Efficacy of an intravaginal progesterone insert and an injection of $PGF_{2\alpha}$ for synchronizing estrus and shortening the interval to pregnancy in postpartum beef cows, peripubertal beef heifers, and dairy heifers[1]

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ABSTRACT: The objective was to test the efficacy of an intravaginal progesterone insert and injection of $PGF_{2\alpha}$ for synchronizing estrus and shortening the interval to pregnancy in cattle. Cattle were assigned to one of three treatments before a 31-d breeding period that employed artificial insemination. Control cattle were not treated, and treated cattle were administered $PGF_{2\alpha}$ or an intravaginal progesterone-releasing insert (CIDR) for 7 d and treated with $PGF_{2\alpha}$ on d 6. The treatments were applied in one of three experiments that involved postpartum beef cows (Exp. 1; n = 851; 56 ± 0.6 d postpartum), beef heifers (Exp. 2; n = 724; 442.5 ± 2.8 d of age), and dairy heifers (Exp. 3; n = 260; 443.2 ± 4.5 d of age). Luteal activity before treatment was determined for individual cattle based on blood progesterone concentrations. In Exp. 1, there was a greater incidence of estrus during the first 3 d of the breeding period in CIDR+$PGF_{2\alpha}$-treated cows compared with $PGF_{2\alpha}$-treated or control cows (15, 33, and 59% for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$, respectively; $P < 0.001$). The improved estrous response led to an increase in pregnancy rate during the 3-d period (7, 22, and 36% for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$, respectively; $P < 0.001$) and tended to improve pregnancy rate for the 31-d breeding period for cows treated with CIDR+$PGF_{2\alpha}$ (50, 55, and 58% for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$, respectively, $P = 0.10$). Improvements in rates of estrus and pregnancy after CIDR+$PGF_{2\alpha}$ were also observed in beef heifers. Presence of luteal activity before the treatment period affected synchronization and pregnancy rates because anestrous cows (Exp. 1) or prepubertal heifers (Exp. 2) had lesser synchronization rates and pregnancy rates during the first 3 d of the breeding period as well as during the entire 31-d breeding period. The $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$ but not the control treatments were evaluated in dairy heifers (Exp. 3). The CIDR+$PGF_{2\alpha}$-treated heifers had a greater incidence of estrus (84%) during the first 3 d of the breeding period compared with the $PGF_{2\alpha}$-treated heifers (57%), but pregnancy rates during the first 3 d or during the 31-d breeding period were not improved for CIDR+$PGF_{2\alpha}$ compared with $PGF_{2\alpha}$-treated heifers. In summary, the concurrent treatment of CIDR and $PGF_{2\alpha}$ improved synchronization rates relative to $PGF_{2\alpha}$ alone or control. Improved estrus synchrony led to greater pregnancy rates for beef cows and beef heifers but failed to improve pregnancy rates for dairy heifers.

Key Words: Estrus, Progesterone, Prostaglandins, Synchronization

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Introduction

Several methods can be used to synchronize estrus in cattle (Patterson et al., 1989; Odde, 1990; Larson

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and Ball, 1992). Most methods employ an injection of $PGF_{2\alpha}$ that regresses the corpus luteum (**CL**). Regression of the CL (luteolysis) is followed by the development of a preovulatory follicle, behavioral estrus, and ovulation (Lauderdale et al., 1974; Roche, 1974). Prostaglandin $F_{2\alpha}$, however, will not regress developing CL that are present on the ovary during the first 5 d of the estrous cycle (Lauderdale, 1972). Therefore, one method to improve synchrony of estrus after a single injection of $PGF_{2\alpha}$ is to treat cattle with a progestogen for 7 d before $PGF_{2\alpha}$ (Macmillan and Peterson, 1993). Administration of the progestogen for 7 d before $PGF_{2\alpha}$ ensures that CL will regress in response to $PGF_{2\alpha}$ because all cattle will have a CL that has developed for at least 7 d. The progestogen will also delay estrus in cattle that naturally undergo CL regression during the progestogen treatment period before $PGF_{2\alpha}$ injection (Roche et al., 1999).

A major limitation to the success of an estrus synchronization program is the presence of anestrous cattle or prepubertal heifers in the breeding herd (Short et al., 1990; Patterson et al., 1992; Schillo et al., 1992). Progestogens offer an advantage in this regard because, in addition to improving estrus synchronization, progestogens will initiate estrus and ovulation in a percentage of prepubertal heifers and anestrous cows (Anderson et al., 1996; Fike et al., 1997; Imwalle et al., 1998). The objective of the present study was to test the efficacy of an intravaginal insert and an injection of $PGF_{2\alpha}$ for synchronizing estrus and shortening the interval to pregnancy in postpartum beef cattle, peripubertal beef heifers, and dairy heifers. Multiple locations were used that employed the same protocol so that the efficacy could be evaluated in a variety of regions within the United States.

Materials and Methods

Cattle

Experiment 1. Primiparous and multiparous suckled beef cows (n = 851) that were at least 20 d postpartum at the start of the trial were used (mean = 56 ± 0.6 d postpartum). The cattle were at one of six locations (Florida [n = 142], Illinois [n = 142], Nebraska [n = 150], Missouri [n = 129], Montana [n = 147], and Oklahoma [n = 141]). Cows were managed according to the standard procedures for each location. In general, cows grazed grass pastures and were fed supplements appropriate to their pasture conditions. The breeding of cattle differed among locations, being purebred or crossbred cattle of European descent (Illinois, Nebraska, Missouri, Montana, and Oklahoma) or Brangus (Florida). The investigator at each location selected a start date when 50% of the study cattle were predicted to be anestrous at the time of treatment. Cows with retained placenta or other obvious reproductive abnormalities were not used in the experiment.

Experiment 2. Beef heifers (n = 724) that were 442.5 ± 2.8 d of age at the start of the trial were used. The heifers were at one of five locations (Florida [n = 139], Illinois [n = 144], Nebraska [n = 123], Missouri [n = 147], and Montana [n = 171]). Heifers were managed according to standard procedures for each location. In general, heifers were maintained on drylots or grass pastures and were fed appropriate feed supplementation. The breeds of cattle were either purebred or crossbred of European descent (Illinois, Nebraska, Missouri, and Montana) or Brangus and crossbred Brahman (Florida). The investigator at each location selected a start date when 50% of the study cattle were predicted to be prepubertal at the time of treatment. Heifers with obvious reproductive abnormalities were not used in the experiment.

Experiment 3. Holstein dairy heifers (n = 260) that were 443.2 ± 4.5 d of age at the start of the trial were used. The heifers were at one of four locations (New York [n = 50], Illinois [n = 32], Missouri [n = 55], and Florida [n = 123]). Heifers were managed according to standard procedures for each location that generally included maintenance on drylots or grass pastures and appropriate feed supplementation. Heifers with obvious reproductive abnormalities were not used in the experiment.

Pretreatment Evaluation and Diagnosis of Ovarian Activity

Seven d before the start of the trial (d –7), cattle were bled, body condition-scored (1 [thin] to 9 [obese]), and evaluated for obvious health and(or) reproductive abnormalities that would preclude individual cattle from the experiments. A second blood sample was collected on d 0. Blood samples were centrifuged for the collection of serum or plasma and analyzed for progesterone concentrations according to the procedures of the individual investigators. Progesterone concentrations were used retrospectively to assign cattle to either anestrous (cows), prepubertal (heifers), or cyclic (cows or heifers) groups. Cattle with blood progesterone concentrations at or below baseline (1 ng/mL) for both blood samples (d –7 and 0) were declared anestrous (cows) or prepubertal (heifers) at the start of the trial. Cattle with blood progesterone concentrations above baseline were declared cyclic (cows or heifers).

Treatments

Cattle were assigned randomly to one of three treatments for the synchronization of estrus. Control cattle were not treated. The $PGF_{2\alpha}$-treated cattle were given a single i.m. injection of $PGF_{2\alpha}$ (33.5 mg of dinoprost tromethamine per 5 mL of solution, equivalent to 25 mg of $PGF_{2\alpha}$; Lutalyse; Pharmacia and Upjohn Company, Kalamazoo, MI). The CIDR+$PGF_{2\alpha}$-treated cattle were administered an intravaginal progesterone-releasing insert containing 1.38 g of progesterone (controlled internal drug-releasing device, **CIDR**, Interag, Hamilton, NZ) for 7 d and injected i.m. with 25 mg of $PGF_{2\alpha}$ on d

6. The CIDR is a T-shaped insert and was placed into the vagina by using a lubricated applicator. The applicator collapses the wings for insertion into the vagina. Expulsion of the CIDR within the vagina causes relaxation of the wings and retention of the CIDR within the vagina by pressure on the vaginal wall. A thin nylon tail attached to the end of the CIDR is exteriorized through the vaginal opening and is used to remove the insert at the completion of the treatment period. The $PGF_{2\alpha}$ injections were given on the same day for cattle assigned to the $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$ treatments. Control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ treatments were evaluated in Exp. 1 and 2, whereas only $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$ were evaluated in Exp. 3.

Detection of Estrus, Artificial Insemination, and Pregnancy Diagnosis

Estrus detection began on the morning of d 8 (2 d after $PGF_{2\alpha}$ injection and 1 d after CIDR removal) and continued for 31 d. Cattle were observed morning and evening for at least 30 min at approximately 12-h intervals. Aids for estrus detection (tail paint, pressure-sensitive patches, etc.) were used at the discretion of individual investigators. Cattle were artificially inseminated during the 31-d breeding period approximately one-half day after observed estrus with semen of known fertility. Semen from different bulls (if used) was blocked across treatments within each location. Repeat matings were given to those cattle returning to estrus after their first mating. Beef cattle (cows and heifers) were exposed to bulls for the purpose of natural mating immediately following the designated 31-d breeding period. For dairy heifers, estrus detection and artificial insemination continued after the designated breeding period. Pregnancy was diagnosed per rectum at 45 to 70 d after artificial insemination by using either ultrasonography or manual palpation.

