Evaluation of a single injection PGF□2□a estrous synchronization system
by Charles Kent Higgins

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in ANIMAL SCIENCE
Montana State University
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Abstract:
Three years of breeding, calving, and production records were utilized to evaluate a single injection PGFgg system for estrous synchronization in range beef cattle. Reproductive performance, effects on calf weaning weight, effects of two years sequential treatment and costs for PGFgct-Synchronized (n=566) and non-synchronized control (n= 575) cattle were analyzed. Non-treated controls were artifically inseminated (Al) 8-12 hours after first observation of standing estrus. Treated cattle received PGF2α (25 mg free acid) either in the PM of day 4 (1975) or AM of day 5 (1976 and 1977) of breeding unless they had been observed in estrus prior to those times. Inseminations to detected estrus continued in treated cattle until 80 + 4 hr post-PGF2α when all remaining undetected animals were mass inseminated and recorded as nonestrus bred. Breeding seasons consisted of 25 days Al plus 20 days natural service (1975 and 1976) or 8.5 days Al plus 48.5 days natural service (1977). For two year treatment analysis cattle were allotted to one of four treatment sequences: (CC) nonsynchronized control for two consecutive years; (CT) control in year I and PGF2α system in year 2; (TC) PGF2α system in year I and control in year 2; (TT) PGF2α system for two consecutive years. Cost assumptions for a 10 day PGF2α and 21 day control system were $3.00/hr labor, $6.75/ unit semen cost, aid $4.50/25 mg PGF2α (treated cattle only) Results demonstrated that Al first service conception rates for control (62.9%) and treated (62.1%) cattle bred to an observed estrus were not significantly different, but were greater (P < .01) than that for treated cattle bred nonestrus (12.3%). Reduced conception rate in the non-estrus bred subgroup resulted in lower (P < .01) conception rates for all cattle in the PGF2α system (38.3%) vs controls (62.9%). Considerable proportions (14.0 to 35.7%) of nonestrus bred cattle were reinseminated three to four days after appointment breeding, indicating these cattle responed to PGF2α but were bred too early relative to ovulation. Pregnancy rate at day 10 (PR10) of breeding for treated cattle was greater (P < .01) than controls. Pregnancy rate at day 25 (PR25) and total pregnancy rate (TPR) were not different. Pregnancy rate at day 32 (PR32) was higher (P < .01) in treated cattle (65.9%) than in controls (56.7%) in the pooled analysis. A trend for an earlier (P < .05) average day of conception in treated cattle was observed. In the two year sequential treatment study, PR10 for CC, CT, TC, and TT were 21.1, 45.5, 24.8 and 43.7 percent, respectively, with CT and TT greater (P < ,01) than CC and TC. PR25, PR32 and total pregnancy rates were not significantly different. Comparison of a 10 day PGF2α and a 21 day control system demonstrated similar pregnancy rates but calves out of synchronized cows were older (P < .01) and heavier (P < .10) than those out of control dams. However, total breeding cost per treated cow ($12.48) was more than double the cost for controls ($6.12), despite reduced labor cost in the PGFgct system.

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EVALUATION OF A SINGLE INJECTION $PGF_{2\alpha}$ ESTROUS SYNCHRONIZATION SYSTEM

by

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ABSTRACT

Three years of breeding, calving, and production records were utilized to evaluate a single injection $PGF_{2\alpha}$ system for estrous synchronization in range beef cattle. Reproductive performance, effects on calf weaning weight, effects of two years sequential treatment and costs for $PGF_{2\alpha}$-synchronized (n=566) and non-synchronized control (n=575) cattle were analyzed. Non-treated controls were artifically inseminated (AI) 8-12 hours after first observation of standing estrus. Treated cattle received $PGF_{2\alpha}$ (25 mg free acid) either in the PM of day 4 (1975) or AM of day 5 (1976 and 1977) of breeding unless they had been observed in estrus prior to those times. Inseminations to detected estrus continued in treated cattle until 80 $\pm$ 4 hr post-$PGF_{2\alpha}$ when all remaining undetected animals were mass inseminated and recorded as nonestrus bred. Breeding seasons consisted of 25 days AI plus 20 days natural service (1975 and 1976) or 8.5 days AI plus 48.5 days natural service (1977). For two year treatment analysis cattle were allotted to one of four treatment sequences: (CC) nonsynchronized control for two consecutive years; (CT) control in year 1 and $PGF_{2\alpha}$ system in year 2; (TC) $PGF_{2\alpha}$ system in year 1 and control in year 2; (TT) $PGF_{2\alpha}$ system for two consecutive years. Cost assumptions for a 10 day $PGF_{2\alpha}$ and 21 day control system were \$3.00/hr labor, \$6.75/unit semen cost, and \$4.50/25 mg $PGF_{2\alpha}$ (treated cattle only) Results demonstrated that AI first service conception rates for control (62.9%) and treated (62.1%) cattle bred to an observed estrus were not significantly different, but were greater ($P < .01$) than that for treated cattle bred nonestrus (12.3%). Reduced conception rate in the nonestrus bred subgroup resulted in lower ($P < .01$) conception rates for all cattle in the $PGF_{2\alpha}$ system (38.3%) vs controls (62.9%). Considerable proportions (14.0 to 35.7%) of nonestrus bred cattle were reinseminated three to four days after appointment breeding, indicating these cattle responed to $PGF_{2\alpha}$ but were bred too early relative to ovulation. Pregnancy rate at day 10 (PR10) of breeding for treated cattle was greater ($P < .01$) than controls. Pregnancy rate at day 25 (PR25) and total pregnancy rate (TPR) were not different. Pregnancy rate at day 32 (PR32) was higher ($P < .01$) in treated cattle (65.9%) than in controls (56.7%) in the pooled analysis. A trend for an earlier ($P < .05$) average day of conception in treated cattle was observed. In the two year sequential treatment study, PR10 for CC, CT, TC, and TT were 21.1, 45.5, 24.8 and 43.7 percent, respectively, with CT and TT greater ($P < .01$) than CC and TC. PR25, PR32 and total pregnancy rates were not significantly different. Comparison of a 10 day $PGF_{2\alpha}$ and a 21 day control system demonstrated similar pregnancy rates but calves out of synchronized cows were older ($P < .01$) and heavier ($P < .10$) than those out of control dams. However, total breeding cost per treated cow (\$12.48) was more than double the cost for controls (\$6.12), despite reduced labor cost in the $PGF_{2\alpha}$ system.

Introduction

Beef producers in the United States have been reluctant to accept artificial insemination (AI) mainly due to added labor requirements associated with estrus detection and required changes in overall management practices.

Techniques for estrous synchronization have been extensively studied during the last two decades in attempts to reduce or eliminate estrus detection while maintaining normal fertility. Prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) has been among the most successful agents for this purpose and is commercially available. However, data is scarce regarding carryover effect of successive years synchronization, effects on calf weaning weight, and economic comparisons between $PGF_{2\alpha}$ synchronization/AI and conventional AI breeding systems. The objectives of this study were to determine these relationships by comparing a single injection $PGF_{2\alpha}$/AI system with a conventional AI system.

Chapter 1

Artificial Insemination and Its Role in Herd Improvement

The advent of AI was one of the most important contemporary discoveries contributing to cattle improvement. The procedure has provided opportunity for progress by several means. Potential for genetic progress has been enhanced through the availability of proven AI sires. An inherent improvement in herd identification, record keeping, and other management practices has allowed producers to capitalize on that genetic potential.

Extensive evidence of increased use of AI and herd improvement in the dairy industry has been offered during the last three decades. From 1951 to 1959, production trends of a well managed dairy cow population in New York state showed a superiority of 28 and 48 percent in milk yield and butterfat production, respectively, for artificially sired cows over those naturally sired (Van Vleck and Henderson, 1963). Blom (1968) documented 35 and 46 percent increases in annual milk production for Red Danish and Danish Friesian breeds, respectively, during the period 1940-1965 in Denmark. Utilization of genetically superior sires through AI increased breeding values for Holstein cows in first lactation from an average of 6 kilograms (kg) per year for 1960-1965 to 28 kg per year for 1970-1975 (Powell et al., 1977). Additional evidence of improved production potential with AI was

offered by Britt (1979) who reported 277 kg higher breeding values for milk yield of sires produced by AI-sired Holstein cows over those produced by naturally sired dams in 1965. This advantage had increased to 527 kg by 1975. Use of proven AI sires coupled with improved nutrition and management practices has resulted in greater than 100 percent improvement in total milk production per dairy cow since 1945 in the United States (U.S. Dept. Ag., 1979). In 1945 less than one percent of lactating dairy cows in the U.S. were artificially bred as compared to an estimated 65 percent in 1980 (Freeman, 1980). Although not as well documented, beef producers have realized improved production through use of superior AI sires. In Montana, AI sired steer calves weighed 27 and 32 kg more at weaning than naturally sired calves in 1961 and 1962 (Mosher, 1964). In a Colorado beef herd, annual average weaning weights improved 61 kg (16 %) during a six year period following implementation of AI, with a 64 kg (24 %) increase in production per animal unit (a.u.)(Syntex, 1976). On several Washington ranches AI sired calves averaged 23 kg heavier than naturally sired calves (Rogers, 1973). In Wyoming, AI sired calves weighed 5.4 kg more at weaning then naturally sired calves (Stevens and Mohr, 1969).

Use of AI in beef cattle has been limited, as less than five percent of U.S. beef cows are artificially bred (Beverly, 1978). Evidence indicative of the lack of top sire use was offered by

Wallace (1980) who reported that offspring of the top 10 Angus and Hereford sires based on number of registered progeny represented only 3.6 and 2.7 percent of total registrations, respectively.

Estrus detection and associated problems have been repeatedly cited as the major deterrent to beef AI. Overemphasis of this problem has perhaps masked other reasons for restricted AI use. Producer resistance to necessary changes in overall management practices may be equally important (Tilton et al., 1973). Use of AI in the beef industry has been largely limited to enterprises characterized by small herd size. Range operations characterized by low cow densities per unit of pasture land have made little use of AI. With introduction of European breeds in the late sixties and early seventies, AI increased in popularity by providing a means of rapidly introducing seedstock whose offspring often commanded premium prices at that time (Black, 1972). Lack of widespread AI in range beef operations prompted research in estrous synchronization. An effective, economical means of controlling and grouping estrus and ovulation in range cows would likely make beef AI more acceptable (Britt, 1979).

Improved beef production resulting from AI has been partially attributable to factors other than superior genetics. Short breeding and calving periods (i.e. 45 to 60 days) have enhanced reproductive efficiency in beef herds (Roberts et al., 1970), provided proper management was maintained (Wiltbank, 1974). Improved management

necessary for quality AI has resulted in shorter breeding and calving seasons in beef herds. Between 1970 and 1975, AI management resulted in a 46 percent increase in proportion of yearling heifers bred during the first three weeks of the breeding season, subsequently resulting in 65 percent more heifers calving during the first 21 days of calving (Syntex, 1976). Pancake (1963) indicated that better management of the cow herd due to a progressive AI program resulted in 95 percent of 220 cows exhibiting estrus during a 25 day breeding period. Woodward (1963) reported 314 of 328 cows bred by AI in a 25 day breeding period.

First service pregnancy rates obtained in artificial breeding programs have varied with management and technician skill; estimates range from 25 to 95 percent, with averages of 60 to 70 percent (Gregory, 1966; American Breeders Service, 1974; Donaldson 1976; Donaldson, 1977a).

1.1 Cost/Return Comparisons

Change in income resulting from any operational transition in a given enterprise hinges on 1) additional costs and reduced returns or income-reducing factors and 2) additional returns and reduced costs or income increasing components (Herbst, 1976). Financial gain or loss encountered from implementation of an AI program is dependent on two broad factors; 1) change in breeding costs with AI versus natural ser-

vice and 2) change in value of AI calves. Highly accurate evaluation of cost-return differences would require use of individual sires both naturally and artificially within the same herd (Tilton et al., 1973).

Results from limited studies regarding economic comparisons of natural and artificial breeding vary widely. Reasons for this variation include ranch size and geographic location, differences in semen and labor charges, percentage calf crop, use of straightbreeding vs. crossbreeding systems, and year differences which include selling price variations (Herman, 1967; Stevens and Mohr, 1969; Learmonth, 1973; Rogers, 1973; Syntex, 1976, Tilton et al., 1973; and Sorensen, 1979).

Direct, additional cost factors encountered in AI over those of natural service include labor for estrus detection and insemination, semen, field tank rental and liquid nitrogen, breeding supplies, special facilities, and occasional expense for high quality feed during the breeding season (Stevens and Mohr, 1969 and Rogers, 1973). Stevens and Mohr (1969) reported 12 of 37 commercial cow calf ranches in Wyoming had lower breeding costs per calf weaned with AI versus natural service; herds with lower costs had higher detection and conception rates. Some sources indicate that breeding costs per AI calf are comparable with natural service, with semen and labor costs recognized as the two largest single items associated with AI

(Learmonth, 1973; Syntex, 1976, Tilton et al., 1973). Contrastingly, Sorensen (1979) reported less cost per cow bred AI compared to natural service when purchase costs of bulls used for natural breeding varied from 400-1000 dollars per head.

Increased value of AI calves primarily results from price premiums received and heavier weaning weights (Perry, 1968 and Stevens and Mohr, 1969). In the latter report with relatively low feeder calf prices existing (< 30 $/cwt.), purebred and commercial ranches average financial gain per AI calf weaned amounted to $30.02 and $3.31, respectively, over those breeding via natural service. Herman (1967) reported that 15 to 30 dollars per head increase in value of weaner calves could be obtained by AI use. Singleton and Petritz (1975) estimated net economic advantage per AI calf at $7.92.

Of significant importance, although difficult to accurately estimate, is increased value of replacement heifers due to superior genetic makeup. Wyoming producer estimates of added value obtained per AI replacement averaged $10.10 per head based on information from 37 commercial operations (Stevens and Mohr, 1969). These estimates were derived from market sales information and expressed producer willingness to pay extra for AI heifers.

Additional income may be derived from sale of calves and cull cows from increased cow numbers made possible by reduced bull numbers. Large ranches (> 750 a.u.) in Washington returned an additional 850

dollars from sale of additional steer and heifer calves and cull cows during years of depressed cattle prices (Rogers, 1973). Reduced bull maintenance expense was reported as an important contributing factor in net returns of ranches in the same study. Rogers (1973) stated that AI increased net ranch income by 3.2, 7.9, and 7.4 percent for small ($\leq$ 80 a.u.), medium ($\leq$ 356 a.u.) and large ranches ($\leq$ 754 a.u.), respectively.

The above evidence indicates that AI can increase profits over those from natural service in purebred and commercial beef operations. Good management and efficient, determined personnel are the keys to this potential. Reported causes of dollar losses in beef cattle AI programs involving over twelve thousand animals in order of importance were inadequate estrus detection, reduced inseminator efficiency, inadequate nutrition, and infectious reproductive diseases (Donaldson, 1977a). All of these factors can be controlled by management.

Chapter 2

Bovine Estrous Cycle

The bovine female reproductive system undergoes a rhythmical change referred to as the estrous cycle, which may be viewed as a series of events dependent on neuroendocrine pathways for successful completion and repeatability. Endogenous governing factors of reproduction include endocrine glands, reproductive hormones, target organs (i.e. ovary), and the nervous system.

Principal events of the cycle may be grossly divided into those associated with follicular growth and those with growth of the corpus luteum (CL). Well-known periods of the 20-21 day cycle occurring in a sequential manner are estrus (day 0-1), metestrus (2-4), diestrus (5-17), and proestrus (18-20).

2.1 Sequence of Events

The following review of cyclic sequences will consider post-ovulatory CL development as the initial event. Use of any initial step in description of sequential events of the cycle inevitably requires explanation of occurrences immediately preceding that step.

2.1.1. Post Ovulatory CL Development and the Luteal Phase

Days 2-4 (metestrus) following ovulation are characterized by conversion of granulosa and theca interna cells to progesterone-

secreting structures that eventually form functional CL (Manns and Hafs, 1976). LH is involved in this developmental period and evidence indicates that cyclic-Amp mediates LH action in inducing luteinization and progesterone synthesis (Espey, 1974). Following ovulation, progesterone levels rise gradually for two to three days coincident with CL development (Cupps, 1972), with some reports of slight but distinct depressed levels at day 4 of the cycle (Sprague et al., 1971 and Hansel and Echternkamp, 1972); CL begin functional progesterone secretion at approximately day 5. The principal function of the CL in nonpregnant cows is control of the length of diestrus (days 5-17) (Melampy and Anderson, 1968). Elevated progesterone during this period exerts negative feedback effects on the hypothalamo-hypophyseal system thereby inhibiting episodic gonadotropin release (Lamming, 1973). Short (1972) suggested that inhibition of gonadotropin release by progesterone might be mediated through suppression of the hypothalamo-hypophyseal system's ability to respond to estrogen of follicular origin during the luteal phase. Progesterone concentrations in peripheral plasma and luteal tissue generally parallel the growth curve of the CL throughout the luteal phase of the cycle, with peak levels (3.9-8.4 ng/ml) occurring at days 14-16 (Zolman et al., 1974; Glencross et al., 1973; Christensen et al., 1974; Chenault et al., 1975). Regulation of LH binding sites controls progesterone production by the CL and it is reported that LH may not autoregulate its own luteal

receptors (Spicer et al., 1980).

Waves of follicular growth occur during the luteal phase with reports of diphasic (Rajakoski, 1960) and/or triphasic (Bane and Rajakoski, 1961) growth periods throughout the cycle. It has been disclosed that often noted mid-cycle estrogen increases originate from an early wave (days 3-10) of increased follicular activity (Smith et al., 1975), although these mid-cycle follicles undergo atresia and are, therefore, not the ovulatory follicle for that particular cycle (Lamming, 1973). Dufour et al. (1972) reported that only after day 18 did the largest follicle ovulate in a trial involving observation of largest and second largest follicles throughout the cycle. Ireland et al. (1979) revealed extremely high concentrations (12-72 ng/ml) of estrogens in follicular fluid during days 5-10, suggesting that they may play integral physiological roles in mid-cycle follicular development.

The physiological significance of temporary mid-cycle estrogen peaks is uncertain. High progesterone levels during this period apparently do not prevent such a rise. Lamming (1973) conjectured that elevated estrogen during the luteal phase might be useful for uterine receptivity of the embryo or for transport of the fertilized ovum. Cupps (1972) recognized the large variations between cows and between cycles with respect to increased estrogen during diestrus and suggested a random pattern similar to that shown by FSH secretion.

Concannon (1972) postulated that this rise may initiate or precipitate normal luteolytic processes in the cow. Cowley et al. (1979) reported that midcycle follicles are important to initiation of luteolysis. It is suggested that estradiol levels during diestrus mediate tonic FSH secretion and subsequent follicular development and that this mechanism increases LH receptor sites within the ovary to facilitate luteotropic mechanisms and ovulation (Cumming, 1975). Mid-luteal estrogen peaks reportedly correspond to occurrence of "short cycles" and may reach sufficient levels for expression of behavioral estrus (Sorensen, 1979).

2.1.2. Luteolysis

The uterus plays a dominant role in regulation of CL lifespan and cyclic periodicity through local release of a luteolytic substance at days 17-19 in the non-pregnant, normally cycling cow. Hysterectomy and ovarian transplant studies with ewes indicate that uterine release of luteolysin is local. Prolongation of CL lifespan was observed when ewes and cows were hysterectomized (Wiltbank and Casida, 1956). Unilateral CL regression has been observed on the side of the conserved uterine horn in partially hysterectomized ewes (Inskeep and Butcher, 1966). Cumming (1975) provided the following evidence which indicates that uterus and ovary must be in close proximity for normal luteolysis in the ewe and cow: 1) uterine excision extends CL lifespan; 2) partial uterine removal extends CL lifespan in proportion to the amount

removed; this effect is confined to the CL adjacent to the portion of uterus removed; 3) transplantation of ovaries to other sites (i.e. neck) within the body lengthens the cycle; 4) uterine transplantation with ovary remaining *in situ* results in prolonged CL life; 5) transplantation of both ovary and uterus together as a single unit of tissue results in normal cyclical function and length; 6) infusion and cross-circulation experiments demonstrate luteolysin in utero-ovarian venous blood at the time of luteolysis.

Much evidence suggests that $PGF_{2\alpha}$ is "the" luteolysin in cows (as reviewed by Stabenfeldt *et al.*, 1978). Neurohormonal mechanisms initiating uterine release of $PGF_{2\alpha}$ at days 17-19 are not well understood, but estrogens appear to be involved (Inskeep, 1973). Goldberg and Ramwell (1975) and Warren *et al.* (1979) reported that estrogen appeared to stimulate uterine prostaglandin synthesis and postulated that rising estrogen levels from growing follicles in late luteal phase may initiate the luteolytic mechanism. McCracken *et al.* (1972) reported that prostaglandin secretion is under estrogen influence. Hansel and Echternkamp (1972) speculated that rises in plasma estrone observed prior to CL regression in cows might be involved in initiation of luteolysis, perhaps through its action on the endometrium. Furthermore, estrogens involvement in luteolytic mechanisms are supported by evidence that estradiol injections cause early regression of CL in heifers with intact uteri (Wiltbank *et al.*, 1961; Brunner *et*

al., 1969; Watson et al., 1980).

Mechanisms of $PGF_{2\alpha}$-induced luteolysis are not as yet unequivocably defined. Some plausible actions include a direct toxic effect on the CL (Henderson and McNatty, 1975), and reduction of ovarian blood flow through vasoconstrictive properties (Goldberg and Ramwell, 1975). More detailed discussion of $PGF_{2\alpha}$ and its effects is presented in Chapter 3.

$PGF_{2\alpha}$ from the uterus via counter-current mechanisms (McCracken et al., 1972), whereby $PGF_{2\alpha}$ diffuses directly from the uterine vein into the ovarian artery at days 17-19, cause CL regression and a concomitant rapid decline in systemic levels of progesterone (Robinson, 1977). Based on levels of plasma progesterone, no animal had lost luteal function by 5 days before estrus (Garverick et al., 1971); however, between day - 5 and - 4 a representative group of cows in this study exhibited more than a 50 percent decrease in plasma progesterone. Other documentation indicates that peak progesterone levels decline by at least 50 percent in 24-48 hours during luteolysis (Henricks et al., 1971; Wetteman et al., 1972; Robertson, 1972; Chenault et al., 1975). These reduced progesterone levels may directly stimulate gonadotropin release or remove a hypothalamo-hypophyseal block that permits release of gonadotropin during proestrus and estrus (Bearden and Fuquay, 1980).

2.1.3 Events Leading to Estrus and Ovulation

During proestrus (days 18-20), follicular growth is enhanced due to progesterone withdrawal following CL regression. Wise et al. (1980) reported that ovarian blood flow and progesterone changes were positively correlated, with lowest blood flow observed during proestrus. With CL demise and development of follicles, estrogen is produced in significant quantities (Wetteman et al., 1972), which is important in onset of sexual receptivity as well as initiation of events leading to preovulatory gonadotropin release (Manns and Hafs, 1976). Reciprocal changes in plasma levels of progesterone and estrogen determine the appearance of behavioral estrus and ovulation (Shemesh et al., 1972).

It is generally accepted that the pre-estrus estrogen peak triggers preovulatory surges of LH and FSH from the pituitary. Rising estrogen levels evoke positive feedback effects on the hypothalamo-pituitary axis stimulating GnRH release (Erb et al., 1971) which in turn cause LH and FSH release (Lamming et al., 1979 and Kesner and Convey, 1979). Pre-estrus estrogen peaks occur 12-24 hours prior to estrus onset (Christensen et al., 1974 and Smith et al., 1975) and precede pre-ovulatory LH and FSH release which coincide with estrus onset (Sprague et al.,1971 and Chenault et al., 1975). Preovulatory gonadotropin surges are usually of short duration, usually returning to basal levels within 18-24 hours (Geschwind, 1972).

Estrogen declines rapidly during estrus (Staigmiller et al., 1979), usually returning to basal levels during that period. Shemesh et al. (1972) reported that many cows permitted mating at a time when estrogen levels were at their lowest point during estrus.

Ovulation in the cow occurs approximately 10-12 hours following estrus completion (Thibault and Levasseur, 1974; Chenault et al., 1975). Espey (1974) described ovulation and follicular rupture. During ovulation, appropriate LH and FSH stimulation initiate a substantial increase in cyclic-Amp which result in significant elaboration of a zymogen enzyme (possibly collegenase). The connective tissue in the follicular wall is progressively degraded due to the action of this enzyne which results in gross reduction in tensile strength. The thin region at the apex of the follicle is most susceptible to distension under the stress of a small degree of intrafollicular pressure, with rupture imminent as follicle walls dissociate under this stress. Rondell (1970) reported that intrafollicular pressure is not involved in rupture of follicles.

If the preceding sequence of events fails to result in conception, they will be repeated in the next estrous cycle.

Chapter 3

Role of $PGF_{2\alpha}$ in Bovine Reproduction

Prostaglandins (PG's) are 20-carbon hydroxylated fatty acids containing cyclopentane rings at C-8 to C-12 (Hansel et al., 1976). Naturally occurring PG's are all derivatives of prostanoic acid, with six different series (A,B,C,D,E,F) exhibiting structural differences in the cyclopentane ring (Lehninger, 1977). Biosynthesis of PG's initiates with essential fatty acids, with $PGF_{2\alpha}$ originating from linoleic acid (Montgomery, 1977).

PG's were initally thought to originate in prostate glands, hence the term prostaglandin; Lauderdale (1974) reviewed evidence that the compounds occur in most mammalian tissues. The same author further indicated that bioactivity of PG's is primarily due to alteration of smooth muscle contractility and modulation of hormonal activity.

Babcock (1966) first suggested that PG might be the naturally occurring uterine luteolytic factor in bovine females. Since that speculation, evidence that maximal $PGF_{2\alpha}$ levels occur in endometrium, ovarian venous plasma, and uterine fluids at days 15 to 19 of bovine estrous cycles (Shemesh and Hansel, 1975 and Lamothe et al., 1977) coupled with documentation of exogenous $PGF_{2\alpha}$-induced luteolysis when administered during the luteal phase (days 5 to 17) of estrous cycles as previously discussed leaves little doubt of direct involvement of $PGF_{2\alpha}$ in normal CL regression in cycling bovine females.

3.1 Role of $PGF_{2\alpha}$ in Luteolysis

Precise mechanisms of $PGF_{2\alpha}$ involvement in events of CL regression have not been determined. Phariss et al. (1972) outlined five possible mechanisms by which $PGF_{2\alpha}$ mediates luteolysis.

The importance of hypothalamic-hypophyseal communication for control of ovarian activity and CL function led to the hypothesis that $PGF_{2\alpha}$ might initiate luteolysis by interfering/blocking normal luteotropic function at the hypothalamus and/or pituitary. Phariss et al. (1972) provided evidence that this is not the case in laboratory rodents, but little information was presented regarding bovines. Low dosages of $PGF_{2\alpha}$ when given systemically in the cow are ineffective in causing luteolysis but identical dosages administered in the ovarian artery cause CL demise (Lamond et al., 1973). Greene (1977) suggested that if $PGF_{2\alpha}$ mediates luteolysis through inhibition of hypothalamic/hypophyseal control mechanisms then the process (luteolysis) should occur throughout the estrous cycle. Although this theory is questionable, exogenous $PGF_{2\alpha}$ is known to cause regression of only functional CL (days 5 to 17). Previous discussion of local uterine control of CL lifespan in the cow along with proof of rapid metabolic clearance of $PGF_{2\alpha}$ (Karim, 1975) suggests that the compound does not direct its effects on the hypothalamo-pituitary axis in causing luteolysis. Evidence of normal LH release following $PGF_{2\alpha}$ (Chenault et al., 1975) further disproves this postulate.

Supposition that $PGF_{2\alpha}$ might cause uterine release of unidentified luteolysin/s (Phariss et al., 1972) was disproven upon demonstration that exogenous $PGF_{2\alpha}$ caused CL regression in hysterectomized cows (Lavoie et al., 1975 and Stellflug et al., 1975).

Induced biochemical alterations in bovine ovaries/CL simulating a "toxic" effect is a possible mechanism of $PGF_{2\alpha}$ involvement in luteolysis (Phariss et al. 1972). Henderson and McNatty (1975, 1977) reported inhibition of progesterone synthesis by $PGF_{2\alpha}$ in granulosa cells in vitro. In the earlier report, these authors hypothesized that $PGF_{2\alpha}$ interfered with gonadotropin stimulation of adenyl cyclase enzyme resulting in abolition of cyclic-Amp and, therefore, decreased progesterone synthesis. The more recent report suggested a "see-saw", antagonistic situation between ovarian receptors for LH and $PGF_{2\alpha}$. It was postulated that saturation of LH receptors by LH may prevent binding of $PGF_{2\alpha}$ to its respective sites and, conversely, occupation of $PGF_{2\alpha}$ sites inhibits interaction of LH with its receptors. Evidence of tight LH binding and a gradual dissociation (several days) was presented. It was proposed that following preovulatory LH surges, saturation of LH binding sites occurs, thereby masking $PGF_{2\alpha}$ receptors for a period of time. This represents plausible explanation as to why $PGF_{2\alpha}$ fails to cause luteal regression in bovines until approximately day 5 of the cycle. Gradual dissocation of LH from its receptors result in concomitant unmasking of $PGF_{2\alpha}$ receptors causing CL to

become increasingly susceptible to lytic action of the compound. These theories are supported by earlier reports that relative binding of $PGF_{2\alpha}$ to bovine CL and luteolysis were associated (Kimball and Lauderdale, 1975) and that $PGF_{2\alpha}$ may cause reduced gonadotropin binding capacity of CL (Hichens et al., 1974).

Evidence opposing LH saturation of luteal receptors in protecting CL from $PGF_{2\alpha}$ was provided by Gonzales-Mencio et al. (1977) who noted that LH infusions 4 hours prior to $PGF_{2\alpha}$ on days 10 to 12 in heifers failed to overcome lytic effects. Although it seems possible that by days 10 to 12 of the cycle the gradual dissociation mechanism of LH from its ovarian receptors as previously described might have progressed to conditions of irreversible $PGF_{2\alpha}$ binding, no reference was made in this regard. Additional opposition to an antiluteotropic action of $PGF_{2\alpha}$ (within ovary) was offered by Hansel et al. (1973) who reported luteotropic (increased progesterone synthesis) rather than luteolytic $PGF_{2\alpha}$ effects on bovine luteal tissue in vitro.

Another possible biochemical process of luteolysis induced by $PGF_{2\alpha}$ is lysosomal digestion of luteal cells. This has been demonstrated in ewes by McClellan et al. (1977), who reported structural degeneration of luteal cells due to increased activity of lysosomal enzymes during natural and exogenous $PGF_{2\alpha}$-induced luteolysis. These authors further indicated that activity of 3β-hydroxysteroid dehydrogenase, an enzyme required for progesterone synthesis, declined

rapidly following exogenous $PGF_{2\alpha}$.

Reduced ovarian blood supply due to vasoconstrictive effects has been postulated as another $PGF_{2\alpha}$ luteolytic mechanism (Phariss et al., 1972). Natural and exogenous $PGF_{2\alpha}$ reduces blood flow to CL-containing ovaries in ewes (Niswender et al., 1976). It was noted that CL receive a majority of blood entering entire ovaries and that during regression, along with reduced total blood volume, a shunting of blood within CL also restricts quantity available to luteal cells. Chamley and O'Shea (1976) supported vascular changes within the ovary as a component of $PGF_{2\alpha}$-induced luteolysis. Ford et al. (1977) reported that $PGF_{2\alpha}$ caused greater constriction of ipsilateral ovarian arteries than contralateral arteries and that $PGF_{2\alpha}$ potentiates vasoconstriction by facilitating release of norepinephrine from sympathetic nerve terminals rather than acting directly on smooth muscle cells.

Opposition to reduced blood flow as a direct component in luteolysis was presented by Fogwell et al. (1977) who showed total blockage of blood flow failed to result in luteal regression in ewes. Baird (as reviewed by Inskeep and Murdoch, 1980) concluded that reduction in blood flow may be a consequence of rather than a cause for CL demise.

Considering the presented evidence, it seems probable that $PGF_{2\alpha}$ plays a multi-faceted role in luteolysis. Most tenable of these elements include 1) anti-gonadotropism via receptor site competition

2) initiation of histochemical regression by lysosomes 3) reduced activity of enzymes involved in progesterone synthesis and 4) induced alterations in ovarian/CL vasculature.

Measurement of $PGF_{2\alpha}$ in blood is difficult because of rapid metabolic clearance and low concentrations; an alternative method has been to quantify the primary $PGF_{2\alpha}$ metabolite (15-keto-13, 14-dihydro-$PGF_{2\alpha}$), which has a longer half life than the parent compound (Stabenfeldt et al., 1978). Blood levels of this metabolite are elevated at the time of luteolysis (Peterson et al., 1974), and preliminary work indicates possible involvement in $PGF_{2\alpha}$-induced luteolysis (Milvae and Hansel, 1980).

An alternative hypothesis regarding CL regression is that endometrial tissue exerts its local luteolytic effects by providing the CL with one or more precursors (i.e. arachidonic acid) which are converted to $PGF_{2\alpha}$ by luteal tissue (Hansel et al., 1973). Hansel et al. (1976) provided evidence that the bovine ovary can convert arachidonic acid to $PGF_{2\alpha}$ and that sufficient levels are produced to elicit decreased progesterone and subsequent increased estrogen levels. However, complete CL regression did not occur in treated animals. Inskeep and Murdoch (1980) reviewed evidence that arachidonic acid (10 mg) injections administered into CL, follicles on ovaries with functional CL, or into lumens of ipsilateral uterine horns failed to cause luteal demise; the authors concluded that conversion of a uterine

compound to $PGF_{2\alpha}$ by CL subsequently resulting in luteolysis seemed unlikely.

3.2 Physiological Response to Exogenous $PGF_{2\alpha}$

$PGF_{2\alpha}$ has been administered via intrauterine, intravaginal, intraovarian, intramuscular, and subcutaneous routes.

3.2.1 Luteal Tissue Response

Hafs et al. (1974) found that 70 percent of original luteal tissue volume disappeared within 24 hours after 5 mg $PGF_{2\alpha}$ deposited in ipsilateral horns of Holstein cows on days 7, 11, and 15 of estrous cycles, with a majority of the remaining tissue lost during subsequent 24 hour periods. Luteal diameter (2.3 cm) in luteal phase heifers declined to 1.8, 1.2, and .6 cm at 1, 2, and 3 days following intramuscular injection of 30 mg $PGF_{2\alpha}$. Rate of luteolysis was retarded by one day and was more variable in heifers receiving 30 mg $PGF_{2\alpha}$, deposited intravaginally.

Subcutaneous administration of 30 mg $PGF_{2\alpha}$-Tham salt to cycling heifers between days 6 to 16 of estrous cycles caused CL regression within two to four days after injection (Lauderdale, 1972).

Louis et al. (1972) infused 5 mg $PGF_{2\alpha}$-Tham salt into contralateral uterine horns of cycling cows at day 11 of the cycle, resulting in decreased luteal diameter from 2.3 cm at treatment to 1.6 and .9 cm at 24 and 48 hours later, respectively. In a second trial, heifers

treated intravaginally with 30 mg $PGF_{2\alpha}$ on day 11 required 96 hours to exhibit comparable degrees of luteolysis.

Rowson et al. (1972) demonstrated that two 0.5 mg dosages $PGF_{2\alpha}$ 24 hours apart deposited in ipsilateral horns resulted in luteolysis; single dosages of 1 mg similarly infused were less effective.

Single intrauterine dosages of 2 mg $PGF_{2\alpha}$ caused complete luteolysis in the cow (Henricks et al., 1974; Fulka et al., 1975; Welch et al., 1975).

Stellflug et al. (1975) reported that single IM injections of 30 mg $PGF_{2\alpha}$-Tham salt or two 15 mg injections at six hour intervals were equally effective in causing luteolysis within similar time periods following treatment.

Incidence of luteolysis in diestrous lactating Holsteins administered 15, 25, or 35 mg IM was not different, but was greater than cows given 5 mg $PGF_{2\alpha}$ (Renegar et al., 1978).

3.2.2 Hormonal Response

Liehr et al. (1972) reported effects of $PGF_{2\alpha}$ on blood progesterone (P_4) levels in beef heifers. Small dosages (500 µg) of $PGF_{2\alpha}$ administered ipsilaterally on day 5 failed to markedly alter blood P_4 levels. Ipsilateral infusion of 6 mg $PGF_{2\alpha}$ on day 9 of estrous cycles reduced P_4 to nondetectable levels within two days post-treatment; P_4 levels in contralaterally treated heifers remained relatively high.

Renegar et al. (1978) found that P_4 levels declined to less than

1 ng/ml within 24 hours after luteolytic dosages of $PGF_{2\alpha}$ (15, 25, and 35 mg).

Thatcher and Chenault (1976) characterized plasma progestins, estradiol, and LH following either 30 mg intramuscular or 10 mg ipsilateral infusion of $PGF_{2\alpha}$ in cycling dairy animals. Progestins declined to basal levels associated with CL demise within 24 hours post-treatment. Plasma estradiol increased linearly by two-fold within 76 hours post-treatment, indicative of follicular growth and maturation following luteolysis and declining progestins. Transitory plasma LH oscillations were observed during the first two days following $PGF_{2\alpha}$, but normal preovulatory surges occurred between 72 and 96 hours following $PGF_{2\alpha}$. These authors concluded that $PGF_{2\alpha}$-treated animals demonstrated variablity in hormonal concentrations and precise timing of physiological events, but all responding animals exhibited similar sequences of hormonal events as animals undergoing natural luteal regression. Although variations in precise onset of response have been noted, other investigations substantiate normal hormonal patterns of progesterone, estradiol, and LH following luteolytic dosages of intrauterine and/or systemic $PGF_{2\alpha}$ (Nancarrow et al., 1974; Henricks et al., 1974; Chenault et al., 1976; Smith et al., 1979). Fogwell et al. (1978) reported that increases in both estradiol and LH are dependent on declining progesterone levels due to $PGF_{2\alpha}$-induced effects, suggesting an indirect effect of $PGF_{2\alpha}$ in eliciting these hormonal re-

sponses.

Intramuscular injections of 30 mg $PGF_{2\alpha}$ caused a 2.5-fold increase in blood prolactin within ten minutes of treatment, with elevated levels persisting for at least two hours (Hafs et al., 1974). Renegar et al. (1978) stated that prolactin increased from 38 ng/ml to peaks of 57, 84, and 95 ng/ml at 1.0 hour after 15, 25, or 35 mg intramuscular $PGF_{2\alpha}$, respectively; this pattern suggests a dose-response relationship of $PGF_{2\alpha}$ and prolactin. Smaller dosage (5 mg) failed to markedly alter prolactin levels. Louis et al. (1974) reported 5-fold increases in prolactin when heifers were given 15, 30, or 60 mg $PGF_{2\alpha}$.

Rapid increases (74 %) in somatotropin at 0.5 hours following 35 mg $PGF_{2\alpha}$ injections have been reported (Renegar et al., 1978); lower dosages (5, 15, or 25 mg) did not greatly modify growth hormone by 4 hours after treatment. Contrastingly, Hafs et al. (1974) reported 2.5, 7, and 26-fold increases in growth hormone within 30 minutes after 15, 30, and 60 mg $PGF_{2\alpha}$ injections, respectively, with levels remaining above basal levels for at least two hours.

Glucocorticoid levels increased linearly to peaks after one hour following 15, 25, and 35 mg $PGF_{2\alpha}$ (Renegar et al., 1978).

3.2.3 Other Physiological Effects

Thatcher and Chenault (1975) reported that 33.5 mg $PGF_{2\alpha}$ given intramuscularly caused no major alterations in blood pressure, heart rate, and uterine or aortic blood temperatures. However, identical

dosages administered by intravenous jugular infusion over a 2 minute period caused major changes in circulatory homeostasis and body temperature.

3.3 Early Stage CL of Pregnancy and $PGF_{2\alpha}$

Documentation regarding mechanisms of CL maintenance in early bovine pregnancy is scarce. In view of this, reference will be made to available knowledge of these aspects in ewes, though it is recognized that differences may exist between the two species.

It is known that in the ewe (Moor and Rowson, 1966) and cow (Betteridge et al., 1978) the conceptus must be in-utero by day 13 and 16 after mating, respectively, for CL maintenance and continued pregnancy. Presence of embryos at this time inhibits luteolysis in the ewe and cow (Hafez and Jainudeen, 1974), despite evidence that uterine venous $PGF_{2\alpha}$ levels are at least as high in early pregnant as in nonpregnant ewes (Inskeep and Murdoch, 1980). This would indicate that the conceptus produces or elicits action of some agent that overrides luteolytic effects of $PGF_{2\alpha}$.

Denamur (1974) demonstrated that luteal maintenance depends on luteotropic support of hypophyseal LH aside from antiluteolytic and/or luteotropic actions of the early conceptus in ewes.

Another prostaglandin, PGE_2, which elicits different effects than $PGF_{2\alpha}$, was studied as a possible antiluteolysin in ewes. Luteolysis has beeninhibited and/or postponed in nonpregnant ewes with PGE_2

(Henderson et al., 1977). Lewis et al. (1978) stated that overall mean concentrations of both PGE_2 and $PGF_{2\alpha}$ in plasma from utero-ovarian venous blood, endometrium, and ovarian arterial tissue were not significantly different between pregnant and nonpregnant ewes on day 14 post-estrus. However, blood concentrations of PGE_2 in ovarian arteries tended to be less in nonpregnant than in pregnant ewes ($P < .10$). The authors suggested that this may have been due to increased uptake and transport of PGE_2 to ovaries of pregnant ewes. It was further stressed that lack of significant differences in PGE_2 concentrations in other measured media between pregnant and nonpregnant ewes did not rule out that PGE_2 may be an antiluteolytic substance in ewes.

Godkin et al. (1978) provided evidence that ovine preimplantation embryos produce a luteotropic agent which contributes to the maintenance of early pregnancy in vitro. It was reported that the ovine embryos produced a substance which directly stimulated progesterone synthesis by both ovine and bovine CL, indicating that the unidentified material is not species specific.

Ford et al. (1979) suggested that the bovine conceptus may produce or stimulate synthesis of a factor which dilates ipsilateral utero-ovarian vasculature, thereby creating optimal conditions for pregnancy. Blood flow to gravid uterine horns of pregnant cows exhibited a transient, dramatic increase on days 14-18 after mating whereas blood flow to nongravid horns remained constant. Blood flow

in nonpregnant cows declined consistently within the same period. This suggests that preimplantation bovine embryos may directly or indirectly counteract vasoconstrictive effects of $PGF_{2\alpha}$ and thereby remove a plausible action of the compound in causing luteolysis as discussed earlier. It was not suggested that the unidentified substance thought to dilate utero-ovarian vasculature might be PGE_2.

Lewis et al. (1980) quantified PGE_2 and the primary $PGF_{2\alpha}$ metabolite (13, 14-dihydro-15- keto-PGF_2: PGFM) concentrations in blastocysts and endometrium of day 16 and 19 pregnant cows in vitro. Day 19 blastocysts produced more PGE_2 than either contralateral or ipsilateral endometrium on the same day ($P < .05$). Production of PGFM, on both days was less from blastocysts than endometrial tissue ($P < .05$). It was suggested that PG's are involved in blastocyst development and/or in maternal recognition of pregnancy.

Other attempts to identify antiluteolytic or luteotropic agents originating from the conceptus or from the uterus in response to a stimulus from the embryo are somewhat inconclusive (Chenault, 1979; Eley et al., 1979; Lewis et al., 1979; Godkin et al., 1980). Perhaps a search for known $PGF_{2\alpha}$ inhibitors such as indomethacin (Karim, 1975) would be of some value.

Chapter 4

Synchronization of Estrus and Ovulation

Knowledge of physiological mechanisms controlling events of the estrous cycle has led to means of artificial control and potential techniques for improvement of reproductive efficiency in commercial beef herds.

Natural and synthetic agents used in synchronization of estrus and ovulation procedures must meet several obvious criteria before they can be useful to beef producers. Foote (1978) reported that these compounds must: 1) effectively synchronize a large portion of estrous cycling females with no adverse effect on fertility; 2) comply with legislative restrictions governing their use in animals produced for human consumption; 3) be applicable with an acceptable amount of management effort; 4) provide for an effective cost/benefit ratio when used under varying production situations. The latter is perhaps the most important criteria to the majority of cattlemen but yet has received least attention.

The many advantages of estrous sychronization are well recognized, but perhaps the most important potential benefits for beef producers are facilitation of AI (Hansel, 1967), potentially shorter breeding and subsequent calving seasons (Lamming, 1973) and uniform calf crops (Foote, 1978). An important, inherent advantage is that management required for successful programs forces closer attention to cattle and

overall production techniques. All of these factors can contribute to more pounds of calf weaned (Wiltbank, 1970).

Two basic approaches have been employed for synchronizing estrus and ovulation in the bovine. The first involves administration of progesterone or synthetic progestagens which prevent estrus and ovulation until CL of treated animals regress, followed by withdrawal of treatment and subsequent estrus and ovulation in a large proportion of treated animals at approximately the same time. The second approach has relied on induction of luteolysis via use of estrogens, oxytocin, anti-LH preparations, uterine irritants and $PGF_{2\alpha}$. Efforts to enhance synchrony with both approaches have involved use of additional compounds such as estrogens and gonadotropins. Both in principle and practice, either basic method requires estrous cycling females in order to be effective.

4.1 Progesterone and Synthetic Progestagens

Progestins have been administered in feed, drinking water, intravaginal pessaries and coils, intramuscular or subcutaneous injections, and as subcutaneous implants. Review of various progestin compounds and routes of administration follows.

4.1.1 Progesterone Injections

Christian and Casida (1948) showed that progesterone (P_4) injections prolonged the diestrus phase of bovine cycles by preventing

estrus and ovulation. Heifers were injected daily (50 mg) over a 14 day period followed by cessation of suppressive treatment with a majority of animals exhibiting estrus within 5-6 days. Although reasonable synchrony was obtained, no fertility data were reported.

Willett (1950) injected 50-100 mg P_4 daily beginning on days 14-15 of the cycle and continued treatment for 13-17 days. Estrus occurred, on the average, 5 days after completion of the injection period. Eleven pregnancies resulted from twenty-two services at synchronized estrus.

Ulberg et al. (1951) conducted trials to determine effects of varying P_4 dosages administered at different times within the cycle and for varying durations on follicular development and onset of estrus. Cycling dairy heifers received 50, 25, 12.5, 6.25 or 3.125 mg P_4 in corn oil during injection intervals ranging from a single injection to 28 consecutive daily injections. The beginning of injection periods varied from day 15 of the cycle until the day of estrus. Results showed that time intervals between end of injections to estrus onset (3-7 days) decreased as dosage level decreased. Inhibition of follicular development was greatest in heifers receiving 50 mg P_4 on day 15 of the cycle (vs. days 17-19). Daily dosages of 25 or 12.5 mg usually prevented estrus and ovulation, but follicular development was not markedly affected. Dosages of less than 12.5 mg/day had little, if any, effect on reproductive parameters considered in this trial.

In a similar experiment Trimberger and Hansel (1955) reported that injected P_4 (50, 75, or 100 mg/day), administered predominantly on the 15th day and continuing for seven days, resulted in acceptable synchrony but 50 percent of the dairy cows treated exhibited abnormal ovarian conditions involving luteal development and extremely poor conception rates (12.5 %) as compared to controls.

In an effort to improve fertility and eliminate daily handling disadvantages required with a series of injections, Nellor and Cole (1956) administered single injections of P_4 (560 mg) to beef heifers followed 14-15 days later by single injections (750-2140 I.U.) of pregnant mare serum gonadotropin (PMSG). PMSG served to enhance follicular development following P_4 withdrawal. Estrus and ovulation were well synchronized as 90 percent showed estrus within 1-4 days after PMSG, but reduced conception (17%) resulted. In a similar trial, Ray et al. (1961) reported more variation (2-38 days) in time of estrus response following PMSG and poor fertility at synchronized breeding.

One hypothesis regarding reduced fertility at the synchronized estrus following P_4 injections was an altered hormone balance resulting from such treatment (Wiltbank et al., 1965). These authors suggested that introduction of estrogen concurrently with P_4 injections might cause less disruption and thus improve fertility. Hereford heifers received either 20 or 40 mg P_4 injections for 18-24 days alone or in

combination with injected estradiol levels ranging between 20-160 mcg. Synchronization varied from 17-100 percent with heifers showing estrus within a 4 day period post-treatment, but fertility of all but one of the treated groups was lower than controls. Although one group of heifers receiving 40 mg P_4 in combination with 80 mcg estradiol had comparable fertility with that of controls in a preliminary experiment, repetition of this same treatment regime did not result in acceptable conception rates and authors concluded that original results were due to chance.

Fertility at second post-treatment estrus following P_4 injections is reportedly near normal, although synchronization at that time is not as complete as that associated with first post-treatment estrus (Hansel, 1959). In an attempt to make the second post-treatment estrus more utilizable and to reduce labor associated with frequent handling in previously mentioned studies, Osland et al. (1970) administered 750 mg P_4 on days 1 and 22 (day 1 = first treatment) followed by 750 I.U. PMSG on day 29 to Hereford cows. Preliminary studies had indicated that estrus tended to be synchronized 8-12 days following a single 750 mg. injection of P_4. Human chorionic gonadotropin (HCG) was administered on day 31 to some cows in order to facilitate ovulation following PMSG. Results showed that 74-93 percent of all treated animals exhibited estrus within five days. Although one group, who received P_4 and PMSG only, had 50 percent AI pregnancy rates, all treated groups had lower fertility versus controls. Incorporation of

HCG into the treatment regime caused detrimental effects on estrus response and fertility. It appears that attempts at simpler treatment regimes were unsuccessful in this trial.

This early evidence shows that although P_4 injections alone or in combination with estrogens and/or gonadotropins have been successfully used in synchronizing estrus and ovulation, the observed lowered fertility at the initial post-treatment estrus coupled with complexity and/or schedule of treatments rendered these techniques impractical for commercial use.

4.1.2 Oral Progestins

Development of orally effective progestins in the early sixties was undertaken to alleviate problems associated with daily P_4 injections. Oral progestin most studied include medroxy-progesterone acetate (MAP), 6-chloro-Δ^6-dehydro-17-acetoxy progesterone (CAP), dihydroxy-progesterone acetophenide (DHPA), and melengestrol acetate (MGA).

4.1.2-1 MAP

Generally, MAP has resulted in best synchronization and highest conception rates of all orally administered progestins. MAP has usually been fed for an 18-20 day period in concentrate rations, followed by withdrawal of suppressive compound and subsequent events of estrus and ovulation.

Hansel and Malven (1960) in preliminary trials reported effective inhibition of estrus and ovulation during treatment in 32 Hereford cows while feeding 500-968 mg MAP/head/day in four pounds of soybean meal for 20 days. Results showed that 50 percent of treated animals exhibited estrus and ovulation within 3-4 days after MAP withdrawal. Of 16 animals not showing estrus, 13 (81 %) had ovulated as determined by rectal palpation. All treated animals were artificially bred, with one-half receiving .5 mg estradiol to determine if such treatment was needed to more closely resemble normal patterns at estrus. Conception rates (25%) were equal in estradiol treated and animals not receiving an estrogen source. These low conception rates and high incidence of ovulation without estrus were found later to be related to excessive MAP dosages (Hansel et al., 1961).

Wiltbank (1970) reviewed results of extensive feed trials involving a MAP-incorporated feed supplement (Repromix^{R}), which was marketed for a short duration in the late sixties and early seventies. Results indicated that first service conception rates were consistently and significantly higher in non-treated controls than in cows and heifers fed the supplement for recommended periods (18 days).

Estrogen has been combined with orally administered MAP in treatment regimes designed to enhance synchrony of LH release and ovulation (Hansel and Schecter, 1972). Eighty-four cycling Holstein heifers received 160-200 mg MAP/head/day for 18 days in drinking water

followed by single subcutaneous injections of estradiol - 17β($E_2\beta$) 24-30 hours after MAP withdrawal. Inseminations were performed at two preset intervals (20-24 hour post-$E_2\beta$, and again 24 hours later). Large proportions of treated animals exhibited estrus within a 24 hour period following MAP cessation. AI conception rates in treated animals (61%) reportedly compared favorably with untreated Holstein heifers; however these designated "controls" were not originally a part of the experiment but were simply animals bred at the same location at approximately the same time. In view of this deficiency the value of this particular trial is questionable; but the unique experimental design employed, i.e. MAP administered in drinking water and supportive estrogen treatment, is notable.

Evidence clearly indicates that MAP effectively synchronized estrus and ovulation but reduced fertility at controlled estrus was the consistent result. Many trials and results involving MAP similar to those presented here have been documented in a comprehensive review (Hansel, 1967).

4.1.2-2 CAP

CAP, a more potent oral progestin versus MAP, was usually fed at the rate of 10 mg per animal per day for an 18 day period. Most reported trials indicate effective synchronization of estrus and ovulation but conception rates at synchronized estrus were generally significantly less than controls or MAP-treated animals (Hansel *et*

al., 1966; Hansel, 1967; Wagner et al., 1968).

Reasons for depressed fertility in CAP trials were not well defined. Sawyer (1964) reported that CAP has a longer half-life than MAP which might result in a longer and more variable period of inhibition on hypothalamic centers controlling estrus behavior and LH release.

4.1.2-3 DHPA

Wiltbank et al. (1967) reported that 500 mg oral DHPA per day for 20 days synchronized estrus in 96 percent of beef heifers within 48 hours of withdrawal. Estrus was 4.5 hours longer ($P < .01$) and was more variable in nontreated animals versus synchronized heifers. However, following AI, 86 percent of controls versus 56 percent of synchronized heifers had fertilized ova 48 hours post-ovulation ($P < .10$). In a second trial, DHPA (400 mg) was fed for 9 days and treated animals received 5 mg estradiol valerate injections on day 2 of feeding. Supportive estradiol treatment failed to improve fertility in treated heifers; pregnancy rates in treated and nontreated animals at 34 days based on rectal palpation were 36 and 50 percent, respectively ($P < .05$).

Lantz et al. (1968) used a similar 9 day DHPA (120 mg/day) feeding regime and estradiol valerate (EV) on day 2 of feeding, but incorporated injections of HCG following EV on day 2 to facilitate LH release. HCG improved pregnancy rates in some heifers, but no statistical analyses were reported.

DHPA alone or in combination with estrogens and/or gonadotropins synchronizes effectively but trends for reduced conception rates in treated animals categorize this compound with other progestins.

4.1.2-4 MGA

MGA is reportedly several hundred times as potent as oral MAP as measured by ovulation inhibition during treatment (Zimbelman and Smith, 1966). As with other oral progestins, conception and/or fertilization rates in controls were generally significantly higher than 14-18 day MGA-treated animals (Zimbelman and Smith, 1966; Lamond et al., 1971; Hill et al., 1971).

Suggested reasons for poor fertility following MGA feeding include abnormal follicular development, alteration of precise hypothalamic control mechanisms mediating gonadotropin secretion, overflow of gonadotropins resulting in overstimulation of follicles following MGA withdrawal (Lamond et al., 1971), and ovulation failure (Hill et al., 1971).

Aside from reduced fertility in treated animals, estrous control with oral progestins might not be accepted for use under range conditions because of management effort required for lengthy feeding periods (Hansel, 1967). Additionally, problems arise in ensuring that animals receive recommended dosages in group feeding situations (Manns and Hafs, 1976).

4.1.3 Intravaginal Pessaries and Coils

Need for more convenient methods of progestin adminstration led to development of intravaginal pessaries and coils impregnated with synthetic progesterone for bovine estrous cycle control.

Intravaginal pessaries (sponges) have been used successfully for estrous control in ewes (Robinson, 1967). Wishart and Hoskin (1968) were among the first to report failure of some treated cows to retain progestin impregnated pessaries in synchronization trials involving 18-20 day treatments. Although acceptable synchronization was generally obtained with vaginal pessaries, most reports corroborate poor retention of pessaries and reduced fertility in animals treated for 18-20 days. (Scanlon et al., 1971, and Sreenan, 1975).

Sreenan (1975) compared estrus response and fertility following long term (20 day) and augmented short term (10 day) pessary treatment in Hereford crossbred heifers. Heifers treated for 10 days were treated with either 900 or 250 mg progesterone pessaries, with both of these groups receiving 5 mg estradiol valerate injections at sponge insertion to facilitate regression of any active corpora lutea. Results indicated that 20 day treatments resulted in excellent synchronization, but pregnancy rates were significantly lower in treated than control animals. Reducing treatment length to 10 days resulted in conception rates that were not significantly different between treated (both 900 and 250 mg progesterone) and control heifers.

However, a significantly higher degree of synchronization was observed in animals receiving the lower progesterone level. Retention of pessaries in 10 day treated animals was 100 percent, as compared to 79.9 percent in those treated for 20 days.

Roche (1976a) was among the first to report stainless steel coils coated with silastic rubber impregnated with progesterone as an effective route of administering the steroid for estrous synchronization. Retention after 18 day treatment was over 90 percent. Over 83 percent of treated animals were in heat on the second and third day after coil removal with 50 percent conception rates obtained in a representative group. The author suggested that continuous slow release of progesterone from the coils with consequent enhanced opportunity for normal clearance rates from body tissues appears to simulate more closely the normal endogenous release rate of steroids from endocrine glands.

Retention rate of coils is reportedly inversely related to their respective diameter (Roche, 1976b). O'Farrell (1977) suggested that larger diameter coils (7 cm vs 5 cm) cause greater irritation to vaginal walls and therefore more straining by cows in efforts to expell the devices.

Roche et al. (1976) reported that non-return rates for controls inseminated to an observed estrus and for 12 day coil plus estradiol and progesterone treated animals bred by appointment at 56 hours

following coil removal were not different. These results and others indicate that 12 day treatment with progesterone coils along with concurrent injections of estrogen and progesterone does not adversely affect conception rates in dairy (Roche 1976b) and/or beef (Roche et al., 1977) animals.

Roche (1978) stressed the importance of estrogen administration at the beginning of 9 or 12 day coil treatments for optimum synchronization. Following short-term progesterone treatment alone, intervals to estrus in dairy heifers is influenced by cycle stage at treatment onset, with animals between day 0 and 3 showing greatest variation in response (Roche, 1974). With estrogen administration either alone or in combination with 200 mg progesterone injections at the time of coil insertion, greater precision and shorter intervals to estrus were observed after coil removal.

Method of estrogen adminstration has been simplified by attaching a gelatin capsule containing the hormone to the inside of coils with no apparent adverse effects on estrus response or fertility as compared to injections (Drew et al., 1978 and Roche, 1978).

Although effective cycle control and good fertility has been achieved with progesterone-releasing-intravaginal-devices, marketing of the coils in the near future does not appear feasible (Short and Kiracoffe, 1980).

4.1.4 Subcutaneous Implants

Development of subcutaneous implants containing progestins was undertaken to insure consistent levels of hormone elution and provide a simpler means of administration than injections, feeding, and pessary routes.

Curl et al. (1968) first reported that administration of subcutaneous implants containing the progestin norethandrolone (168 mg) for 16 days controlled estrus and ovulation in cows; first service conception rates were lower in treated animals (42.9 vs 75.0%). Wideman et al. (1969) reported lower ($P < .05$) fertility in heifers receiving 200 mg norethandrolone for 16 days than those receiving the same implant for 9 days plus an injection of estradiol valerate. It was indicated that implants containing norethandrolone in both the wall and lumen of the implant more successfully synchronized estrus than implants containing the active compound in the lumen only.

Anderson et al. (1969) reported reduced variation in intervals to ovulation in beef heifers receiving 2 mg estrogen injections at the time of implant removal following synchronization with norethandrolone (9 days) and estradiol valerate (5 mg - day 1). No fertility data were reported.

Wiltbank et al. (1971) reported lower pregnancy rates in all norethandrolone-estradiol valerate treated cattle than in controls. However, differences in pregnancy rates between animals receiving

estradiol valerate plus the implant for 9 days were not significant. The same authors reported results from a separate trial in which estradiol injections administered 24 hours after implant removal culminated in 98-100 percent of beef heifers exhibiting estrus within 48 hours. Animals treated in this manner, however, had lower first service pregnancy rates than controls ($P < .05$).

During the early seventies trials were carried out with another subcutaneous implant in combination with estradiol valerate for estrus synchronization. Five mg Norgestomet (SC 21009) in hydron polymer implants placed midway on the back of the ear along with a 5 or 6.5 mg. injection of estradiol valerate on the day of implantation has resulted in effective synchronization 3-4 days following implant removal and comparable fertility with control heifers (Burrell et al., 1972 and Humphrey et al., 1977) and lactating cows (Whitman et al., 1972).

These early trials paved the way for development of the Synchronate B^{R}(SMB) treatment. SMB consists of an implant containing 6 mg norgestomet administered for 9 days combined with an injection of 3 mg norgestomet and 6 mg estradiol valerate administered at time of implantation. The supportive injections of norgestomet and estradiol serve to immediately elevate progestin levels and regress any active corpora lutea, respectively. Conception rates in most trials indicate

SMB treated animals as comparable to those obtained in controls (as reviewed by Wiltbank and Spitzer, 1978). An additional advantage of SMB is that it may induce cyclic activity in some anestrus cows (Mares et al., 1979, and Pexton, 1980).

Improved fertility is reportedly possible when 24 or 48 hour calf removal at the time of implant removal is combined with SMB (Peterson et al., 1979 and Kaltenbach and Dunn, 1979), with efficacy of calf removal thought to be related to cow condition at time of treatment (Kiser et al.,1979). Hopper et al. (1977) reported that 48 hour calf removal following SMB did not improve conception rates over cows receiving 125 µg GNRH 30 hours after implant removal and bred 12 hours after GNRH administration.

Although SMB has been proven as an effective estrous synchronizer and apparently has no detrimental effects on fertility, the treatment has not received FDA clearance for commercial use as of this writing.

4.2 Luteolytic Agents

Induction of CL regression in the bovine has been accomplished by infusion or placement of irritants into the uterus and systemic administration of agents that have a luteolytic action. Most of these treatments were studied regarding effects on cycle length and ovarian function rather than efficacy for estrous synchronization. More importantly, these investigations contributed to knowledge of local uterine control of CL lifespan.

Most luteolytic agents/treatments were effective in regressing CL of intact females only when administered within early stages (days 1-7) of the estrous cycle, with inconsistent trends often noted. Treatments of this type include intrauterine devices (Hansel and Wagner, 1960 and Hawk, 1968), anti-LH preparations (Snook et al. 1969), uterine irritants such as nitrofurazone (Ginther and Meckley, 1972) and iodine (Nakahara et al., 1971; Seguin et al., 1974; Kindahl et al., 1977) solutions, and oxytocin (Armstrong and Hansel, 1959; Hansel and Wagner, 1960; Brunner et al., 1969).

Injections of estrone and estradiol have been demonstrated to regress CL in heifers and cows (Loy et al., (1960); Wiltbank et al., 1961), with estradiol reported as more effective in eliciting CL demise (Kaltenbach et al., 1964). Estradiol is apparently more effective at inducing luteolysis in later cycle stages (beyond day 7) than agents previously discussed (Brunner et al., 1969). Problems encountered with estradiol injections include inconsistency in post-treatment interval to CL regression and incidence of estrus and ovulation (Wiltbank et al., 1961), cystic ovaries and luteinized follicles (Kaltenbach et al., 1964), and poor conception rates at estradiol-induced estrus (Wiltbank et al., 1961). Estrogen's supportive role in effective progestagen treatments (i.e. SMB) for estrous synchronization was previously discussed.

$PGF_{2\alpha}$ has been most successful of all luteolytic agents for use

in estrous control; a natural $PGF_{2\alpha}$ product received Food and Drug Administration clearance for commerical use in November of 1979 (Moody, 1980).

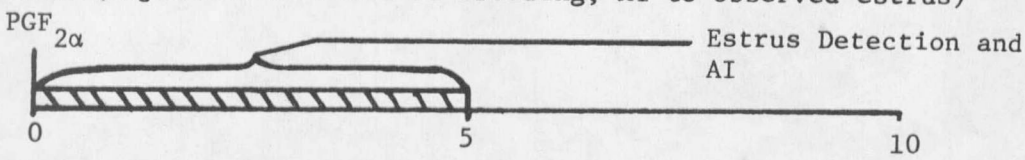
4.2.1 Estrus Response and Fertility Following Single $PGF_{2\alpha}$ Treatment

$PGF_{2\alpha}$ is luteolytic only when administered to estrous cycling bovines during the luteal phase of the estrous cycle (days 5-16). On any given day, 75 to 80 percent of all estrous cycling animals in a group are theoretically between days 5 and 21 of the cycle, assuming random distribution of 5 percent cycling per day. The remaining 20 to 25 percent are within days 1-5. This latter group is of most concern in single treatment $PGF_{2\alpha}$ systems; cows between days 5-16 will theoretically respond to treatment and cows within days 17-21 should show heat along with responding animals.

Systems for estrous synchronization with single injections of $PGF_{2\alpha}$ have been devised. Two basic schemes are described in Figure 4.1 that follows. Abbreviations of these systems will be used in the text for convenience.

It was pointed out earlier that intrauterine administration of $PGF_{2\alpha}$ resulted in luteolysis. However, skill and patience required for this route coupled with potential hazards of uterine infection or damage suggests subcutaneous (SQ) or intramuscular (IM) injection would be more acceptable to producers (Cummins et al., 1974).

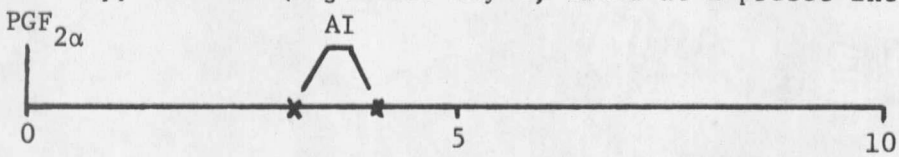
1.a. LAIE (injection at start of breeding; AI to observed estrus)



Day Of Breeding Season

- Fails to manipulate 0-5 day cows in a randomly cycling herd.
- Breeding periods indicated represent theoretical period of $PGF_{2\alpha}$ response; total AI period unrestricted.

b. L-AI-Appointment (injection day 0, breed at 2 preset intervals).



Day Of Breeding Season

- Fails to manipulate 0-5 cows.
- Abbreviated systems in text:

  L-AI-72, 96

  L-AI-72, 90

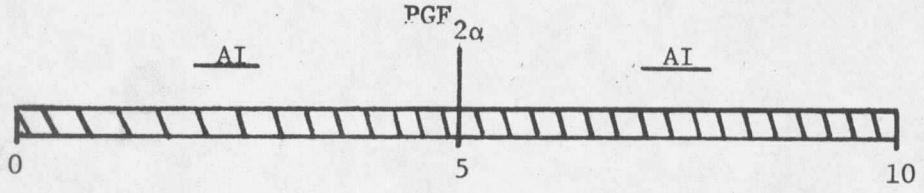
  L-AI-70, 88

  L-AI-E

Figure 4.1

Basic Single Injection $PGF_{2\alpha}$ Systems for Estrous Synchronization

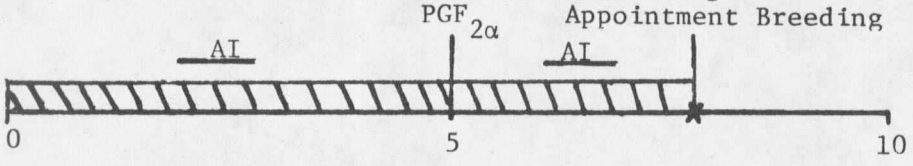
2.a. AI-L-AI-E (AI until am of day 5 - inject all not detected - AI)



Day Of Breeding Season

- Allows manipulation of 0-5 day cows by permitting time for CL development.
- Majority respond at day 8.

b. AI-L-AI-E-Appointment (AI until day 5- inject all not detected - AI by estrus until preset appointment breeding).



Day Of Breeding Season

- Abbreviated systems in text:

  AI-L-AI-E-72

  AI-L-AI-E-80

  AI-L-AI-E

Figure 4.1 - Continued.

Lauderdale (1972) reported that heifers in luteal phase of estrous cycles showed estrus at 3 days (mean) following single (SQ) injections of 30 mg $PGF_{2\alpha}$-Tham Salt.

Stellflug et al (1973) reported significant differences ($P < .10$) in intervals to estrus onset (55 vs 50 hour) in Holstein heifers following single (IM) injections of 30 or 60 mg $PGF_{2\alpha}$-Tham salt.

Lauderdale et al. (1973) reported no significant differences in AI pregnancy rates at 35 to 60 days after insemination among non-treated controls and two $PGF_{2\alpha}$ treated groups (30 mg Tham-salt). One treated group received $PGF_{2\alpha}$ on day 0 of the breeding season and animals were bred to an observed estrus for 7 days (LAIE); the other $PGF_{2\alpha}$ injected group was identically treated but was appointment bred at both 72 and 90 hour post-$PGF_{2\alpha}$ (LAI -72, 90). All animals were in diestrus at the outset of the trial. Total AI pregnancy rates for control, LAIE, and LAI-72, 90 groups were 58, 57, and 58 percent, respectively. Controls in this study were heat detected and bred for 18-21 days; this indicates that more $PGF_{2\alpha}$ treated animals were pregnant earlier in the breeding season than controls.

Lauderdale et al.(1974) assigned beef and dairy cattle to one of three treatments at four different locations. Non-treated controls were heat detected and inseminated for 18-25 days. Two $PGF_{2\alpha}$ treated groups (30 mg Tham-salt) were employed; LAIE animals ($PGF_{2\alpha}$-day 0) were heat detected and bred accordingly during days 1 through 7, while

LAI-72, 96 animals were inseminated at both 72 and 96 hours following $PGF_{2\alpha}$ injection. Of all $PGF_{2\alpha}$ treated cattle exhibiting estrus, 92% were detected by day 4 post-$PGF_{2\alpha}$. Fertility was calculated based on number pregnant/number inseminated (controls and LAIE) and number pregnant/number responding (LAI-72, 90). Cows in the latter group were considered to have responded if during days 1 through 7 after injection an estrus was observed or a CL was formed as determined by rectal palpation. Pregnancy rates calculated in this manner were not significantly different. However, percent pregnant of total number assigned to each treatment was 42, 30, and 40 for controls, LAIE, and LAI-72, 96, respectively. Although this measurement reflects important differences in estrus detection and conception rates, no statistical analyses were reported for these values.

Oxender (1974) assigned crossbred cows with functional CL as determined by rectal palpation to control, LAIE, and an appointment breeding group in which two inseminations at 70 and 88 hours (post-$PGF_{2\alpha}$) were performed (LAI-70, 88). Pregnancy rates at 35 to 45 days after insemination were not significantly different.

Doornbos and Anderson (1979) examined estrus response and fertility of lactating Hereford cows assigned to two $PGF_{2\alpha}$ treated groups and one non-treated control group. All treatment groups were artifically inseminated during a 45 day breeding program (no cleanup bulls). Controls were bred to observed estrus throughout the breeding season;

one treated group was heat detected and bred during days 1-5 of AI and all animals not bred by day 6 received $PGF_{2\alpha}$ (IM, 25 mg free acid) and AI by estrus continued (AI-L-AI-E); the third group received identical dosages of $PGF_{2\alpha}$ on day 1 (LAIE). Percent estrus response following $PGF_{2\alpha}$ and average hours to estrus were 44, 52 and 41, 55 for AI-L-AI-E and LAIE, respectively. No significant differences were observed in first service pregnancy rates among the three groups. More ($P < .05$) AI-L-AI-E cows (100%) were pregnant at the end of breeding than control (90%) or LAIE (89%) animals. Both $PGF_{2\alpha}$ - treated groups had higher pregnancy rates early in the breeding season (day 12) than controls.

Lambert et al. (1975) reported comparative fertility results in trials involving virgin heifers and both early and late calving cows. All animals were assigned to either a non-treated control or $PGF_{2\alpha}$ (25 mg free acid) treated group. Treated animals were bred by estrus through day 4 at which time all those not yet bred received $PGF_{2\alpha}$; AI by estrus continued until 72 hours post-treatment when appointment breeding of all non-bred animals occurred (AI-L-AI-E-72). Breeding seasons consisted of 22-30 days AI plus 20 days of natural service. Within each class of animals, no significant differences were seen in total AI pregnancy rates or total pregnancy rates. However, significantly more treated aniamls were pregnant within the first 10 days of breeding.

Han and Moody (1979) reported comparative reproductive performance of lactating cows assigned to control, LAIE, and AI-L-AI-E-80 groups. The breeding season consisted of 9 days AI plus 48 days natural service in all groups. Total AI pregnancy rates were significantly higher in LAIE (42.1%) and AI-L-AI-E-80 (53.4%) cows than in controls (22.3%). No significant differences in AI first service or total pregnancy rates were noted. However, AI first service pregnancy rates of cows bred to observed estrus was greater than those bred at 80 hours post-$PGF_{2\alpha}$ (non-estrus inseminations) within the AI-L-AI-E-80 system (65.0 vs. 21.4%; $P < .001$). Comparisons of treated groups (LAIE vs AI-L-AI-E-80) revealed no significant differences.

Hanks et al. (1980) corroborated much lower AI conception rates in non-estrus bred cows (at 80 hrs.) than in those bred by estrus within an AI-L-AI-E-80 breeding scheme ($P < .01$).

Evidence suggests that first service pregnancy rates in cattle bred to an observed estrus following single injection $PGF_{2\alpha}$ treatment is comparable with non-treated controls. Appointment breeding at pre-set intervals often results in breeding of anestrus and nonresponding cows and is a potential costly mistake with single injection $PGF_{2\alpha}$ schemes. Also, variation in time of estrus response following $PGF_{2\alpha}$ in other trials further indicates that breeding by estrus may be more effective than appointment breeding in single injection schemes.

4.2.2. Estrus Response and Fertility Following Two Treatments With $PGF_{2\alpha}$

A disadvantage of single treatment with $PGF_{2\alpha}$ is that animals within days 1 - 4 of the estrous cycle fail to respond. Double injection systems involving administration of $PGF_{2\alpha}$ (natural products and synthetic analogues) 10 - 12 days apart have been devised to allow manipulation of this group.

Estrous cycling females responding to initial injections (days 5 - 16) will have passed through induced estrus and formed a functional CL (days 7 - 8) by the second injection date 10 - 12 days later. Animals not responding (days 1 - 4 and 17 - 21) will have formed a regressable CL 10 - 12 days later (will be at days 11 - 16 and days 7 - 10 of the cycle). Theoretically, all cycling animals should be synchronizable at second treatment with such a scheme.

Thatcher and Chenault (1976) illustrated differences in proportion showing estrus after single and double treatment with $PGF_{2\alpha}$ (33.5 mg Tham-salt). Cycling heifers were treated twice at a twelve day interval. The distribution of heifers within various cycle stages (days 0 - 5, 6 - 16, and 17 - 21) at the two injection dates was significantly different ($P < .01$); 97 percent were determined to be in a potentially responsive stage at the time of the second injection (days 6 - 21). Proportions of heifers expressing behavioral estrus after one and two $PGF_{2\alpha}$ injections were significantly different (60 and 84%,

respectively). These figures indicate that approximately 13 percent (97 vs. 84) of those considered to be in a responsive stage of the cycle at the second injection date failed to exhibit estrus.

Ellicott et al. (1975) compared first service pregnancy rates of non-treated control heifers and heifers receiving $PGF_{2\alpha}$ (IM, 30 mg Tham-salt) twice at 10 day intervals. Controls were inseminated according to estrus and treated animals were appointment bred 60 hours following second treatment. First service pregnancy rates for controls and treated animals were 62.5 and 33 percent, respectively. These results represent outcome of a trial involving small numbers of experimental animals (15 controls and 16 treated). No statistical analyses were reported.

Cooper (1974) reported estrus response following two injections of ICI 80,996 ($PGF_{2\alpha}$ analogue - 500 µg). Dairy heifers were palpated and determined to be cycling prior to treatment assignment. Proportions of treated animals showing estrus within 48 - 72 and 48 - 96 hours following second injection were 90.1 and 98 percent, respectively. Estrus response was reportedly earlier and more closely synchronized after the second treatment than after the initial injection. This trend was also observed in a trial involving a separate $PGF_{2\alpha}$ analogue (ICI 79,939 - 500 µg) administered 10 days apart in dairy heifers (Dobson et al., 1975). Treated animals returned to estrus 48 - 96 hours following the first injection and 48 - 55 hours following second

treatment. Johnson (1978) suggested that this consistently observed tendency for enhanced synchrony following second treatment (vs initial treatment) is due to relatively more animals being at a comparable stage of the estrous cycle at the time of second treatment. Animals responding to initial injections (days 5 - 16) are theoretically grouped between days 7 and 10 by the time of second injection; thus, more animals at second treatment are at a a comparable stage of luteal development than at first injection.

Hafs et al. (1975a) documented intervals to estrus and subsequent fertility of lactating crossbred cows ($\bar{X}$ 55 days postpartum) and virgin Friesian heifers treated with natural $PGF_{2\alpha}$ (2x) 12 days apart. Cows were assigned to non-treated control and two $PGF_{2\alpha}$ treated groups (30 and 60 mg/injection). Heifers were divided into control and three $PGF_{2\alpha}$ treated groups that differed only in dosage level administered (20, 30, or 40 mg/injection). All treated cattle were inseminated at both 70 and 88 hours following second treatment without regard to estrus. Intervals to estrus were not affected by dosage administered in either heifers or cows; data for all dosage levels were pooled on this basis. Ten of 59 (17 percent) heifers exhibited estrus within the first two days following initial injections, while none of 59 showed heat within 48 hours following the second injection. Most heifers (68 percent) showed heat on the third and fourth days following second treatment. Similarly, no cows showed estrus within 48

hours following the second injection; the majority (62 percent) were in standing estrus on days 3 and 4 following second injection. However, 28 and 23 percent of heifers and cows, respectively, showed heat from 5 - 11 days after second treatment; this indicates much variation in interval to estrus following $PGF_{2\alpha}$. Non-return rates for control (62 percent) and treated heifers (59 percent) were not different. Calving rates for treated and control cows were identical (42 percent).

Hafs et al. (1975b) compared fertility of non-treated controls and two groups of $PGF_{2\alpha}$ treated animals. Treated cattle (either 30 mg $PGF_{2\alpha}$ or 0.5 mg ICI 80,996) were inseminated either once (80 hours) or twice (70 and 88 hours) after the second injection without regard to heat periods. Pregnancy rates were based on pregnancy diagnosis by palpation or by non-return to estrus. No significant differences were noted in first service or total AI pregnancy rates betweeen controls and treated cattle or between treated cattle inseminated by appointment either once or twice. Fertility of cattle treated with natural $PGF_{2\alpha}$ or the analogue was not different.

Results of extensive field trials involving ICI 80,996 (0.5 mg) administered twice at 11 day intervals and comparison of single and double insemination following second injections have been published (Cooper et al., 1976). Non-treated controls (bull bred) and treated cattle (inseminated once at 72 hours or twice at 72 and 96 hours) were randomly assigned based on postpartum interval (cows) or age and weight

(heifers). Of significant importance is that this trial was conducted under commerical production conditions rather than rigidly controlled conditions. Pregnancy rates of treated cattle (synchronized AI) and controls (21 days natural service) were 44 (double insemination), 36.1 (single insemination), and 47.3 (control) percent, respectively. Differences between single and double insemination groups were significant ($P < .001$). This indicates that two inseminations result in better fertility than single inseminations following ICI 80,966 (2x) when AI takes place at post-treatment intervals employed in this trial. These results agree with those of Schultz et al. (1977), who reported significant differences ($P < .05$) in pregnancy rates of cattle inseminated once at 72 hours (17.4 %) versus those bred either twice at 72 and 96 hours (36.9%) or by detection (38.8%) following ICI 80,996 in trials conducted in the southern United States. Controls in this trial also had significantly higher pregnancy rates than 72 hour appointment bred cattle at this location. Interestingly, the same authors reported no significant differences among all groups of identically treated cattle in Northern States. Other available data (Esslemont et al., 1977) indicate no significant differences in either first service or total pregnancy rates between animals bred by appointment at 72 and 96 hours following two treatments of ICI 80,996 and non-treated controls.

Moody and Lauderdale (1977) compared fertility of non-treated

control and two $PGF_{2\alpha}$ - treated (2x - 25 mg Tham salt) groups. Controls were bred at observed heat and treated cattle were bred either once at 80 hours following second treatment or by detection. First service conception rates were significantly lower ($P < .001$) in appointment bred animals (41%) than in controls (62%) or treated, bred by estrus (59%) cattle. Analysis comparing first service pregnancy rates of only those appointment bred animals observed in estrus within the synchronized AI period (days 2 - 5) with other groups also showed lower ($P < .001$) fertility for timed-inseminated animals; this data suggests that interval to estrus response following double treatment with $PGF_{2\alpha}$ may be too variable to achieve acceptable fertility and/or cost efficiency from a single appointment breeding when compared to AI by estrus. Total pregnancy rates at day 5 of AI breeding (total AI 25 - 45 days) were higher ($P < .001$) in both treated groups than in controls; total pregnancy rates at day 21 did not differ ($P < .05$).

Roche (1977) employed a double injection system (ICI 80,996) involving a split insemination of treated cattle; following initial treatment cows were bred according to estrus and those failing to respond (unbred) were injected 11 days later and subsequently bred by appointment at both 72 and 96 hours following $PGF_{2\alpha}$. These animals were compared to non-treated controls. No differences in fertility were reported.

Burfening et al. (1978) assigned 193 lactating beef cows and 59 virgin beef heifers to non-treated control and $PGF_{2\alpha}$ (25 mg free acid equivalent) treated groups. Controls were estrus detected and bred accordingly. Treated heifers and cows were bred to an observed estrus following initial $PGF_{2\alpha}$ treatment; those failing to exhibit estrus within the ensuing 11 days were reinjected and appointment bred at 60 (heifers) and 84 hours (cows) post-$PGF_{2\alpha}$. Pooled analysis (cows and heifers) indicated first service conception rate was lower ($P < .01$) in appointment bred animals than both controls and treated cattle bred by estrus after first injection. Pregnancy rates at the end of AI were 88, 86, and 69 percent for control, treated-bred by estrus, and treated-bred by appointment groups. Due to reduced fertility in timed-inseminated animals within the treated group, more controls were pregnant ($P < .05$) than $PGF_{2\alpha}$ treated animals. Reduced fertility in appointment bred cattle was due to inseminations too early or too late relative to ovulation, and breeding of nonestrus cattle which includes noncycling animals and those failing to respond to first treatment (not within days 5 - 16). Reduced fertility in appointment bred animals (double insemination @ 72 and 96 hours) following inseminations by estrus in similar split insemination trials has been reported (Fulka et al., 1978).

Additional hormone treatment (i.e. GnRH, estradiol) following $PGF_{2\alpha}$ has been investigated in attempts to reduce variability in the intervals to preovulatory LH surge, estrus, and ovulation; if success-

ful, these combination treatments could improve fertility at single, timed inseminations following $PGF_{2\alpha}$.

Graves et al. (1975) reported that GnRH (250 µg) reduced variation in intervals to ovulation in $PGF_{2\alpha}$ treated cows. Other trials involving GnRH (100 µg) following injections of $PGF_{2\alpha}$ at 48 (Thatcher and Chenault, 1976) or 60 hours (Tobey and Hansel, 1975; Kinkie, 1976; Burfening et al., 1978) have resulted in somewhat inconsistent results; there is an apparent trend for no dramatic changes in fertility following $PGF_{2\alpha}$ and GnRH combination treatments.

Inskeep et al. (1975) were able to enhance synchrony of estrus in $PGF_{2\alpha}$ treated animals by administering 400 µg estradiol benzoate 48 hours following $PGF_{2\alpha}$. Welch et al. (1975) reported that 400 µg estradiol benzoate reduced variation in intervals to LH release and estrus onset when administered 48 hours post-$PGF_{2\alpha}$: no differences in conception rate were noted between animals receiving the combined treat-treatment versus those receiving only $PGF_{2\alpha}$. Peters et al. (1977) reported that 400 µg estradiol benzoate significantly ($P < .05$) increased precision of estrus synchrony when administered at either 40 or 48 hours following the second of two $PGF_{2\alpha}$ treatments (25 mg free acid equivalent). No significant effect on pregnancy rates was observed, however. It was further indicated that double injection systems of $PGF_{2\alpha}$ resulted in no better fertility than single treatment, regardless if combined with estradiol or not.

A considerable body of evidence suggests that interval to estrus response following the second of two $PGF_{2\alpha}$ treatments may be too variable to expect optimal conception rates at a single, timed insemination. Some work shows that fertility at such inseminations is comparable with controls. All pertinent literature emphasizes the importance of estrous cycling cattle prior to double treatment with $PGF_{2\alpha}$. Other work implies that a portion of potential respondents after second injections fail to show behavioral estrus (see Thatcher and Chenualt, 1976); these may be silent ovulators. More critical work to determine proportion of silent ovulations after second treatment is needed to determine if appointment breeding, AI by detection, or some combination of the two is desirable under commercial conditions. Attention to variation in body size and condition in such trials will be important.

Chapter 5

Progesterone - $PGF_{2\alpha}$ Combinations For Estrous Synchronization

Considering that progestagens prevent estrus and ovulation and $PGF_{2\alpha}$ regresses functional CL, combination treatment might be expected to allow manipulation of relatively more animals than single $PGF_{2\alpha}$ treatment alone. Progesterone implants, injections, and intravaginal coils administered 5 - 7 days prior to $PGF_{2\alpha}$ have been used in attempts to prevent animals in late diestrus and proestrus from progressing into the first one-fourth of a new cycle (days 1-4) when $PGF_{2\alpha}$ is ineffective. Withdrawal of progesterone source near $PGF_{2\alpha}$ injection permits normal endocrine sequences to occur and these animals should theoretically exhibit estrus and ovulation along with animals responding to $PGF_{2\alpha}$ treatment. Combination treatments of this kind have been compared to both single and double injection systems involving natural and synthetic $PGF_{2\alpha}$.

Roche(1976c) assigned fall calving Hereford crossbred cows with post-partum intervals of 46 - 160 days to one of three treatments: a) non-treated controls were inseminated according to detected estrus b) two injections ICI 80,996 either eleven or twelve days apart c) progesterone - impregnated intravaginal coils for 7 days plus single treatment with 500 g ICI 80,996 at coil removal. Treated cows exhibiting estrus or those secreting mucus indicative of estrus were inseminated

twice (at 72 and 96 hours) following $PGF_{2\alpha}$. Significantly more treated cows ($P < .005$) were pregnant within the first 15 days of breeding than controls. Pregnancy rates between the treated groups were not different. Calving rates for cows inseminated on the basis of observed estrus were higher ($P < .025$) than those bred on the basis of estrus mucus. In a similar trial involving spring calving, lactating cows and identical treatments (described above), significantly higher ($P < .05$) pregnancy rates were obtained with the progestagen plus $PGF_{2\alpha}$ regimen (60%) than with two treatments of $PGF_{2\alpha}$ (44%).

Chupin and Pelot (1976) compared efficacy of SC 21009 implants and ICI 80,996 alone or in combination, and AI by estrus or at predetermined times. Treatments were 1) SC 21009 implants (6 mg) for 7 - 11 days plus IM injections of SC 21009 (3 mg) and estradiol valerate (5 mg) at implant insertion (SMB standard treatment), 2) SC 21009 implant for 7 - 11 days plus 500 µg ICI 80,996 at implant removal, 3) two treatments with ICI 80,996 10 - 12 days apart. Inseminations to observed estrus resulted in higher calving rates for SMB (48.4%) and ICI 80,996 (45.9%) when given alone than the combined treatment (35.6%). Inseminations at predetermined intervals post-treatment (at 48 and 72 hours for SMB treated; at 60 and 84 hours for combined and ICI 80,996 treated) resulted in non-significant differences. Non-treated controls performance was not different from all treated groups. The lowered calving rate (per cent AI of total

treated) for the combination group resulting from AI by estrus when compared to those bred at pre-determined times suggests that progestagen pretreatment may have suppressed behavioral estrus in some cows.

Stauffer et al. (1976) assigned 155 Hereford and Hereford X Angus cows to one of five treatments: 1) SC 21009 (6 mg) implant for 8 days, 2) implant plus $PGF_{2\alpha}$ at implantation, 3) implant plus $PGF_{2\alpha}$ at implant removal, 4) implant plus $PGF_{2\alpha}$ at insemination and 5) non-treated controls. Dosage level for $PGF_{2\alpha}$ in all instances was 30 mg/injection. All inseminations (17 days AI) were according to detected estrus with a natural service cleanup period (42 days) following AI. Conception and pregnancy rates were based on calving date and breed of calf (genetic markers). Results indicated that $PGF_{2\alpha}$ at implant removal enhanced synchrony when compared to other treated groups as evidenced by significantly ($P < .01$) less variation in the interval to estrus ($2.1 \pm .48$ days). Conception rates were significantly lower ($P < .05$) in animals receiving $PGF_{2\alpha}$ either at implant insertion (40%) or removal (42%) than in controls (60%), those receiving the implant only 69%), and those receiving $PGF_{2\alpha}$ at insemination (56%). Pregnancy rates at the end of breeding (AI + bull) were not significantly different.

Chupin et al. (1977) reported more precise estrus synchrony in combination $PGF_{2\alpha}$ - progestagen (ICI 80,996 and SC 21009) treated animals than in those receiving $PGF_{2\alpha}$ (2x) only. Proportion of cows

not observed in estrus within 96 hour post-treatment was lower ($P < .05$) in the combination - treated group. A higher ($P < .05$) pregnancy rate was obtained in the combination group with two inseminations post-treatment (by appointment) than with a single breeding and was also higher ($P < .05$) than that obtained with two inseminations following $PGF_{2\alpha}$ treatment alone. The combination system resulting in best estrous synchronization involved $PGF_{2\alpha}$ administration 48 hours prior to implant removal.

Moody et al. (1980) reported that 150 mg progesterone injections administered at either 5 or 24 days prior to $PGF_{2\alpha}$ (single treatment - 25 mg) did not improve pregnancy rates over those receiving $PGF_{2\alpha}$ only. However, there was a trend for more precision of estrus onset following combined treatments.

The limited data regarding combined progesterone - $PGF_{2\alpha}$ treatments suggests that more precision in the interval to estrus onset may be possible with such treatment than with $PGF_{2\alpha}$ alone. More investigation involving reasons for depressed fertility observed in some trials and study of optimal times for appointment breeding following combined treatment is needed. Some trials suggest that combined treatment may result in fewer cows exhibiting estrus than in those treated with $PGF_{2\alpha}$ alone. Reasons for this apparent tendency were not addressed; it may be a result of residual progesterone inhibition of estrus. More experimentation involving blood hormone measurements

prior to, during, and after combined and $PGF_{2\alpha}$ - only treatments may explain this.

Chapter 6

Materials and Methods

Breeding, calving, and productin records of estrous synchronization trials conducted in cooperation with Montana State Prison Ranch during spring 1975 through 1977 were utilized as the data base. All yearly breeding trials involved suckled cows (age 2 to 11 years) that were more than 45 days postpartum. One year (1975) also involved virgin heifers 12 to 20 months of age. Lactating cows were randomly assigned to treatments based on previous calving dates; virgin heifers were assigned based on birth date (age).

Cattle were predominantly Hereford and Hereford X Angus crosses and were managed under typical Montana range conditions. Alfalfa hay was fed according to need during the wintering period. During breeding all animals were run together on native range and were supplemented with block salt.

In each year, cattle were assigned to either a $PGF_{2\alpha}$ or control system (Figure 6.1). Controls were artifically inseminated (AI) 8-12 hours after first observation of standing estrus. Treated cattle received $PGF_{2\alpha}$ (25 mg free acid-IM) either in the PM of day 4 (1975) of AM of day 5 (1976 and 1977) of breeding unless they had been observed in estrus prior to those times. Inseminations to detected estrus continued in treated cattle until 80 ± 4 hour post-$PGF_{2\alpha}$ when all remaining undetected animals were mass inseminated and recorded as nonestrus bred. Breeding seasons consisted of 25 days AI plus 20

DAYS OF BREEDING SEASON	$PGF_{2\alpha}$	CONTROL
0 or 1 AM[1]	Start estrus detection and AI	Start estrus detection and AI
4 PM or 5 AM[2]	Single injection $PGF_{2\alpha}$ (to all not previous observed in estrus)	AI
7 or 8 P.M.[3]	80-hr post-$PGF_{2\alpha}$ nonestrus breeding (insemination of all not previously detected in estrus)	AI
8.5 or 25[4]	End AI (turn in bulls)	End AI (turn in bulls)
45 or 57[5]	End of breeding (bulls removed)	End of breeding (bulls removed)

[1] Day 0 - 1975; Day 1 - 1976 and 1977

[2] Day 4 - 1975; Day 5 - 1976 and 1977

[3] Day 7 - 1975; Day 8 - 1976 and 1977

[4] Day 8.5 - 1977; Day 25 - 1975 and 1976

[5] Day 45 - 1975 and 1976; Day 57 - 1977

Figure 6.1

BREEDING SCHEDULES FOR $PGF_{2\alpha}$ AND CONTROL SYSTEMS

days natural service (1975 and 1976) or 8.5 days AI plus 48.5 days natural service (1977). The trial involving virgin heifers (1975) commenced approximately 20 days prior to that of the lactating cows. All initial AI services were with either Hereford or Black Angus semen, with individual AI bulls randomly assigned to treatments each year Cattle observed in estrus within 15 days of an initial AI service in 1975 and 1976 were re-inseminated with Red Angus semen to provide a genetic marker (hair coat color) as an aid in determining the AI service resulting in conception. In 1977, all repeat inseminations were with Red Angus semen along with observation and recording of natural service breeding dates for an additional 12.5 days (21 days total estrus detection).

Day of conception for all cattle was based on actual calving date minus 285 days (cows) or 280 days (heifers) base gestation lengths. Calculated conception dates falling within $\pm$ 10 days of AI breeding dates were considered as AI conceptions. In a few instances this basic guideline was altered based on birth weight, sex, and sire breed of calf.

Comparative reproductive performance of nonsynchronized control and treated cattle bred to an observed estrus or bred nonestrus at 80 hours post-$PGF_{2\alpha}$ was measured on a within years and pooled basis in terms of the following:

1. Cumulative insemination rate (%) at day 8 or 9 =

$$\frac{\text{number inseminated by day 8 or 9 of breeding}}{\text{total in group}} \times 100$$

(Note: Applies only to cattle bred to an estrus observed prior to 80 hour appointment breeding.)

2. AI first service conception rate (%) =

$$\frac{\text{number pregnant to first service}}{\text{number of initial AI services}} \times 100$$

3. Cumulative percent pregnant by day 10 (PR10), 24 (PR25), 32 (PR32) and total pregnancy rate (TRP) =

$$\frac{\text{number pregnant by } n^{th} \text{ day of breeding}}{\text{total in group}} \times 100$$

4. Average day of conception within breeding season.

5. Proportion repeat inseminated (%) =

$$\frac{\text{total number repeats}}{\text{total in group}} \times 100$$

Estrous cycling rate (%) estimates for each year were based on 21 day cumulative estrus detection rates in control versus 7 or 8 day detection rates in the treated group (number detected in respective group ÷ total number per group X 100).

For two-year treatment analysis, cattle were allotted to one of four treatment sequences: (CC) nonsynchronized control for two consecutive years, n = 128; (CT) control in year 1 and $PGF_{2\alpha}$ system in year 2, n = 116; (TC) $PGF_{2\alpha}$ system in year 1 and control in year 2, n = 124; (TT) $PGF_{2\alpha}$ system for two consecutive years, n = 131. Data was analyzed for individual two year sets (1975 and 1976; 1976 and 1977) and for the pooled two year components. Reproductive performance

was measured in terms of PR10, PR25, PR32 and TPR and were based on the respective rates observed in the second year after two year sequential treatment. Cumulative pregnancy rates at day 10, 25, and 32 were utilized to represent proportion pregnant during the synchronized period (day 10), a conventional length AI program (day 25), and that rate accounting for pregnancies resulting from conceptions one estrous cycle following (20-23 days) the peak synchronization response period in treated cattle (day 32), respectively.

Weaning performance was evaluated in terms of 1) average unadjusted weaning weight (kilograms) per cow exposed for breeding and per cow weaning a calf based on calf weights taken in the second year after two year sequential treatment; 2) two-year total unadjusted kg weaned per cow exposed and per cow weaning a calf for two successive years.

Partial budgeting was utilized to compare potential cost/return differences between $PGF_{2\alpha}$ and control breeding systems. Breeding costs were calculated for the first ten days of breeding in the $PGF_{2\alpha}$ system and the first 21 days in the control system using actual results obtained in 1975 breeding trials. For cost estimates the following assumptions were made:

1. Existing facilities (i.e. corrals, holding pens) were adequate for either system.

2. Labor for heat detection and insemination costs 3.00/hour (Watts and Downer, 1980). Heat detection and insemination for control animals (21 days) and the cattle in the $PGF_{2\alpha}$ system during days 1 through 6 of breeding required 8 man hours/day. The labor requirement increased to 16 man hours

per day during the peak response period (days 7 to 10) for cattle in the $PGF_{2\alpha}$ system.

3. Semen cost per insemination was $6.75. This cost was based on the average cost per ampule of semen from two Angus and two Polled Hereford bulls with ratios of 101 for 205-day adjusted weight as listed by American Breeders Service in 1980.

4. Cost for $PGF_{2\alpha}$ was 4.50 per 25 mg dose (Upjohn Company recommended price).

5. Bulls were turned out immediately following AI in both groups.

ASSUMPTIONS FOR COST ESTIMATION

Parameter	$PGF_{2\alpha}$-10	C-21
Labor Cost/Hr.	$3.00	$3.00
Total Man-Hours Required	112	168
Total Labor Cost	$336.00	$504.00
Semen Cost/unit	$6.75	$6.75
$PGF_{2\alpha}$ Cost/25 mg.	4.50	-

A total of 555 animals were assigned to the $PGF_{2\alpha}$ (n = 276) and control (n = 279) systems in 1975 breeding trials. Comparative reproductive performance of cattle in the 10 day $PGF_{2\alpha}$ system versus those in the 21 day control system was measured in terms of average day of conception and pregnancy rate as a percentage of the total assigned to each group. Calves resulting from these pregnancies were compared in terms of average age (days) at weaning and average weaning weight

(pounds and kilograms).

Breeding costs per cow in each system and breakeven selling prices required to recover costs at the pregnancy rates achieved were calculated. Hypothetical pregnancy rates required to recover additional breeding costs ($5.25, 6.25 and 7.25 per cow) at various calf selling prices (i.e. 50, 60, 70, 80, and 90 cents/lb.) were formulated. The impact of calf selling price, pregnancy rate, and additional breeding cost on returns per treated cow were also calculated.

Chapter 7

Results and Discussion

Estimated cycling rates based on detected estrus in nontreated controls (21 days) and treated cattle (7 or 8 days) for individual and pooled years are shown in table 1. The 7-day (1975 virgin heifers and 1975 lactating cows) and 8-day (1976 and 1977 lactating cows) estrus responses in treated cattle reflect differences in time of $PGF_{2\alpha}$ administration in yearly trials (PM of day 4 in 1975 and AM of day 5 in 1976 and 1977). Responses in the treated cattle include only those observed in estrus prior to the 80-hour nonestrus mass insemination. Results indicated that more controls (21 days) were detected in estrus than treated cattle in all years except 1977, and this pattern was reflected in the pooled analysis (61.6 vs. 52.7%, $P < .01$). The trend for higher detection rates (percent cycling estimates) in controls may be due in part to onset of postpartum behavioral estrus in a proportion of nonsynchronized controls between days 8 and 21 of breeding. Casida et al. (1968) reported that as days postpartum increased, incidence of behavioral estrus increased in beef cows. The observed inconsistency (1977) in the data may have been due to a less intensive natural service observation period (days 10 through 20) following AI when compared with that associated with the synchronization and AI period during days 1 through 9. Estimated cycling rate for treated cattle in 1977 (68.2%) was greater ($P < .10$) than in other years,

while the estimate for 1975 cows (43.9%) was lower ($P < .10$) than all others.

Cumulative insemination rates at day 8 or 9 of breeding for control and treated cattle bred to an observed estrus are displayed in table 2. Insemination rates for treated cattle are numerically identical to estimated cycling rates (table 1) but are represented as day 8 or 9 because inseminations of treated cattle detected in the PM of day 7 or 8 were performed in the AM of the next day. Due to synchronization, more ($P < .01$) cattle in the $PGF_{2\alpha}$ system than controls were inseminated within the first 8 or 9 days of breeding in each breeding group and in the pooled analysis.

First service conception rates for controls, treated cattle bred at observed estrus, treated cattle bred nonestrus at 80-hours post-$PGF_{2\alpha}$, and all treated cattle are illustrated in table 3. First service conception rates for control and treated cattle bred at observed estrus did not differ ($P > .10$) but were higher ($P < .01$) than those for treated cattle bred nonestrus, which agrees with results of similar investigations (Han and Moody, 1979 and Hanks et al., 1980). Lowered conception rates in the nonestrus bred subgroup may be attributable to one or more of the following factors: (1) insemination of anestrous cattle; (2) insemination of cattle failing to respond to $PGF_{2\alpha}$; (3) failure to detect behavioral estrus in some animals prior to 80-hour post-$PGF_{2\alpha}$ (Donaldson, 1977) and (4) cattle responding to

$PGF_{2\alpha}$ but failing to exhibit behavioral estrus prior to the 80-hour appointment breeding and therefore were inseminated too early or too late relative to ovulation. Reduced conception rate in nonestrus bred cattle resulted in lower ($P < .01$) conception rates for the $PGF_{2\alpha}$ system when compared to controls in all years except 1977. Although controls (60.0%) had higher conception rates than all treated cattle (51.1%) in 1977, the difference was not significant ($P > .10$). Because more cattle were cycling in 1977 versus other years, relatively fewer cattle were anestrous at the time of the nonestrus breeding in 1977 and proportionately more cattle conceived at the 80-hour breeding than in other years, although significant ($P < .10$) differences were limited to the 1977 (21.4%) and 1975 (8.7%) comparison; first service conception rates for the total $PGF_{2\alpha}$ system (51.1%) were higher ($P < .10$) than in other years. These data stress the importance of estrous cycling cattle at the outset of breeding for successful $PGF_{2\alpha}$ synchroniztion and AI programs.

Percent repeat inseminations at 104 to 168 hours post-$PGF_{2\alpha}$ for cattle bred nonestrus at 80-hours post-$PGF_{2\alpha}$ is depicted in table 4. The proportion of nonestrus bred cattle observed in estrus and repeat inseminated three to four days after the 80-hour breeding ranged from 14.0 (1975 virgin heifers) to 35.7 percent (1977 lactating cows) and averaged 21.6 percent (pooled). These results indicate that a considerable proportion of the nonestrus bred cattle responded to

$PGF_{2\alpha}$ but failed to exhibit estrus prior to the 80-hour breeding and thus were inseminated too early relative to ovulation. The estrus response period following single $PGF_{2\alpha}$ treatment observed in this study agrees with other investigators (Donaldson, 1977b; Macmillan et al., 1980) who reported that cattle responding to single $PGF_{2\alpha}$ treatment exhibited estrus for up to seven days. Significant year differences in the percentage of treated, nonestrus bred cattle observed in estrus and reinseminated at 104 to 168 hours post-$PGF_{2\alpha}$ were observed. Values for 1977 cows (35.7%) were greater ($P < .10$) than for 1975 heifers (14.0%), 1976 cows (17.3%), and pooled (21.6%) groups. Because proportionately more animals were cycling in 1977, relatively more cattle responded to treatment resulting in increased opportunity for rebreeding three to four days after the 80-hour appointment inseminations. For producers who choose to utilize the described $PGF_{2\alpha}$ system, this suggests that as the proportion cycling increases the greater the impact of the variation in the interval to onset of estrus following $PGF_{2\alpha}$ with regard to semen requirements during the synchronized period.

Total percentage repeat inseminated for control and treated cattle is shown in table 5. This data includes results of years involving 25 day AI periods (1975 and 1976). As might be expected, more ($P < .01$) cattle in the $PGF_{2\alpha}$ system were rebred than controls in each year, and this was largely due to repeats of cattle bred nonestrus

at 80-hours post-$PGF_{2\alpha}$, although more ($P < .05$) treated cattle bred to an estrus observed prior to 80 hours post-$PGF_{2\alpha}$ were rebred than controls in each year. The proportion of nonestrus bred (47.8%) and all cows in the $PGF_{2\alpha}$ system (31.7%) repeat bred in 1975 cows was greater ($P < .01$) than in 1975 heifers and 1976 cows, despite the fact that estimated cycling rates in treated cattle were lower ($P < .10$) in 1975 cows (43.9%) (see table 1). Increased proportion rebred in treated cattle may be explained by: 1) repeats (at 104-168 hours post-$PGF_{2\alpha}$) in nonestrus bred cattle responding to treatment but bred too early as discussed previously; 2) repeats in nonestrus bred cattle that resumed initial postpartum estrous cycles between appointment breeding and day 25; 3) opportunity to rebreed cattle who may have short-cycled after synchronized estrus.

Data regarding first service conception rate and repeat inseminations suggest that producers could substantially reduce semen costs by inseminating only those cattle observed in estrus following single $PGF_{2\alpha}$ treatment in herds that are cycling at rates similar to those observed in this study. The presence of noncycling cattle and variation in the interval to onset of estrus following $PGF_{2\alpha}$ are major obstacles encountered with the described $PGF_{2\alpha}$ system involving nonestrus inseminations at 80-hours post-treatment. The small percentage of cattle that conceive nonestrus may not justify the semen wastage and associated costs incurred due to these problems. The possibility

exists that some cows conceiving at nonestrus inseminations actually were in standing estrus prior to 80-hours post-$PGF_{2\alpha}$ but were not detected (Macmillan et al., 1980). Intensity of estrus behavior varies considerably when a large proportion of cattle are in estrus as during peak synchronization periods (Refsal and Seguin, 1980) and this may have contributed to errors in estrus detection.

Cumulative pregnancy rates at day 10, 25, and 32 and total pregnancy rates for controls, treated cattle bred at observed estrus, treated cattle bred nonestrus at 80-hour post-$PGF_{2\alpha}$, and for all cattle in the $PGF_{2\alpha}$ system are shown in tables 6 through 9 (yearly trials) and 10 (pooled). PR10 for cattle in the $PGF_{2\alpha}$ system was consistently greater ($P < .01$) than for controls in each yearly trial and in the pooled analysis. Table 10 demonstrates that PR25 and TPR tended to be slightly higher for all cattle in the $PGF_{2\alpha}$ system (51.2 and 80.2%) versus controls (47.3 and 76.3%) but differences were not significant ($P > .10$). Nonsignificant differences in total pregnancy rates between control and treated cattle after a 45 day breeding season observed in this study disagrees with results of Lambert et al., (1975, 1976). PR32 for cattle in the $PGF_{2\alpha}$ system (65.9%) was greater ($P < .01$) than for controls (56.7%) due to natural service conceptions one estrous cycle (20 to 23 days) following synchronized estrus (table 10). Within the $PGF_{2\alpha}$ system, cattle bred to an observed estrus had higher ($P < .01$) pregnancy rates at all periods

than cattle bred nonestrus (table 10). The latter observation is due to presence of noncycling and infertile cattle in the nonestrus subgroup within the $PGF_{2\alpha}$ system.

In 1977 total pregnancy rate for control (88.3%) and all treated cattle (94.3%) was higher ($P < .05$) than in all other years. This observation is due to a higher percent cycling at the outset of breeding as previously mentioned and also because of a longer (≈ 12 days) total breeding season versus other years. In 1975 cows (table 7), the pregnancy rates at day 25 (46.3%), 32 (58.5%), and total pregnancy rates (81.0%) for all treated cattle were nonsignificantly higher than controls (42.1, 50.3, and 71.1%, respectively), despite the fact that the estimated cycling rate for treated (43.9%) cattle was lower ($P < .01$) than for controls (61.6%) (see table 1). This may indicate that errors in estrus detection may have been greater in treated cattle during the peak response period (days 6 through 8) when compared with the 21 day detection period in controls, despite the likelihood that technicians expected peak activity in the treated group two to four days following $PGF_{2\alpha}$. Time constraints associated with heat detection and AI during peak response in a herd of this size (n=323) may have reduced the intensity of estrus detection required to identify submissive cows and those who may not have exhibited signs of estrus as readily as other cows. This stresses the importance of adequate labor during peak response in synchronization

programs. In large herds, it may be necessary to gather groups of "active" cows and designate individuals to observe estrus at the corrals while others continue to gather cows from pastures, thereby increasing the efficiency of estrus detection. The effect of herd size on efficiency of estrus detection is compounded by size and workability of pastures and facilities.

Average day of conception for cattle in the $PGF_{2\alpha}$ system and controls are shown in table 11. An earlier ($P < .05$) average day of conception for cattle in the $PGF_{2\alpha}$ system versus controls was observed for 1975 heifers (5 days), 1976 cows (3 days), 1977 cows (3 days) and pooled groups (3 days). The earlier average conception dates (3 to 5 days) in these groups is due to significantly more conceptions within the first ten days of breeding as discussed previously. As with other parameters, the percent cycling rate at the outset of breeding has profound effects on the average day of conception. The lower percentage of cows detected in estrus in the treated group (43.9%, table 1) prior to the 80-hour nonestrus breeding in 1975 cows relative to other years resulted in the only case of nonsignificant differences ($P > .10$) in average day of conception. As cycling rates increase, the magnitude of the difference between average conception dates for synchronized and conventionally inseminated cattle should increase in favor of treated cattle. Lambert (1977) demonstrated that cattle in a $PGF_{2\alpha}$ system similar to that employed in this study conceived an

average of seven days earlier than controls.

Two Year Sequential Treatment Study

Cumulative preganacy rates at day 10, 25, and 32 of breeding and total pregnancy rates based on values observed in the second year after two year sequential treatment are shown in table 12. Trends observed in the individual two year data sets (1975 and 1976; 1976 and 1977) were consistent and, therefore, the data was pooled.

Pregnancy rates by day 10 of breeding in year two for CC, CT, TC, and TT were 21.1, 45.5, 24.8, and 43.7 percent, respectively, with CT and TT greater ($P < .01$) than CC and TC. No beneficial carryover effect of synchronization in the first year was evident in view of similar PR10 for TT versus CT (43.7 vs. 45.5%, respectively) and TC versus CC (23.8 vs 25.1%, respectively). Pregnancy rates at day 25 and 32 and total pregnancy rates were not significantly different ($P > .10$) among two year treatment sequences (pooled data), although PR32 for TT (72.5%) and CT (71.5%) tended to be higher than CC (64.1%) and TC (62.9%). This tendency is due to opportunity for second service conceptions (TT and CT) approximately one estrous cycle (20 to 23 days) following peak synchronization (day 7 to 8) in treated cattle during year two. Nonsignificant ($P > .10$) differences in total pregnancy rates for TT (80.2%) and CC (80.5%) after year two observed in the present study disagrees with the results of Greene et al. (1977), who reported higher ($P < .10$) total pregnancy rates after year two for

cattle in an identical $PGF_{2\alpha}$ system for two consecutive years than for cattle in a nonsynchronized control system for two successive years. Lambert (1977) stated that higher total pregnancy rates for cattle in an identical $PGF_{2\alpha}$ system versus controls could be explained by the opportunity for treated cattle to cycle three times rather than two times as is the case for controls during a 45-day breeding season. However, only cattle exhibiting estrus within the first four to five days of breeding prior to $PGF_{2\alpha}$ administration would have sufficient time to cycle three times during 45 days assuming estrous cycles were of normal duration, and this would apply for both treated and non-treated cattle. Significant ($P < .05$) differences in total pregnancy rates among two year data sets were observed, with 1976 and 1977 data greater than 1975 and 1976 for CC (92.5 vs. 75%), CT (96.9 vs. 72.3%), and TT (96.6 vs. 75.2%). Pregnancy rates in the early segment of the breeding season (PR10 for CT and TT and PR25 for all treatments) for the 1976 and 1977 two year component were greater ($P < .05$) than that for the 1975 and 1976 data. Again, these data collectively demonstrate the impact of a higher percentage of cows detected in estrus (% cycling) and a longer breeding season in 1977.

Average weaning weight (kilograms) per cow exposed for breeding and per cow weaning a calf in the second year after two year sequential treatment are shown in table 13. Differences among treatments in average weaning weight per cow exposed for breeding largely reflect

differences in total pregnancy rates among treatments in the second year. In view of the tendency for nonsignificant differences in total pregnancy rates (table 12), no statistically significant differences in weaning weights per cow exposed were observed. However, cattle in TT consistently weaned more kilograms of calf per cow exposed (2.2 to 7.5 kg) than cattle in CC due to nonsignificant but slightly higher total pregnancy rates (1975 and 1976; 1976 and 1977) and also due to significantly higher PR10 which likely resulted in a relatively higher percentage of older calves in TT. Comparison of cattle synchronized in year one and nonsynchronized in year two (TC) with cattle nonsynchronized in both years (CC) indicate no carryover advantage of synchronization in year one on weaning weight per cow exposed.

Among cows weaning a calf, average weaning weights in year two largely reflect differences resulting from cattle becoming pregnant earlier, calving earlier, and weaning older calves with heavier average weaning weights. Although a tendency for greater (5.6 kg) average weaning weight per cow weaning a calf was seen in TT (186.6 kg/cow) than in CC (181.0 kg/cow) after pooled analysis, the means were not significantly different ($P > .10$). The tendency for greater average weaning weights in cattle synchronized two years in succession versus cattle nonsynchronized both years is likely due to increased age of calves resulting from significantly more ($P < .10$) conceptions

within the first ten days of breeding in TT. Although cows nonsynchronized in year one and synchronized in year two (CT) had greater average weaning weights (3.1 to 4.9 kg) than cows in CC due to higher ($P < .01$) PR10 in year two, the means were not significantly different ($P > .10$). These data indicate that cattle synchronized in the second year (CT and TT) weaned nonsignificantly heavier calves than those not synchronized in year two (CC and TC) due to a higher percentage of older calves. No significant carryover advantage of synchronization from year one to year two is apparent. Significant ($P < .01$) year effects in weaning weight per cow exposed and per cow weaning a calf were observed, with the 1976 and 1977 two year data set greater than that for 1975 and 1976. More cycling cows at the outset of breeding in 1977 and subsequently higher PR10 and TPR versus other years resulted in relatively more calves of greater age (increased weaning weight per cow weaning a calf) and relatively more calves (increased weaning weight per cow exposed).

Two-year total kilograms weaned per cow exposed for breeding and per cow weaning a calf are shown in table 14. There were no significant differences ($P > .10$) among treatment sequences in either two-year total kilograms weaned per cow exposed or per cow weaning a calf. However, cattle in TT weaned more kilograms of calf than those in CC (pooled data) primarily due to significantly more conceptions within the first ten days of breeding. Although nonsignificant, the 10 to 11

kilogram (22 to 24 pound) advantage in two year total kilograms weaned per cow weaning a calf observed in TT versus CC indicates an important advantage of the described $PGF_{2\alpha}$ system. This suggests that synchronization for two consecutive years with the single injection $PGF_{2\alpha}$ system employed in the present study may result in more pounds of salable product for commercial beef producers over that obtainable with two successive years of conventional AI when the same sires are used in each system. Cattle in TT weaned 6 to 8 kilograms more per cow weaning a calf than those in CT which may indicate a cumulative advantage of two successive years synchronization. However, this observation must be approached with caution in view of non significant differences in weaning weights and variation in the raw data. Large error mean squares indicated that extreme variation in calf weaning weights existed. Significant year effects were observed, with 1976 and 1977 results greater ($P < .01$) than that of 1975 and 1976 for two year total kilograms weaned. Enhanced environmental conditions (i.e. "easier" wintering period, earlier onset of green grass, etc) and their potential positive effects on cow condition and percent cycling prior to breeding (Meacham et al., 1979) may have contributed to increased weaning performance of cattle in all treatment sequences in the 1976 and 1977 data.

Economic Analysis-$PGF_{2\alpha}$ vs. Control

Average day of conception and pregnancy rate (%) for cattle in $PGF_{2\alpha}$ (10 days) and control (21 days) systems during 1975 are depicted in table 15. Results demonstrate that treated cattle (6.62) conceived approximately four days earlier ($P < .01$) than controls (10.84). Total pregnancy rates at day 10 in treated cattle (38.7%) and at day 21 in controls (35.8%) were not significantly different ($P > .10$), which demonstrates that treated cattle exhibited comparable reproductive performance (pregnancy rates) in approximately half the time required in controls. However, the pregnancy rates of both groups were rather low.

Age at weaning (days) and average weaning weight (pounds and kilograms) of calves resulting from $PGF_{2\alpha}$ and control systems are shown in table 16. Calves out of synchronized cows were 7.7 days older ($P < .01$) and 14.3 pounds (6.5 kg) heavier ($P < .10$) than those out of control cows. Variation in gestation length may partially explain why the difference in age at weaning ($\simeq$ 7 days) was greater than the difference in average day of conception ($\simeq$ 4 days) between control and treated cattle. Alternatively, it is possible that this discrepancy was due to treatment effects.

Comparative breeding costs for the 10 day $PGF_{2\alpha}$ ($PGF_{2\alpha}$ - 10) and 21 day control (C-21) systems are depicted in table 17. Total cost and costs per cow exposed, per pregnant cow, and per calf weaned for

semen, labor, and $PGF_{2\alpha}$ ($PGF_{2\alpha}$-10 only) were calculated. Of 279 control cattle there were 178 inseminations in the first 21 days resulting in a total semen cost of \$1201.50 (178 X \$6.75 = \$1201.50) compared to \$2045.25 in $PGF_{2\alpha}$-10 (303 inseminations X \$6.75), indicating that total semen costs were 46 percent higher in treated cattle. Semen cost per cow exposed (\$7.41 vs. \$4.31), per pregnant cow (\$19.11 vs. \$12.02), and per calf weaned (\$21.53 vs. \$12.91) was higher for $PGF_{2\alpha}$-10 than for C-21, with semen costs representing 59.3 and 70.4 percent (table 18) of the total cost of the $PGF_{2\alpha}$-10 and C-21 systems, respectively. Higher semen costs are inherent with the described $PGF_{2\alpha}$ system because all cattle (276) were inseminated at least once by day 7 and a considerable number (27) of repeats (responding cows bred too early) on days 8 through 10 were required. These data suggest that semen cost of the $PGF_{2\alpha}$ system may be a prohibitive factor when compared to the control system at the cycling rates observed in this study (≈ 55%) and that producers could reduce semen costs by elimination of the 80-hour nonestrus breeding and by breeding only those cattle exhibiting estrus. This would reduce or eliminate semen wastage due to insemination of both noncycling cattle and those bred too early due to variation in the interval to estrus onset. Total labor cost for $PGF_{2\alpha}$-10 (\$336.00) was 33.3 percent less than that for C-21 (\$504.00) due primarily to reduced total man-hour requirements. Since total labor cost was reduced in the synchronized

system, labor cost per cow exposed ($1.22 vs. $1.81), per pregnant cow ($3.14 vs. $5.04), and per calf weaned ($3.54 vs. $5.42) was also less, with labor cost representing 9.8 and 29.6 percent (table 18) of the total cost of the $PGF_{2\alpha}$-10 and the C-21 systems, respectively. The estimated total man-hour requirements for $PGF_{2\alpha}$-10 (112) and C-21 (168) in the present study are similar to those reported by Donaldson (1980) for a 10 day $PGF_{2\alpha}$ system (100) and a 21 day conventional system (174). It is realized that absolute man-hour requirements and labor cost per hour employed in this study are not applicable for all production situations due to a multitude of variables, but the comparative relationship between systems indicates that total labor requirements and associated costs are less in a 10 day $PGF_{2\alpha}$ system versus a 21 day conventional system under the assumptions of this study. Two hundred thirty-six of the total group in the $PGF_{2\alpha}$-10 system received $PGF_{2\alpha}$ resulting in a cost of $1062.00 (236 X $4.50 = $1062) representing 30.9 percent (table 18) of the total cost. Total breeding cost per treated cow ($12.48) was more than double the cost for control ($6.12) cattle.

Breakeven selling price/pound required to recover the additional breeding cost per cow exposed at the average pregnancy rate (37.3%) of the $PGF_{2\alpha}$-10 and C-21 systems is shown in table 19. Pregnancy rates of $PGF_{2\alpha}$-10 (38.7%) and C-21 (35.8%) were averaged (37.3%) to facilitate calculation and was considered appropriate since the difference

between systems was not significant (P > .10, table 15). Average weaning weights of calves from the two systems were multiplied by the average pregnancy rate to arrive at pounds of calf weaned per cow assigned for each system, which was 5.4 pounds in favor of the $PGF_{2\alpha}$-10 system. The additional breeding cost per cow exposed (12.48 - 6.12 = $6.36) in the $PGF_{2\alpha}$-10 system was divided by the additional pounds of calf weaned per cow exposed (5.4) resulting in a $1.18/lb breakeven selling price. This indicates that it would not be possible to recover additional breeding costs of the $PGF_{2\alpha}$-10 system at the pregnancy rates achieved (37.3%) unless calves could be sold at $1.18/lb.

Table 20 and Figure A.1 depicts breakeven selling price required to recover additional breeding costs ($5.25, $6.25, and $7.25) per cow at various pregnancy rates based on the actual difference in weaning weight of calves from the two systems. This is an extrapolation from methods and results shown in table 19. These data demonstrate that as pregnancy rate of treated cattle increases, there is a concomitant decrease in the breakeven selling price per pound of calf at a given additional breeding cost when weaning weight advantage of calves is 14.3 pounds/calf. At the average pregnancy rate (37.3%) achieved in this study, breakeven selling price for calves was $0.97, $1.16, and $1.34 for additional breeding costs per cow of $5.25, $6.25, and $7.25, respectively. In order to increase pregnancy rates with the described $PGF_{2\alpha}$-10 system, producers will be required to adjust management

factors conducive to an increase in percent cycling prior to the breeding season. Additionally, producers will likely be able to reduce the additional breeding cost per cow and thus reduce breakeven selling prices by elimination of the nonestrus, 80-hour appointment breeding and insemination of only those cows observed in estrus.

Figures A.2 through A.6 depict expected returns per treated cow at various pregnancy rates when additional breeding costs per cow ($5.25, $6.25, and $7.25) and calf prices (50, 60, 70, 80 and 90 cents per pound) vary. The formula used to arrive at expected returns was:

$$PWR-C = ED$$

where P = selling price per pound

W = difference in weaning weight (constant at 14.3 lbs)

R = pregnancy rate

C = additional breeding cost

ED = expected returns per treated cow

As might be expected, these data demonstrate that increased pregnancy rates, increased calf prices, and decreased additional breeding costs elicit a positive effect on returns per treated cow. When the variable for calf selling price was 50 cents/lb (figure A.2), very little opportunity for profit was possible even at the lowest ($5.25) additional breeding cost, with a minimum pregnancy rate of 74 percent required to recover that cost. When additional costs were increased to $7.25 per cow, even a pregnancy rate of 100 percent would not allow

recovery of breeding costs at 50 cent calves. However, increasing calf prices to 90 cents/lb (figure A.6) increased the opportunity for profit, with minimum pregnancy rates of 41, 49, and 57 percent required to recover additional breeding costs per cow of $5.25, $6.25, and $7.25, respectively. The impact of higher priced calves (90 vs. 70 and 50 cents/lb) at all pregnancy rates and additional cost levels on return/cow is depicted in figure A.7, which is a composite of figures A.2, A.4, and A.6. This data illustrates that, along with increased absolute returns, rate of return/cow increases as calf prices increase.

Chapter 8

Conclusions

Assessment of the feasibility of $PGF_{2\alpha}$ synchronization/AI programs for commercial beef herds must include the overall effect of a controlled breeding program in a given operation. As with any endeavor, there are tradeoffs involved in implementation of an estrous synchronization program. The present study indicated potential for increased weaning weight of calves with a single injection $PGF_{2\alpha}$ system due to significantly higher pregnancy rates in the first ten days of breeding when compared to controls. However, breeding costs per cow were twice as high for treated cattle due to drug and semen requirements for the described $PGF_{2\alpha}$ system involving appointment breeding, despite reduced total man-hour requirements and associated labor costs. Percent cycling, resulting pregnancy rates, and additional breeding costs along with calf prices were emphasized as factors affecting short-term economic feasibility of the described $PGF_{2\alpha}$ system. Results suggest that when calves are selling for less than 60 cents/lb, the opportunity for profit from the use of the 10 day $PGF_{2\alpha}$ system even at high pregnancy rates (80 to 90%) is extremely limited under the assumptions of this study. The minimum pregnancy rate required to breakeven at highest calf prices (90 cents/lb) and lowest additional breeding cost per cow ($5.25) was 41 percent. Bailie and Dury (1976) reported that pregnancy rates of 40 percent or

more would be necessary under most commercial conditions to make $PGF_{2\alpha}$-synchronization feasible. Producers can reduce breeding costs by insuring that cattle are cycling prior to treatment and can further reduce costs by inseminating only those cattle showing estrus following $PGF_{2\alpha}$ (Smith and McMillan, 1978; Adkins, 1980). Identification of estrous cycling cattle prior to treatment may be accomplished by observation of herds for a minimum of 21 days prior to treatment, which may involve supportive use of gomer bulls fitted with chinball markers and/or various detection aids, and by rectal palpation to determine cattle with a functional CL. Palpation reportedly reduces total cost of $PGF_{2\alpha}$ synchronization (Canady and Copeland, 1978; Adkins, 1980), but effectiveness is limited by technician expertise and cost per cow. Furthermore, it has been reported that palpation of a corpus luteum immediately prior to breeding did not prove that cattle were regularly cycling, with evidence of corpus luteum formation in prepubertal heifers and postpartum cows before the occurrence of first estrus (Miller, 1979 and Donaldson, 1980).

It is recognized that the cost assumptions employed in this study are not applicable for all situations because of the variability in semen and labor costs. The labor cost (3.00/hr) may be an underestimation for many producers, but this cost was based on the assumption that estrus detection and insemination would be performed by existing on-ranch help. As labor costs per unit time increase, the

difference in labor cost in favor of the $PGF_{2\alpha}$ system versus conventional AI would be expected to increase due to a substantial savings in total man-hour requirements based on the results of this study. Furthermore, producers will have opportunity to devote time and effort to other areas of production due to reduced number of days work required with a ten day $PGF_{2\alpha}$ system versus a conventional length AI program.

Handling of cow-calf pairs under range conditions is an important aspect when considering implementation of $PGF_{2\alpha}$ synchronization. Cattle in single-injection synchronization programs have to be handled a minimum of one extra time when compared to conventional AI, and more so if a double injection system and/or appointment breeding is utilized. The negative effects of these extra handlings have not been adequately investigated with regard to cow and calf performance. There is some evidence indicating that "chute stress" and stress-related blood parameters (i.e. corticoids) may suppress estrus (Hardin et al., 1980) and reduce fertility (Cumming et al., 1976) following prostaglandin treatment. $PGF_{2\alpha}$-synchronization systems that minimize handlings of suckled cows may result in better performance, and will be easier on man and beast.

The peak response period following $PGF_{2\alpha}$ requires optimal conditions for efficient heat detection. Producers making the transition from conventional AI to synchronization/AI may have to adjust pas-

tures, facilities, and their own expectations to facilitate estrus detection of responding cows. Since sorting during peak response may be difficult, producers may want to hold cows in small pastures or drylot at this time. Herd size and temperament of cattle will dictate necessary changes.

Producers have expressed concern regarding labor intensity at calving following successful synchronization programs. Due to variation in gestation length, cattle conceiving on a given day will calve over a ten to fourteen day period, with a maximum of 25 percent calving on any one day (Ruttle and Dunn, 1980). Estrous synchronization may actually increase the efficiency of labor during peak calving periods if adequate breeding records are maintained.

Successful estrus synchronization with $PGF_{2\alpha}$ and potential for increased weaning weight can not be obtained without an important prerequisite: estrous cycling cattle. This has been emphasized time and again in the literature and was reiterated in the present study. The semen wastage encountered with appointment breeding following single $PGF_{2\alpha}$ treatment observed in this study and others (Donaldson, 1977b and Dailey et al., 1979) suggests that breeding only those cows in estrus may be more cost efficient for producers who choose to use a ten-day system.

APPENDICES

APPENDIX A

TABLE 1

Estimated Cycling Rates (%) Based on Estrus Detection Rates in Control (21 days) and $PGF_{2\alpha}$ (7 or 8 days) Systems

Breeding Group	Treatment			
	21 Day Control		7 or 8 Day $PGF_{2\alpha}$[1,2]	
1975 Heifers	(74/120)	61.7[a]	(62/112)	55.3[a]
1975 Cows	(98/159)	61.6[a]	(72/164)	43.9[b]
1976 Cows	(129/202)	63.9[a]	(104/202)	51.5[b]
1977 Cows	(53/94)	56.4[a]	(60/88)	68.2[a]
Pooled	(354/575)	61.6[a]	(298/566)	52.7[b]

[1]7 day response in 1975; 8 day response in 1976 and 1977.

[2]See text for significant year differences.

[a,b]Means within rows bearing different superscripts are significantly different ($P < .01$).

TABLE 2

Cumulative Insemination Rates (%) at Day 8 or 9 of Breeding for Control and $PGF_{2\alpha}$-Treated Cattle Bred at Observed Estrus

Breeding	Day	Treatment			
		Control		$PGF^{1}_{2\alpha}$	
1975 Heifers	8	(26/120)	21.6[a]	(62/112)	55.3[b]
1975 Cows	8	(39/159)	24.5[a]	(72/164)	43.9[b]
1976 Cows	9	(62/202)	30.7[a]	(104/202)	51.5[b]
1977 Cows	9	(35/94)	37.2[a]	(60/88)	68.2[b]
Pooled		(162/575)	28.2[a]	(298/566)	52.7[b]

[1]See text for significant year differences.

[a,b]Means within rows bearing different superscripts are significantly different ($P < .01$)

TABLE 3

AI First Service Conception Rates[1] (%) for Control, Treated Cattle Bred at Estrus ($PGF_{2\alpha}$-E), Treated Cattle Bred Non-Estrus ($PGF_{2\alpha}$-80), and All Treated Cattle ($PGF_{2\alpha}$-System)

Breeding Group	Control		$PGF_{2\alpha}$-E		$PGF_{2\alpha}$-80		$PGF_{2\alpha}$-System	
1975 Heifers	(46/76)	60.5[a]	(38/62)	61.3[a]	(6/50)	12.0[b]	(43/112)	38.4[c]
1975 Cows	(65/111)	58.6[a]	(44/72)	61.1[a]	(8/92)	8.7[b]	(52/164)	31.7[c]
1976 Cows	(96/140)	68.6[a]	(64/104)	61.5[a]	(13/98)	13.3[b]	(77/202)	38.1[c]
1977 Cows	(21/35)	60.0[a]	(39/60)	65.0[a]	(6/28)	21.4[b]	(45/88)	51.1[a]
Pooled	(228/362)	62.9[a]	(185/298)	62.1[a]	(33/268)	12.3[b]	(217/566)	38.3[c]

[1]See text for significant year differences.

[a,b,c]Means within rows bearing different superscripts are significantly different ($P < .01$).

TABLE 4

Repeat Inseminations (%) at 104 to 168 hour Post-$PGF_{2\alpha}$ in Cattle Bred Nonestrus at 80-hour Post-$PGF_{2\alpha}$

Breeding Group	No. Bred Nonestrus @ 80-hour	No. Repeats @ 104 to 168-hours	Percent
1975 Heifers	50	7	14.0[a]
1975 Cows	92	24	26.1[bc]
1976 Cows	98	17	17.3[ab]
1977 Cows	28	10	35.7[c]
Pooled	268	58	21.6[ab]

[a,b,c]means without a common superscript are different ($P < .10$)

TABLE 5

Total Repeat Inseminations (%) for Controls, Treated Cattle Bred at Estrus ($PGF_{2\alpha}$-E), Treated Cattle Bred Nonestrus at 80-hours ($PGF_{2\alpha}$-80) and All Treated Cattle ($PGF_{2\alpha}$-System) During 25 days of AI

Breeding Group	AI Period (Days)	Control	$PGF_{2\alpha}$-E	$PGF_{2\alpha}$-80[1]	$PGF_{2\alpha}$-System[1]
1975 Heifers	25	(2/120) 1.7[a]	(5/62) 8.1[b]	(10/50) 20.0[c]	(15/112) 13.4[bc]
1975 Cows	25	(6/112) 5.4[a]	(8/72) 11.1[b]	(44/92) 47.8[c]	(52/104) 31.7[d]
1976 Cows	25	(5/202) 2.5[a]	(8/104) 7.7[b]	(26/98) 26.5[c]	(34/202) 16.8[d]

[1]See text for significant year differences.

[a,b,c,d]Means within rows bearing different superscripts are significantly different ($P < .10$)

TABLE 6

Cumulative Pregnancy Rates (%) at Day 10, 25, and 32 and Total Pregnancy Rates for 1975 Virgin Heifers

Treatment	PR10	PR25	PR32	TPR[1]
Control	(18/120) 15.0[a]	(48/120) 40.0[a]	(56/120) 46.7[a]	(82/120) 72.5[a]
$PGF_{2\alpha}$ System	(46/112) 41.1[b]	(54/112) 48.2[a]	(69/112) 61.6[b]	(87/112) 77.7[ab]
bred at observed estrus	(38/62) 61.3[c]	(43/62) 69.4[b]	(49/62) 79.0[c]	(54/62) 87.1[b]
bred nonestrus @ 80-hours	(8/50) 16.0[a]	(11/50) 22.0[c]	(20/50) 40.0[a]	(33/50) 66.0[a]

[1]TPR = Total Pregnancy Rate in 45 days.

[a,b,c]Means within columns bearing different superscripts are significantly different ($P < .05$).

TABLE 7

Cumulative Pregnancy Rate (%) at Day 10 (PR10), 25(PR25), and 32(PR32) and Total Pregnancy Rate for 1975 Cows

Treatment	PR10		PR25		PR32		TPR[1]	
Control	(27/159)	17.0[a]	(67/159)	42.1[a]	(80/159)	50.3[ac]	(113/159)	71.1[a]
$PGF_{2\alpha}$ System	(62/164)	37.8[b]	(76/164)	46.3[a]	(96/164)	58.5[a]	(133/164)	81.0[a]
bred at observed estrus	(44/72)	61.1[c]	(49/72)	68.1[b]	(55/72)	76.4[b]	(65/72)	90.3[b]
bred nonestrus @ 80-hour	(18/92)	19.6[a]	(27/92)	29.3[c]	(41/92)	44.6[c]	(68/92)	73.9[a]

[1]TPR = total pregnancy rate in 45 days.

[a,b,c,d]Means within columns bearing different superscripts are significantly different ($P < .10$).

TABLE 8

Cumulative Pregnancy Rate (%) at Day 10 (PR10), 25(PR25), and 32(PR32) and Total Pregnancy Rate for 1976 Cows

Treatment	PR10		PR25		PR32		TPR[1]	
Control	(57/202)	25.2[a]	(99/202)	49.0[a]	(122/202)	60.4[a]	(146/202)	77.2[a]
$PGF_{2\alpha}$ System	(86/202)	42.6[b]	(101/202)	50.0[a]	(136/202)	67.3[ab]	(151/202)	74.8[a]
bred at observed estrus	(65/104)	62.5[c]	(69/104)	66.3[b]	(78/104)	75.0[b]	(84/104)	80.7[a]
bred nonestrus @ 80-hour	(21/98)	21.4[a]	(32/98)	32.6[c]	(58/98)	59.2[a]	(67/98)	68.4[b]

[1]TPR = total pregnancy rate in 45 days.

[a,b,c]Means within columns bearing different superscripts are signficantly different ($P < .05$).

TABLE 9

Cumulative Pregnancy Rate (%) at Day 10 (PR10), 25(PR25), and 32(PR32) and Total Pregnancy Rate for 1977 Cows

Treatment	PR10	PR25	PR32	TPR[1]
Control	(27/94) 28.7[a]	(58/94) 61.7[a]	(68/94) 72.3[a]	(83/94) 88.3[a]
$PGF_{2\alpha}$ System	(48/88) 54.5[b]	(59/88) 67.0[a]	(72/88) 81.8[ab]	(83/88) 94.3[a]
bred at observed estrus	(39/60) 65.0[b]	(44/60) 73.3[ab]	(51/60) 85.0[b]	(57/60) 95.0[a]
bred nonestrus at 80-hours	(9/28) 32.1[a]	(15/28) 53.6[ac]	(21/28) 75.0[a]	(26/28) 92.9[a]

[1]TPR = total pregnancy rate in 57 days.

[a,b,c]Means within columns bearing different superscripts are significantly different ($P < .10$).

TABLE 10

Cumulative Pregnancy Rate (%) at Day 10 (PR10), 25(PR25), and 32(PR32) and Total Pregnancy Rate (TPR) for Pooled Years

Treatment	PR10	PR25	PR32	TPR[1]
Control	(123/575) 21.4[a]	(272/575) 47.3[a]	(326/575) 56.7[a]	(439/575) 76.3[ab]
$PGF_{2\alpha}$ System	(242/566) 42.8[b]	(290/566) 51.2[a]	(373/566) 65.9[b]	(454/566) 80.2[a]
bred at observed estrus	(186/298) 62.4[c]	(205/298) 68.8[b]	(233/298) 78.2[c]	(260/298) 87.2[c]
bred nonestrus at 80-hours	(56/268) 20.9[a]	(85/268) 31.7[c]	(140/268) 52.2[a]	(194/268) 72.4[b]

[1]TPR - See text for significant year differences.

[a,b,c]Means within columns bearing different superscripts are significantly different ($P < .10$).

TABLE 11

Average Day of Conception for Treated and Control Cattle
(Yearly Trials and Pooled)

Breeding Group	Average Day of Conception (DOC)			
	Control		Treated	
	NO.	DOC	NO.	DOC
1975 Heifers	87	23[a]	87	18[b]
1975 Cows	113	20	133	18
1976 Cows	156	19[a]	151	16[b]
1977 Cows	83	20[a]	83	17[b]
Pooled	439	21[a]	454	18[b]

[a,b]Means (DOC) within rows bearing different superscripts are significantly different ($P < .05$).

TABLE 12

Cumulative Pregnancy Rates (%) at Day 10(PR10), 25(PR25) and 32(PR32) and Total Pregnancy Rate (TPR) Based on Values Observed in Year Two After Two Year Sequential Treatment.

Data[2] Component	Treatment Sequence	(No.)	PR10 (%)	PR25 (%)	PR32 (%)	TPR[1] (%)
1975-1976	CC	88	26.1[a]	47.7	56.8[a]	75.0
	CT	83	42.1[b]	48.1	66.3[ab]	72.3
	TC	99	24.2[a]	49.4	61.6[ab]	76.8
	TT	101	38.6[b]	48.5	69.3[b]	75.2
1976-1977	CC	40	27.5[a]	69.9	79.9	92.5[ab]
	CT	33	54.5[b]	66.6	84.8	96.9[a]
	TC	25	20.0[a]	56.0	67.9	84.0[b]
	TT	30	60.0[b]	73.3	83.3	96.6[ab]
Pooled	CC	128	26.6[a]	54.7	64.1	80.5
	CT	116	45.7[b]	53.4	71.6	79.3
	TC	124	23.4[a]	50.8	62.9	78.2
	TT	131	43.5[b]	54.2	72.5	80.2

[1] T_{PR} = Total Pregnancy rates in 45 (1975 and 1976) and 57 days (1976 and 1977).

[a,b,c] Means within columns for specific data components with different superscripts are significantly different ($P < .10$).

[2] See text for significant data set differences.

TABLE 13

Average Weaning Weight (kilograms) Per Cow Exposed For Breeding and Per Cow Weaning a Calf in Year Two

Data[1] Component	Treatment Sequence	(No.)	WW(kg)per Cow Exposed	(No.)	WW(kg)per cow Weaning a Calf
1975-1976	CC	88	130.1	61	175.6
	CT	83	115.7	51	182.5
	TC	99	126.0	65	181.9
	TT	101	132.2	67	183.8
	EMS[a]		7450.2		845.8
1976-1977	CC	40	159.8	31	193.9
	CT	33	180.8	29	197.0
	TC	25	143.5	17	188.9
	TT	30	167.3	24	201.2
	EMS[a]		6099.2		963.4
Pooled	CC	128	137.3	92	181.0
	CT	116	133.2	80	185.4
	TC	124	131.6	82	184.8
	TT	131	141.3	91	186.6
	EMS[a]	-	7103.9	-	950.0

[1]See text for significant data differences.

[a]EMS = Error mean square; DF 1975-1976 = 367,240
DF 1976-1977 = 124,97
DF Pooled = 491,337

TABLE 14

Two-Year Total Kilograms (kg) Weaned Per Cow Exposed and Per Cow Weaning a Calf

Data[1] Component	Treatment Sequence	(No.)	Kg Weaned Per Cow Exposed	(No.)	Kg Weaned Per Cow Weaning a Calf
1975-1976	CC	88	304.9	61	363.1
	CT	83	296.4	51	368.8
	TC	99	302.8	65	366.9
	TT	101	304.2	67	374.0
	EMS[a]	-	11110.8	-	2449.2
1976-1977	CC	40	322.9	31	378.3
	CT	33	358.1	29	380.7
	TC	25	317.6	17	373.8
	TT	30	346.7	24	388.8
	EMS[a]		9893.4		2488.5
Pooled	CC	128	308.7	92	367.3
	CT	116	312.9	80	372.2
	TC	124	307.7	82	369.4
	TT	131	314.9	91	378.3
	EMS[a]		10802.9		2460.5

[1]See text for significant data set differences.

[a]EMS = Error mean square; DF 1975-1976 = 367, 240
DF 1976-1977 = 124, 97
DF Pooled = 491, 337

TABLE 15

Average Day of Conception and Pregnancy Rate[1] (%) of Cattle in a 10 Day $PGF_{2\alpha}$ ($PGF_{2\alpha}$-10) Versus 21 Day Control (C-21) System

Treatment	No	Average Day of Conception	Pregnancy Rate (%)
C-21	100	10.84[a]	(100/279) 35.8[a]
$PGF_{2\alpha}$-10	107	6.62[b]	(107/276) 38.7[a]

[1] Pregnancy Rate = $\frac{\text{No. Pregnant}}{\text{Total Number Assigned}}$ X 100

[a,b] Means within average day conception column are significantly different ($P < .01$).

TABLE 16

Average Age at Weaning (days) and Average Weaning Weight of Calves (kg and lb) resulting from $PGF_{2\alpha}$ (10 days) and Control (21 days) Systems

Treatment	N	Age at Weaning (Days)	Average Weaning Weight	
			Pounds	Kg
C-21	93	208.1[a]	437.6[c]	198.9[c]
$PGF_{2\alpha}$-10	95	215.8[b]	451.9[d]	205.4[d]

[a,b]Means within age at weaning column bearing different superscripts are significantly different ($P < .01$).

[c,d]Means within weaning weight columns bearing different superscripts are significantly different ($P < .10$).

TABLE 17

Breeding Costs (Total, Per Cow Exposed, Per Pregnant Cow, and Per Calf Weaned) for Control (C-21) and $PGF_{2\alpha}$ ($PGF_{2\alpha}$-10) Systems

System	Total Cost	Cost Per Cow Exposed		Cost Per Pregnant Cow		Cost Per Calf Weaned	
		No.	$	No.	$	No.	$
C-21							
Semen	1201.50	279	4.31	100	12.02	93	12.91
Labor	504.00	279	1.81	100	5.04	93	5.42
Total	1705.50		6.12		17.06		18.33
$PGF_{2\alpha}$-10							
Semen	2045.25	276	7.41	107	19.11	95	21.53
Labor	336.00	276	1.22	107	3.14	95	3.54
$PGF_{2\alpha}$	1062.00	276	3.85	107	9.93	95	11.18
Total	3443.25		12.48		32.18		36.25

TABLE 18

Semen, Labor, and $PGF_{2\alpha}$ Costs as a Percentage of Total Cost(%T) for $PGF_{2\alpha}$-10 and C-21 System

System	Total Cost	Semen		Labor		$PGF_{2\alpha}$	
		Cost($)	%T	Cost($)	%T	Cost($)	%T
C-21	1705.00	1201.50	70.4	504.00	29.6	-	-
$PGF_{2\alpha}$-10	3443.25	2045.25	59.3	336.00	9.8	1062.00	30.9

TABLE 19

Breakeven Selling Price Per Pound Required to Recover Additional Breeding Costs of $PGF_{2\alpha}$-10 System at 37.3% Pregnance Rate.

Treatment	Average Weaning Weight		Average[1] Pregnancy Rate		Pounds Calf Weaned Per Cow Assigned
$PGF_{2\alpha}$-10	451.9		.373		168.6
C-21	437.6		.373		163.2
	14.3	X	.373	=	5.4

5.4 lbs/cow weaning weight advantage = $\frac{6.36}{5.4}$ = $1.18
$6.36/cow additional breeding cost

[1]Average Pregnancy Rate = Average of $PGF_{2\alpha}$-10 and C-21 Systems (see text).

TABLE 20

Breakeven Selling Price Per Pound of Calf[1] (P) Required to Recover Various Additional Breeding Costs Per Treated Cow (C) at Various Pregnancy Rates

Pregnancy Rate	Additional Pounds Weaned/Cow	P($) @ C=5.25	P($) @ C=6.25	P($) @ C=7.25
100	14.3	.37	.44	.51
90	12.9	.41	.48	.56
80	11.4	.46	.55	.64
70	10.0	.53	.63	.73
60	8.6	.61	.73	.84
50	7.2	.73	.87	1.01
40	5.7	.92	1.09	1.27
30	4.3	1.22	1.45	1.68
20	2.9	1.81	2.16	2.50

[1] Breakeven Price (P) = $\frac{C}{WR}$

where C = additional breeding cost.
W = average increase in weaning weight/cow.
R = pregnancy rate

APPENDIX B

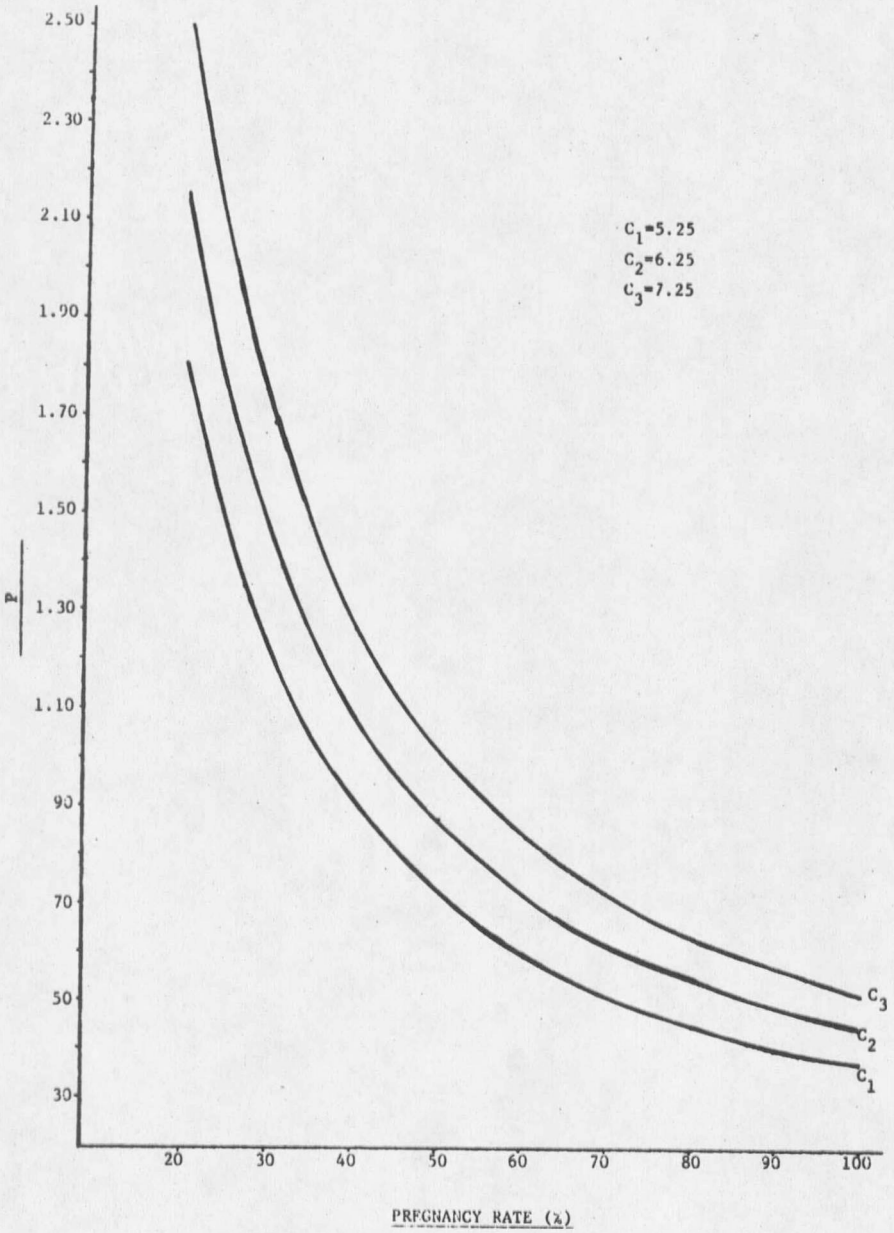


Figure A.1 Breakeven Selling Price Per Pound of Calf (P) Required to Recover Additional Breeding Costs Per Treated Cow (C) at Various Pregnancy Rates.

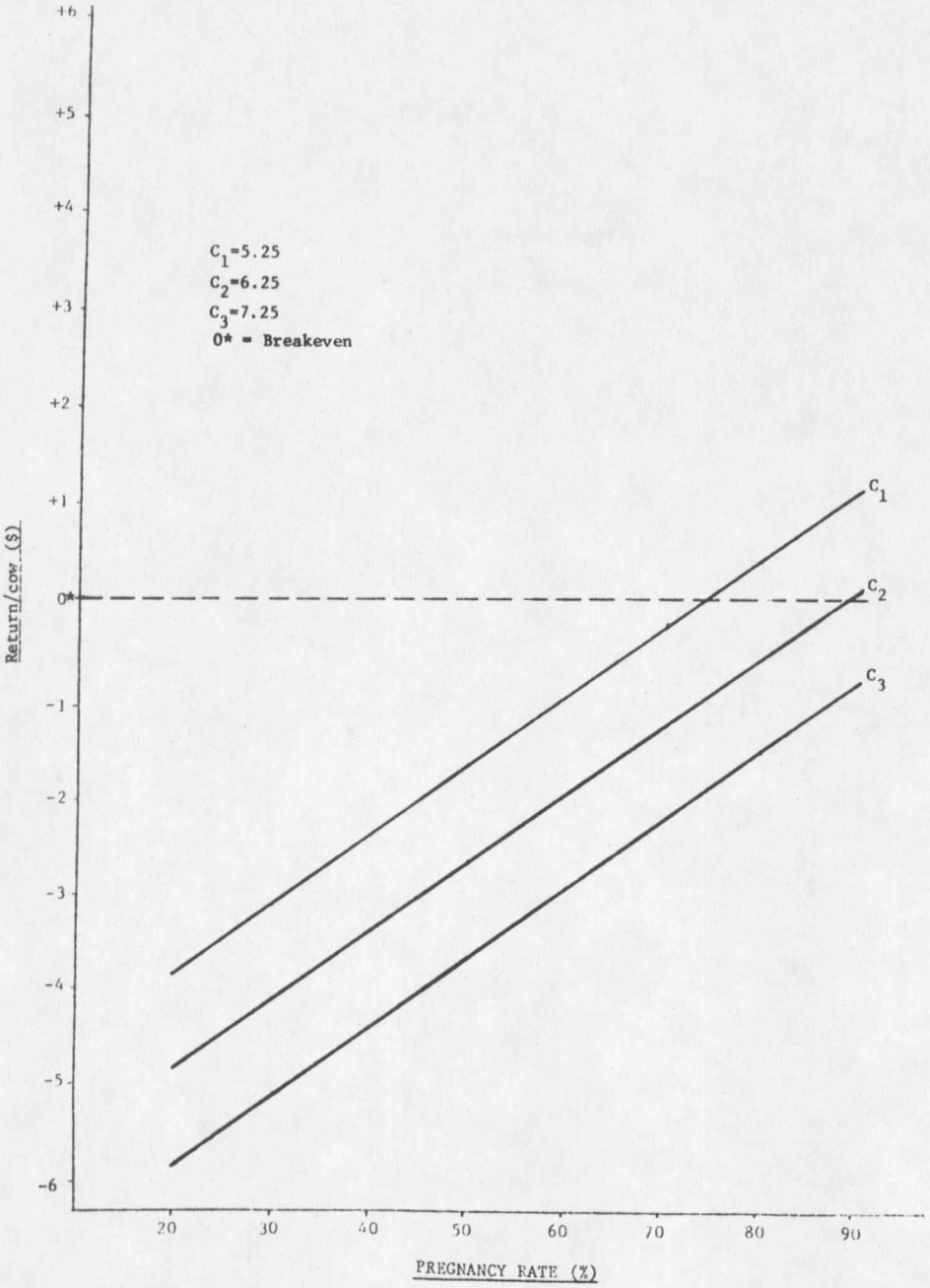


Figure A.2 Expected Returns Per Treated Cow at Various Pregnancy Rates and Additional Breeding Costs When Calves Sell @ .50/lb.

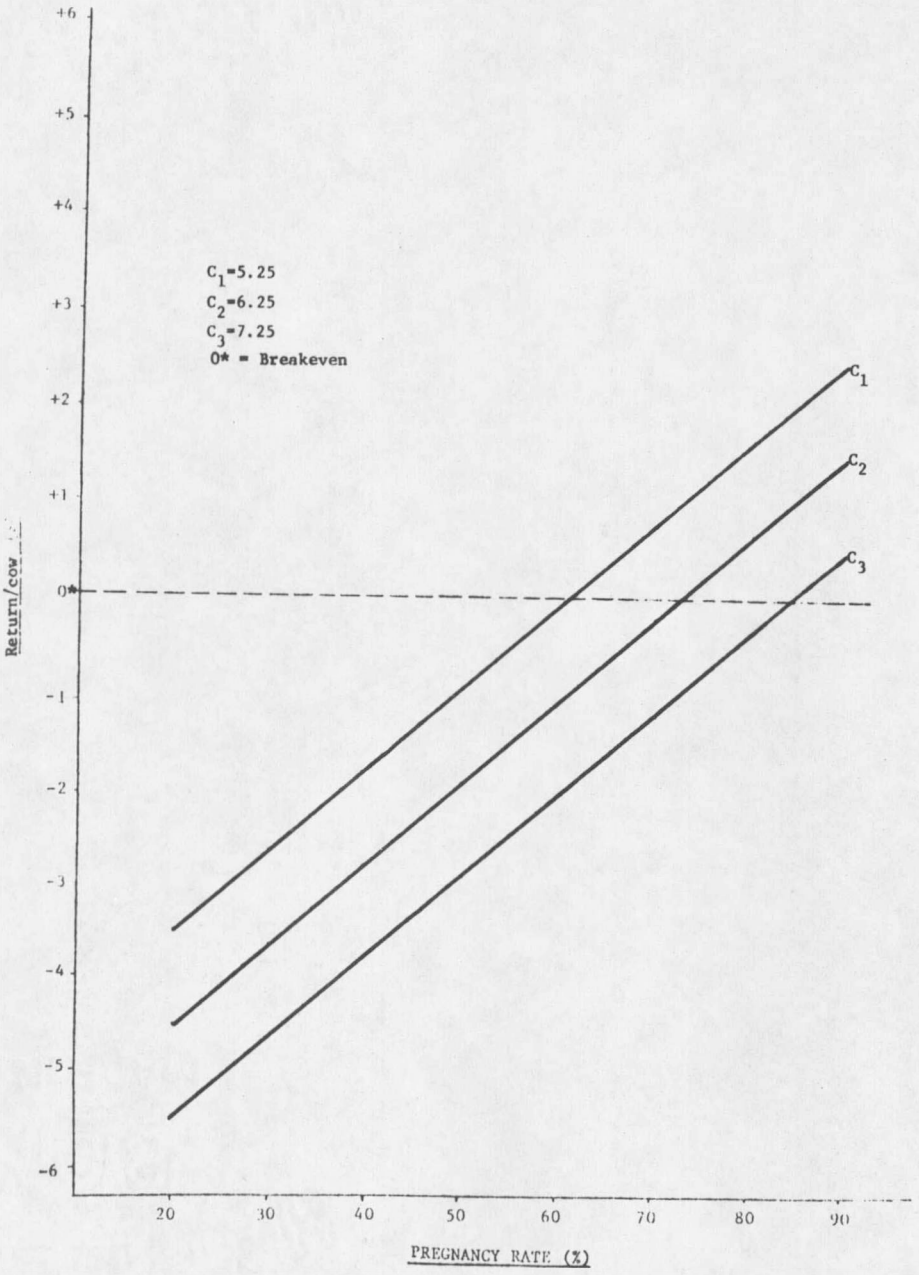


Figure A.3 Expected Returns Per Treated Cow at Various Pregnancy Rates and Additional Breeding Costs When Calves Sell @ .60/lb.

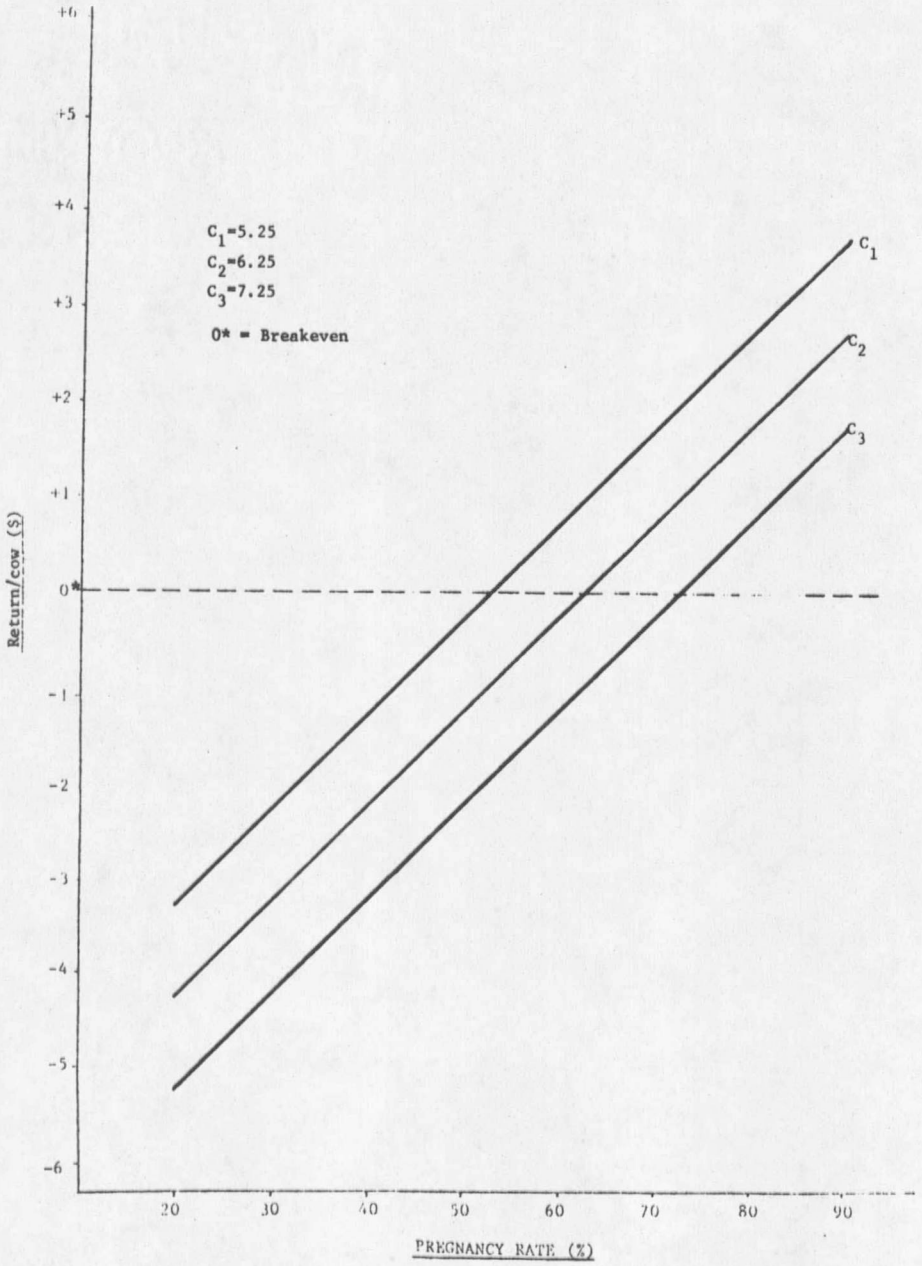


Figure A.4 Expected Returns Per Treated Cow at Various Pregnancy Rates and Additional Breeding Costs When Calves Sell @ .70/lb.

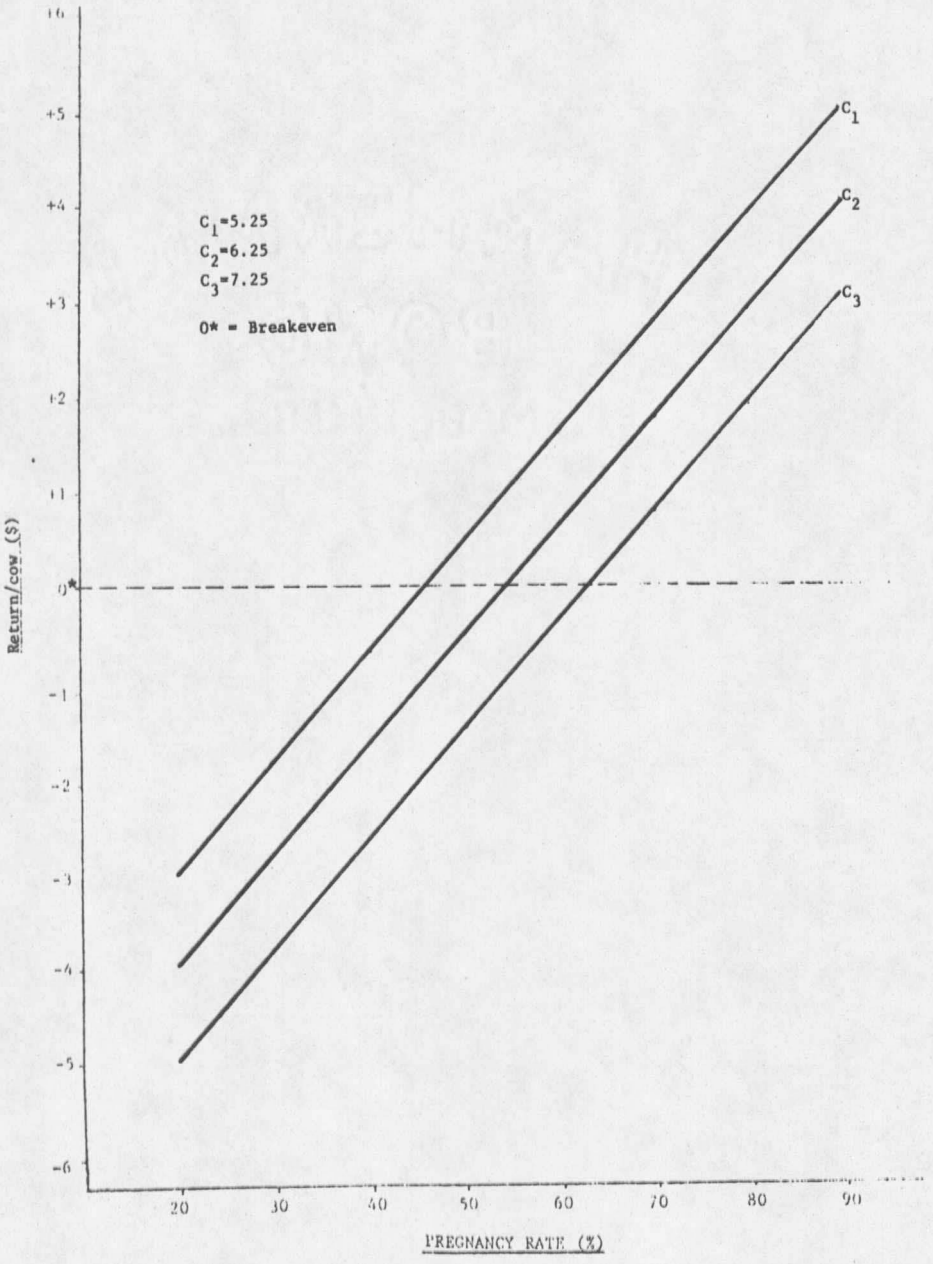


Figure A.5 Expected Returns Per Treated Cow at Various Pregnancy Rates and Additional Breeding Costs When Calves Sell @ .80/lb.

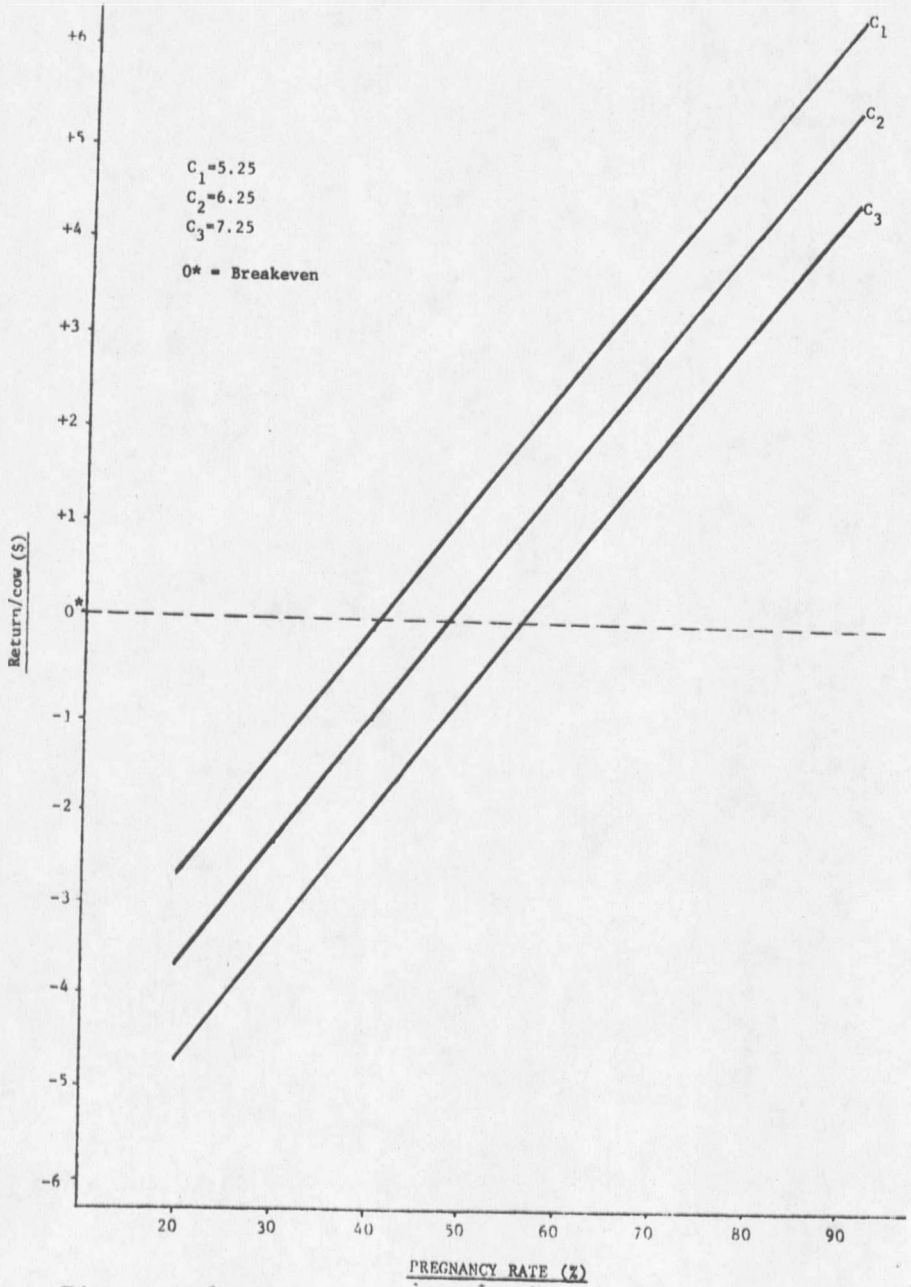


Figure A.6 Expected Returns Per Treated Cow at Various Pregnancy Rates and Additional Breeding Costs When Calves Sell @ .90/lb.

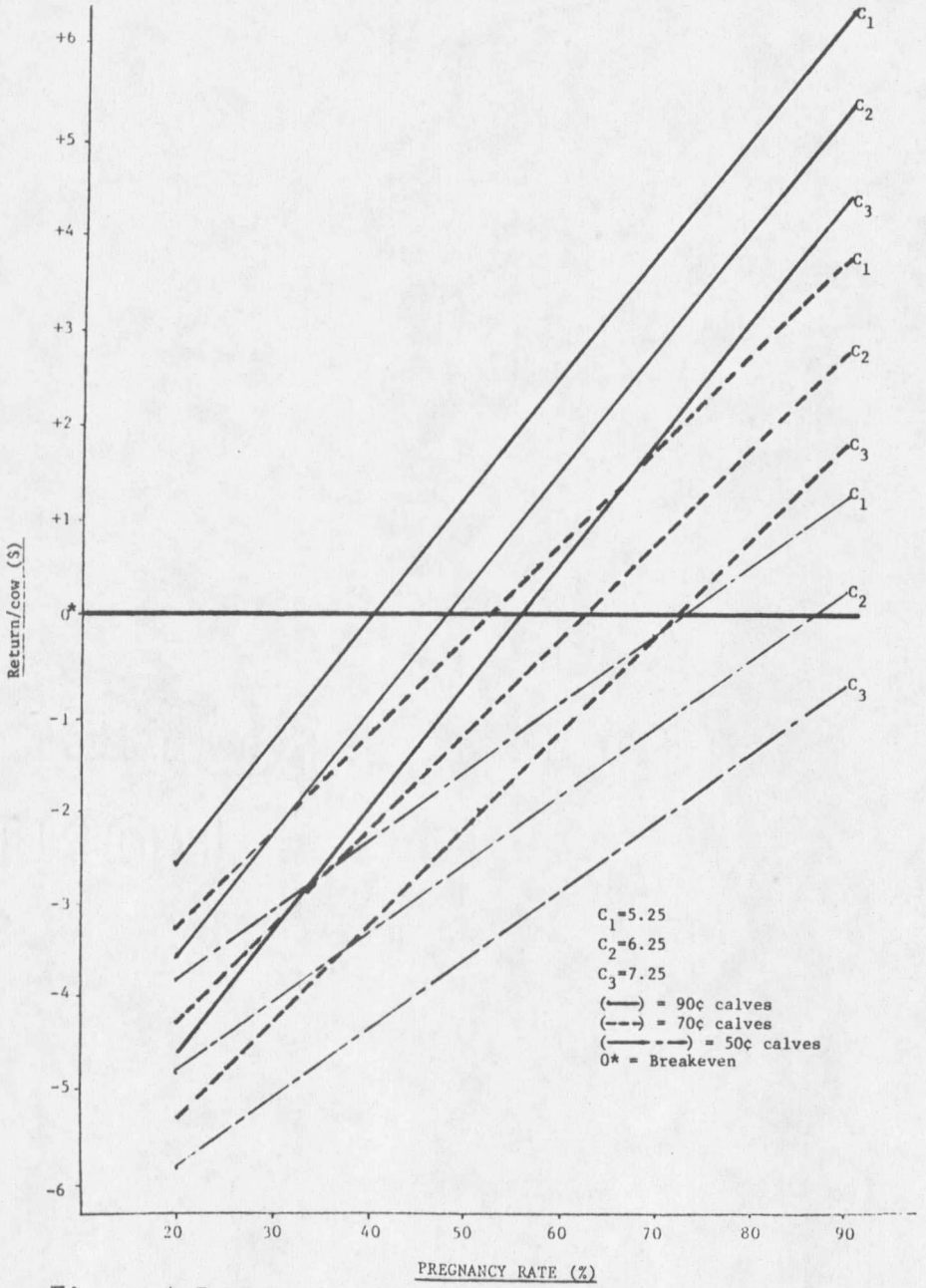


Figure A.7 Impact of Calf Selling Price on Absolute Returns and Rate of Return Per Treated Cow.

LITERATURE CITED

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Adkins, V. 1980. Evaluation of estrous synchronization management systems using prostaglandin $F_{2\alpha}$. M.S. Thesis, Montana State University, Bozeman.

American Breeders Service. 1974. American Breeders Service AI Management Manual, American Breeders Service, DeForest, WI.

Anderson, R. R., D. Wideman, L. C. Faulkner and J. N. Wiltbank. 1969. Synchronizing ovulation with norethandrolone and estrogen. J. Anim. Sci. 29:183 (Abstr.).

Armstrong, D. T. and W. Hansel. 1959. Alteration of the bovine estrous cycle with oxytocin. J. Anim. Sci. 18:533.

Babcock, J. C. 1966. Discussion of a paper by W. Hansel entitled "Luteotropic and Luteolytic Mechanisms in Bovine Corpora Lutea". J. Reprod. Fertil. Suppl. 1:47.

Bailie, J. H. and N. S. Dury. 1976. The economic implications of the use of 'Estrumate' (ICI80,996; cloprostenol) in the control of the bovine oestrus cycle - the beef suckler herd. VIIIth Inter. Congr. on Anim. Repord. and AI, Krakow, p. 431.

Bane, A. and E. Rajakoski. 1961. The bovine estrous cycle. Cornell Vet. 51:77.

Bearden, H. J. and J. Fuquay. 1980. Applied Animal Reproduction. Reston Publishers, Reston, VA.

Betteridge, K. O., M. D. Eaglesome, G. Randall, D. Mitchell and E. Sugden. 1978. Maternal progesterone levels as evidence of luteotrophic or antiluteolytic effects of embryos transferred to heifers 12 to 17 days after estrus. Theriogenology 9:86 (Abstr.)

Beverly, J. R. 1978. The outlook for estrous synchronization. Proc. 12th Conf. on AI of Beef Cattle, p. 27.

Black, D. 1972. Application of artificial insemination in animal reproduction. Proc. West. Sec. Amer. Soc. Anim. Sci. 23:XXVII.

Blom, E. 1968. In The Artificial Insemination of Farm Animals, E. J. Perry, ed., Rutgers Univ. Press, Quinn and Boden, Rahway, N.J.

Britt, J. H. 1979. Prospects for controlling reproductive processes in cattle, sheep, and swine from recent findings in reproduction. J. Dairy Sci. 62:651.

Brunner, M. A., L. E. Donaldson and W. Hansel. 1969. Exogenous hormones and luteal function in hysterectomised and intact heifers. J. Dairy Sci. 52:1849.

Burfening, P. J., D. C. Anderson, R. A. Kinkie, J. Williams and R. L. Friedrich. 1978. Synchronization of estrus with $PFG_{2\alpha}$ in beef cattle. J. Anim. Sci. 47:999.

Burrell, C., J. N. Wiltbank, D. G. LeFever and G. Rodeffer. 1972. Ear implant (SC210099) for estrous control in heifers. Proc. West. Sec. Amer. Soc. Anim. Sci. 23:547.

Canady, J. D. and D. D. Copeland. 1978. The role of prostaglandins in the beef herd. National Extension Industry Invitational Workshop on Beef Cattle Reproductive Management, USDA and Science and Education Foundation, p. 98.

Casida, L. E., E. R. Hauser and W. J. Tyler. 1968. Studies on the postpartum cow. Wisconsin Agr. Exp. Sta. Res. Bull. 270:1.

Chamley, W. A. and J. D. O'Shea. 1976. Luteal function in sheep injected with prostaglandin $F_{2\alpha}$ directly into the corpus luteum. Prostaglandins. 11:133.

Chenault, J. R. 1979. Steroid Δ^4 - 5β - reductase in bovine pre-attached conceptus. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 285.

Chenault, J. R., W. W. Thatcher, P. S. Kalra, R. M. Abrams and C. J. Wilcox. 1975. Transitory changes in plasma progestins, estradiol, and luteinizing hormone approaching ovulation in the bovine. J. Dairy Sci. 58:709.

Chenault, J. R., W. W. Thatcher, P. S. Kalra, R. M. Abrams and C. J. Wilcox. 1976. Plasma progestins, estradiol, and luteinizing hormone following $PGF_{2\alpha}$ injection. J. Dairy Sci. 59:1342.

Christensen, D. C., M. L. Hopwood, G. D. Niswender and J. N. Wiltbank. 1974. Levels of hormones in the serum of cycling beef cows. J. Anim. Sci. 38:577.

Christian, R. E. and Casida, L. E. 1948. The effects of progesterone in altering the estrous cycle of the cow. J. Anim. Sci. 7:540.

Chupin, D. and J. Pelot. 1976. Progestagens and/or prostaglandins for estrous synchronization in dairy cows. VIIIth Int. Cong. on Anim. Reprod. and A.I., Krakow, p. 447.

Chupin, D., J. Pelot and P. Mauleon. 1977. Control of estrus and ovulation in dairy cows. Theriogenology 7:339.

Concannon, P. W. 1972. In vitro progesterone synthesis in bovine corpora lutea as influenced by estradiol and prostaglandins. Ph.D. Thesis, Cornell University, Ithaca, N.Y.

Cooper, M. J. 1974. Control of oestrous cycles of heifers with a synthetic prostaglandin analogue. Vet. Rec. 95:200.

Cooper, M. J., D. Hammond, D. B. Harker and P. S. Jackson. 1976. Control of the bovine oestrous cycle with ICI 80,996 (cloprostenol) Field results in 3,810 beef cattle. Proc. VIIIth Inter. Congr. on Anim. Reprod. and A.I., Krakow, p. 449.

Cowley, J. L., J. J. Ireland, J. A. Wortman and R. L. Fogwell. 1979. Luteal function in cows following destruction of ovarian follicles at midcycle. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 289.

Cumming, I. A. 1975. The ovine and bovine oestrous cycle. J. Reprod. Fertil. 43:583.

Cumming, I. A., M. B. White, R. Baxter and J. K. Findlay. 1976 Effect of oestradiol benzoate, LH-RH, and 'Stress' on the intervals between prostaglandin analogue treatment, the preovulatory LH peak and ovulation in cattle. Proc. VIIIth Inter. Cong. on Anim. Reprod. and A.I., Krakow, p. 453.

Cummins, L., I. Cumming, R. Lawson, J. Findlay, M. Cerine and T. Hartney. 1974. Synchronization of oestrus in cattle with prostaglandin $F_{2\alpha}$. Proc. Australian Soc. Anim. Prod. 10:283.

Cupps, P. T. 1972. Reproductive performance of the beef cow: physiological factors. Proc. West. Sec. Amer. Soc. Anim. Sci. 23:XXII.

Curl, S. E., W. Durfey, R. Patterson and D. W. Zinn. 1968. Synchronization of estrus in cattle with subcutaneous implants. J. Anim. Sci. 27:1189 (Abstr.).

Dailey, R. A., R. E. James, C. H. Cook, D. B. Dowler, R. E. Spencer, and S. P. Washburn. 1979. