Proceedings, Applied Reproductive Strategies in Beef Cattle
October 3 and 4, 2006, Rapid City, South Dakota

FACTORS THAT INFLUENCE FERTILITY IN NATURAL AND SYNCHRONIZED BREEDING PROGRAMS

George Perry
South Dakota State University, Brookings, South Dakota

Introduction

Reproductive failure is a major source of economic loss in the beef industry. The majority of this loss occurs because cows do not become pregnant during a defined breeding season. Therefore, the goal of any breeding program is to maximize the number of females that become pregnant. This means that fertility plays a major role in the success of any breeding program. This review will focus on the factors that affect pregnancy rates over specific days of the breeding season in both natural service and synchronized breeding programs. Since pregnancy rates are a product of both estrous detection rates and conception rates, comparisons will be made between synchronized and non-synchronized cows bred by natural service or by artificial insemination.

Artificial insemination provides a method to inseminate a large number of females to a single sire that has been selected/proven to be an industry leader for economically relevant traits. Thus, genetic change in a herd can occur quickly through the use of artificial insemination. With natural service, herd bulls are also selected for economically relevant traits but are limited on the number of cows/heifers they can service during the breeding season. During the breeding season, a herd bull's job is to detect cows/heifers in standing estrus and breed them at the appropriate time. For successful artificial insemination of cattle to occur, the producer (herd manager) must take the place of the herd bull in detecting the cows/heifers that are ready to be inseminated.

Synchronizing estrus is an effective way to minimize the time and labor required to detect standing estrus in cattle that are going to be artificially inseminated. However, estrous synchronization can also benefit overall herd management. Cows that respond and conceive to a synchronized estrus have the following advantages: 1) exhibit standing estrus at a predicted time, 2) conceive earlier in the breeding season, 3) calve earlier in the calving season, and 4) wean calves that are older and heavier at weaning. In addition, some estrous synchronization protocols (progestin-based protocols) can induce a proportion of anestrous cows to begin estrous cycles. This will decrease the anestrous postpartum interval and allow for more chances for cows to conceive during a defined breeding season. A study conducted at Colorado State University indicated cows that conceived to a synchronized estrus calved on average 13 days earlier and weaned calves 41 pounds heavier than cows that were not synchronized (Schafer et al., 1990).

Estrous synchronization simply implies the estrous cycles of a group of heifers/cows are manipulated to cause them to exhibit standing estrus around the same time. However, the question is often asked, "Do estrous synchronization protocols increase or decrease fertility?" To answer this question, fertility must be compared between non-synchronized and synchronized females bred by natural service or artificial insemination.

Fertility of Synchronized and Non-synchronized Females

Natural Service

Nonsynchronized females: When cows are bred by natural service, the time required to detect estrus is not a concern since the bull will be detecting the cows that exhibit standing estrus, but the serving capacity of the bull becomes a critical management consideration. Recommendations for the bull to female ratio in nonsynchronized cows ranges from 1:10 to 1:60. This range depends on the age, experience, and semen quality of the bull, and size and terrain of the breeding pasture. No differences were detected between a bull to female ratio of 1:25 and 1:60 for estrous detection or pregnancy rates in the first 21 days of the breeding season provided the bulls were highly fertile and had large scrotal circumferences (Rupp et al., 1977).

Synchronized females: When cows are synchronized and bred by natural service, management considerations should be made for the serving capacity of the bull. Healy et al., (1993) reported a tendency ($P < 0.10$) for pregnancy rates over a 28-day synchronized breeding season to be reduced when a bull to female ratio of 1:50 (77%) was used compared to a bull to female ratio of 1:16 (84%); however, no difference was detected between a bull to female ratio of 1:16 and 1:25 (84% and 83%, respectively). In the following studies, a bull to female ratio of up to 1:25 was used.

A single injection of prostaglandin $F_{2\alpha}$ (**PG**) on day 4 of the breeding season (bulls introduced on day 1) resulted in more cycling cows becoming pregnant during days 5 to 9 of the breeding season compared to cycling cows not injected with PG (55.7 vs. 25.0%, respectively; Whittier et al., 1991). In addition, pregnancy rates were similar ($P > 0.10$) for cows in which estrus was synchronized with a single injection of PG and exposed to a bull for 80 hours (19%) compared to non-synchronized cows exposed to a bull for 21 days (33%; Landivar et al., 1985). When cows were synchronized with a single injection of PG on day 4 of the breeding season, there were no differences in pregnancy rates over the first 25 days of the breeding season (1 cycle) between synchronized and non-synchronized cows (Whittier et al., 1991). Therefore, the greatest benefit of estrous synchronization (PG) with natural service is the ability to get more cows pregnant during the first 5 to 7 days of the breeding season (**Table 1**). Cows that exhibit estrus early in the breeding season will also have additional chances to conceive during a defined breeding season. The average estrous cycle is 21 days (range 18 to 23 days), allowing one chance every 21 days for a cow to conceive. During a 65-day breeding season, cows that cycle naturally have only three chances to conceive, but cows that are synchronized and show estrus the first few days of the breeding season have up to four chances to conceive.

Table 1. Comparison between synchronized and non-synchronized pregnancy rates when bred by natural service in cows and heifers

Study	Cows/ Heifers	Period of Time	Synchronization Method	Pregnancy Rate Anestrual	Pregnancy Rate Estrual
				Unknown	
(Whittier et al., 1991)	Cows	4 days	1 shot PG	13.6%	55.7%[a]
			Not synchronized	22.7%	25.0%[b]
(Plugge et al., 1989)	Heifers	7 days	MGA + PG	62%[a]	
			Syncro-Mate B	67%[a]	
			Not synchronized	23%[b]	
Lamb et al., 2006	Cows	10 days	CIDR	43%[a]	
			Not synchronized	35%[c]	
(Landivar et al., 1985)	Cows	80 hours	1 shot PG	19%	
		21 days	Not synchronized	33%	
(Whittier et al., 1991)	Cows	25 days	1 shot PG	59.1%	86.1%
			Not synchronized	59.1%	76.3%
Lamb et al., 2006	Cows	30 days	CIDR	64.4%	
			Not synchronized	64.7%	

Pregnancy rates within a study and estrous cycling status having different superscripts are different [ab]$P < 0.01$; [ac] $P < 0.05$