Statistical Analyses

Data were analyzed by using the Statistical Analysis System (SAS Inst. Inc., Cary, NC). Postpartum interval, age, and body condition score were analyzed by using least square analysis of variance (PROC GLM of SAS) with a model containing the effects of treatment, location, and the treatment × location interaction. The effects of treatment were tested by using treatment × location as the error term. Differences between locations were tested by the Duncan's multiple-range test. The percentages of cyclic cattle were tested for the effects of treatment, location, and the treatment × location interaction by using the categorical modeling procedure (PROC CATMOD) of SAS (SAS Inst. Inc).

Percentage of cattle in estrus, first-service conception rate (number of cattle pregnant to first mating divided by the number of cattle inseminated), and pregnancy rate (number of pregnant cattle divided by the number of treated cattle) were tested by using PROC CATMOD. The effects of treatment, cyclic status (acyclic [anestrous or prepubertal] compared with cyclic), treatment × cyclic status, and location were tested. Cyclic status was not included in the analyses of Exp. 3 because 95% of the dairy heifers were cyclic at the time of treatment. Two planned contrasts were used in the analysis. The first contrast (Contrast 1) compared control cattle with cattle treated with an estrus synchronization drug (i.e., control vs $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$). The second contrast (Contrast 2) compared the two synchronization protocols (i.e., $PGF_{2\alpha}$ vs CIDR+$PGF_{2\alpha}$). The data for percentage of cattle in estrus, first-service conception rate, and pregnancy rate were evaluated for each of two intervals of the breeding period. Cattle responding to estrus synchronization were expected to be in estrus within the first 3 d of the breeding period (i.e., 48 to 120 h after $PGF_{2\alpha}$ administration or 24 to 96 h after CIDR removal). Therefore, the above statistical analyses were performed on data collected during the first 3 d of the breeding period (i.e., percentage of cattle in estrus on d 1, 2, and 3; conception rate for cattle inseminated on d 1, 2, and 3; and cumulative 3-d pregnancy rate). The above statistical analyses were then performed on data collected during the entire 31-d breeding period (i.e., percentage of cattle in estrus, first-service conception rate, and pregnancy rate [all services]).

Interval to first estrus and interval to pregnancy were analyzed by using least square analysis of variance (PROC GLM of SAS) with a model containing the effects of treatment, cyclic status [acyclic (anestrous or prepubertal) compared with cyclic], treatment × cyclic status, location, treatment × location, cyclic status × location, and treatment × cyclic status × location. The effects of treatment, cyclic status, and treatment × cyclic status were tested using their respective interactions with location as the error term. Contrast 1 and Contrast 2 (described above) were also tested. Differences between locations were tested by the Duncan's multiple-range test.

In additional to analysis of variance, survival analyses (PROC LIFETEST of SAS) were used to evaluate the effects of treatment and cyclic status on interval to first estrus and interval to pregnancy. For interval to first estrus, the survival analysis regressed the proportion of cattle that were not observed in estrus on the days of the breeding period. Data for cattle that were never observed in estrus were included in the statistical analyses as censored observations (i.e., the minimum interval to estrus was 31 d but the true interval to estrus was unknown). Differences between the survival curves were tested with the Wilcoxon test. Initially, treatment and cyclic status were tested independently as two different strata. The effects of treatment were then tested for data sorted by cyclic status. Contrasts were tested by pooling $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$ data and comparing with control (Contrast 1) or deleting control cattle from the data set and comparing $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$ directly (Contrast 2). Survival analyses for interval to pregnancy were performed using the

Table 1. Least squares means (± SEM) for age, body condition score, postpartum interval, and cyclic status for beef cows (Exp. 1), beef heifers (Exp. 2), and dairy heifers (Exp. 3) located at different sites[a]

Item	Florida	Illinois	Nebraska	Missouri	Montana	Oklahoma	New York	All locations
Exp. 1								
Number	142	142	150	129	147	141	—	851
Postpartum interval, d	74.5[a] ± 1.6	53.9[c] ± 1.6	52.5[c] ± 1.5	63.9[b] ± 1.7	39.8[d] ± 1.6	54.6[c] ± 1.6	—	56.2 ± 0.7
Age, yr	4.2[b] ± 0.2	3.9[b] ± 0.2	4.4[b] ± 0.2	5.9[a] ± 0.2	5.8[a] ± 0.2	5.6[a] ± 0.2	—	4.9 ± 0.1
Body condition score[b]	4.7[c] ± 0.1	5.4[a] ± 0.1	4.6[c] ± 0.1	5.5[a] ± 0.1	5.1[b] ± 0.1	4.7[c] ± 0.1	—	5.0 ± 0.1
Number anestrous, %	79 (56)	24 (17)	101 (67)	54 (42)	95 (65)	94 (67)	—	447 (53)
Number cyclic, %	63 (44)	118 (83)	49 (33)	75 (58)	52 (35)	47 (33)	—	407 (47)
Exp. 2								
Number	139	144	123	147	171	—	—	724
Age, d	611[a] ± 7	414[b] ± 6	418[b] ± 7	420[b] ± 6	379[c] ± 6	—	—	442 ± 3
Body condition score	6.0[a] ± 0.1	5.4[b] ± 0.1	4.6[c] ± 0.1	6.0[a] ± 0.1	5.6[b] ± 0.1	—	—	5.5 ± 0.1
Number prepubertal, %	27 (19)	8 (6)	100 (81)	64 (44)	114 (67)	—	—	313 (43)
Number cyclic, %	112 (81)	136 (94)	23 (19)	83 (56)	57 (33)	—	—	411 (57)
Exp. 3								
Number	123	32	—	55	—	—	50	260
Age, d	567[a] ± 10	478[b] ± 13	—	380[d] ± 6	—	—	439[c] ± 10	443 ± 5
Body condition score	5.7[b] ± 0.1	5.2[d] ± 0.1	—	5.5[c] ± 0.1	—	—	7.4[a] ± 0.1	5.9 ± 0.1
Number prepubertal, %	12 (10)	0 (0)		0 (0)	—	—	0 (0)	12 (5)
Number cyclic, %	111 (90)	32 (100)		55 (100)	—	—	50 (100)	248 (95)

[a]Alphabetic superscripts represent the results of the Duncan's multiple-range test. Means with different superscript within a row differ at $P < 0.05$.
[b]1 (thin) to 9 (obese).

methods described for interval to first estrus. Data for cattle that never conceived to artificial insemination were censored for the pregnancy analyses.

Results

Retention of the CIDR Insert

At the time of removal, the CIDR was not present in 1%, 4%, and 5% of CIDR+PGF$_{2\alpha}$-treated cattle in Exp. 1, 2, and 3, respectively. The assumption is that the CIDR fell out of the vagina at some time during the treatment period. The cattle that lost CIDR were excluded from statistical analyses and were not included in the following data summaries.

Characteristics of Study Cattle

Age and body condition score (Exp. 1, 2, and 3) as well as days from calving to treatment (Exp. 1) were similar ($P > 0.10$) for cattle assigned to different treatments. Locations, however, differed ($P < 0.001$) for age and body condition score of animals (Exp. 1, 2, and 3) as well as days from calving to treatment (Exp. 1; Table 1). Percentages of cattle diagnosed as anestrous compared with cyclic (Exp. 1) or prepubertal compared with cyclic (Exp. 2) were similar for cattle assigned to each treatment but differed across locations ($P < 0.001$ for Exp. 1 and 2). By design, approximately 50% of cattle were acyclic (either anestrous [Exp. 1] or prepubertal [Exp. 2]) at the start of treatment. Treatment × location interactions were not detected for percentage of cyclic cattle assigned to each treatment. Most dairy heifers (Exp. 3) were cyclic with the exception of 12 heifers located in Florida.

Experiment 1 (Beef Cows)

There was an effect of treatment ($P < 0.001$), cyclic status ($P < 0.001$), and location ($P < 0.001$) on the percentage of beef cows detected in estrus within the first 3 d of the breeding period (Table 2; the assumption was that cows in estrus during the first 3 d of the breeding period were synchronized in response to treatment). The treatment × cyclic status interaction was not significant. Relative to treated cows, a lesser percentage of cows assigned to the Control group were in estrus on each of the first 2 d of the breeding period (Figure 1). Across all locations and both cyclic statuses, the percentages of cows in estrus within 3 d were 15 (42/285), 33 (93/283), and 59% (166/283) for control, PGF$_{2\alpha}$, and CIDR+PGF$_{2\alpha}$ groups, respectively. Contrast 1 (control vs PGF$_{2\alpha}$ and CIDR+PGF$_{2\alpha}$; $P < 0.001$) and Contrast 2 (PGF$_{2\alpha}$ vs CIDR+PGF$_{2\alpha}$; $P < 0.001$) were significant. Percentages of cows diagnosed as anestrous or cyclic before the treatment period that were in estrus within 3 d were 25 (110/447) and 47% (191/404), respectively.

Subsequent analyses were performed for the entire 31-d breeding period (Table 3). There was neither an effect of treatment nor a treatment × cyclic status interaction for the percentage of cows detected in estrus during the 31-d breeding period (77%; 653/851). Pretreatment cyclic status ($P < 0.001$) and location ($P < 0.001$), however, affected the number of cows detected in estrus. Across all sites, percentages of cows diagnosed as anestrous or cyclic before the treatment period

Table 2. Synchronization rate, conception rate, and pregnancy rate for beef cows during the first 3 d of the breeding period (Exp. 1)[a]

