusted for sex by calculating the difference between BW of steers and heifer, dividing by 2, and adjusting the actual BW accordingly (i.e. adding to heifer calves and subtracting from steer calves). Calving interval was calculated by determining the time between the birth of first and second calf for cows that had become pregnant. For non-pregnant cows, values were assigned with the assumption that they became pregnant 10 days after the end of the breeding season plus a 286 day gestational period (Reynolds et al., 1980).

2.2. Sample collection and analysis

To determine the effects of treatment on the length of postpartum anestrous, blood samples were collected via jugular venipuncture, using commercial evacuated tubes (Vacutainer®; Becton-Dickinson, Inc., Franklin Lakes, NJ, USA) containing sodium heparin, starting at the date of EW and throughout the breeding season, on 10-day intervals. Blood samples were collected immediately prior to cow and calf separation. Tubes were immediately placed on ice and centrifuged at 3000g for 25 min, within two hours after collection. Plasma was harvested and stored at −20°C for further analysis. Concentrations of progesterone were determined using Coat-A-Count solid phase ^{125}I radioimmunoassay kits (Siemens Medical Solutions Diagnostics, Los Angeles, CA, USA) in year 1, and using the ELISA procedure described by Galvão et al. (2004) in year 2. All samples were analyzed in duplicates. The intra- and inter-assay coefficients of variation were 9.8% and 12.9% in year 1, and 4.6% and 8.7% in year 2. The minimum detectable concentration was 0.1 ng/mL and 100 μL of plasma volume was assayed in both years. Date of resumption of cyclicity was defined as the first sampling day when progesterone concentrations were ≥1.5 ng/mL (Cooke and Arthington, 2009) for two consecutive sampling dates.

2.3. Statistical analysis

Since weaning treatment was applied directly to the cow or calf, cow or calf was the experimental unit for all analyses. Analysis for cow BW, BW change, BCS, calving and postpartum interval were achieved by ANOVA for a completely randomized design using the MIXED procedure of SAS (SAS Inst., Inc., Carry, NC). The model statement for the analysis of cow response variables contained the effects of treatment, year, and the interaction for treatment × year. Data were analyzed using treatment (year × pasture) as the random effect. An unstructured multivariate structure with no standard covariance or heterogeneous variance for each time was also used to model residual error. Analysis of cow pregnancy rate was analyzed by comparing cow treatment using the GENMOD procedure of SAS. Survival analysis was performed using the non-parametric Kaplan–Meier estimate of the survival curve. For hypothesis testing the difference between survival curves' Log-Rank and Wilcoxon tests were used. Analysis for calf BW and BW gain was also achieved by ANOVA for a completely randomized design using the MIXED procedure of SAS. The model statement included the effects of year, treatment, and all possible interactions. Data were analyzed using the treatment (year × pasture) interaction as the random effect. Initial calf BW was included in the model as a covariate for analyses of calf BW at the end of the breeding season and BW gain. Treatment comparisons for both cow and calf response variables were made by using single degree of freedom orthogonal contrasts. The two treatment comparisons were: (1) EW versus CON and IW, and (2) CON versus IW. Tests with P-values ≤ 0.05 were considered statistically significant and those that had values > 0.05 but ≤ 0.10 were considered trends.

3. Results

At the beginning of the breeding season (day 0), some cows were cycling (EW, n=7 and 4; IW, n=2 and 0; and CON, n=9 and 1 for years 1 and 2, respectively). Those cows and calves were removed from the experiment and their data were excluded from the analyses. There was a year, but no treatment × year interaction for cow BW at the beginning and the end of the breeding season. Cow BW on day 0 did not differ (P=0.98) among treatments (Table 1). However, at the end of the breeding season (day 90), EW cows were heavier (P < 0.01) than the average of IW and CON cows (Table 1). Cow BCS in year 2 did not differ (P=0.57) among treatments on day 0 but on day 90, cow BCS tended to be greater (P=0.08) for EW versus the average of IW and CON cows (Table 1). There was no treatment × year interaction for postpartum interval or cow pregnancy rate. Although not statistically significant, EW cows had a numerically lesser postpartum interval compared to IW cows and the average of IW and CON cows (P=0.15 and 0.14, respectively; Table 1). Additionally, EW and IW cows had resumption of cyclicity earlier (P < 0.01 for both Wilcoxon and Log-rank tests) than CON cows (average days to resume cyclicity: 65 ± 1.6, 67 ± 1.3, and 75 ± 1.5 for EW, IW, and CON cows, respectively). On day 20 (average 117 days postpartum), more (P=0.06) EW cows were cycling than CON cows (Fig. 1) and IW cows were intermediate. By day 40, there was a greater (P=0.01) percentage of IW cows cycling than CON cows.

Table 1
Cow body weight (BW), body condition score (BCS), postpartum interval (PPI), and pregnancy rate of control (CON), interval- (IW), and early-weaning (EW) treatments[a].

Item	Control[b]	Interval-weaned[b]	Early-weaned[b]	SEM	Contrasts	
					(CON and IW) versus EW	CON versus IW
Cow BW (kg)						
Day 0	367	369	369	6.9	0.93	0.90
Day 41	370	365	374	4.6	0.25	0.47
Day 90	359	356	385	2.6	0.001	0.33
BW gain (kg)	−9	−13	17	2.7	0.001	0.35
Cow BCS[c]						
Day 0	4.3	4.6	4.4	0.21	0.91	0.33
Day 41	4.3	4.5	4.8	0.19	0.21	0.60
Day 90	3.9	4.1	4.6	0.20	0.08	0.40
Change	−0.4	−0.5	+0.2	0.22	0.09	0.86
Cow PPI (days)	159	144	137	6.3	0.14	0.15
Pregnancy rate (%)[d]	70.4	88.6	92.0	0.10	0.15	0.05

[a] Values reported are least squares means.
[b] Control (CON) cows had their calves removed for 48 h once at the start of the breeding season (day 0); interval-weaned (IW) cows had their calves removed for 48 h five times, 20 day apart throughout the breeding season; early-weaned (EW) cows had their calves permanently removed by the start of the breeding season.
[c] Cow body condition score was estimated using a nine-point scale where 1 = emaciated to 9 = obese; data collected only in year 2.
[d] Pregnancy was diagnosed by transrectal ultrasonography at approximately 45 day following the end of the breeding season (day 90) in both years.

There was no treatment × year interaction for pregnancy rate. Overall pregnancy rate (years 1 and 2 combined) was greater ($P = 0.05$) for EW versus IW cows, with IW cows being intermediate (Table 1).

Calf age at the start of the study did not differ ($P = 0.68$) among treatments (94 ± 24.3, 95 ± 19.8, and 91 ± 21.0 days for CON, IW, and EW calves, respectively). There was no treatment × year interaction for calf BW, however, average calf BW adjusted for sex on day 0 was greater ($P = 0.04$) for IW versus CON calves, despite random treatment allocation. On day 90, calf BW was greater ($P < 0.01$) for EW calves compared to the average of CON and IW calves (Table 2). Body weight gain during the breeding season was greater ($P < 0.01$) for EW calves than the average of CON and IW calves, and did not differ ($P = 0.31$) among IW and CON calves (Table 2).

4. Discussion

Early weaning has traditionally been recommended as a management approach to improve reproductive efficiency, principally in thin primiparous cows. However, some authors (Yavas and Walton, 2000a) have reported that complete weaning at early ages could be impractical due to increased labor and costs, changes in management, and reduced growth rate of weaned calves. Nevertheless,

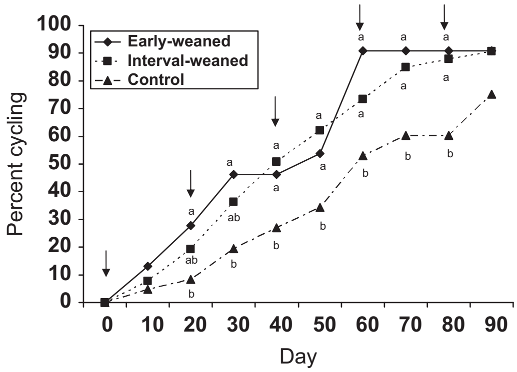

Fig. 1. Percentage of cows cycling during the 90-day breeding season (starting early January and ending early April). Blood samples were collected at the date of EW, throughout the breeding season, on 10 day intervals. Date of resumption of cyclicity was defined as the first sampling day when progesterone concentrations were ≥1.5 ng/mL for two consecutive sampling dates. Early-weaned (EW) cows had their calves permanently removed at the start of the breeding season (day 0); control (CON) cows had their calves removed for 48 h once at the start of the breeding season; interval-weaned (IW) cows had their calves removed for 48 h five times, 20 days apart throughout the breeding season. Data from cows not cycling on day 0. Arrows indicate dates when calves were temporarily separated from their dams. Day 0, control and IW; days 20, 40, 60, and 80, IW only. a,b; $P \leq 0.05$.

previous studies had shown that EW improves pregnancy rate, cow BW and BCS, while reducing postpartum anestrous interval and voluntary forage intake (Arthington and Kalmbacher, 2003; Arthington and Minton, 2004; Galindo–Gonzalez et al., 2007; Houghton et al., 1990; Myers et al., 1999b; Quintans et al., 2009; Schultz et al., 2005; Short et al., 1996). Arthington and Kalmbacher (2003) reported that during a 90-day breeding season EW cows gained 30 kg and NW cows lost 4 kg, resulting in a greater BW for EW cows. The hypothesis of the current experiment was that the use of repeated 48-h calf withdrawals, as an alternative management approach to EW, would result in better cow reproductive performance compared with a traditional 48-h calf withdrawal, without impacting pre-weaning calf performance. In the current experiment, overall pregnancy rate was greater ($P = 0.04$) for EW cows than CON cows, and EW cows gained more ($P < 0.01$) BW compared to CON- and IW-cows during the 90-day breeding season, agreeing with these previous reports. Moreover, Pimentel et al. (1979) reported a 43% improvement in overall conception of multiparous *Bos taurus* cows whose calves were weaned at 90 days versus 200 days of age. In agreement with our hypothesis, multiple calf removal improved cow pregnancy rate, which did not differ from EW management. Thus, multiple stimulation of the reproductive axis might have a beneficial effect on reproductive performance, compared to a single stimulus done at the beginning of the breeding season. Forty-eight-hour calf withdraw is only effective after replenishment of anterior pituitary LH stores because it generates endogenous LH pulses by removing the suppressive effects of the suckling stimulus on the GnRH pulse mechanism (Yavas and Walton, 2000b). Temporary weaning increases GnRH and therefore LH pulse frequency, and

Table 2
Effect of control (CON), interval- (IW), and early-weaning (EW) treatments on calf BW (adjusted for sex)[a].

Item	Control[b] (kg)	Interval-weaned[c] (kg)	Early-weaned[d] (kg)	SEM (kg)	Contrasts	
					(CON and IW) versus EW	CON versus IW
Day 0	84	94	88	2.8	0.93	0.04
Day 90	132	127	170	3.1	< 0.01	0.31
BW gain	41	36	80	3.1	< 0.01	0.31

[a] Values reported are least squares means.
[b] Control calves were removed for 48 h from their dams once at the start of the breeding season (day 0).
[c] Interval-weaned calves were removed for 48 h from their dams five times, 20 days apart throughout the breeding season.
[d] Early-weaned calves were permanently removed from their dams by the start of the breeding season.

follicular receptor concentrations for LH; these responses are followed by ovulation (Edwards, 1985; Yavas and Walton, 2000a).

In the current study, an improved cow pregnancy rate was achieved with multiple calf withdrawals versus a single 48-h withdrawal. This beneficial result is likely due to an earlier resumption of postpartum cyclicity in IW versus CON cows. Although few cows were cycling in the first 20 days of the breeding season, after 40 days, more ($P<0.05$) IW cows were cycling than CON cows (51.4%, 18 of 35; and 25.9%, 7 of 25, respectively). Our results are in agreement with other reports which have shown that EW results in early resumption of estrous cycles in the breeding season, consequently resulting in shorter periods of postpartum anestrus compared to non-weaned contemporaries (Arthington and Minton, 2004; Bell et al., 1998; Quintans et al., 2009). An explanation of hastening postpartum anestrus period in IW cows could be due to the stimulation of the hypothalamic-pituitary axis for five times, 20 days apart throughout the breeding season.

The majority of papers regarding temporary weaning in the literature involves a single temporary weaning at the beginning of the breeding season, or coupled with exogenous hormone protocols. To our knowledge, these data are the first to report repeated temporary calf withdrawal throughout the breeding season. Although stores of anterior pituitary LH are replenished between 15 and 30 days postcalving (Cermak et al., 1983; Moss et al., 1985; Nett et al., 1988), short cycles are common after weaning-induced ovulation (Yavas and Walton, 2000b). Therefore, the repeated temporary calf withdrawal, during the early breeding season, could give more anestrous cows a chance to respond to the calf removal stimulus. This management strategy could, therefore, be an effective tool for managing anestrus in first calf cows.

Because calves were kept in a pen within the same pasture of their dams, the effect of a 48-h calf withdraw could have been hindered due to possible tactile contact. A lack of normal LH pulses and ovulation in the postpartum period caused by the suppressive influence of suckling is not dependent only of neurosensory pathways within the teat or udder (Cutshaw et al., 1992; Williams et al., 1993). Hoffman et al. (1996) reported that cows maintained with their own nonsuckling calves cycled about eight days later than cows whose calves were weaned after treatments were initiated at days 4–9 postpartum. Although not measured in the present study, it was observed that cows in the first temporary weaning stayed nearby the calf confinement pens, but during subsequent temporary weaning periods, we observed that IW cows spent more time away from their confined calf. Therefore, the continual presence and tactile stimulation of the cow next to their confined calf may have influenced the effectiveness of the first 48-h temporary weaning.

Cow BCS is a subjective measure of the cow's body energy reserves. A relationship between losses in body condition within two months after calving and anestrus has been reported (Ducrot et al., 1994), and cows with optimal BCS after calving have greater pregnancy rates (Rae et al., 1993). Spitzer et al. (1995) reported that primiparous cows with the greatest BCS at calving had a greater pregnancy rate by 40 and 60 days of the breeding season. In the present study, EW cows tended ($P=0.08$) to have a greater BCS at the end of the breeding season than CON and IW cows. This response is likely associated with a decrease in the net energy requirement of the cow, which improves the ability to gain BW (Arthington and Minton, 2004). Although not a specific objective of the current study, it is important to note that initial cow BCS could be an important determinant of the impact of calf separation on subsequent reproductive response.

Early-weaned calves, in this study, were heavier at the time of normal weaning than IW and CON. Previous studies at this research site have shown that performance of EW calves is highly dependent upon the availability of high quality forage (Arthington and Kalmbacher, 2003) and concentrate supplementation (Vendramini et al., 2006). The greater BW gain for the EW cows and calves agree with results from Peterson et al. (1987), who concluded that EW cows and their calves were 43% more efficient in converting TDN into calf gain than NW cow–calf pairs.

In summary, compared to traditional, single-time, 48-h calf withdrawal, repeated 48-h calf withdrawals resulted in greater cow pregnancy rate with a reduced period of postpartum anestrus. We concluded that repeated 48-h calf withdrawals may be an effective option for the management of first-calf cows, particularly for producers that are unable or unwilling to early-wean (permanently separate) cows and calves at the start of the breeding season.

Conflict of interest statement

The authors declare that none of them have any potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the work submitted that could inappropriately influence the current scientific work.

Acknowledgments

The authors would like to express appreciation to Mr. Austin Bateman, Mr. Clay Newman, and Ms. Andrea Dunlap for technical assistance. The authors wish to acknowledge CAPES from Brazil for a fellowship to P.G.M.A. Martins.

References

Arthington, J.D., Kalmbacher, R.S., 2003. Effect of early weaning on the performance of three-year-old, first-calf beef heifers and calves reared in the subtropics. J. Anim. Sci. 81, 1136–1141.

Arthington, J.D., Minton, J.E., 2004. The effect of early weaning on feed intake, growth, and postpartum interval in thin, Brahman-crossbred primiparous cows. Prof. Anim. Sci. 20, 34–38.

Arthington, J.D., Spears, J.W., Miller, D.C., 2005. The effect of early weaning on feedlot performance and measures of stress in beef calves. J. Anim. Sci. 83, 933–939.

Bell, D.J., Spitzer, J.C., Burns, G.L., 1998. Comparative effects of early weaning or once-daily suckling on occurrence of postpartum estrus of primiparous beef cows. Theriogenology 50, 707–715.

Blanco, M., Villalba, D., Ripoll, G., Sauerwein, H., Casasús, I., 2009. Effects of early weaning and breed on calf performance and carcass and meat quality in autumn-born bull calves. Livest. Sci. 120, 103–105.

Cermark, D.L., Braden, T., Manns, J., Niswender, G.D., Nett, T.M., 1983. Contents of hypothalamic GnRH, pituitary FSH and LH, and pituitary receptors for GnRH and estradiol in postpartum suckled beef cows. J. Anim. Sci (Suppl. 1), 32.

Ciccioli, N.H., Wettemann, R.P., Spicer, L.J., Lents, C.A., White, F.J., Keisler, D.H., 2003. Influence of body condition at calving and postpartum nutrition on endocrine function and reproductive performance of beef cows. J. Anim. Sci. 81, 3107–3120.

Cooke, R.F., Arthington, J.D., 2009. Plasma progesterone concentrations as puberty criteria for Brahman-crossbred heifers. Livest. Sci. 123, 101–105.

Cutshaw, J.L., Hunter, J.F., Williams, G.L., 1992. Effects of transcutaneous thermal and electrical stimulation of the teat on pituitary luteinizing hormone, prolactin and oxytocin secretion in ovariectomized, estradiol-treated beef cows following acute weaning. Theriogenology 37, 915–934.

Ducrot, C., Gröhn, Y.T., Humblot, P., Bugnard, F., Sulpice, P., Gilbert, R.O., 1994. Postpartum anestrus in French beef cattle: an epidemiological study. Theriogenology 42, 753–764.

Edwards, S., 1985. The effects of short term calf removal on pulsatile LH secretion in the postpartum beef cow. Theriogenology 23, 777–785.

FASS, 2010. Guide for the care and use of agricultural animals in agricultural research and teaching, 3rd ed. Federation of Animal Science Societies, Champaign, IL, United States.

Galindo–Gonzalez, S., Arthington, J.D., Yelich, J.V., Hansen, G.R., Lamb, G.C., De Vries, A., 2007. Effects of cow parity on voluntary hay intake and performance responses to early weaning of beef calves. Livest. Sci. 110, 148–153.

Galvão, K.N., Santos, J.E.P., Juchem, S.O., Cerri, R.L.A., Coscioni, A.C., Villaseñor, M., 2004. Effect of addition of a progesterone intravaginal insert to a timed insemination protocol using estradiol cypionate on ovulation rate, pregnancy rate, and late embryonic loss in lactating dairy cows. J. Anim. Sci. 82, 3508–3517.

Hess, B.W., Lake, S.L., Scholljegerdes, E.J., Weston, T.R., Nayigihugu, V., Molle, J.D.C., Moss, G.E., 2005. Nutritional controls of beef cow reproduction. J. Anim. Sci. 83, E90–E106.

Hoffman, D.P., Stevenson, J.S., Minton, J.E., 1996. Restricting calf presence without suckling compared with weaning prolongs postpartum anovulation in beef cattle. J. Anim. Sci. 74, 190–198.

Houghton, P.L., Lemenager, R.P., Horstman, L.A., Hendrix, K.S., Moss, G.E., 1990. Effects of body composition, pre- and postpartum energy level and early weaning on reproductive performance of beef cows and preweaning calf gain. J. Anim. Sci. 68, 1438–1446.

Kunkle, W.E., Sand, R.S., Rae, D.O., 1999. Effects of Body Condition on Productivity in Beef Cattle. Document, vol. SP 144. University of Florida, Cooperative Extension Service, Gainesville.

Moss, G.E., Parfet, J.R., Marvin, C.A., Allrich, R.D., Diekman, M.A., 1985. Pituitary concentrations of gonadotropins and receptors for GnRH in suckled beef cows at various intervals after calving. J. Anim. Sci. 60, 285–293.

Myers, S.E., Faulkner, D.B., Ireland, F.A., Parrett, D.F., 1999a. Comparison of three weaning ages on cow–calf performance and steer carcass traits. J. Anim. Sci. 77, 323–329.

Myers, S.E., Faulkner, D.B., Ireland, F.A., Berger, L.L., Parrett, D.F., 1999b. Production systems comparing early weaning to normal weaning with or without creep feeding for beef steers. J. Anim. Sci. 77, 300–310.

Nett, T.M., Cermak, D., Braden, T., Manns, J., Niswender, G., 1988. Pituitary receptors for GnRH and estradiol, and pituitary content of gonadotropins in beef cows. II. Changes during the postpartum period. Domest. Anim. Endocrinol. 5, 81–89.

Peterson, G.A., Turner, T.B., Irvin, K.M., Davis, M.E., Newland, H.W., Harvey, W.R., 1987. Cow and calf performance and economic considerations of early weaning of fall-born beef calves. J. Anim. Sci. 64, 15–22.

Pimentel, C.A., Deschamps, J.C., Oliveira, J.A.F., Cardelino, R., Pimentel, M.A., 1979. Effects of early weaning on reproductive efficiency in beef cows. Theriogenology 11, 421–427.

Quintans, G., Viñoles, C., Sinclair, K.D., 2004. Follicular growth and ovulation in postpartum beef cows following calf removal and GnRH treatment. Anim. Reprod. Sci. 80, 5–14.

Quintans, G., Vázquez, A.I., Weigel, K.A., 2009. Effect of suckling restriction with nose plates and premature weaning on postpartum anestrous interval in primiparous cows under range conditions. Anim. Reprod. Sci. 116, 10–18.

Rae, D.O., Kunkle, W.E., Chenoweth, P.J., Sand, R.S., Tran, T., 1993. Relationship of parity and body condition score to pregnancy rates in Florida beef cattle. Theriogenology 39, 1143–1152.

Reynolds, W.L., DeRouen, T.M., Moin, S., Koonce, K.L., 1980. Factors influencing gestation length, birth weight and calf survival of Angus, Zebu and Zebu cross beef cattle. J. Anim. Sci. 51, 860–867.

Schultz, C.L., Ely, D.G., Aaron, D.K., Burden, B.T., Wyles, J., 2005. Comparison of an early and normal weaning management system on cow and calf performance while grazing endophyte-infected tall fescue pastures. J. Anim. Sci. 83, 478–485.

Short, R.E., Grings, E.E., MacNeil, M.D., Heitschimidt, R.K., Haferkamp, M.R., Adams, D.C., 1996. Effects of time of weaning, supplement, and sire breed of calf during the fall grazing period on cow and calf performance. J. Anim. Sci. 74, 1701–1710.

Smith, M.F., Burrel, W.C., Shipp, L.D., Sprott, L.R., Songster, W.N., Wiltbank, J.N., 1979. Hormone treatments and use of calf removal in postpartum beef cows. J. Anim. Sci. 48, 1285–1294.

Spitzer, J.C., Morrison, D.G., Wettemann, R.P., Faulkner, L.C., 1995. Reproductive responses and calf birth and weaning weights as affected by body condition at parturition and postpartum weight gain in primiparous beef cows. J. Anim. Sci. 73, 1251–1257.

Story, C.E., Rasby, R.J., Clark, R.T., Milton, C.T., 2000. Age of calf at weaning of spring-calving beef cows and the effect on cow and calf performance and production economics. J. Anim. Sci. 78, 1403–1413.

Vendramini, J.M.B., Sollenberger, L.E., Dubeux, J.C.B., Interrante, S.M., Stewart, R.L., Arthington, J.D., 2006. Concentrate supplementation effects on forage characteristics and performance of early weaned calves grazing rye-ryegrass pastures. Crop Sci. 46, 1595–1600.

Waterman, R.C., Geary, T.W., Paterson, J.A., Lipsey, R.J., 2012. Early weaning in Northern Great Plains beef cattle production systems: I. Performance and reproductive response in range beef cows. Livest. Sci. 148, 26–35.

Yavas, Y., Walton, J.S., 2000a. Induction of ovulation in postpartum suckled beef cows: a review. Theriogenology 54, 1–23.

Yavas, Y., Walton, J.S., 2000b. Postpartum acyclicity in suckled beef cows: a review. Theriogenology 54, 24–55.