Some estrous synchronization protocols that utilize progesterone (CIDR), norgestomet (Syncro-Mate B), or GnRH can initiate estrous cycles resulting in a shorter anestrous postpartum period or earlier onset of puberty (Yavas and Walton, 2000a; Lucy et al., 2001; Perry et al., 2004a). In a small study, peripubertal heifers treated with melengestrol acetate (**MGA**, an orally active progestin) for 10 days resulted and a similar number of MGA treated heifers and control heifers attaining puberty by day 7 after MGA withdrawal, but by day 10 following MGA treatment, 50% more of the treated heifers attained puberty compared to the control animals (Imwalle et al., 1998). Synchronization with a progestin [norgestomet (Syncro-Mate B) or MGA] resulted in more ($P < 0.01$) heifers becoming pregnant (67% and 62%) during the first 7 days of the breeding season compared to non-synchronized heifers (23%, Plugge et al., 1989), furthermore, when a CIDR was inserted 7 days before the start of the breeding season and removed the day the bull was introduced (no injections) more ($P < 0.05$; 43%) CIDR treated cows became pregnant by day 10 compared to non-synchronized cows (35%; Lamb et al., 2006). However, when a single injection of PG was administered to a group of anestrous cows, no difference was detected between synchronized and non-synchronized cows (13.6% and 22.7%, respectively, Whittier et al., 1991). Therefore, estrous synchronization protocols capable of inducing puberty and shortening the anestrous postpartum period can result in an even greater percentage of cows having a chance to become pregnant during the first few days of the breeding season.

Artificial Insemination

Artificial insemination (**AI**) with semen collected from genetically superior sires is the most efficient and economical method for the genetic improvement of economically important traits in the beef industry. Estrous synchronization makes AI more feasible due to the reduction in time and labor required for estrous detection. Therefore, it is also necessary to compare fertility between synchronized and non-synchronized females bred by AI (**Tables 2 and 3**). When AI is combined with estrous synchronization, the limitation on serving capacity of a single bull is removed, and a large number of females can be bred to a single sire during the first few days of the breeding season. This can result in a more uniform calf crop that is older and heavier at weaning.

Table 2. Comparison between synchronized and non-synchronized pregnancy rates when bred by artificial insemination during the synchronized period

Study	Cows/ Heifers	Period of Time	Synchronization Method	Pregnancy Rate: Anestrual	Pregnancy Rate: Estrual	Pregnancy Rate: Unknown
(Lucy et al., 2001)	Cows	3 days	1 shot PG	11%[b]	34%[c]	
			Progesterone + PG	26%[a]	46%[b]	
			Not synchronized	4%[c]	11%[a]	
(Lucy et al., 2001)	Heifers	3 days	1 shot PG	6%[b]	19%[b]	
			Progesterone + PG	28%[a]	49%[a]	
			Not synchronized	6%[b]	9%[c]	
(Landivar et al., 1985)	Cows	80 hours	1 shot PG			19%
		21 days	Not synchronized			30%
(Heersche et al., 1979)	Heifers	5 days	Norgestomet + PG			60%
		21 days	Not synchronized			61%
(Beal et al., 1988)	Cows/ Heifers	7 days	MGA-PG		40%[a]	
			Not synchronized		24%[b]	
(Beal, 1983)	Cows	5 days	2 shots PG			28%[ab]
			Progesterone + PG			49%[a]
			Not synchronized			10%[c]
(Miksch et al., 1978)	Heifers	5 days	Syncro-Mate B			36%[b]
			Not synchronized			17%[c]
(Miksch et al., 1978)	Heifers	5 days	Syncro-Mate B			39%
			Not synchronized			28%
(Miksch et al., 1978)	Cows	5 days	Syncro-Mate B	48%[a]	64%[a]	
			Not synchronized	8%[b]	20%[b]	
(King et al., 1988)	Cows	5 days	Syncro-Mate B			50%[a]
			Not synchronized			16%[b]

Pregnancy rates within a study and estrous cycling status having different superscripts are different $^{ab;\ ac}P < 0.01$ $^{bc}P < 0.05$

Table 3. Comparison between synchronized and non-synchronized pregnancy rates when bred by artificial insemination during the first cycle of the breeding season

Study	Cows/ Heifers	Period of Time	Synchronization Method	Pregnancy Rate	
				Anestrual	Estrual
(Lucy et al., 2001)	Cows	31 days	1 shot PG	47%	65%[a]
			Progesterone + PG	46%	71%[a]
			Not synchronized	42%	58%[c]
(Lucy et al., 2001)	Heifers	31 days	1 shot PG	25%[b]	56%[c]
			Progesterone + PG	50%[a]	69%[a]
			Not synchronized	31%[b]	64%[c]
(Beal et al., 1988)	Cows/ Heifers	30 days	MGA-PG		72%
			Not synchronized		69%
(Beal, 1983)	Cows	24 days	2 shots PG	52%	
			Progesterone	53%	
			Not synchronized	56%	
(Miksch et al., 1978)	Heifers	27 days	Syncro-Mate B	64%	
			Not synchronized	62%	
(Miksch et al., 1978)	Heifers	27 days	Syncro-Mate B	74%	
			Not synchronized	67%	
(Miksch et al., 1978)	Cows	21 days	Syncro-Mate B	67%	79%
			Not synchronized	45%	76%
(King et al., 1988)	Cows	21 days	Syncro-Mate B	67%[a]	
			Not synchronized	56%[c]	
(King et al., 1988)	Cows	25 days	Syncro-Mate B	75%[a]	
			Not synchronized	61%[b]	

Pregnancy rates within a study and estrous cycling status having different superscripts are different [ab]$P < 0.01$; [ac]$P < 0.05$

Cows synchronized with a single injection of PG and artificially inseminated for an 80-hour period had similar ($P > 0.10$) pregnancy rates (19%) compared to cows artificially inseminated for a 21-day period (30%; Landivar et al., 1985). However, when fertility is compared over the synchronized period, a single injection of PG 2 days before the start of the AI breeding season resulted in more ($P < 0.01$) cows pregnant during the first 3 days of the breeding season (22%) compared to non-synchronized females (7%, Lucy et al., 2001). Furthermore, cows synchronized with two injections of PG 11 days apart also resulted in more ($P < 0.01$) cows pregnant (28%) during the first 5 days of the breeding season compared to non-synchronized cows (10%, Beal, 1983).