Item	Florida	Illionis	Nebraska	Missouri	Montana	Oklahoma	All locations
Synchronization rate[b]							
Anestrous							
Control	2/26 (8)	0/5 (0)	8/34 (24)	3/22 (14)	1/32 (3)	2/32 (6)	16/151 (11)
$PGF_{2\alpha}$	3/25 (12)	3/14 (21)	16/34 (47)	1/19 (5)	2/29 (7)	5/33 (15)	30/154 (19)
CIDR+$PGF_{2\alpha}$	16/28 (57)	3/5 (60)	23/33 (70)	3/13 (23)	6/34 (18)	13/29 (45)	64/142 (45)
Cyclic							
Control	3/22 (14)	12/41 (29)	6/16 (38)	2/22 (9)	3/16 (19)	0/17 (0)	26/134 (19)
$PGF_{2\alpha}$	13/22 (59)	15/33 (45)	11/16 (69)	6/26 (23)	11/18 (61)	7/14 (50)	63/129 (49)
CIDR+$PGF_{2\alpha}$	16/19 (84)	33/44 (75)	15/17 (88)	19/27 (70)	9/18 (50)	10/16 (63)	102/141 (72)
Conception rate[c]							
Anestrous							
Control	2/2 (100)	0	0/8 (0)	2/3 (67)	1/1 (100)	1/2 (50)	6/16 (38)
$PGF_{2\alpha}$	2/3 (67)	1/3 (33)	9/16 (56)	0/1 (0)	2/2 (100)	3/5 (60)	17/30 (57)
CIDR+$PGF_{2\alpha}$	9/16 (56)	2/3 (67)	11/23 (48)	2/3 (67)	3/5 (60)	9/13 (69)	36/63 (57)
Cyclic							
Control	2/3 (67)	5/12 (42)	5/6 (83)	0/2 (0)	3/3 (100)	0	15/26 (58)
$PGF_{2\alpha}$	11/13 (85)	12/15 (80)	6/11 (55)	5/6 (83)	6/11 (55)	4/7 (57)	44/63 (70)
CIDR+$PGF_{2\alpha}$	11/16 (69)	24/32 (75)	8/15 (53)	7/19 (37)	6/9 (67)	8/10 (80)	64/101 (63)
Pregnancy rate[d]							
Anestrous							
Control	2/26 (8)	0/5 (0)	0/34 (0)	2/22 (9)	1/32 (3)	1/32 (3)	6/151 (4)
$PGF_{2\alpha}$	2/25 (8)	1/14 (7)	9/34 (26)	0/19 (0)	2/29 (7)	3/33 (9)	17/154 (11)
CIDR+$PGF_{2\alpha}$	9/28 (32)	2/5 (40)	11/33 (33)	2/13 (15)	3/33 (9)	9/29 (31)	36/141 (26)
Cyclic							
Control	2/22 (9)	5/41 (12)	5/16 (31)	0/22 (0)	3/16 (19)	0/17 (0)	15/134 (11)
$PGF_{2\alpha}$	11/22 (50)	12/33 (36)	6/16 (38)	5/26 (19)	6/18 (33)	4/14 (29)	44/129 (34)
CIDR+$PGF_{2\alpha}$	11/19 (58)	24/43 (56)	8/17 (47)	7/27 (26)	6/18 (33)	8/16 (50)	64/140 (46)

[a]Cows were diagnosed as anestrous or cyclic before the treatment period by analyses of blood progesterone concentrations. Treatments were Control (no synchronization treatment), $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38 g progesterone insert [CIDR] for 7 d with a single injection of 25 mg $PGF_{2\alpha}$ on d 6).
[b]Number in estrus/number treated (%); treatment ($P < 0.001$), cyclic status ($P < 0.001$), location ($P < 0.001$).
[c]Number pregnant/number inseminated (%); treatment ($P > 0.10$), cyclic status ($P > 0.10$), location ($P > 0.10$).
[d]Number pregnant/number treated (%); treatment ($P < 0.001$), cyclic status ($P < 0.001$), location ($P < 0.001$).

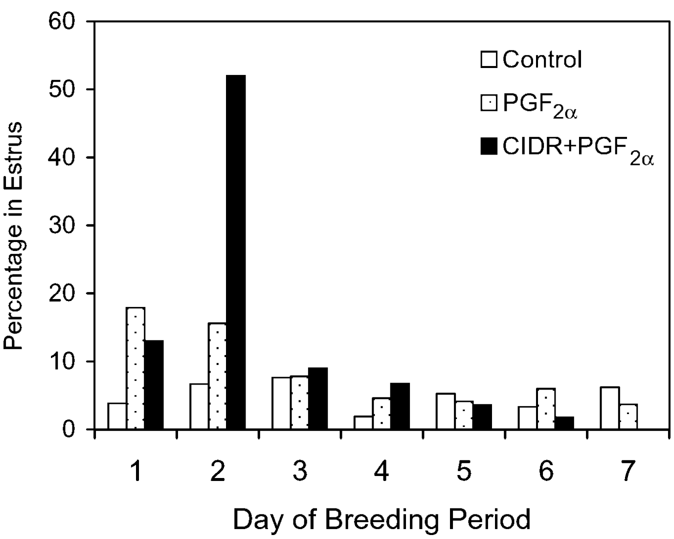

Figure 1. Percentage in estrus during the first 7 d of the breeding period for beef cows (Exp. 1) treated with control (no synchronization treatment), $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$), or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

that were later detected in estrus were 67 (300/447) and 87% (353/404), respectively.

There were effects of treatment ($P < 0.001$; Contrast 1, $P < 0.001$; Contrast 2, $P < 0.01$), cyclic status ($P = 0.06$), treatment × cyclic status ($P < 0.05$), and location ($P < 0.001$) on the day of the breeding period that first estrus was observed (interval to first estrus). The average day of first estrus was 10.9 ± 0.8, 9.4 ± 0.7, and 7.7 ± 0.9 for anestrous cows and 12.3 ± 0.7, 8.1 ± 0.7, and 4.2 ± 0.7 for cyclic cows in the control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ groups, respectively.

In addition to analyses of variance, survival analyses were used to test the effects of treatment and cyclic status on interval to first estrus. There was an effect of treatment ($P < 0.001$) and cyclic status ($P < 0.001$) on the survival curves for cows not observed in estrus (Figure 2). For both anestrous (Figure 2A) and cyclic (Figure 2B) cows, the CIDR+$PGF_{2\alpha}$ treatment group underwent the most rapid decline in numbers of cows not observed in estrus. The control cows underwent the slowest decline and $PGF_{2\alpha}$ cows were intermediate between control and CIDR+$PGF_{2\alpha}$. Differences in survival curves for individual treatments were significant when anestrous cows ($P < 0.01$; Figure 2A) and cyclic cows ($P < 0.001$; Figure 2B) were analyzed separately.

Table 3. Number of beef cows in estrus, first-service conception rate, and pregnancy rate, during the 31-d breeding period (Exp. 1)[a]

Item	Florida	Illinois	Nebraska	Missouri	Montana	Oklahoma	All locations
Number in estrus[b]							
Anestrous							
Control	18/26 (69)	5/5 (100)	31/34 (91)	16/22 (73)	16/32 (50)	15/32 (47)	101/151 (67)
$PGF_{2\alpha}$	16/25 (64)	13/14 (93)	32/34 (94)	13/19 (68)	13/29 (45)	18/33 (55)	105/154 (68)
CIDR+$PGF_{2\alpha}$	22/28 (79)	5/5 (100)	31/33 (94)	7/13 (54)	12/34 (35)	17/29 (59)	94/142 (66)
Cyclic							
Control	19/22 (86)	37/41 (90)	15/16 (94)	18/22 (82)	10/16 (63)	11/17 (65)	110/134 (82)
$PGF_{2\alpha}$	21/22 (95)	26/33 (79)	16/16 (100)	23/26 (88)	15/18 (83)	13/14 (93)	114/129 (88)
CIDR+$PGF_{2\alpha}$	19/19 (100)	38/44 (86)	17/17 (100)	27/27 (100)	13/18 (72)	15/16 (94)	129/141 (91)
First-service conception rate[c]							
Anestrous							
Control	12/17 (71)	4/5 (80)	10/31 (32)	10/15 (67)	10/16 (63)	11/15 (73)	57/99 (58)
$PGF_{2\alpha}$	10/16 (63)	7/13 (54)	15/32 (47)	10/12 (83)	7/12 (58)	13/18 (72)	62/103 (60)
CIDR+$PGF_{2\alpha}$	12/22 (55)	4/5 (80)	14/31 (45)	5/6 (83)	8/11 (73)	13/17 (76)	56/92 (61)
Cyclic							
Control	11/19 (58)	24/37 (65)	7/15 (47)	12/16 (75)	6/10 (60)	9/11 (82)	69/108 (64)
$PGF_{2\alpha}$	15/21 (71)	22/26 (85)	7/16 (44)	15/22 (68)	8/15 (53)	9/13 (69)	76/113 (67)
CIDR+$PGF_{2\alpha}$	14/19 (74)	27/37 (73)	8/17 (47)	11/26 (42)	10/13 (77)	12/15 (80)	82/127 (65)
Pregnancy rate[d]							
Anestrous							
Control	12/25 (48)	4/5 (80)	13/34 (38)	11/21 (52)	10/32 (31)	13/32 (41)	63/149 (42)
$PGF_{2\alpha}$	11/25 (44)	10/14 (71)	20/34 (59)	11/18 (61)	7/28 (25)	13/33 (39)	72/152 (47)
CIDR+$PGF_{2\alpha}$	15/28 (54)	5/5 (100)	17/33 (52)	5/12 (42)	9/33 (27)	13/29 (45)	64/140 (46)
Cyclic							
Control	11/22 (50)	28/41 (68)	9/16 (56)	13/20 (65)	6/16 (38)	10/17 (59)	77/132 (58)
$PGF_{2\alpha}$	16/22 (73)	23/33 (70)	10/16 (63)	16/25 (64)	8/18 (44)	10/14 (71)	83/128 (65)
CIDR+$PGF_{2\alpha}$	17/19 (89)	33/43 (77)	9/17 (53)	14/26 (54)	12/18 (67)	14/16 (88)	99/139 (71)

[a]Cows were diagnosed as anestrous or cyclic before the treatment period by analyses of blood progesterone concentrations. Treatments were control (no synchronization treatment), $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on d 6).
[b]Number in estrus/number treated (%); treatment ($P > 0.10$), cyclic status ($P < 0.001$), location ($P < 0.001$).
[c]Number pregnant/number inseminated (%); treatment ($P > 0.10$), cyclic status ($P > 0.10$), location ($P < 0.001$).
[d]Number pregnant/number treated (%); treatment ($P = 0.10$), cyclic status ($P < 0.001$), location ($P < 0.001$).

For anestrous cows, Contrast 1 was significant ($P < 0.01$) and Contrast 2 tended to be significant ($P = 0.07$). Both Contrast 1 ($P < 0.001$) and Contrast 2 ($P < 0.01$) were significant for cyclic cows.

