Economic evaluation of estrous synchronization programs on Northern Range cow-calf operations
by Satoshi Yamamoto

A thesis submitted in partial fulfillments of the requirements for the degree of Master of Science in Animal Science
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Abstract:
Estrous synchronization protocols are used to manipulate the estrous cycles of beef cows in order to make artificial insemination easier to apply. Several studies have characterized protocols with respect to pregnancy rate, cost, and labor demand; however, few reports have studied the effects of estrous synchronization programs on enterprise profitability. Therefore, the objectives of this research were to: 1) evaluate the effects of estrous synchronization programs on enterprise profitability in Northern Range cow-calf operations and 2) identify optimum protocols and specific management decisions, if any exist. Also, because a computer model of range beef production capable of simulating the numerous variables related to estrous synchronization programs, a third objective was to develop a simulation model with these capabilities. The model accounted for a variety physiological and economic parameters. Special variables to mimic the effects of estrous synchronization were probability of response to a protocol when a female is cycling or non-cycling and the elapsed time from administration until estrus. A northern range cow-calf production unit was simulated, applying estrous synchronization to either none of the herd, only yearling heifers, or both yearlings and mature cows. Protocols evaluated were: one-injection PGF2a system, two-injection PGF2α system, MGA/PGF2α, Select Synch, CO-Synch, and CIDR/PGF2α. The length of breeding season was either 45 or 66 d. Relative to natural service, calving percentage in the early period of calving season, calf weaning weight and age, herd pregnancy rate, and number of pregnant cows sold were increased by applying estrous synchronization. Production costs were increased due to added cost of estrous synchronization; however, costs associated with bulls were reduced and increased revenue covered the cost for estrous synchronization and produced added profit. Hence, depending on protocols applied, estrous synchronization with artificial insemination could be more profitable than natural service. As a heifer protocol, MGA/PGF2α was suitable, and for mature cows, protocols that can induce cyclicity in anestrous cows were effective and beneficial. Estrous synchronization can help producers achieve a short breeding season and increase profitability over and above that possible via genetic improvement through artificial insemination.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date Nov 25 '02

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ABSTRACT

Estrous synchronization protocols are used to manipulate the estrous cycles of beef cows in order to make artificial insemination easier to apply. Several studies have characterized protocols with respect to pregnancy rate, cost, and labor demand; however, few reports have studied the effects of estrous synchronization programs on enterprise profitability. Therefore, the objectives of this research were to: 1) evaluate the effects of estrous synchronization programs on enterprise profitability in Northern Range cow-calf operations and 2) identify optimum protocols and specific management decisions, if any exist. Also, because a computer model of range beef production capable of simulating the numerous variables related to estrous synchronization programs, a third objective was to develop a simulation model with these capabilities. The model accounted for a variety physiological and economic parameters. Special variables to mimic the effects of estrous synchronization were probability of response to a protocol when a female is cycling or non-cycling and the elapsed time from administration until estrus. A northern range cow-calf production unit was simulated, applying estrous synchronization to either none of the herd, only yearling heifers, or both yearlings and mature cows. Protocols evaluated were: one-injection $PGF_{2\alpha}$ system, two-injection $PGF_{2\alpha}$ system, MGA/$PGF_{2\alpha}$, Select Synch, CO-Synch, and CIDR/$PGF_{2\alpha}$. The length of breeding season was either 45 or 66 d. Relative to natural service, calving percentage in the early period of calving season, calf weaning weight and age, herd pregnancy rate, and number of pregnant cows sold were increased by applying estrous synchronization. Production costs were increased due to added cost of estrous synchronization; however, costs associated with bulls were reduced and increased revenue covered the cost for estrous synchronization and produced added profit. Hence, depending on protocols applied, estrous synchronization with artificial insemination could be more profitable than natural service. As a heifer protocol, MGA/$PGF_{2\alpha}$ was suitable, and for mature cows, protocols that can induce cyclicity in anestrous cows were effective and beneficial. Estrous synchronization can help producers achieve a short breeding season and increase profitability over and above that possible via genetic improvement through artificial insemination.

CHAPTER 1

INTRODUCTION

Compared to natural service, artificial insemination (AI) is one of the most valuable management tools used by beef and dairy cattle producers to access genetically superior sires (Odde, 1990; Sprott, 1999; Stenquist and Geary, 2001a,b). As a reproductive management tool to make AI easier to apply, estrous synchronization has been researched since the 1960's (Patterson et al., 1989a; Odde, 1990).

In the U.S. beef industry, only a small percentage of beef producers use estrous synchronization (Geary et al, 1998, 2001; Sprott, 1999), while in the dairy industry, it is frequently applied (Britt, 1985; Fogwell et al., 1986; Fetrow and Blanchard, 1987,1988; Britt and Gaska, 1998). Reasons why few beef producers use estrous synchronization and AI include: 1) beef cattle are maintained on rangeland, 2) AI requires more labor than natural service for estrous detection and insemination, and 3) many producers lack the needed management skills, facilities, and understanding of estrous synchronization with AI systems (Odde, 1990; Sprott, 1999; Stenquist and Geary, 2001b).

Several studies have focused on the advantages and disadvantages of estrous synchronization protocols as related to pregnancy rate, cost (semen and synchronization agents), and labor demand (Mares et al., 1977; Miksch et al., 1978; Spitzer et al., 1978; Kiser et al., 1980; Pace and Sulivan, 1980; Spitzer et al., 1981; Brown et al., 1986a,b; Brown et al., 1988; Mauck et al., 1988; Yelich et al., 1988, 1995; Patterson et al., 1989b; Carpenter et al., 1991; Macmillan and Peterson, 1993; Fanning et al., 1995; Fike et al., 1997; Stevenson et al., 1997, 1998, 2000; Anderson and Day, 1998; DeJarnette, 1998; Geary, 1998; Geary et al., 1998, 2001; Lammoglia et al, 1998; McDowell et al, 1998; Deutscher et al., 2000; Kojima et al, 2000; Lamb et al., 2000; Lucy et al., 2001). However, few reports have discussed the effects of estrous synchronization programs on enterprise profitability (Higgins, 1981; Gaines et al, 1993; Lowman et al, 1994). Furthermore, the latter studies were written based on different protocols, and different management conditions; hence, results cannot be extrapolated to other environments.

This led me to review literature in terms of estrous synchronization protocols, management considerations, and potential benefits.