When estrous synchronization protocols are used that will initiate estrous cycles [progesterone (CIDR), norgestomet (Syncro-mate-B), and GnRH protocols], an even greater benefit can be realized. Cows treated with a CIDR for 7 days before the start of the breeding season and an injection of PG at time of CIDR removal resulted in 26% of anestrous and 46% of estrous-cycling cows becoming pregnant during the first 3 days of the breeding season compared to only 4% of anestrous and 11% of estrous-cycling control cows (Lucy et al., 2001). Cows synchronized with Syncro-Mate B (**SMB**) resulted in more cycling and anestrous cows pregnant ($P < 0.01$; 64% and 48%, respectively) during the first 5 days of the breeding season compared to cycling and anestrous non-synchronized cows (20% and 8%, respectively, Miksch et al., 1978). Furthermore, when heifers were synchronized with SMB, a greater ($P < 0.05$) percentage became pregnant (36%) during the first 5 days of the breeding season compared to non-synchronized heifers (17%, Miksch et al., 1978). Estrous synchronization protocols that utilize GnRH are also able to initiate estrous cycles in anestrous cows. When a GnRH-based protocol (Ovsynch; 100 μg GnRH, i.m. on d -9; 25 mg PG, i.m. on d -2; 100 μg GnRH, i.m. on d 0 and timed AI on day 1) was compared to SMB with timed-AI, similar pregnancy rates were obtained ($P > 0.10$) by both protocols among anestrous cows (43% and 49%, respectively, Geary et al., 1998). Therefore, estrous synchronization protocols capable of inducing puberty and shortening the anestrous postpartum period can result in anestrous cows having a chance to become pregnant during the first few days of the breeding season and more opportunities to conceive during the breeding season.

Initiation of Estrous Cycles

The anestrous postpartum interval is a major contributing factor to cows failing to become pregnant and calving on a yearly interval (Short et al., 1990; Yavas and Walton, 2000b). However, treatment with some progestins can induce ovulation in anestrous postpartum cows (Yavas and Walton, 2000a; Lucy et al., 2001; Perry et al., 2004a), thereby shortening the anestrous postpartum interval. Consequently, many estrous synchronization protocols include progestin exposure. However, all progestins are not equally effective at inducing the initiation of estrous cycles in anestrous postpartum cows. Evidence for this difference is based on differences in the ability of progesterone (CIDR) and MGA to induce ovulation in anestrous cows (**Figure 1**). Fewer anestrous cows treated with MGA (0.5 mg MGA•cow^{-1}•d^{-1} for 7 days) ovulated compared to progesterone-treated [1.9 g of progesterone contained in a controlled internal drug releasing device (**CIDR**) for 6 days] cows (33% and 91%, respectively, Perry et al., 2004a), and fewer anestrous cows that spontaneously initiated estrous cycles (23%) or MGA-treated anestrous cows (46%) exhibited normal length luteal phases compared to progesterone-treated cows (100% and 100%, Smith et al., 1987; Perry et al., 2004a). However, by day 22 after treatment withdrawal there was no difference ($P > 0.05$) between the percentage of CIDR treated cows that had ovulated (91%) and the percentage of MGA-treated cows that had ovulated (61%, Figure 1, Perry et al., 2004a). These data indicate that following a CIDR protocol (progesterone exposure) a large percentage of cows should exhibit estrus, and following an MGA protocol (14 day of MGA and an injection of PG on day 33) an equally large percentage of cows should exhibit estrus. For example, when heifers were synchronized by progestin exposure (MGA or norgestomet), more heifers became pregnant ($P < 0.01$, MGA 62% and SMB 67%) during the first 7 days of the breeding season compared to non-synchronized heifers (23%), but there was no difference between MGA and norgestomet in the percentage of heifers pregnant during the first 7 days of the breeding season (Plugge et al., 1989). Furthermore, when a group of cycling cows and heifers were synchronized with a 7-day MGA protocol (MGA-PG), pregnancy rates after 7 days (40%) of artificial insemination were greater in synchronized animals compared to non-synchronized animals (24%, Beal et al., 1988).

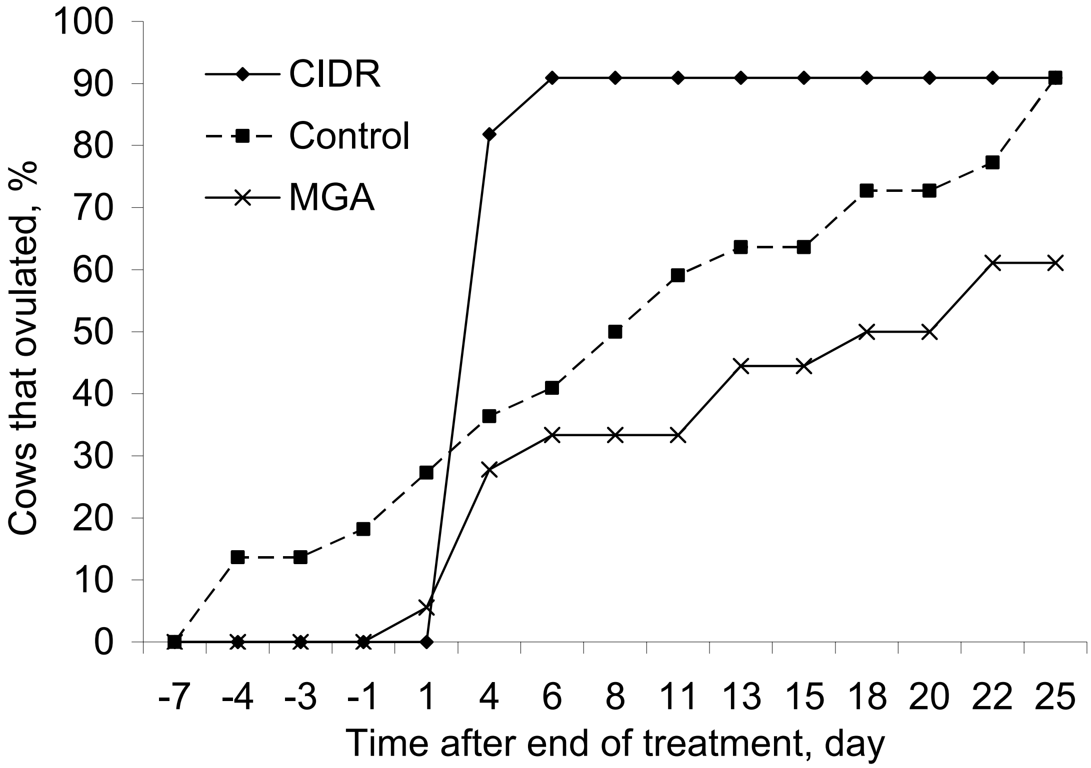

Figure 1. Effect of treatment on the cumulative percent of animals that had ovulated (ovulation is shown as having occurred 4 days before the first day. Circulating concentrations of progesterone were > 1 ng/mL) by day of treatment (day 0 = last day of feeding melengestrol acetate [MGA], and day of controlled internal drug-releasing device [CIDR] removal). Control animals received no treatment. Treatment $P < 0.01$; Day $P < 0.01$; Treatment x Day $P < 0.01$. (Perry et al., 2004a)