During the 3-d breeding period (i.e., inseminations to synchronized estrus), no differences in first-insemination conception rates were detected among treatments, cyclic statuses, or locations. The treatment × cyclic status interaction was not significant (Table 2). The conception rate for the first 3 d was 61% (182/299). Pregnancy rates during the first 3 d of the breeding period were affected by treatment ($P < 0.001$), cyclic status ($P < 0.001$), and location ($P < 0.001$). Across all locations and both cyclic statuses, the percentages of cattle pregnant within the first 3 d of the breeding period were 7 (21/285), 22 (61/283), and 36% (100/281) for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$, respectively (Contrast 1, $P < 0.001$; Contrast 2, $P < 0.001$). Three-day pregnancy rates for cows diagnosed as anestrous or cyclic before the treatment period were 13 (59/446) and 31% (123/403), respectively.

During the entire 31-d breeding period, no differences in first-insemination conception rates were detected among treatments or cyclic statuses, but conception rates differed among locations ($P < 0.001$; Table 3). The treatment × cyclic status interaction was not significant. Across all locations, the first-service conception rate was 63% (402/642). Pregnancy rate during the 31-d breeding period tended to be affected by treatment ($P = 0.10$) and was affected by cyclic status ($P < 0.001$) and location ($P < 0.001$). The percentages of pregnant cattle were 50 (140/281), 55 (155/280), and 58% (163/279) for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ groups, respectively. Pregnancy rates for cows diagnosed as anestrous or cyclic before the treatment period were 45 (199/441) and 65% (259/399), respectively.

For cows conceiving during the breeding season, there was a tendency for an effect of treatment ($P = 0.06$; Contrast 1, $P < 0.05$; Contrast 2, $P > 0.10$) and an effect of location ($P < 0.05$) on the interval to pregnancy. The effect of cyclic status was not significant ($P > 0.10$). The average day of pregnancy was 12.4 ± 1.0, 10.1 ± 0.9, and 8.7 ± 0.9 for cows in the control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ groups, respectively.

Survival analyses were also used to test the effects of treatment and cyclic status on interval to pregnancy. There was an effect of treatment ($P < 0.001$) and cyclic status ($P < 0.001$) on the survival curves for nonpregnant beef cows (Figure 3). For both anestrous (Figure 3A) and cyclic (Figure 3B) cows, the CIDR+$PGF_{2\alpha}$ treatment group underwent the most rapid decline in the number of nonpregnant cows. The control cows underwent the slowest decline and the $PGF_{2\alpha}$-treated cows were intermediate between control and CIDR+$PGF_{2\alpha}$. The survival curves for nonpregnant beef cows were similar statistically for individual treatments in cows diagnosed as anestrous before the treatment period (Figure 3A), but survival curves for individual treatments differed for cyclic cows (P < 0.001; Figure 3B). For cyclic cows, Contrast 1 was significant (P < 0.01) but Contrast 2 was not significant.

Experiment 2 (Beef Heifers)

There was an effect of treatment (P < 0.001), cyclic status (P < 0.001), and location (P < 0.001) on the percentage of beef heifers detected in estrus within the first 3 d of the breeding period (Table 4). The treatment × cyclic status interaction was not significant. Relative to treated heifers, a lesser percentage of beef heifers

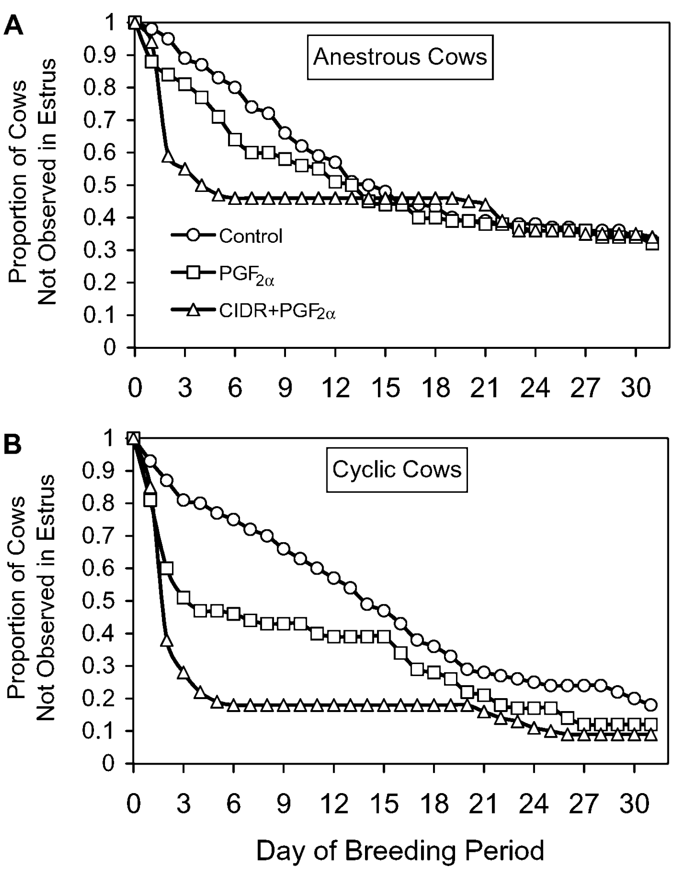

Figure 2. The proportion of beef cows (Exp. 1) not observed in estrus on each day during the 31-d breeding period (survival analyses). Survival curves are presented for cows classified as A) anestrous or B) cyclic before the treatment period. Cows were assigned to control (no synchronization treatment) or were treated with $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

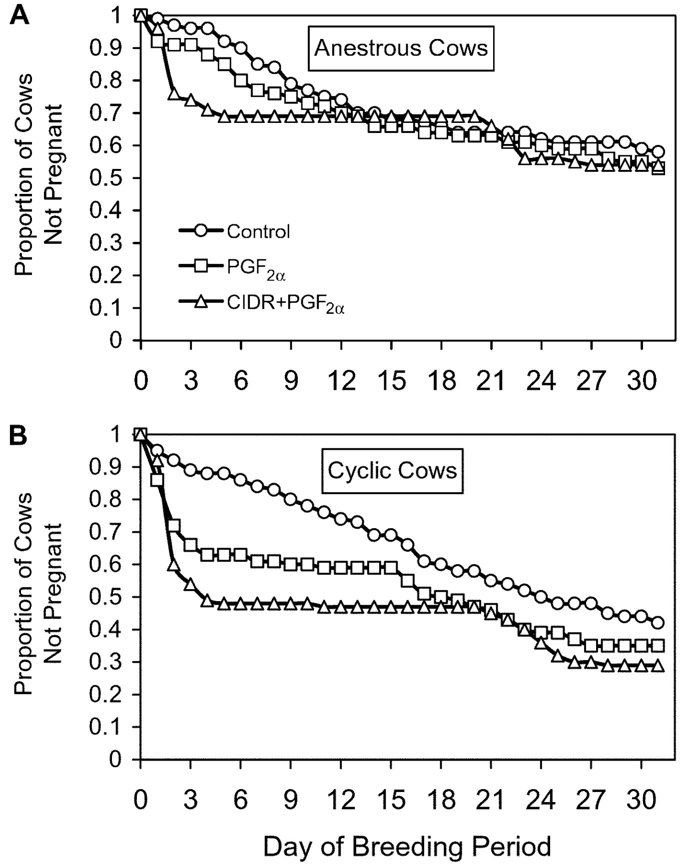

Figure 3. The proportion of beef cows (Exp. 1) not pregnant on each day during the 31-d breeding period (survival analyses). Survival curves are presented for cows classified as A) anestrous or B) cyclic before the treatment period. Cows were assigned to control (no synchronization treatment) or were treated with $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

assigned to the control group were in estrus on each of the first 2 d of the breeding period (Figure 4). Across all locations and both cyclic statuses, the percentages of beef heifers in estrus within 3 d were 13 (33/251), 27 (67/252), and 65% (143/221) for Control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ groups, respectively (Contrast 1, P < 0.001; Contrast 2, P < 0.001). Percentages of beef heifers diagnosed as prepubertal or cyclic before the treatment period that were in estrus within 3 d were 22 (69/313) and 42% (174/411), respectively.

There was an effect of treatment (P < 0.01), cyclic status (P < 0.001), and location (P < 0.001) on the percentage of beef heifers in estrus during the 31-d breeding period (Table 5). The treatment × cyclic status interaction was not significant. Across all locations and both cyclic statuses, the percentages of beef heifers in estrus for the 31-d breeding period were 73 (183/251), 71 (178/252), and 82% (182/221) for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ groups, respectively. Contrast 2 (P < 0.01) but not Contrast 1 was significant. Percentages of beef

Table 4. Synchronization rate, conception rate, and pregnancy rate for beef heifers during the first 3 d of the breeding period (Exp. 2)[a]

Item	Florida	Illinois	Nebraska	Missouri	Montana	All locations
Synchronization rate[b]						
Prepubertal						
Control	2/8 (25)	0/4 (0)	1/35 (3)	3/21 (14)	2/39 (5)	8/107 (7)
$PGF_{2\alpha}$	5/10 (50)	0/3 (0)	0/33 (0)	5/18 (28)	1/37 (3)	11/101 (11)
CIDR+$PGF_{2\alpha}$	4/9 (44)	1/1 (100)	13/32 (41)	22/25 (88)	10/38 (26)	50/105 (48)
Cyclic						
Control	6/39 (15)	6/48 (13)	0/7 (0)	8/29 (28)	5/21 (24)	25/144 (17)
$PGF_{2\alpha}$	13/38 (34)	19/48 (40)	2/9 (22)	16/32 (50)	6/24 (25)	56/151 (37)
CIDR+$PGF_{2\alpha}$	29/35 (83)	32/40 (80)	6/7 (86)	18/22 (82)	8/12 (67)	93/116 (80)
Conception rate[c]						
Prepubertual						
Control	2/2 (100)	0	0/1 (0)	2/3 (67)	2/2 (100)	6/8 (75)
$PGF_{2\alpha}$	5/5 (100)	0	0	1/5 (20)	0/1 (0)	6/11 (55)
CIFR+$PGF_{2\alpha}$	2/4 (50)	0/1 (0)	9/13 (69)	15/22 (68)	3/10 (30)	29/50 (58)
Cyclic						
Control	3/6 (50)	4/6 (67)	0	4/8 (50)	2/5 (40)	13/25 (52)
$PGF_{2\alpha}$	8/13 (62)	8/19 (42)	1/2 (50)	10/16 (63)	2/6 (33)	29/56 (52)
CIDR+$PGF_{2\alpha}$	20/29 (69)	18/32 (56)	5/6 (83)	8/18 (44)	6/8 (75)	57/93 (61)
Pregnancy rate[d]						
Prepubertal						
Control	2/8 (25)	0/4 (0)	0/35 (0)	2/21 (10)	2/39 (5)	6/107 (6)
$PGF_{2\alpha}$	5/10 (50)	0/3 (0)	0/33 (0)	1/18 (6)	0/37 (0)	6/101 (6)
CIDR+$PGF_{2\alpha}$	2/9 (22)	0/1 (0)	9/32 (28)	15/25 (60)	3/38 (8)	29/105 (28)
Cyclic						
Control	3/39 (8)	4/48 (8)	0/7 (0)	4/29 (14)	2/21 (10)	13/144 (9)
$PGF_{2\alpha}$	8/38 (21)	8/48 (17)	1/9 (11)	10/32 (31)	2/24 (8)	29/151 (19)
CIDR+$PGF_{2\alpha}$	20/35 (57)	18/40 (45)	5/7 (71)	8/22 (36)	6/12 (50)	57/116 (49)

[a]Heifers were diagnosed as prepubertal or cyclic before the treatment period by analysis of blood progesterone concentrations. Treatments were control (no synchronization treatment), $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg $PGF_{2\alpha}$ on d 6).
[b]Number in estrus/number treated (%); treatment ($P < 0.001$), cyclic status ($P < 0.001$), location ($P < 0.001$).
[c]Number pregnant/number inseminated (%); treatment ($P > 0.10$), cyclic status ($P > 0.10$), location ($P > 0.10$).
[d]Number pregnant/number treated (%); treatment ($P < 0.001$), cyclic status ($P < 0.05$), location ($P < 0.001$).

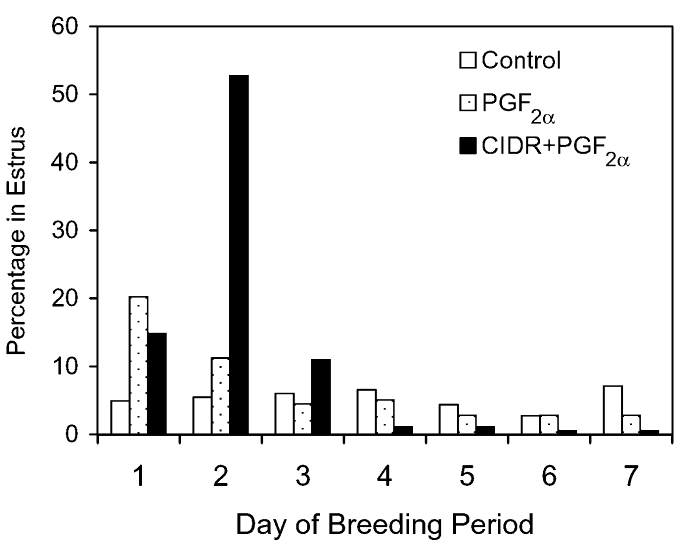

Figure 4. Percentage in estrus during the first 7 d of the breeding period for beef heifers (Exp. 2) treated with control (no synchronization treatment), $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$), or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

heifers diagnosed as prepubertal or cyclic before the treatment period that were later detected in estrus were 57 (178/313) and 89% (365/411), respectively.

There was an effect of treatment ($P < 0.01$; Contrast 1, $P < 0.05$; Contrast 2, $P < 0.01$) on the day of the breeding period that first estrus was observed. Cyclic status and location were not significant ($P > 0.10$). The average day of first estrus was 11.1 ± 1.0, 11.2 ± 1.1, and 5.1 ± 1.1 for heifers in the control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ groups, respectively.

Survival analyses characterized the proportion of beef heifers that had not been observed in estrus during the breeding period. There was an effect of treatment ($P < 0.001$) and cyclic status ($P < 0.001$) on the survival curves for heifers not observed in estrus during the breeding period (Figure 5). For both prepubertal (Figure 5A) and cyclic (Figure 5B) beef heifers, the CIDR+$PGF_{2\alpha}$ treatment group underwent the most rapid decline in numbers of heifers not observed in estrus. For heifers diagnosed as prepubertal before the treatment period, the survival curves for control and $PGF_{2\alpha}$ groups appeared to be similar (Figure 5A). For cyclic heifers, the survival curve for $PGF_{2\alpha}$ was intermediate initially between control and CIDR+$PGF_{2\alpha}$ groups but then overlapped with control at approximately d

10 of the breeding period (Figure 5B). The treatment effect on the decrease in the percentage of heifers not seen in estrus was significant for both prepubertal ($P < 0.001$) and cyclic ($P < 0.001$) heifers. Contrasts 1 and 2 were significant for prepubertal ($P < 0.05$ and $P < 0.001$, respectively) and pubertal ($P < 0.001$ and $P < 0.001$, respectively) heifers.

During the 3-d breeding period, no differences in first-insemination conception rates were detected among treatments, cyclic statuses, or locations (Table 4). The treatment × cyclic status interaction was not significant. The conception rate for the first 3 d was 58% (140/243). Pregnancy rate during the first 3 d of the breeding period was affected by treatment ($P < 0.001$), cyclic status ($P < 0.05$), and location ($P < 0.001$). Across all locations and both cyclic statuses, the percentages of heifers pregnant as a result of artificial insemination within the first 3 d of the breeding period were 8 (19/251), 14 (35/252), and 39% (86/221) for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$, respectively (Contrast 1, $P < 0.001$; Contrast 2, $P < 0.001$). Three-day pregnancy rates for beef heifers diagnosed as prepubertal or cyclic before the breeding season were 13 (41/313) and 24% (99/411), respectively.

During the entire 31-d breeding period, no differences in first-insemination conception rates were detected among treatments or cyclic statuses, but conception rates differed among locations ($P < 0.05$; Table 5). The treatment × cyclic status interaction was not significant. Across all locations and both cyclic statuses, the first-service conception rate was 57% (301/530). Pregnancy rate for the 31-d breeding period was affected by treatment ($P < 0.001$), cyclic status ($P < 0.001$) and location ($P < 0.001$). The percentages of pregnant cattle were 50 (123/247), 43 (106/244), and 60% (132/220) for control, $PGF_{2\alpha}$, and CIDR+$PGF_{2\alpha}$ groups, respectively. Contrast 2 ($P < 0.001$) was significant. Pregnancy rates for beef heifers diagnosed as prepubertal or cyclic before the breeding season were 36 (109/307) and 62% (252/404), respectively.

For heifers conceiving during the breeding season, no differences in intervals to pregnancy were detected among treatments, cyclic statuses, or locations. The treatment × cyclic status interaction was also not significant. For all heifers, the average day of pregnancy was 10.6 ± 0.4. Survival analyses were subsequently used to test the effects of treatment and cyclic status on interval to pregnancy. There was an effect of treat-

Table 5. Number of beef heifers in estrus, first-service conception rate, and pregnancy rate during the 31-d breeding period (Exp. 2)[a]

Item	Florida	Illinois	Nebraska	Missouri	Montana	All locations
Number in estrus[b]						
Prepubertal						
Control	7/8 (88)	2/4 (50)	22/35 (63)	18/21 (86)	9/39 (23)	58/107 (54)
$PGF_{2\alpha}$	7/10 (70)	1/3 (33)	14/33 (42)	14/18 (78)	9/37 (24)	45/101 (45)
CIDR+$PGF_{2\alpha}$	6/9 (67)	1/1 (100)	26/32 (81)	25/25 (100)	17/38 (45)	75/105 (71)
Cyclic						
Control	34/39 (87)	41/48 (85)	4/7 (57)	29/29 (100)	17/21 (81)	125/144 (87)
$PGF_{2\alpha}$	36/38 (95)	39/48 (81)	8/9 (89)	29/32 (91)	21/24 (88)	133/151 (88)
CIDR+$PGF_{2\alpha}$	35/35 (100)	35/40 (88)	6/7 (86)	21/22 (95)	10/12 (83)	107/116 (92)
First-service conception rate[c]						
Prepubertal						
Control	4/7 (57)	1/2 (50)	9/22 (41)	11/16 (69)	6/8 (75)	31/55 (56)
$PGF_{2\alpha}$	5/7 (71)	0/1 (0)	5/14 (36)	5/14 (36)	4/7 (57)	19/43 (44)
CIDR+$PGF_{2\alpha}$	3/6 (50)	0/1 (0)	13/26 (50)	18/25 (72)	8/16 (50)	42/74 (57)
Cyclic						
Control	20/34 (59)	24/41 (59)	1/4 (25)	21/29 (72)	10/16 (63)	76/124 (61)
$PGF_{2\alpha}$	21/36 (58)	16/39 (41)	2/8 (25)	21/29 (72)	8/15 (53)	68/127 (54)
CIDR+$PGF_{2\alpha}$	23/35 (66)	19/35 (54)	5/6 (83)	11/21 (52)	7/10 (70)	65/107 (61)
Pregnancy rate[d]						
Prepubertal						
Control	4/8 (50)	1/4 (25)	9/35 (26)	12/19 (63)	6/38 (16)	32/104 (31)
$PGF_{2\alpha}$	5/10 (50)	0/3 (0)	6/33 (18)	9/18 (50)	5/35 (14)	25/99 (25)
CIDR+$PGF_{2\alpha}$	4/9 (44)	1/1 (100)	16/32 (50)	20/25 (80)	11/37 (30)	52/104 (50)
Cyclic						
Control	24/39 (62)	30/48 (63)	1/7 (14)	25/29 (86)	11/20 (55)	91/143 (64)
$PGF_{2\alpha}$	23/38 (61)	20/48 (42)	4/9 (44)	25/32 (78)	9/18 (50)	81/145 (56)
CIDR+$PGF_{2\alpha}$	29/35 (83)	24/40 (60)	5/7 (71)	14/22 (64)	8/12 (67)	80/116 (69)

[a]Heifers were diagnosed as prepubertal or cyclic before the treatment period by analyses of blood progesterone concentrations. Treatments were control (no synchronization treatment), $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on d 6).

[b]Number in estrus/number treated (%); treatment ($P < 0.01$), cyclic status ($P < 0.001$), location ($P < 0.001$).

[c]Number pregnant/number inseminated (%); treatment ($P > 0.10$), cyclic status ($P > 0.10$), location ($P < 0.05$).

[d]Number pregnant/number treated (%); treatment ($P < 0.001$), cyclic status ($P < 0.001$), location ($P < 0.001$).

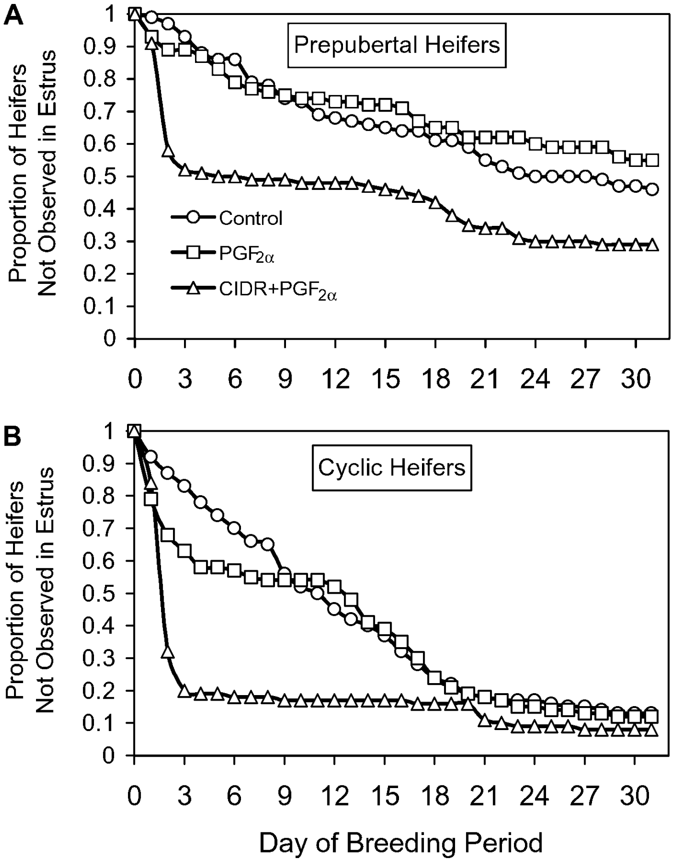

Figure 5. The proportion of beef heifers (Exp. 2) not observed in estrus on each day during the 31-d breeding period (survival analyses). Survival curves are presented for heifers classified as A) prepubertal or B) cyclic before the treatment period. Heifers were assigned to control (no synchronization treatment) or were treated with $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

ment ($P < 0.001$) and cyclic status ($P < 0.001$) on survival curves for nonpregnant beef heifers during the 31-d breeding period (Figure 6). For both prepubertal (Figure 6A) and cyclic (Figure 6B) heifers, the CIDR+$PGF_{2\alpha}$ treatment group underwent the most rapid decline in numbers of nonpregnant heifers. Survival curves for control and $PGF_{2\alpha}$-treated heifers appeared to be similar for prepubertal heifers (Figure 6A) and only differed slightly for cyclic heifers (Figure 6B). The treatment effect on the decrease in the percentage of nonpregnant heifers was significant for prepubertal ($P < 0.001$) and cyclic ($P < 0.01$) heifers. Contrast 1 tended to be significant for prepubertal heifers ($P = 0.09$) but was not significant for cyclic heifers. Contrast 2 was significant for prepubertal ($P < 0.001$) and cyclic ($P < 0.01$) heifers.

Experiment 3 (Dairy Heifers)

The effects of cyclic status were not evaluated in dairy heifers because 95% of the dairy heifers were pubertal at the time of treatment (Table 1). In addition, only $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$ groups were evaluated in dairy heifers. There was an effect of treatment ($P < 0.001$) on the percentage of dairy heifers in estrus within the first 3 d of the breeding period (Table 6). Location was not significant. The majority of $PGF_{2\alpha}$-treated dairy heifers were in estrus on d 1, whereas the majority of CIDR+$PGF_{2\alpha}$-treated dairy heifers were in estrus on d 2 (Figure 7). Across all locations, the percentages of dairy heifers in estrus during the first 3 d for $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$ groups were 57 (79/138) and 84% (103/122), respectively.

The effects of treatment and location were not significant for the percentage of dairy heifers detected in estrus during the entire 31-d breeding period (92%; 238/260) (Table 7). There was no effect of treatment, location, or treatment × location on the day of the breeding period that first estrus was observed (5.0 ± 0.4). The survival curves for dairy heifers not observed in

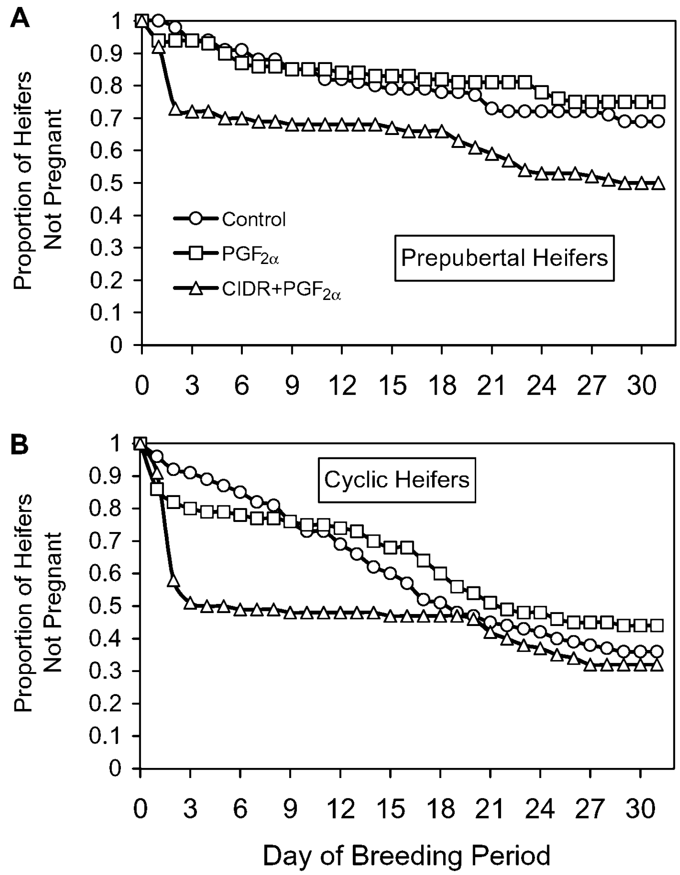

Figure 6. The proportion of beef heifers (Exp. 2) not pregnant on each day during the 31-d breeding period (survival analyses). Survival curves are presented for heifers classified as A) prepubertal or B) cyclic before the treatment period. Heifers were assigned to control (no synchronization treatment) or were treated with $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

Table 6. Synchronization rate, conception rate, and pregnancy rate for dairy heifers during the first 3 d of the breeding period (Exp. 3)[a]

Item	New York	Illinois	Florida	Missouri	All locations
Synchronization rate[b]					
$PGF_{2\alpha}$	16/30 (53)	9/16 (56)	34/63 (54)	20/29 (69)	79/138 (57)
CIDR+$PGF_{2\alpha}$	17/20 (85)	11/16 (69)	52/60 (87)	23/26 (88)	103/122 (84)
Conception rate[c]					
$PGF_{2\alpha}$	12/16 (75)	4/9 (44)	18/34 (53)	17/19 (89)	51/78 (65)
CIDR+$PGF_{2\alpha}$	11/17 (65)	5/11 (45)	26/51 (51)	13/23 (57)	55/102 (54)
Pregnancy rate[d]					
$PGF_{2\alpha}$	12/30 (40)	4/16 (25)	18/63 (29)	17/28 (61)	51/137 (37)
CIDR+$PGF_{2\alpha}$	11/20 (55)	5/16 (31)	26/59 (44)	13/26 (50)	55/121 (45)

[a]Treatments were $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on d 6).
[b]Number in estrus/number treated (%); treatment ($P < 0.001$), location ($P > 0.10$).
[c]Number pregnant/number inseminated (%); treatment ($P > 0.10$), location ($P = 0.06$).
[d]Number pregnant/number treated (%); treatment ($P > 0.10$), location ($P < 0.05$).

estrus were similar for $PGF_{2\alpha}$ and CIDR+$PGF_{2\alpha}$-treated heifers (Figure 8A).

During the 3-d breeding period, no differences in first-insemination conception rates were detected among treatments. Conception rates tended to differ among locations ($P = 0.06$; Table 6). The conception rate for the first 3 d was 59% (106/180). Pregnancy rates during the first 3 d of the breeding period were not affected by treatment but differed among locations ($P < 0.05$). Across all locations, the percentage of dairy heifers pregnant within the first 3 d of the breeding period was 41% (106/258).