CHAPTER 2

LITERATURE REVIEW

Introduction

This chapter will summarize and present scientific studies regarding the potential of estrous synchronization with AI programs to improve enterprise profit. This review will consist of the following broad topic areas: 1) physiology of estrous cycles in cattle, 2) commercial estrous synchronization protocols, 3) important management factors associated with the application of estrous synchronization and AI, 4) potential benefits of estrous synchronization and AI in commercial cow-calf operations, and 5) efficiency and relevance of simulation models to this study.

Physiology of Estrous Cycles

Estrous Cycle

The estrous cycle of cows is approximately 21 d and is composed of a luteal phase and a follicular phase (Hafez, 1993a; Figure 1).

Luteal Phase. The luteal phase lasts 16 to 17 d and consists of the development, maintenance, and regression of the corpus luteum (**CL**). Formation of the CL is complete by about 5 d after ovulation and is maintained until d 17. During this period, as the CL matures, progesterone (**P_4**) is secreted. Increased circulating P_4 acts on the hypothalamus and anterior pituitary to prevent the secretion of gonadotropin-releasing hormone

(**GnRH**), follicle-stimulating hormone (**FSH**), and luteinizing hormone (**LH**); hormones that promote new follicular growth and ovulation. Progesterone secretion must be maintained to support pregnancy. Maternal recognition of pregnancy occurs between d 15 to 19 (Thatcher et al., 1986; Roberts et al., 1990). If the uterus does not recognize pregnancy, prostaglandin $F_{2\alpha}$ (**$PGF_{2\alpha}$**) is secreted by the uterus, which causes regression of the CL (Whittier, 1998; Taylor and Field, 1999).

Follicular Phase. The follicular phase lasts 3 to 6 d. As the CL regresses, secretion of P_4 decreases, leading to increased production of GnRH, FSH, and LH. The new dominant follicle of the current follicular wave (discussed in the next section) develops further and secretes estrogen (primary estradiol; **E_2**), which causes the physical sign of estrus and is the initiator of an impending ovulation. Estrus lasts approximately 8 to 30 h (average 18 h) and ovulation occurs approximately 6 to 18 h (average 14 h) after the end of estrus (ABS Global, Inc., 1996). After the ovum is released from the follicle, the remaining cells luteinize to form the CL and the luteal phase starts again (Hafez, 1993a; Taylor and Field, 1999).

Follicular Wave

Ultrasound technology has enabled researchers to observe follicular development on the ovaries (Ginther et al., 1996; Bao and Garverick 1998; DeJarnette, 2001). Follicular growth (recruitment) occurs in waves throughout the 21-d estrous cycle. There are usually two to four follicular waves during each estrous cycle (Bao and Garverick, 1998) as each follicular wave takes 7 to 12 d before follicular turnover (atresia of the dominant follicle and reinitiation of a new follicular wave) occurs (Ginther et al., 1989a,b). The first wave usually emerges on a day of ovulation of the previous cycle (d 1 in the estrous cycle, Ginther et al., 1989a, 1996; Roche and Boland, 1991). Each wave is characterized by rapid growth of a group of similar size follicles (cohort). As the wave proceeds, follicles die one by one (atresia), and finally, only one follicle (dominant follicle) remains and grows to a much larger size. The dominant follicle has the ability to regulate and restrict the growth of other smaller follicles and to produce E_2. The dominant follicle is capable of ovulating if it receives sufficient gonadotropin (FSH and LH) support (Draincourt, 1991; Roche and Boland, 1991). However, if luteolysis has not yet occurred and P_4 concentrations are too high, the dominant follicle undergoes atresia, and is followed by initiation of a new follicular wave and formation of a new dominant follicle. The dominant follicle of the last wave of the estrous cycle becomes the follicle that will ovulate (Figure 2).

Postpartum Anestrous Period

After calving, follicular waves are observed during the early stages of the postpartum period (Savio et al., 1990). Thus, dominant follicles are present during the postpartum anestrous period, but they do not mature or ovulate (Spicer and Echternkamp, 1986). This is due to absence of appropriate LH pulses as dominant follicles in this stage are unable to produce sufficient E_2 (Spicer and Echternkamp, 1986; Lucy et al., 1992; Yavas and Walton, 2000). Absence of LH pulses in the early postpartum period is due to depletion of LH stores in the anterior pituitary, suckling, and inadequate energy intake

(Lucy et al., 1992; Yavas and Walton, 2000). Pituitary stores of LH are restored between d 15 and 30 postpartum (Williams, 1990; Yavas and Walton, 2000).

Following parturition, the concentration of P_4 is undetectable until a few days before the first normal estrus and ovulation (Hafez, 1993a). However, a silent ovulation (ovulation without estrus) can occur within 5 wk postpartum that is followed by a short estrous cycle (Fernandez, 1993). Ova from this short cycle can be fertilized, but pregnancy is not maintained, probably due to early CL regression (Ramirez-Godinez et al., 1982). The concentration of P_4 will increase during the first luteal phase, which follows the silent ovulation; hence the second postpartum ovulation is associated with estrus (Hafez, 1993a; Allrich, 1994).

Estrous Synchronization Protocols

Although there are estrous synchronization protocols other than those cited here which have proven effective in scientific studies, those cited in the following section are considered to be the most practical and popular (Geary, 1997; Taylor and Field, 1999; Stenquist and Geary, 2001a). Some protocols can induce normal estrous cycles or ovulation in anestrous cows, but those are effective only for cows that are close to starting to cycle on their own. No protocols are able to restore infertility of cows caused by environmental, genetic, physiologic, and metabolic factors including breed, strain, nutritional level, suckling, milk production, frequency of milking, and level of and genetic potential for milk yield (Hafez, 1993a; Stenquist and Geary, 2001a).

Traditional Synchronization Protocols

The luteolytic property of $PGF_{2\alpha}$ has made synchronization programs feasible in commercial herds. By regressing the CL of an ovary, $PGF_{2\alpha}$ decreases P_4 levels and allows cows to progress into estrus. For $PGF_{2\alpha}$ to be effective, each cow must have a functionally mature CL. A single injection of $PGF_{2\alpha}$ is not effective in heifers that have not reached puberty or in anestrous cows. Hence, to achieve synchrony of estrus with $PGF_{2\alpha}$, a large number of cows in the herd must be cycling. Following are four estrous synchronization and AI systems that utilize $PGF_{2\alpha}$. Compared to most other protocols, these are less expensive and easier to administer.