Estrous Detection

When pregnancy rates from 13,942 first service artificial inseminations were compared to 6,310 first services by natural service, no difference ($P > 0.10$) was detected between artificial insemination and natural service (Williamson et al., 1978). Furthermore, no differences were detected between synchronized pregnancy rates when cows were bred by AI or natural service (Plugge et al., 1989). However, for successful artificial insemination of cattle to occur, the producer (herd manager) must take the place of the herd bull in detecting the cows/heifers ready to be inseminated. Detecting standing estrus (also referred to as heat detection or detecting standing heat) is simply looking for the changes in animal behavior associated with a cow/heifer standing to be mounted by a bull or another cow/heifer. Accurate detection of animals in standing estrus is the goal of good estrous detection and plays a vital role in the success of any artificial insemination program. In a study conducted at Colorado State University, animals were administered an estrous synchronization protocol, then monitored for standing estrus 24 hours a day or twice a day for 30 minutes. By day 5 after estrous synchronization, 95% of animals monitored 24 hours a day were detected in standing estrous, while only 56% of animals observed twice a day for 30 minutes were detected in standing estrus (Downing et al., 1998). With a 95% estrous detection rate and a 70% conception rate (95% X 70% = 67%), 67% of the animals will be pregnant; whereas, only a 39% (55% X 70% = 39%) pregnancy rate will occur with a 55% estrus detection rate (**Table 4**).

Table 4. Effect of estrous detection rate on increasing pregnancy rate

Estrous Detection Rate	**55%**	**60%**	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**	**95%**
Conception Rate	70%	70%	70%	70%	70%	70%	70%	70%	70%
Pregnancy Rate	**39%**	**42%**	**46%**	**49%**	**53%**	**56%**	**60%**	**63%**	**67%**

The success of any artificial insemination program requires detecting the animals that are ready to be bred (standing estrus) and inseminating them at the correct time. Failing to detect estrus and mis-detection of estrus can result in significant economic losses (Heersche and Nebel, 1994). Accurate estrus detection can be a difficult and time-consuming activity. When estrus was detected in 500 Angus cows with Heat Watch estrus-detection aids (24 hour a day estrus detection), the length of estrus averaged 10 hours (ranged from 0.5 hours to 24 hours), and 26% of cows exhibited estrus for less than 7 hours and had fewer than 1.5 mounts per hour (Rorie et al., 2002).

To maximize detection of standing estrus, it is extremely important to visually monitor cattle as much as possible. Observations should occur as early and as late as possible as well as during the middle of the day. Continuous observation of over 500 animals exhibiting natural estrus in 3 separate studies indicated 55.9% of cows initiated standing estrus from 6 p.m. to 6 a.m. (**Table 5**). Furthermore, when cows were observed for standing estrus every 6 hours (6 a.m., noon, 6 p.m., and midnight), estrous detection increased by 10% with the addition of a mid-day observation and by 19% when observed four times daily (every 6 hours) compared to detecting standing estrus at 6 a.m. and 6 p.m. alone (Hall et al., 1959). Therefore, detection of standing estrus can be one of the most time-consuming chores related to artificial insemination. Several estrous detection aids have been developed to assist with this time-consuming chore. These estrus-detection aids can effectively determine which cows are or have been in standing estrus, therefore relieving some of the time required to visually observe cattle for standing estrus. A comparison between visual estrus detection every 3 hours (8 times daily), a marker animal, and Estrus Alert patches resulted in a similar ($P > 0.79$) percentage of animals correctly identified in standing estrus (92%, 92%, and 91%, respectively; Perry, 2005). However, increased visual observation, in addition to the use of estrous-detection aids, could improve fertility by detecting the most possible number of animals ready to be inseminated and the most appropriate time for insemination.

Table 5. Time of day when cows exhibit standing estrus

Time of day	Cows exhibiting standing estrus
6 a.m. to 12 noon	26.0 %
12 noon to 6 p.m.	18.1 %
6 p.m. to midnight	26.9 %
Midnight to 6 a.m.	29.0 %

Data adapted from (Hurnik and King, 1987; Xu et al., 1998, G.A. Perry unpublished data).

Fixed-Time Insemination

To expand the use of artificial insemination and increase the adoption rate of other emerging reproductive technologies, precise methods of controlling ovulation must be developed. Numerous studies have been conducted to induce ovulation in cattle at a specific time, thereby eliminating the time and labor required to detect estrus. Methods of inseminating cattle at a fixed-time with consistently high pregnancy rates may be a reality in the near future. Stevenson et al. (2000) reported higher pregnancy rates ($P < 0.05$) for cattle artificially inseminated following detection of standing estrus (44%; Select Synch - GnRH on day -9, PG on day -2 and detect estrus) compared to cattle bred by timed AI (33%; CO-Synch – Select Synch with timed insemination and a second injection of GnRH on day 0). However, Lemaster et al., (2001) reported higher ($P < 0.05$) pregnancy rates for timed AI following the CO-Synch protocol (31%) compared to AI following estrus detection with the Select Synch protocol (21%).

Currently, most fixed-time insemination protocols (ovulation synchronization protocols) utilize GnRH to ovulate a dominant follicle around the time of insemination. The Ovsynch (Pursley et al., 1998) and CO-Synch (Geary and Whittier, 1998) protocols include the same hormonal treatments to synchronize ovulation [on day -9, GnRH is administered, on day -2, PG is administered, and 48 hours later (day 0) GnRH is administered to induce ovulation around the time of insemination]. The MGA-select timed-AI protocol (MGA is fed for 14 days, on day 26 GnRH is administered, on day 33 PG is administered, and 72 hours later GnRH is administered to induce ovulation around the time of insemination, Perry et al., 2002b) also utilizes GnRH to induce ovulation around the time of insemination. The use of GnRH at the time of insemination resulted in a wide range of follicle sizes being induced to ovulate (Perry et al., 2005), and although dominant bovine follicles (≥ 10 mm) have the ability to ovulate in response to a GnRH-induced gonadotropin surge, a larger dose of LH was required to induce ovulation of a 10 mm follicle compared to larger follicles (Sartori et al., 2001).

A decrease in pregnancy rates occurred when small follicles were induced to ovulate following fixed-time AI in both heifers and cows (CIDR Protocol – Lamb et al., 2001 T.W. Geary unpublished data; CO-Synch protocol – Perry et al., 2004b; Perry et al., 2005; **Figure 2**). In addition, when the length of proestrus was varied to induce ovulation of small (< 12 mm) or large (≥ 12 mm) follicles, pregnancy rates were decreased in animals induced to ovulate small follicles compared to animals induced to ovulate large follicles (Mussard et al., 2003). The ovulatory follicle may affect fertility through the preparation of the oocyte for embryonic development, preparation of follicular cells for luteinization, and/or preparation of the uterine environment for the establishment and maintenance of pregnancy. However, when embryos of similar quality were transferred into cows induced to ovulate small (< 12 mm) or large (> 12 mm) follicles, cows induced to ovulate small follicles had significantly lower pregnancy rates compared to cows induced to ovulate large follicles (Mussard et al., 2003). The preceding study indicates the uterine environment is likely a major factor in decreased fertility following induced ovulation of small dominant follicles.

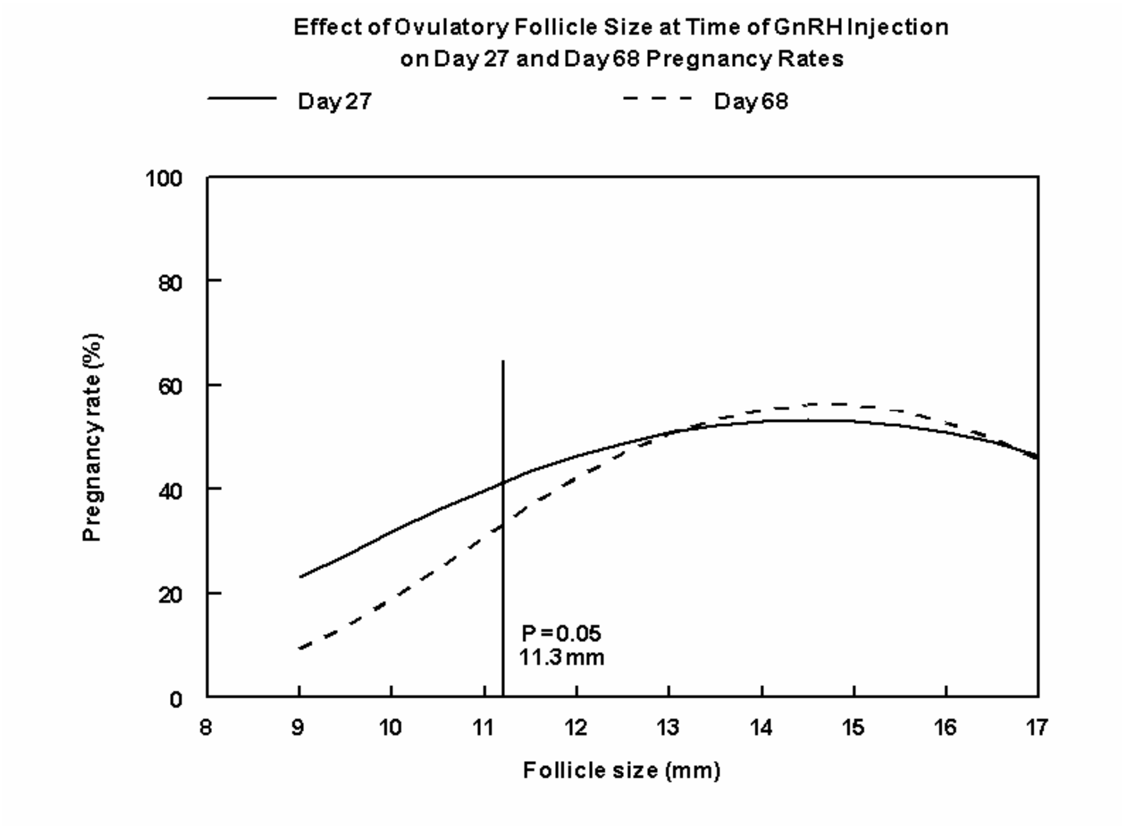

Figure 2. Regression analysis of the effect of ovulatory follicle size at time of GnRH injection/insemination on pregnancy rates 27 and 68 days after insemination. Follicle sizes at which pregnancy rates were decreased ($P < 0.05$) below the maximal pregnancy rates are indicated with vertical lines. (Perry et al., 2005)

Variation does exist in the proportion of animals induced to ovulate small follicles by different fixed-time insemination protocols. Following the CO-Synch protocol, 30% of cows and 52% of heifers (G.A. Perry unpublished data) were induced to ovulate follicles < 11.5 mm in diameter. However, when fixed-timed AI was performed in cows with or without a CIDR from day -9 to -2 [on day -9, GnRH was administered, on day -2, PG was administered, and 48 hours later (day 0) GnRH was administered and animals were inseminated], the percentage of cows that ovulated follicles < 11.5 mm was 7% for CIDR-treated cows and 15% for cows not receiving a CIDR (T.W. Geary unpublished data). Therefore, different timed-insemination protocols are more effective at reducing the percentage of small follicles induced to ovulate. However, regardless of synchronization protocol, reduced fertility does appear to occur whenever small follicles are induced to ovulate.

Furthermore, pregnancy rates were increased when animals were detected in standing estrus within 24 hours of fixed-time insemination regardless of follicle size induced to ovulate (Perry et al., 2004; Perry et al., 2005). Cows that initiate standing estrus around the time of fixed-time insemination had elevated preovulatory concentrations of estradiol compared to cows that do not exhibit standing estrus and similar concentrations to cows that spontaneously initiate estrus and ovulation (Perry and Busch, 2005). Efficient transportation of sperm through the female reproductive tract requires that the female be in estrus or under the influence of estrogen (Hawk, 1983). In a recent review by Santos et al., (2004) fertilization failure in lactating beef cows ranged from 0 to 25% and in lactating dairy cows from 12 to 45%. Estrogen may influence fertilization rates through both sperm transport and fertilization efficiency by altering the uterine environment around the time of fertilization. Uterine pH decreased at the initiation of standing estrus (Elrod and Butler, 1993) to a pH similar to seminal plasma (Acott and Carr, 1984). Furthermore, uterine pH was decreased in animals that exhibited standing estrus at the time of fixed-time AI compared to animals not in standing estrus (Perry and Perry, 2006; Nelson et al., 2006).

During final maturation, sperm lose their ability to biosynthesize, repair, grow, and divide, and become very simple in their metabolic function (Hammerstedt, 1993). This results in sperm becoming completely dependent on their external environment. While in the epididymis, sperm are stored for a long period of time in a relatively quiescent state, but upon ejaculation or dilution of caudal epididymis fluid, motility is increased (Acott and Carr, 1984; Carr and Acott, 1984). However, a consequence of the increased motility is a reduction in viability from several weeks to only several hours in the female tract (Austin, 1975). Medium pH influenced the motility of sperm collected from the caudal epididymis (Acott and Carr, 1984). Goltz et al., (1988) showed the motility of demembraned bull sperm increased as the pH of medium was raised from 6.6 to 7.1. An increase in sperm motility above basal levels appears to be necessary to assist the sperm in penetrating the viscous oviductal mucus and the cumulus matrix that surrounds the oocyte (Suarez and Dai, 1992) as well as the oocyte so fertilization can occur (Stauss et al., 1995). Therefore, changes in uterine pH from initiation of standing estrus (low pH) until ovulation may play a vital role in fertilization.

Following fertilization, luteal secretion of progesterone during the subsequent estrous cycle is required for the survival of the embryo/fetus (McDonald et al., 1952), and has been associated with fertility in cattle by stimulating both uterine secretions (Geisert et al., 1992) and embryonic growth and development (Garrett et al., 1988; Mann et al., 1996). Uterine secretions including nutrients, growth factors, immunosuppressive agents, enzymes, ions, and steroids contribute to early conceptus growth/survival (Geisert et al., 1992; Gray et al., 2001). Cows with normal developing embryos had higher concentrations of progesterone on days 3 and 6 after insemination compared to cows with degenerating embryos (Maurer and Echternkemp, 1982). Following timed-AI protocols, serum concentrations of progesterone were affected ($P < 0.04$) by the size of the dominant follicle induced to ovulate (**Figure 3**). More specifically, the rise of progesterone following GnRH-induced ovulation was decreased ($P < 0.01$) in cows that ovulated ≤ 12 mm follicles compared to cows that ovulated larger follicles. Furthermore, cows induced to ovulate ≤ 12 mm follicles had decreased ($P < 0.05$) pregnancy rates compared to cows induced to ovulate larger follicles (29% vs. 71%, respectively, Perry et al., 2002a).

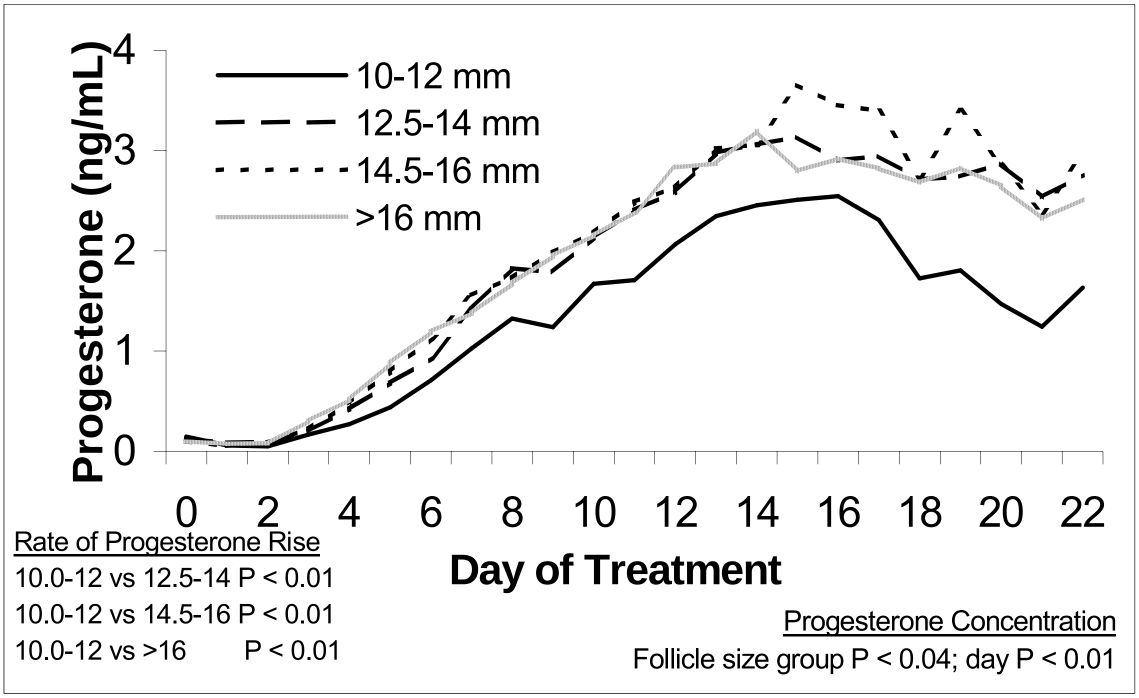

Figure 3. Effect of ovulatory follicle size, across both anestrous and cycling cows, on mean serum concentrations of progesterone from day 0 (second GnRH injection) through day 22, and rate of progesterone increase from day 0 to peak progesterone concentration. (Perry et al., 2005)

Implications

Synchronizing estrus in cows and heifers is an effective way to maximize the use of time and labor required to detect standing estrus in cattle. In addition, by using estrous synchronization, more cows can conceive and become pregnant early in the breeding season with no decrease in fertility. Some estrous synchronization protocols can even induce estrous cycles and shorten the anestrous postpartum period allowing cows to conceive earlier in the breeding season. However, when estrous synchronization is used together with artificial insemination, one of the largest factors that influences fertility is efficiency and accuracy of estrous detection. With fixed-timed insemination protocols, fertility can be reduced in a proportion of animals (cows induced to ovulate follicles < 11.5 mm). However, if the appropriate amount of time and effort cannot be spent detecting estrus, fixed timed-insemination protocols may result in overall greater pregnancy rates.

In conclusion, when fertility is defined as the percentage of cows that conceive in the first few days of the breeding season, synchronized cows will have increased fertility compared to non-synchronized cows. When fertility is defined as the percentage of cows that conceive during the first cycle (first 21 to 25 days) of the breeding season, estrous synchronized females will have similar or better fertility than non-synchronized females depending on the percent of animals that are anestrous or prepubertal and the synchronization protocol used. Therefore, estrous synchronization can be a tremendous management tool to get more cows pregnant early in the breeding season with no decrease in fertility.

Literature Cited

Acott, T. S., and D. W. Carr. 1984. Inhibition of bovine spermatozoa by caudal epididymal fluid: Ii. Interaction of ph and a quiescence factor. Biol. Reprod. 30:926-935.