During the 31-d breeding period, no differences in first-insemination conception rates were detected among treatments, but conception rates differed among locations ($P < 0.01$; Table 7). Across all locations, the first-service conception rate was 54% (126/233). No differences in pregnancy rates for the 31-d breeding period were detected among treatments, but pregnancy rates

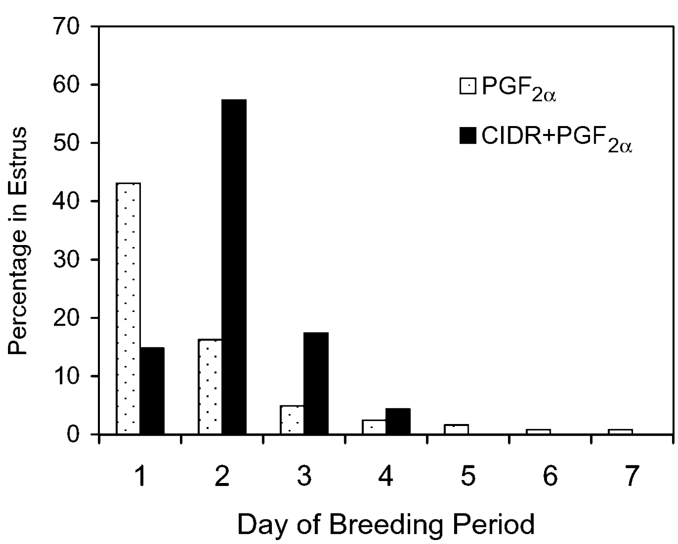

Figure 7. Percentage in estrus during the first 7 d of the breeding period for dairy heifers (Exp. 3) treated with $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38 g of progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

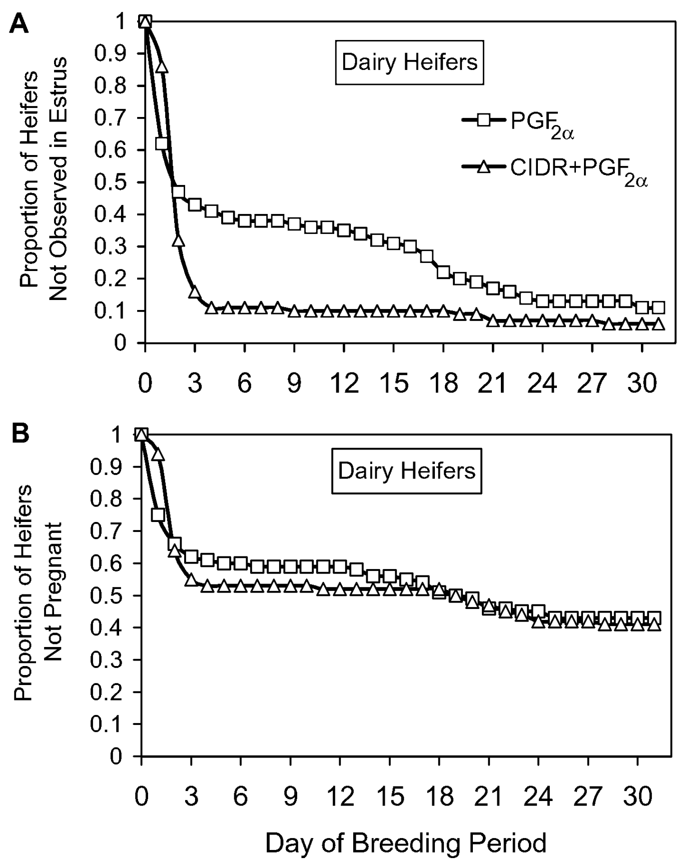

Figure 8. The proportion of dairy heifers (Exp. 3) either not observed A) in estrus or B) not pregnant on each day during the 31-d breeding period (survival analyses). Heifers were treated with $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$ (1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on the day before CIDR removal).

Table 7. The number of dairy heifers in estrus, first-service conception rate, and pregnancy rate during the 31-d breeding period (Exp. 3)[a]

Item	New York	Illinois	Florida	Missouri	All locations
Number in estrus[b]					
$PGF_{2\alpha}$	28/30 (93)	13/16 (81)	56/63 (91)	26/29 (90)	123/138 (89)
CIDR+$PGF_{2\alpha}$	19/20 (95)	13/16 (81)	58/60 (97)	25/26 (96)	115/122 (94)
First-service conception rate[c]					
$PGF_{2\alpha}$	17/25 (68)	4/13 (31)	26/56 (46)	19/25 (76)	66/119 (55)
CIDR+$PGF_{2\alpha}$	12/19 (63)	5/13 (38)	28/57 (49)	15/25 (60)	60/114 (53)
Pregnancy rate[d]					
$PGF_{2\alpha}$	18/27 (67)	5/16 (31)	34/63 (54)	20/28 (71)	77/134 (57)
CIDR+$PGF_{2\alpha}$	12/20 (60)	6/16 (38)	36/59 (61)	17/26 (65)	71/121 (59)

[a]Treatments were $PGF_{2\alpha}$ (single injection of 25 mg of $PGF_{2\alpha}$) or CIDR+$PGF_{2\alpha}$(1.38-g progesterone insert [CIDR] for 7 d with a single injection of 25 mg of $PGF_{2\alpha}$ on d 6).
[b]Number in estrus/number treated (%); treatment ($P > 0.10$), location ($P > 0.10$).
[c]Number pregnant/number inseminated (%); treatment ($P > 0.10$), location ($P < 0.01$).
[d]Number pregnant/number treated (%); treatment ($P > 0.10$), location ($P < 0.05$).

differed among locations ($P < 0.05$). The percentage of pregnant dairy heifers at the end of the breeding period was 58% (148/255). Effects of treatment or treatment × location were not detected for the interval to pregnancy (6.3 ± 0.6), but interval to pregnancy tended to differ among locations ($P = 0.10$). Effects of treatment on the survival curves for nonpregnant dairy heifers were not detected (Figure 8B).

Discussion

A 7-d administration of the CIDR with an injection of $PGF_{2\alpha}$ on d 6 of insertion was an effective method for estrus synchronization in cattle. Beef cows and beef and dairy heifers had improved rates of synchronized estrus (3-d period) compared with either $PGF_{2\alpha}$ or control (no treatment). The beneficial effects on synchronization of estrus can be seen clearly when survival curves are examined (Figures 2, 5, and 8A). The effect of the CIDR was most striking early in the breeding period immediately following CIDR withdrawal when the proportion of cattle that were not observed in estrus nor inseminated dramatically decreased for CIDR+$PGF_{2\alpha}$ groups. By the end of the breeding period (31 d later), the control or $PGF_{2\alpha}$-treated cattle generally had similar proportions of cattle not observed in estrus compared with CIDR+$PGF_{2\alpha}$ groups. This would be expected in locations with a high degree of cyclic cattle and good estrous observations. Numbers of control cattle that were not observed in estrus steadily declined throughout the breeding period. Numbers of $PGF_{2\alpha}$-treated cattle not observed in estrus, however, underwent an initial decline associated with the synchronized estrus and then a second decline between d 12 and 21 of the breeding period. The second decline of approximately 20 to 30% (Figures 2B, 5B, and 8A) was probably caused by the return to estrus for cattle that were not synchronized after $PGF_{2\alpha}$ treatment because they were in the early luteal phase when $PGF_{2\alpha}$ treatment is not effective in regression of the CL (Lauderdale, 1972). In addition, some $PGF_{2\alpha}$-treated cattle may have had short estrous cycles following treatment (Short et al., 1990). This second phase decline in $PGF_{2\alpha}$-treated cattle was not as evident in anestrous or prepubertal cattle.

The effect of the CIDR+$PGF_{2\alpha}$ treatment on time of first estrus in anestrous beef cows (Figure 2A) and prepubertal beef heifers (Figure 5A) that we observed confirmed the advantages of progestogen treatment for cattle that are not cyclic at the beginning of the breeding season (Patterson et al., 1989; Odde, 1990; Larson and Ball, 1992; Macmillan and Peterson, 1993). The mechanism of progestogen action on the ovary involves increased LH secretion that causes an increase in follicular development leading to ovulation (Anderson et al., 1996; Imwalle et al., 1998). For anestrous cows, the proportion of cattle that were not observed in estrus declined rapidly in the CIDR+$PGF_{2\alpha}$ group. The data for prepubertal beef heifers were similar to the data for anestrous beef cows in that a large proportion of the CIDR+$PGF_{2\alpha}$-treated heifers were in estrus early in the breeding period. The observed treatment differences in the proportion of estrual cattle were maintained throughout the breeding period so that the control or $PGF_{2\alpha}$-treated prepubertal beef heifers never attained the same rates of estrus compared with the CIDR+$PGF_{2\alpha}$-treated heifers. In addition to being an effective tool for synchronization of anestrous cattle, the CIDR+$PGF_{2\alpha}$ treatment was also efficacious in cattle diagnosed as cyclic before treatment. The overall response to the CIDR+$PGF_{2\alpha}$ treatment will depend on the proportion of cattle that are cyclic at the start of the breeding season, with the most desirable response occurring in herds with greater percentages of cyclic cattle.

There is the potential for the development of persistent follicles when progestogens are used in estrus synchronization programs (Anderson and Day, 1994; Fike et al., 1999). Persistent follicles are problematic in breeding programs because oocytes from persistent follicles are inherently less healthy and cause a decreased conception rate following insemination (Ahmad et al., 1995; Revah and Butler, 1996; Roche et al., 1999). An effect of the CIDR+PGF$_{2\alpha}$ treatment on conception rates in beef cows, beef heifers, or dairy heifers during the 3-d synchronization period (Tables 2, 4, and 6) or during the 31-d breeding period (Tables 3, 5, and 7) was not detected. Therefore, use of a CIDR in the manner described has no apparent effect on conception to a single insemination.

Pregnancy rate is a function of estrus detection rate and conception rate. Therefore, it is not surprising that the CIDR+PGF$_{2\alpha}$-treated cattle had improved pregnancy rates relative to control or PGF$_{2\alpha}$-treated cattle because estruses in the CIDR+PGF$_{2\alpha}$-treated cattle were concentrated to the first 3 d of the breeding period. The dramatic effects of the CIDR+PGF$_{2\alpha}$ treatment on pregnancy can be seen when survival curves for the reduction of nonpregnancy are examined. In both beef cows (Figure 3) and beef heifers (Figure 6), there was a marked decline in numbers of nonpregnant cattle after synchronization with the CIDR+PGF$_{2\alpha}$ treatment. The response in pregnancy rate can be seen in anestrous and cyclic cows as well as in prepubertal and cyclic heifers. The improved rate of pregnancy in prepubertal beef heifers treated with the CIDR was noteworthy because prepubertal heifers in the control or PGF$_{2\alpha}$ treatments never attained pregnancy rates that were similar to those of the CIDR+PGF$_{2\alpha}$-treated heifers.

These experiments were designed to test the effects of the CIDR+PGF$_{2\alpha}$ on estrus synchronization and pregnancy. Before treatment, cattle were classified as either acyclic (anestrous cows or prepubertal heifers) or cyclic (cows or heifers). The CIDR+PGF$_{2\alpha}$ improved the synchronization of estrus and pregnancy rate in the acyclic and cyclic cattle. As a group, however, cattle diagnosed as acyclic before the treatment period had inferior reproductive performance compared with their cyclic herd mates. The effects of cyclic status were significant for 3-d and 31-d estrus and pregnancy rates. The use of the CIDR+PGF$_{2\alpha}$ treatment in estrus synchronization programs can improve responses but cannot completely overcome the limitations encountered when a large percentage of the herd is anestrous or prepubertal.

The experimental design for dairy heifers (Exp. 3) was different from that employed for beef cows or beef heifers because a control group was not used. The assumption was that the majority of the dairy heifers would be cyclic at the time of treatment. Therefore, a direct comparison between PGF$_{2\alpha}$ and CIDR+PGF$_{2\alpha}$ treatments was evaluated. The 3-d synchronization rate for the dairy heifers was greater for the CIDR+PGF$_{2\alpha}$-treated heifers compared with the PGF$_{2\alpha}$ heifers. However, the improvements in synchronization rate did not translate into an improved 3-d pregnancy rate (Table 6) or an improvement in the number pregnant dairy heifers at the end of the breeding period (Table 7). The failure to improve pregnancy rates may be explained by a numerically lower conception rate for CIDR+PGF$_{2\alpha}$ dairy heifers during the 3-d breeding period. The difference in conception rate was not statistically significant but nevertheless precluded an improvement in pregnancy rate immediately after estrus synchronization. Decreases in conception rate for the CIDR+PGF$_{2\alpha}$ group were not observed when beef cows or beef heifers were treated with CIDR+PGF$_{2\alpha}$. One possibility is that management or breed differences between beef and dairy cattle affected the physiological responses to synchronization with CIDR+PGF$_{2\alpha}$. Alternatively, there may have been too few dairy heifers assigned to the experiment. A larger dairy experiment may be necessary to clarify the effects of the CIDR on conception rate in dairy heifers.

The experimental design employed in the present study has been used in the past to test the efficacy of a progestogen for estrus synchronization (Chenault et al., 1990). The CIDR+PGF$_{2\alpha}$ was evaluated against a control group receiving no treatment as well as a treated group receiving a single injection of PGF$_{2\alpha}$. The PGF$_{2\alpha}$ was given as a single injection so that the effects of the CIDR could be evaluated directly. The efficacy of the single PGF$_{2\alpha}$ injection for estrus synchronization is obviously less than that of a two-injection protocol (Odde et al., 1990). A variety of estrus synchronization protocols could have been evaluated against the CIDR+PGF$_{2\alpha}$, but the experimental approach that we used was selected because of its simplicity (i.e., a single PGF$_{2\alpha}$ injection vs a single PGF$_{2\alpha}$ injection and a CIDR). The use of multiple locations across the United States that employed a variety of beef and dairy management systems demonstrated the robust nature of the treatment protocol. Location was generally significant for synchronization rates, conception rates, and pregnancy rates. These significant effects of location were expected and reflected the multiplicity of confounding factors at each location. Regardless of the effects of location, the effects of treatment were generally consistent across locations (i.e., improved synchrony and pregnancy with CIDR+PGF$_{2\alpha}$ over control or PGF$_{2\alpha}$).

The data were analyzed by a combination of analysis of variance, categorical modeling, and survival analyses. Data collected during the first 3 d of the breeding period as well as data collected over the entire breeding period were examined. We selected the first 3 d of the breeding period because this corresponded to 48 to 120 h after PGF$_{2\alpha}$ injection and 24 to 96 h after CIDR withdrawal. These periods were considered typical periods of estrus in response to the treatments that we imposed. Therefore, by analyzing the first 3 d, we could evaluate potentially negative effects of each treatment on conception rate to the synchronized estrus. When the first 7 d of the breeding period were examined (Figures 1, 4, and 7), we found that the bulk of the treated heifers were in estrus within the first 3 d. In retrospect, we could have started the breeding period 1 d earlier because we may have missed some PGF$_{2\alpha}$-treated heifers that were in estrus on the day after PGF$_{2\alpha}$ injection (before estrus detection began). This may have slightly diminished the overall response within the $PGF_{2\alpha}$ group, particularly during the initial 3-d period.

We also employed survival analyses for testing the effects of treatment and cyclic status on the interval to first estrus (and hence, insemination) and the interval to pregnancy. The survival approach is superior to the more common alternative of performing analysis of variance for interval to first estrus and interval to pregnancy. Both approaches were used in the present study, and we found that the survival analyses were more sensitive (i.e., more likely to detect statistical differences). The problem with analyses of variance for these data is that the data set consists of a large number of cattle with extremely short intervals (those cattle that responded to estrus synchronization) and additional cattle whose intervals are spread across the breeding period. The calculated mean interval to estrus and insemination or pregnancy is not representative of the "average" cow in the herd. For example, the average interval to first estrus for CIDR+$PGF_{2\alpha}$-treated cyclic beef cows was 4.2 d, a period when very few cows in this group were actually in estrus. Survival analyses are more appropriate because data are examined across the entire breeding period. In addition, cows that are not seen in estrus or never become pregnant are not omitted from the analyses but instead are considered censored data.

In summary, the use of an estrus synchronization insert containing progesterone (CIDR) for the purposes of synchronizing estrus and advancing the date of pregnancy was evaluated at multiple locations in the United States. The protocol was a 7-d CIDR treatment with a luteolytic dose of $PGF_{2\alpha}$ injected on d 6 of the CIDR treatment. The CIDR increased the percentage of cattle in estrus and pregnant during the initial days of the breeding period. The CIDR+$PGF_{2\alpha}$ treatment was effective in both acyclic and cyclic cattle enrolled in these studies. Use of a CIDR in combination with $PGF_{2\alpha}$ in the way described should be an effective method for estrus synchronization at a variety of locations.

Implications

Estrus synchronization is an important tool for increasing the rate of implementation of artificial insemination in beef and dairy herds. Methods for estrus synchronization should be relatively simple to employ and should be robust so that they can be applied under a variety of management conditions. The CIDR+$PGF_{2\alpha}$ program met these criteria as it was effective at multiple locations in the United States that employed cattle of different genetic backgrounds and management conditions. The efficacy of the CIDR in these studies suggests that the insert will be a reliable option for estrus synchronization in cattle when used in conjunction with an injection of $PGF_{2\alpha}$.

Literature Cited

Ahmad, N., F. N. Schrick, R. L. Butcher, and E. K. Inskeep. 1995. Effect of persistent follicles on early embryonic losses in beef cattle. Biol. Reprod. 52:1129–1135.

Anderson, L. H., and M. L. Day. 1994. Acute progesterone administration regresses persistent dominant follicles and improves fertility of cattle in which estrus was synchronized with melengestrol acetate. J. Anim. Sci. 72:2955–2961.

Anderson, L. H., C. M. McDowell, and M. L. Day. 1996. Progestin-induced puberty and secretion of luteinizing hormone in heifers. Biol. Reprod. 54:1025–1031.

Chenault, J. R., J. F. McAllister, and C. W. Kasson. 1990. Synchronization of estrus with melengestrol acetate and prostaglandin $F_{2\alpha}$ in beef and dairy heifers. J. Anim. Sci. 68:296–303.

Fike, K. E., M. L. Day, E. K. Inskeep, J. E. Kinder, P. E. Lewis, R. E. Short, and H. D. Hafs. 1997. Estrus and luteal function in suckled beef cows that were anestrus when treated with an intravaginal device containing progesterone with or without a subsequent injection of estradiol benzoate. J. Anim. Sci. 75:2009–2015.

Fike, K. E., M. E. Wehrman, B. R. Lindsey, E. G. Bergfeld, E. J. Melvin, J. A. Quintal, E. L. Zanella, F. N. Kojima, and J. E. Kinder. 1999. Estrus synchronization of beef cattle with a combination of melengestrol acetate and an injection of progesterone and 17β-estradiol. J. Anim. Sci. 77:715–723.

Imwalle, D. B., D. J. Patterson, and K. K. Schillo. 1998. Effects of melengestrol acetate on onset of puberty, follicular growth, and patterns of luteinizing hormone secretion in beef heifers. Biol. Reprod. 58:1432–1436.

Larson, L. L., and P. J. H. Ball. 1992. Regulation of estrous cycles in dairy cattle: a review. Theriogenology 38:255–267.

Lauderdale, J. W. 1972. Effects of $PGF_{2\alpha}$ injection on pregnancy and estrous cycle of cattle. J. Anim. Sci. 35(Suppl. 1):246 (Abstr.).

Lauderdale, J. W., B. E. Seguin, J. N. Stellflug, J. R. Chenault, W. W. Thatcher, C. K. Vincent, and A. F. Loyancano. 1974. Fertility of cattle following $PGF_{2\alpha}$ injection. J. Anim. Sci. 38:964–967.

Macmillan, K. L., and A. J. Peterson. 1993. A new intravaginal progesterone releasing device for cattle (CIDR-B) for oestrous synchronization, increasing pregnancy rates, and the treatment of postpartum anestrus. Anim. Reprod. Sci. 33:1–25.

Odde, K. G. 1990. A review of synchronization of estrus in postpartum cattle. J. Anim. Sci. 68:817–830.

Patterson, D. J., G. H. Kiracofe, J. S. Stevenson, and L. R. Corah. 1989. Control of the bovine estrous cycle with melengestrol acetate (MGA): a review. J. Anim. Sci. 67:1895–1906.

Patterson, D. J., R. C. Perry, G. H. Kiracofe, R. A. Bellows, R. B. Staigmiller, and L. R. Corah. 1992. Management considerations in heifer development and puberty. J. Anim. Sci. 70:4018–4035.

Revah, I., and W. R. Butler. 1996. Prolonged dominance of follicles and reduced viability of bovine oocytes. J. Reprod. Fertil. 106:39–47.

Roche, J. F. 1974. Synchronization of oestrus and fertility following artificial insemination in heifers given prostaglandin $F_{2\alpha}$. J. Reprod. Fertil. 37:135–138.

Roche, J. F., E. J. Austin, M. Ryan, M. O'Rourke, M. Mihm, and M. G. Diskin. 1999. Regulation of follicle waves to maximize fertility in cattle. J. Reprod. Fertil. Suppl. 54:61–71.

Schillo, K. K., J. B. Hall, and S. M. Hileman. 1992. Effects of nutrition and season on the onset of puberty in the beef heifer. J. Anim. Sci. 70:3994–4005.

Short, R. E., R. A. Bellows, R. B. Staigmiller, J. G. Berardinelli, and E. E. Custer. 1990. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. J. Anim. Sci. 68:799–816.