One-Injection $PGF_{2\alpha}$ with Breeding After Injection. All cows are injected with one dose of $PGF_{2\alpha}$ and bred 12 h after standing estrus. With this protocol, producers can expect that $PGF_{2\alpha}$ will cause luteolysis in cycling cows, but not in anestrous cows and heifers that have not reached puberty. Approximately 60 to 70% of cycling cows are expected to display estrus during the next 4 to 5 d. The estimated pregnancy rate is dependent upon the percentage of cows responding and the conception rate, but is generally about 37%. The estimated cost per pregnant female is approximately $36 (Geary, 1997; Stenquist and Geary 2001a).

One-Injection $PGF_{2\alpha}$ with 10 Days of Breeding. During the first 5 d, females are observed for estrus and bred. During this period, those cycling females that have not been inseminated are assumed to have developed a mature CL (d 5 to 17 of estrous cycle) that will respond to $PGF_{2\alpha}$. On d 6, all cows not bred previously are injected with one dose of $PGF_{2\alpha}$ and bred 12 h after standing estrus by d 10. Approximately 90% of cycling cows will be bred during the first 10 d of breeding season. The estimated pregnancy rate for a typical herd is approximately 50%. The estimated cost per pregnant female is approximately $34 (Geary, 1997; Stenquist and Geary 2001a).

Two-Injection $PGF_{2\alpha}$ with Breeding After Each Injection. All cows are given one shot of $PGF_{2\alpha}$. Approximately 60 to 70% of cycling cows should be in estrus during the next 4 to 5 d. Females are bred 12 h after standing estrus. Cows not bred after the first injection receive a second injection 11 to 14 d later and are bred 12 h after they are detected in estrus. With this protocol, producers can expect that $PGF_{2\alpha}$ will cause luteolysis in cycling cows with a mature CL. By waiting for 11 to 14 d, the mature CL of the next cycle is expected to respond to the second injection. The estimated pregnancy rate for a typical herd is approximately 50%. The estimated cost per pregnant female is approximately $37 (Geary, 1997; Stenquist and Geary 2001a).

Two-Injection $PGF_{2\alpha}$ with Breeding After the Second Injection. Two shots of $PGF_{2\alpha}$ are given with an 11 to 14 d interval. Like the other two-shot program, 60 to 70% of cycling cows will show estrus after the first injection. These cattle and the remainder of cycling cattle should not be bred at this time. Estrous detection and AI should be conducted for 4 to 5 d only after the second injection. Synchrony of estrus is about 70 to 80% of cycling cows. The estimated pregnancy rate generally results in approximately 50%. The estimated cost per cow pregnant is approximately $39 (Geary, 1997; Stenquist and Geary 2001a).

<u>MGA/$PGF_{2\alpha}$</u>. Melengestrol acetate (**MGA**) is a synthetic progestin which suppresses estrus in cattle. In this procedure, MGA (0.5 mg•head^{-1}•day^{-1}) is fed for 14 d and one shot of $PGF_{2\alpha}$ is given 17 d after MGA withdrawal. With this regimen, females are expected to be in their late luteal phase when they are injected with $PGF_{2\alpha}$ injection. Peak estrous response among treated females is 48 to 72 h after $PGF_{2\alpha}$ injection. Although it takes 31 d, this program is easy to administer if cattle are eating out of a feedbunk.

This protocol can induce estrus among some anestrous females by mimicking a normal estrous cycle. A luteal phase, i.e., high concentration of P_4, will be established by feeding MGA. Brown et al. (1988) reported a 40.3% pregnancy rate in anestrous heifers. Considering the 31-d period and that most lactating cows usually would not have calved early enough to receive this treatment, this protocol is used primarily in heifers. The estimated pregnancy rate is 55%. The estimated cost per pregnant female is approximately $35. Also, timed AI without estrous detection at 72 h to 80 h after $PGF_{2\alpha}$ injection results in about 55% pregnancy rate at about $37 per pregnant female (Geary, 1997; Stenquist and Geary 2001a).

Recent studies reported an improvement to this protocol by extending the interval between last MGA feeding and $PGF_{2\alpha}$ injection from 17 d to 19 d (Deutscher et al., 2000; Lamb et al., 2000). With this procedure, first service conception rate and pregnancy rate were as high or higher than for the 17-d system, although they were not statistically different in both papers. However, in both papers, it was found that a higher percentage of heifers cycled by 72 h after $PGF_{2\alpha}$ injection in the 19-d system than those in the 17-d system. In a field trial by Deutscher et al. (2000), statistical differences were reported in estrous detection during the 5-d synchronization period (10% more in the 19-d system), pregnancy rate during the 5-d AI period (7.6% higher in the 19-d system), pregnancy rate after 30 d of breeding (5.5% higher in the 19-d system), and estrous response within 84 h after $PGF_{2\alpha}$ injection (15% more in the 19-d system). The theory behind this improvement was that preovulatory follicles would be more mature by delaying the $PGF_{2\alpha}$ administration by 2 d (Lamb et al., 2000). Deutscher et al. (2000) suggested that heifers in the later stages of their estrous cycles had higher pregnancy rate. The AI conception rate was the highest in heifers in their late luteal phase, and decreased with decreased CL age (67% for late luteal phase and 43% for early luteal phase heifers). Deutscher et al. (2000) reported that 53% of heifers in the 19-d system were in later stages of their estrous cycles (d 15, 16, or 17), while only 2% of heifers in the 17-d system were in this category. This may be the reason that the 19-d system yielded better results than the 17-d system.

Syncro-Mate B®. This procedure consists of an ear implant of a synthetic progestin (Norgestomet) and an injection of norgestomet and estradiol valerate on the first day and removal of the implant 9 d later. After removing implants, cows are expected to display estrus during the next 4 to 5 d and should be inseminated 12 h after first detected in estrus. Norgestomet blocks the release of E_2 that causes ovulation and prevents females from displaying estrus. Estradiol valerate has luteolytic properties and remains in the blood for about 5 d. This causes regression of the mature CL and any new CL that develop during this period. When the implant is removed, females should have a dominant follicle but no CL, so they exhibit estrus and ovulate as this dominant follicle grows and produces E_2. Estrus generally occurs within 36 to 48 h after implant removal. Timed AI without heat detection (48 to 54 h after implant removal) or a combination of both AI with heat detection and timed AI can be applied. The estimated pregnancy rate is approximately 55% for AI with heat detection and 50% for mass AI. The estimated cost per pregnant female is approximately $41 for AI with heat detection and $47 for mass AI. This program is difficult to administer and expensive due to the ear implants, and fertility is variable (Zaied et al., 1976; Spitzer et al., 1978, 1981; Odde, 1990; Odde and Holland, 1994; Geary, 1997; Stenquist and Geary, 2001a). Like MGA/$PGF_{2\alpha}$, this protocol can also induce estrus among anestrous females by mimicking a short estrous cycle. Progestin applied in the MGA/$PGF_{2\alpha}$ and Syncro-Mate B protocols acts synergistically with E_2 to induce behavioral estrus (Hafez, 1993b). Brown et al. (1988) reported a 26.2% pregnancy rate with anestrous heifers using Syncro-Mate B.

Currently, Syncro Mate B is no longer produced and probably will never return to the market.

Synchronization of Ovulation

Recent studies have revealed that GnRH can be used to manipulate the follicular wave patterns in cattle (Twagiramungu et al., 1995). By causing the release of both LH and FSH, administration of GnRH eliminates large follicles by either ovulation or atresia. Emergence of a new follicular wave occurs within 3 to 4 d after treatment regardless of the stage of the estrous cycle. As a result, administration of GnRH initiates development of luteal tissue associated with ovulation of a dominant follicle, which will respond to

$PGF_{2\alpha}$ 6 to 7 d later. Hence, one dose of $PGF_{2\alpha}$ synchronizes luteal regression and ovulation in animals previously administered GnRH. Because GnRH stimulates secretion of both LH and FSH, this protocol and its variations can induce ovulation in anestrous cows (DeJarnette, 1998, 2001; Stenquist and Geary 2001a). However, ovulation of a dominant follicle does not occur in all cases. This is because the ability of a follicle to ovulate depends on its developmental stage at the time of treatment (Twagiramungu, et al., 1995). Cows without a dominant follicle on one of their ovaries will not respond to an injection of GnRH. Silcox et al. (1993) reported that exogenous GnRH caused ovulation when administered during the growing or static phase of each follicular wave, but did not affect follicles when administered during the regression phase (initiation of the recruitment of the cohort of the next wave). Cycling cows, that have recently undergone follicular turnover and initiated recruitment of a cohort of follicles which contains the ovulatory follicles (i.e., final follicular wave of an estrous cycle) at the time of a GnRH injection, may undergo normal luteolysis and exhibit estrus during the next 5 to 7 d.

Select Synch. This protocol is relatively easy and simple to administer and includes a GnRH injection followed 7 d later by a $PGF_{2\alpha}$ injection. This protocol has demonstrated a higher pregnancy rate than $PGF_{2\alpha}$ treatment alone (DeJarnette, 1998; Wallace, 1998; Stevenson et al., 2000). Females are observed for signs of estrus from 24 h before $PGF_{2\alpha}$ injection and for the next 4 or 5 d after $PGF_{2\alpha}$ injection and inseminated 12 h after standing estrus. Most females show estrus 2 to 4 d after $PGF_{2\alpha}$ injection, but some exhibit standing estrus 6 to 7 d after GnRH injection (Geary, 1997; Geary et al., 2000;

DeJarnett, 2001; Stenquist and Geary 2001a). Estimated pregnancy rate is approximately 55%. Estimated cost per pregnant female is approximately $37 (Geary, 1997; Stenquist and Geary 2001a). In a couple of experiments by Stevenson et al. (1998, 2000), pregnancy rates in noncycling cows were approximately 30%. Because the success with this protocol depends on good estrous detection and breeding of cows in standing estrus, conception rates will tend to be higher and less variable than with timed AI protocols (DeJarnett, 2001). A 7-d interval is easy for scheduling reproductive management for a herd (e.g., GnRH injection on Monday is followed by $PGF_{2\alpha}$ injection on next Monday; Thatcher et al., 1993).

Ovsynch. This protocol is only slightly different from the Select Synch protocol, and involves one more GnRH injection 2 d after $PGF_{2\alpha}$ injection and timed insemination (timed AI without estrous detection) 16 to 24 h later. The second GnRH injection synchronizes the LH surge and induces a fertile ovulation in cows that have not yet exhibited estrus (Twagiramungu et al, 1995; Taylor and Field, 1999). Geary et al (1998) demonstrated a higher pregnancy rate among beef cows receiving Ovsynch as opposed to Syncro-Mate B® (54% vs 42%). Geary et al. (1998) reported a 49% pregnancy rate among anestrous cows that received the Ovsynch protocol. The disadvantage of this protocol is that it requires intensive labor, i.e., four times for animal handling (Geary et al, 1998; DeJarnett, 2001). Estimated cost per pregnant female is $53 (Geary, 1997; Stenquist and Geary 2001a).

CO-Synch. This protocol was derived from the Ovsynch protocol. The synchronization injections are the same as in the Ovsynch protocol, but timed AI is conducted at the same time as the second GnRH injection (Geary and Whittier, 1998; Geary et al., 2001), which is less labor intense than Ovsynch (3 times of handling). Geary (1998) and Geary et al. (2001) reported that a similar pregnancy rate to Ovsynch was achieved from CO-Synch. Also, Geary et al. (2001) reported a 48% pregnancy rate among anestrous cows receiving either protocol. Both Ovsynch and CO-Synch are expensive due to the two GnRH injections and the fact that all cows are inseminated rather than only those cows observed in estrus (Geary, 1998). Estimated cost per pregnant female is $53 (Geary, 1997; Stenquist and Geary 2001a).

Although the Ovsynch and CO-Synch programs allow mass AI without estrous detection, the addition of some estrous detection to these protocols is beneficial. Some cows show natural estrus between d 6 (1 d before $PGF_{2\alpha}$ injection) and d 9 (day of the second GnRH injection). These cows should be bred 12 h after detected in estrus, and any subsequent injection should not be administered (DeJarnett, 2001).

Potentially New Protocol

CIDR/$PGF_{2\alpha}$. A controlled intravaginal drug-releasing (**CIDR**) device was first developed in New Zealand as a source of exogenous P_4 (Macmillan and Peterson, 1993). The CIDR is a T-shaped device that is placed into the vagina with a lubricated applicator. The applicator collapses the wings to permit insertion into the vagina. Expulsion of the CIDR from the applicator within the vagina allows relaxation of the wings and retention of the CIDR within the vagina by exerting pressure on the vaginal wall. A thin nylon tail attached to the end of the CIDR is kept outside of vagina and is used to remove the insert at the completion of the treatment period (Lucy et al., 2001).

The protocol includes CIDR insertion on d 0 and removal on d 7 with an injection of $PGF_{2\alpha}$ on d 6 or 7 (Macmillan and Peterson, 1993; Lucy et al., 2001). A future option may include the use of estradiol benzoate with or without $PGF_{2\alpha}$ 24 to 30 h after the CIDR removal (Fike et al., 1997; Lammoglia et al., 1998). In cyclic females, the exogenous P_4 from the CIDR maintains circulating P_4 concentration so that estrus will be synchronized after withdrawal of the CIDR and administration of $PGF_{2\alpha}$ and/or estradiol benzoate).

This treatment can induce estrous cycles in anestrous females. Insertion of the CIDR causes a quick rise in serum concentration of P_4 and mimics a short luteal phase. Lucy et al. (2001) reported a 71% and 46% pregnancy rate among cyclic and anestrous cows, respectively, during a 31-d AI period following synchronization with a CIDR for 7 d and a $PGF_{2\alpha}$ injection on d 6. In this experiment, 46% of cyclic and 26% of anestrous cows became pregnant during the first 3 d. Macmillan and Peterson (1993) reported the peak in estrous response was 48 h after device removal. Yavas and Walton (2000) have suggested the CIDR regimen has the potential to induce normal estrous cycles and ovulation in cows as early as 3 to 4 wk postpartum.

Summary

Table 1 summarizes the pregnancy rate of each protocol from previous studies. Sources of literature for Table 1 are listed in Table 2. Those numbers without sources are cited from Stenquist and Geary (2001a). Specific conditions of the experiments are noted with superscripts. Pregnancy rates are defined as the number of pregnant females divided by the number of females that received the synchronization treatment.

Management Considerations

Estrous synchronization with AI requires sound management and planning to be successful. Although AI enables producers to utilize genetically superior sires, facilitates crossbreeding, and improves record keeping, compared to natural service, AI requires: 1) better management, 2) skilled labor, 3) special facilities, and 4) extra time and commitment for estrous detection (Stenquist and Geary, 2001b). A management goal is to have a high percentage of females exhibiting normal estrous cycles before the breeding season. No synchronization program will enhance overall pregnancy rates, increase conception, or improve reproductive performance in anestrous cattle when poor management is responsible for that condition (Fogwell et al., 1986; Stenquist and Geary, 2001a).

Nutrition

Nutritional management is one of the critical factors affecting reproduction efficiency of cattle (Randel, 1990). Nutritional status affects postpartum interval (**PPI**, discussed later), body fat stores, and milk production. These factors interrelate with each other because nutritional status depends on suckling status and vice versa (Short et al., 1994). All of these nutritional factors and interactions among them affect the neuroendocrine control of reproduction (Short and Adams, 1988).

Body condition score (**BCS**) is a practical indicator of nutritional status of females (Wetteman, 1994; Kunkle et al., 1994). Higher BCS is associated with higher pregnancy rates (when considering BCS of 3 to 6). Kunkle et al. (1994) recommended a minimum BCS of 5.0 at breeding to ensure yearly calving intervals in beef cows. Geary et al. (1998) and DeJarnette (1998) reported minimum BCS for estrous synchronization programs as ≥ 5 and > 4, respectively.

For cows, the most important nutritional period is from 3 mo before calving to 3 mo after calving (Stenquist and Geary, 2001b). After calving, the first priority for their partitioning of nutrients is lactation. Cows require additional nutrition to start normal estrous cycles and conceive. Estrous cycles usually can be maintained if BCS is 4 or greater (Short et al., 1990). Short et al. (1990) stated the relationship between BCS at calving and the length of PPI as the lower BCS associated with longer PPI whereas PPI was not affected when BCS was above 7. Also, postcalving dietary intake affects the length of PPI when BCS at calving is less than 6. There is not a strong effect when cows are fed adequate or higher amounts, but PPI is lengthened when cows are fed lower amounts (Short et al., 1990).

In replacement heifers, nutritional management from weaning to breeding is critical because puberty is directly related to age and weight (Paterson et al., 1992; Bagley, 1993). Heifers reaching puberty later in their first breeding season will calve later and rebreed later. For heifers to calve as a 2-yr-old, they must conceive at 14 to 15 mo of age, and to attain high pregnancy rates at this time, they should weigh 60 percent or more of their mature weight (Taylor and Field, 1999; Stenquist and Geary, 2001b). Patterson et al. (1989b) reported a higher pregnancy rate in heifers that were heavier and received higher energy diets than those that were lighter and received lower energy diets. Also, first-calf heifers are still growing after parturition, hence they have nutritional requirements for growth, in addition to nutritional requirements for milk production and rebreeding (Deutscher, 1985a).

Herd Management

Replacement Heifers. Replacement heifers should be bred so that they calve 2 to 3 wk earlier than the main herd because they typically have an 80 to 90 d PPI, which is 20 to 30 d longer than the PPI for mature cows (Patterson et al., 1992; Bagley, 1993). Breeding heifers to calve ahead of the cow herd involves some practical implications: 1) it enables heifers to be bred on schedule with the mature cows the following year, and 2) in the early part of the calving season, members of the calving crew are still fresh and can pay more attention to heifers (Deutscher, 1985b; Stenquist, 2001). When replacement heifers are retained from earlier calving cows, those heifers will be older at the beginning of their first breeding season and more likely to have reached puberty and targeted body weights than those retained from later calving cows (DeJarnett, 2001).

Heifer Bulls. The sires chosen for breeding heifers should be different from those chosen for mature cows. Sires chosen for breeding to replacement heifers should be selected from bulls with lower birth weight expected progeny differences with high accuracy to prevent dystocia (Cook et al., 1993).

Postpartum Interval. Nutritional status, body reserves, and suckling all affect PPI length (Short et al., 1990, 1994). Short et al. (1990, 1994) suggested that the length of breeding season has a direct effect on percentage of anestrous cows at the beginning of the following breeding season. They recommended 45-d or shorter breeding season. Assuming that gestation length is about 283 d, a 45-d breeding season enables cows 37 to 82 d to return to estrous cyclicity by the beginning of the following breeding season. In addition, a short breeding season may produce more uniform and heavier calves. With longer breeding seasons, such as 60 or 80 d, more cows will be in the early postpartum anestrous period at the beginning of next breeding season and some cows will not have calved by the start of the next breeding season. Stenquist and Geary (2001b) suggested a minimum PPI of 45-d at the start of the breeding season. Carpenter et al. (1991) and Stevenson et al. (1998) suggested a critical PPI for estrous synchronization programs as ≥ 60 d and ≥ 40 d, respectively.

Herd Identification. Each female should be individually identified to allow accurate record keeping and heat detection. Ear tags and brisket tags are available and a backup system such as freeze brands or tattoos is useful. Useful records include day of first postpartum estrus, date of breeding, pregnancy status, and anticipated calving date (Stenquist and Geary, 2001b).

Estrous Detection. Estrus lasts approximately 8 to 30 h (average 18 h; ABS Global, Inc., 1996). Our definition of estrus is the time period when a female permits others to mount her while she remains standing. Other observable signs are restlessness, attempting to mount other females, bawling, walking in search of a bull, and a clear mucus discharge from the vulva. In AI programs, females should be observed at least twice a day for 1 to 2 h, preferably in the early morning and late evening. Addition of one hour of estrous detection around mid-day can significantly increase estrous detection efficiency. Estrous synchronization increases the intensity and duration of estrous behavior among cows and helps to increase estrous detection efficiency (Selk, 1994).

Timing of AI. Cows should be inseminated roughly 12 h after the first observation of estrous behavior (Selk, 1994; Geary, 2001). Ovulation occurs approximately 6 to 18 h (average 14 h) after the end of estrus (ABS Global, Inc., 1996), but semen must reside in the female reproductive tract for 2 to 6 h to acquire fertility (capacitation) and generally remains viable for 24 to 30 h. Saacke et al. (2000) performed AI at either 0, 12, or 24 h after onset of estrus. Fertility was highest at the 24 h insemination and lowest at the 0 h insemination, but embryo quality was good at the 0 h insemination and poor at the 24 h insemination. The 12 h insemination resulted in the second highest fertilization rate and moderate embryo quality. They stated that pregnancy rate would be the highest when cows were inseminated at about 12 h after onset of estrus.

Clitoral Stimulation. Clitoral stimulation applied at the time of AI may increase pregnancy rate of cows, but does not appear to be effective in heifers (Randel et al., 1975; Short et al., 1979). In cows, clitoral stimulation for 3 to 5 sec increases AI pregnancy rate by 4 to 15 percent, while in heifers, it decreases AI pregnancy rate 3 to 5%. Manual stimulation of the reproductive tract may hasten the LH surge and ovulation in cows or increase muscle contractions toward the site of fertilization to prevent retrograde semen loss. Different results between cows and heifers are not well understood. Differences in maturity, sexual experience, body size, or management variables (time of AI and skill of technician) may affect differential responses between heifers and cows. Also, it might be related to retention of semen in the uterus and cervix (Tom Geary; personal communication). Generally, cows have a wider cervical opening than heifers because of having given birth. Clitoral stimulation might help to cause muscle contractions that help prevent the loss of semen back into the vagina more in cows. On the other hand, in heifers, retrograde semen flow may not be a problem.

Miscellaneous Considerations

Estrous Synchronization with Natural Service. Taylor and Field (1999) indicated the possibility of using bulls instead of AI with estrous synchronization protocols. Lowman et al. (1994) reported that bulls were able to cope with 14 to 18 cows in a relatively short time. Pruitt et al. (1982) reported that the number of ejaculations by bulls did not affect pregnancy rates of cows they serviced. However, data from Pexton et al. (1989) indicated that the pregnancy rate of natural service for 5 d after estrous synchronization protocols (Two-injection of $PGF_{2\alpha}$ with breeding after the second injection and Syncro-Mate B®) was lower than the pregnancy rate of natural service for 23 d in non-synchronized females (43.5% and 58.9%, respectively). Certainly, natural service limits the opportunity to use proven sires (Sprott, 1999). Potential problems related to the use of estrous synchronization with natural service include 1) appropriate bull:cow ratio because bulls vary in serving capacity and semen fertility (Sprott, 1999), and 2) number of bulls needed to breed synchronized females during a short time of period and cost for bulls (DeJarnett, 2001). Healy et al. (1993) synchronized heifers ($MGA/PGF_{2\alpha}$), assigned them into three groups with different bull:heifer ratios (1:50, 1:25, and 1:16), and compared to a non-synchronized control group in which bull:heifer ratio was 1:50. Pregnancy rates of the first 6 d were not different by treatments. Average day of conception was different by treatments, however, it was only 2 d earlier in one synchronized group (bull:heifer = 1:16) than in the control group. Based on their result, they estimated effects of the bull:heifer ratio on costs and incomes for synchronization with natural service, and suggested that estrous synchronization with natural service did not provide an advantage in terms of reproductive performance or economic efficiency.

Bull exposure. Exposing postpartum cows to bulls may shorten the interval between calving to the first postpartum estrus (DeJarnett, 2001). Fernandez et al. (1993) exposed females to mature bulls either 1) continuously after calving, 2) during first 30 d postpartum, or 3) after first 30 d postpartum. They reported that PPI was shorter in cows assigned to either treatment than in non-exposed cows. Although the physiological interactions that induce this response are still unclear, this is probably because bull exposure might induce a physiological change in the hypothalamo-hypophyseal axis that increases the concentration of LH (Fernandez et al., 1996).

Temporary calf removal. Kiser et al. (1980) reported that 48-h calf removal (short-term weaning) increased AI pregnancy rate in cows received Syncro-Mate B protocol. Yelich et al (1995) reported a similar result with the $MGA/PGF_{2\alpha}$ protocol. Geary (1998) and Geary et al. (2001) reported that 48-h calf removal before timed AI increased pregnancy rates by approximately 10% with the Ovsynch and CO-Synch protocols. Makarechian and Arthur (1990) and Fanning (1995) reported that 48-h calf removal has no deleterious effect on calf weaning weight. Hoffman et al. (1996) summarized this mechanism briefly. For postpartum cows, suckling lowers serum concentrations of LH; hence, temporary or permanent weaning increases concentration of LH and pulse frequency and amplitude of LH, which shortens the postpartum anestrus. Stagg et al. (1998) reported that PPI was shortened by removing calves from cows for 5 d. However, their results indicated that there was no difference in LH pulse frequency between treated and control cows during this 5-d calf removal period.

Potential Benefits of Estrous Synchronization with AI

Estrous synchronization is a method to manipulate estrous cycles of cows within a herd so that they can express estrus at about the same time, which minimizes the amount of time required for estrous detection and facilitates AI (Stenquist and Geary, 2001a,b). Potential benefits of this synchrony are discussed below.

Added Value

Compared to natural service, estrous synchronization enables producers to plan a shorter breeding season. Successfully applying synchronization programs with AI to the start of a breeding season allows three opportunities of breeding (one AI and two natural services) in a 45-d breeding season, which would require a 63-d breeding season without estrous synchronization. Calving distribution is also shortened, resulting in 1) older (earlier birth date) and heavier (days x average daily gain) calves at weaning and 2) increased uniformity among calves (less difference in age between calves born at the beginning and end of the calving season, Higgins, 1981; Odde, 1990; Short et al., 1990, 1994; Gaines et al., 1993; Wallace, 1998; Sprott, 1999; DeJarnett, 2001; Stenquist and Geary, 2001a,b; Stenquist, 2001). Higgins (1981) reported that synchronized cows conceived approximately 4 d earlier than non-treated cows. Calves from synchronized cows were 7.7 d older and 6.5 kg heavier than those out of non-treated cows. Gaines et al. (1993) estimated 3.8 kg of body weight and $2.00 of profit gain per calf and Lowman et al. (1994) reported that the estrous synchronization programs with AI shortened breeding season for 13 d and £10 of profitability gain per cow exposed.

Improved Management

Artificial insemination facilitates crossbreeding in some instances, and can improve herd quality because of the availability of genetically proven sires. A short breeding season may contribute to maintaining a 365-d of calving interval. When the breeding season is shortened, calving distribution should be less variable. Cows may calve earlier, permitting a longer PPI prior to the next breeding season. A longer PPI may improve necessary postpartum fertility (Odde, 1990; Short et al., 1990, 1994; Wallace, 1998; Sprott, 1999; DeJarnett, 2001; Stenquist and Geary, 2001a; Stenquist, 2001).

As reviewed in the previous section, some synchronization protocols can increase the number of females cycling at the beginning of the breeding season and induce estrous cycles in anestrous cows and prepubertal heifers. Using estrous synchronization with a defined breeding season may increase overall pregnancy rate, which may lower culling and replacement rates when non-pregnancy is the main reason behind annual culling decisions (Stenquist and Geary, 2001a). Development or purchase of replacement heifers represents a significant cost in cow-calf operations because of higher nutrition demands than mature cows (Tess, 1999). Also, the costs of synchronization agents used in the synchronization programs might be covered by the expected profitability and short AI period follows the concentrated labor for estrous detection that will be decreased relative to when synchronization is not applied (Higgins, 1981; Gaines et al., 1993; Wallace, 1998; Sprott, 1999; Stenquist and Geary, 2001a; Stenquist, 2001). Figure 3 depicts these prospects.

Simulation Models

Conducting experiments to evaluate entire production systems is difficult, expensive, and impractical to replicate. Hence, models are useful alternatives when real life is out of human comprehension and knowledge (Whittemore, 1986). Considering the large number of combinations of management options within the beef industry and the resources and time required to experimentally evaluate cattle enterprises, computer simulation is an important alternative for evaluating total systems (Naazie et al., 1999; Tess and Kolstad, 2000a). Simulation models offer methods by which various combinations can be tested at low costs in a short time (Bourdon and Brinks, 1987a).

This section will review: 1) simulation studies which evaluated reproductive management strategies, 2) key variables of simulation models to express reproductive events with numerical methods, and 3) the relevance of computer simulation models to this study.

Simulation Studies of Reproductive Traits
(Key Variables, Strategies, and Results)

The simulation model used by Bourdon and Brinks (1987b,c) was a modified version of the Texas A&M model (Sanders and Cartwright, 1979a,b). Bourdon and Brinks (1987b) simulated fertility as a function of two factors: the probability of estrus and the probability of conception. To determine both probabilities, they considered BCS, weight change, PPI (cows), maturity (heifers) and a fixed potential for cycling (or conception). Their results indicated that an increase in age at puberty decreased economic efficiency. Also, the increased potential for fertility by keeping older cows decreased biological efficiency. They concluded that survivability of calves might be a more important factor in reproduction than fertility. In their companion paper, Bourdon and Brinks (1987c) simulated the effects of various culling strategies on biological and economic efficiency. They simulated different culling ages and sex-controlled production of calves. For economic efficiency, they simulated costs rather than income. Their results indicated that culling cows at younger ages increased biological efficiency, but not necessarily economic efficiency. Simulated optimal culling for economic efficiency was 8 yr of age.

Johnson and Notter (1987a,b) developed a stochastic simulation model of reproduction to investigate the relationship between underlying genetic variation in reproductive potentials and resulting phenotypic expression on reproductive ability. They generated phenotypic values of both PPI and single-service conception rate as functions of two presumed underlying continuous genetic variables. Their simulated outputs were: date of first service, first-service conception rate, number of services during a 63-d breeding season, annual conception rate, calving date, 205-d adjusted calf weaning weight, and PPI. By comparing their results with values found in the literature, they found that their model could provide a reasonable simulation of bovine reproductive performance. They suggested that culling open cows reduced genetic variances of derived reproductive traits. Subsequently, Notter and Johnson (1987, 1988) used this model to estimate breeding value of reproductive traits under AI or pasture mating systems. However, this model did not include the analyses of ranch profitability.

Azzam et al. (1990) modeled reproductive events as stochastic variables. One constraint of their model was the lack of separate variables regarding nutrition and body condition, and the annual variability in pasture quality. They simulated the effect caused by the length of breeding season and reported that a short breeding season (45 d) resulted in higher weaning weight and older age in calves than 70-d or 120-d breeding seasons. This model did not include economic analyses. Later, Azzam and Azzam (1991) used this model to produce pregnancy rates as inputs for their decision model to analyze age of cow, reproductive status (pregnant or non-pregnant), different breeding seasons (summer or winter), various culling and replacement decisions (whether non-pregnant cows should be retained until the next breeding season), and their effects on net income. Their results showed that net incomes were maximized when all open cows were culled and replaced by pregnant heifers in the fall.

Werth et al. (1991a,b) used this reproductive model (Azzam et al., 1990) to simulate reproductive performance. Outputs from the model were used as inputs into an economic model which calculated net income of the operation. They stated that a short breeding season (less than 45 d) reduced the chances of pregnancy among cows. Hence, it might increase a number of non-pregnant cows although uniformity in calf age and size were expected. They stated the opposite prospect for a long breeding season (more than 70 d); that is, increased number of pregnant cows, and more calves would be weaned with younger age and lighter weight compared with those from a short breeding season. The length of simulated breeding season was 45, 70, or 120 d. They analyzed the interaction between the length of breeding season and 1) the length of PPI (48, 65, or 90 d; Werth et al., 1991a), or 2) the conception rate at first service (50, 60, 70, or 80%; Werth et al., 1991b). Their results indicated that PPI of moderate length increased the net income and that the optimum length of the breeding season might depend on the conception rate at first service. Also, they suggested that breeding heifers 3 wk before cows provided an economic benefit when PPI was long and when first service conception rate was low. Finally, they concluded that a long breeding season (more than 70 d) was more beneficial than a short one (less than 45 d). Selling light calves born late would be more profitable than selling non-pregnant cows resulting from a short breeding season.

A Model in Use

Although there are many simulation models, each one was developed or modified for a particular situation, i.e., regions, specific management decisions, or operation systems. Hence, the objectives and the concepts of each model are different from each other, including this study. Furthermore, as reviewed above, some constraints should be considered in each model, and few models can analyze enterprise profitability besides biological simulation of cattle. However, the Montana State University (**MSU**) model developed by Tess and Kolstad (2000a,b) performed well in simulating biological and economic efficiencies and profitability of the cow-calf operations in the Northern Great Plains and the Rocky Mountain West.

The MSU model is a dynamic model which includes both deterministic and stochastic components. Stochastic models include random variables among individuals and simulate individual animal performance, while deterministic models simulate only the mean performance of the group. Hence, stochastic models can simulate more realistically than deterministic models (Azzam et al., 1990). The output from a stochastic model can be compared with that of a real system which uses conventional statistical methods because both sets of outputs are random variables (Dent and Blackie, 1979).

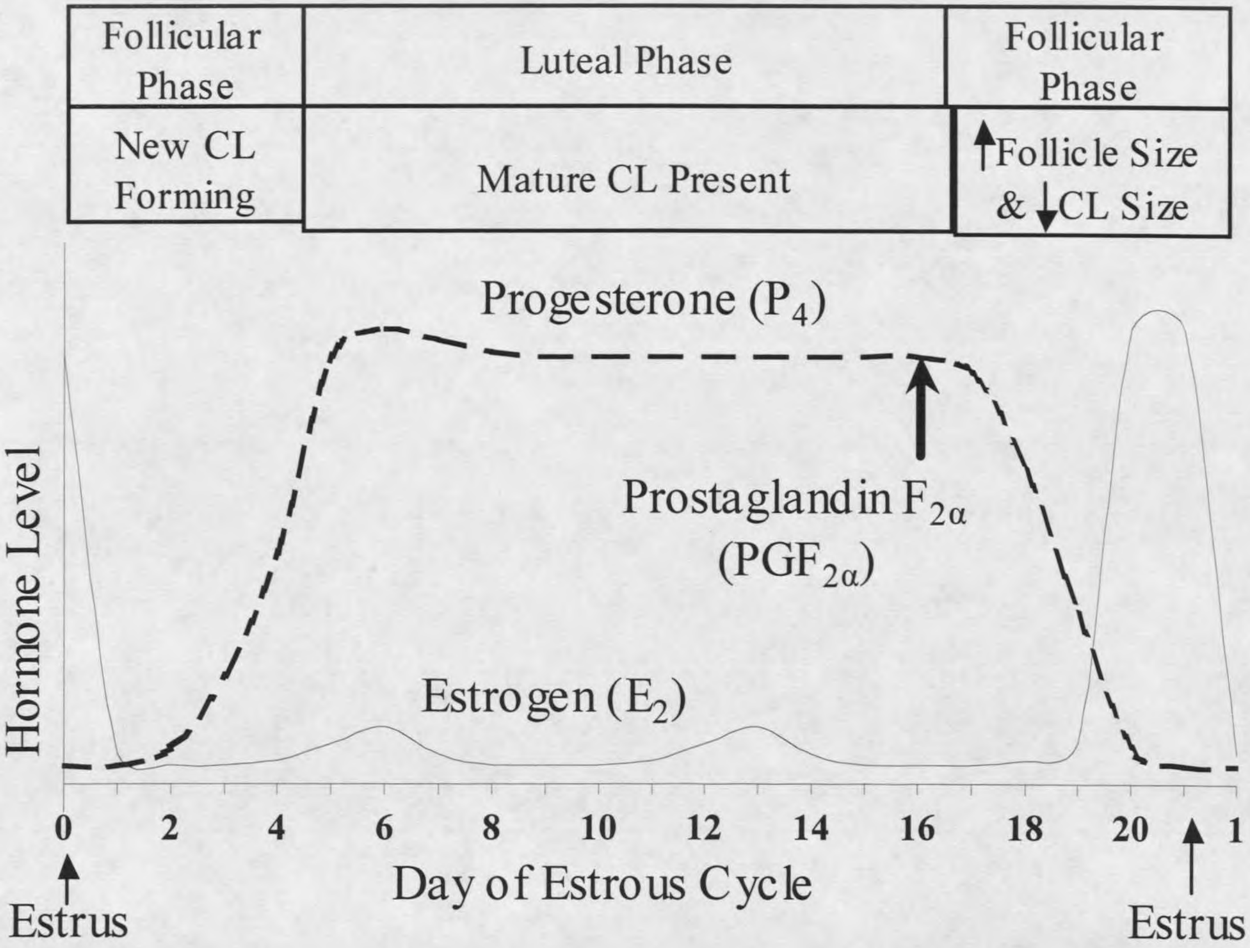

Figure 1. Bovine estrous cycle