Austin, C. R. 1975. Sperm fertility, viability and persistence in the female tract. J. Reprod. Fertil. Suppl.:75-89.

Beal, W. E. 1983. A note on synchronization of oestrous in post-partum cows with a prostaglandin f2α and progesterone-releasing device. Anim. Prod. 37:305-308.

Beal, W. E., J. R. Chenault, M. L. Day, and L. R. Corah. 1988. Variation in conception rates following synchronization of estrus with melengestrol acetate and prostaglandin f2 alpha. J. Anim. Sci. 66:599-602.

Carr, D. W., and T. S. Acott. 1984. Inhibition of bovine spermatozoa by caudal epididymal fluid: I. Studies of a sperm motility quiescence factor. Biol. Reprod. 30:913-925.

Downing, E. R., D. Schutz, D. Couch, D. G. LeFever, J. C. Whittier, and T. W. Geary. 1998. Methods of estrous detection to increase pregnancies using the select synch protocol., Colorado State University Beef Program Report 175-179.

Elrod, C. C., and W. R. Butler. 1993. Reduction of fertility and alteration of uterine ph in heifers fed excess ruminally degradable protein. J. Anim. Sci. 71:694-701.

Garrett, J. E., R. D. Geisert, M. T. Zavy, and G. L. Morgan. 1988. Evidence for maternal regulation of early conceptus growth and development in beef cattle. J. Reprod. Fertil. 84:437-446.

Geary, T. W., and J. C. Whittier. 1998. Effects of a timed insemination following synchronization of ovulation using the Ovsynch or CO-Synch protocol in beef cows. Prof. Anim. Sci. 14:217-220.

Geary, T. W., J. C. Whittier, E. R. Downing, D. G. LeFever, R. W. Silcox, M. D. Holland, T. M. Nett, and G. D. Niswender. 1998. Pregnancy rates of postpartum beef cows that were synchronized using Syncro-Mate-B or the Ovsynch protocol. J. Anim. Sci. 76:1523-1527.

Geisert, R. D., G. L. Morgan, E. C. Short, Jr., and M. T. Zavy. 1992. Endocrine events associated with endometrial function and conceptus development in cattle. Reprod. Fertil. Dev. 4:301-305.

Goltz, J. S., T. K. Gardner, K. S. Kanous, and C. B. Lindemann. 1988. The interaction of ph and cyclic adenosine 3',5'-monophosphate on activation of motility in triton x-100 extracted bull sperm. Biol. Reprod. 39:1129-1136.

Gray, C. A., K. M. Taylor, W. S. Ramsey, J. R. Hill, F. W. Bazer, F. F. Bartol, and T. E. Spencer. 2001. Endometrial glands are required for preimplantation conceptus elongation and survival. Biol. Reprod. 64:1608-1613.

Hall, J. G., C. Branton, and E. J. Stone. 1959. Estrus, estrous cycles, ovulation time, time of service, and fertility of dairy cattle in Louisiana. J. Dairy Sci. 42:1086-1094.

Hammerstedt, R. H. 1993. Maintenance of bioenergetic balance in sperm and prevention of lipid peroxidation: A review of the effect on design of storage preservation systems. Reprod. Fertil. Dev. 5:675-690.

Hawk, H. W. 1983. Sperm survival and transport in the female reproductive tract. J. Dairy Sci. 66:2645-2660.

Healy, V. M., G. W. Boyd, P. H. Gutierrez, R. G. Mortimer, and J. R. Piotrowski. 1993. Investigating optimal bull:Heifer ratios required for estrus-synchronized heifers. J. Anim. Sci. 71:291-297.

Heersche, G., Jr., and R. L. Nebel. 1994. Measuring efficiency and accuracy of detection of estrus. J. Dairy Sci. 77:2754-2761.

Heersche, G., G. H. Kiracofe, R. C. DeBenedetti, S. Wen, and R. M. McKee. 1979. Synchronization of estrus in beef heifers with a norgestomet implant and prostaglandin f2α. Theriogenology 11:197-208.

Hurnik, J. F., and G. J. King. 1987. Estrous behavior in confined beef cows. J. Anim. Sci. 65:431-438.

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.

King, M. E., M. D. Holland, H. S. Mauck, D. G. LeFever, and K. G. Odde. 1988. Synchronization of estrus in beef cows with norgestomet-alfaprostol or Syncro-Mate B. Theriogenology 30:785-795.

Lamb, G. C., C. R. Dahlen, K. A. Vonnahme, G. R. Hansen, J. D. Arseneau, **G. A. Perry**, J. Clement, and J. D. Arthington.Effects of estrous synchronization with a CIDR prior to the breeding season in bull-breeding herds on pregnancy rates. J. Anim. Sci. 84(Suppl. 1):433 Abstr. 580

Lamb, G. C., J. S. Stevenson, D. J. Kesler, H. A. Garverick, D. R. Brown, and B. E. Salfen. 2001. Inclusion of an intravaginal progesterone insert plus GnRH and prostaglandin f2alpha for ovulation control in postpartum suckled beef cows. J. Anim. Sci. 79:2253-2259.

Landivar, C., C. S. Galina, A. Duchateau, and R. Navarro-Fierro. 1985. Fertility trial in Zebu cattle after a natural or controlled estrus with prostaglandin f2 alpha, comparing natural mating with artificial insemination. Theriogenology 23:421-429.

Lemaster, J. W., J. V. Yelich, J. R. Kempfer, J. K. Fullenwider, C. L. Barnett, M. D. Fanning, and J. F. Selph. 2001. Effectiveness of GnRH plus prostaglandin f2alpha for estrus synchronization in cattle of Bos Indicus breeding. J. Anim. Sci. 79:309-316.

Lucy, M. C., H. J. Billings, W. R. Butler, L. R. Ehnis, M. J. Fields, D. J. Kesler, J. E. Kinder, R. C. Mattos, R. E. Short, W. W. Thatcher, R. P. Wettemann, J. V. Yelich, and H. D. Hafs. 2001. 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. J. Anim. Sci. 79:982-995.

Mann, G. E., S. J. Mann, and G. E. Lamming. 1996. The inter-relationship between the maternal hormone environment and the embryo during the early stages of pregnancy. J. Reprod. Fertil. Abstract series 21:abstract 37.

Maurer, R. R., and S. E. Echternkemp. 1982. Hormonal asynchrony and embryonic development. Theriogenology 17:11-22.

McDonald, L. E., R. E. Nichols, and S. H. McNutt. 1952. Study of corpus luteum ablation and progesterone replacement therapy in cattle. Am. J. Vet. Res. 13:446-451.

Miksch, E. D., D. G. LeFever, G. Mukembo, J. C. Spitzer, and J. N. Wiltbank. 1978. Synchronization of estrus in beef cattle II. Effect of an injection of norgestomet and an estrogen in conjunction with a norgestomet implant in heifers and cows. Theriogenology 10:201-221.

Mussard, M. L., C. R. Burke, and M. L. Day. 2003. Ovarian follicle maturity at induced ovulation influences fertility in cattle. In: Society for Theriogenology annual conference and symposium., Columbus, OH. p 179-185.

Nelson, J. R., B. L. Perry, and G. A. Perry. 2006. Effects of standing estrus and concentrations of estradiol on uterine pH. J. Anim. Sci. 84(Suppl. 1):451 Abstr. 637

Perry, G. A. 2005. Comparison of the efficiency and accuracy of three estrous detection methods to indicate ovulation in beef cattle. South Dakota State University Beef Report p. 122-127.

Perry, G. A., and D. C. Busch. 2005. Effect of ovulatory follicle size and standing estrus on estradiol concentrations, LH surge, and ovulation. J. Anim. Sci. 83(Suppl. 1):216 Abstr. 306

Perry, G. A., M. F. Smith, and T. W. Geary. 2004a. Ability of intravaginal progesterone inserts and melengestrol acetate to induce estrous cycles in postpartum beef cows. J. Anim. Sci. 82:695-704.

Perry, G. A., M. F. Smith, A.J. Roberts, M.D. MacNeil, and T.W. Geary. 2004. Effect of ovulatory follicle size on pregnancy rates and fetal mortality in beef heifers. J. Anim. Sci. 82(Suppl. 2):101 Abstr. 99

Perry, G. A., M. F. Smith, M. C. Lucy, J. A. Green, T. E. Parks, M. D. Macneil, A. J. Roberts, and T. W. Geary. 2005. Relationship between follicle size at insemination and pregnancy success. Proc. Natl. Acad. Sci. U.S.A. 102:5268-5273.

Perry, G. A., M. F. Smith, and D. J. Patterson. 2002b. Evaluation of a fixed-time artificial insemination protocol for postpartum suckled beef cows. J. Anim. Sci. 80:3060-3064.

Perry, G. A., M. F. Smith, A. J. Roberts, M. D. MacNeil, and T. W. Geary. 2004b. Effect of ovulatory follicle size on pregnancy rates and fetal mortality in beef heifers. J. Anim. Sci. 82(Suppl. 1.):102(Abstr. 101).

Perry, G. A., and B. L. Perry. 2006. Influence of preovulatory concentrations of estradiol on interval to ovulation and uterine pH. J. Anim. Sci. 84(Suppl. 1):149 Abstr. 201

Perry, G. A., T. W. Geary, M. C. Lucy, and M. F. Smith. 2002a. Effect of follicle size at time of GnRH-induced ovulation on luteal function and fertility. In: Western Section, American Society of Animal Science, Fort Collins, CO. p 45-48.

Plugge, B. L., G. H. Deutscher, and R. L. Davis. 1989. Comparison of melengestrol acetate (MGA) and lutalyse combination to Syncro-Mate B (SMB) in estrous synchronization programs utilizing AI or natural service. J. Anim. Sci. 67(Suppl. 2):87.

Pursley, J. R., R. W. Silcox, and M. C. Wiltbank. 1998. Effect of time of artificial insemination on pregnancy rates, calving rates, pregnancy loss, and gender ratio after synchronization of ovulation in lactating dairy cows. J. Dairy Sci. 81:2139-2144.

Rorie, R. W., T. R. Bilby, and T. D. Lester. 2002. Application of electronic estrus detection technologies to reproductive management of cattle. Theriogenology 57:137-148.

Rupp, G. P., L. Ball, M. C. Shoop, and P. J. Chenoweth. 1977. Reproductive efficiency of bulls in natural service: Effects of male to female ratio and single- vs multiple-sire breeding groups. J. Am. Vet. Med. Assoc. 171:639-642.

Santos, J. E., W. W. Thatcher, R. C. Chebel, R. L. Cerri, and K. N. Galvao. 2004. The effect of embryonic death rates in cattle on the efficacy of estrus synchronization programs. Anim. Reprod. Sci. 82-83:513-535.

Sartori, R., P. M. Fricke, J. C. Ferreira, O. J. Ginther, and M. C. Wiltbank. 2001. Follicular deviation and acquisition of ovulatory capacity in bovine follicles. Biol. Reprod. 65:1403-1409.

Schafer, D. W., J. S. Brinks, and D. G. LeFever. 1990. Increased calf weaning weight and weight via estrus synchronization. Beef program report. Colorado State University. p 115-124.

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.

Smith, V. G., J. R. Chenault, J. F. McAllister, and J. W. Lauderdale. 1987. Response of postpartum beef cows to exogenous progestogens and gonadotropin releasing hormone. J. Anim. Sci. 64:540-551.

Stauss, C. R., T. J. Votta, and S. S. Suarez. 1995. Sperm motility hyperactivation facilitates penetration of the hamster zona pellucida. Biol. Reprod. 53:1280-1285.

Stevenson, J. S., K. E. Thompson, W. L. Forbes, G. C. Lamb, D. M. Grieger, and L. R. Corah. 2000. Synchronizing estrus and(or) ovulation in beef cows after combinations of GnRH, norgestomet, and prostaglandin f2alpha with or without timed insemination. J. Anim. Sci. 78:1747-1758.

Suarez, S. S., and X. Dai. 1992. Hyperactivation enhances mouse sperm capacity for penetrating viscoelastic media. Biol. Reprod. 46:686-691.

Whittier, J. C., R. W. Caldwell, R. V. Anthony, M. F. Smith, and R. E. Morrow. 1991. Effect of a prostaglandin f2 alpha injection 96 hours after introduction of intact bulls on estrus and calving distribution of beef cows. J. Anim. Sci. 69:4670-4677.

Williamson, N. B., R. S. Morris, and G. A. Anderson. 1978. Pregnancy rates and non-return rates following artificial and natural breeding in dairy herds. Aust. Vet. J. 54:111-114.

Xu, Z. Z., D. J. McKnight, R. Vishwanath, C. J. Pitt, and L. J. Burton. 1998. Estrus detection using radiotelemetry or visual observation and tail painting for dairy cows on pasture. J. Dairy Sci. 81:2890-2896.

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

Yavas, Y., and J. S. Walton. 2000b. Postpartum acyclicity in suckled beef cows: A review. Theriogenology 54:25-55.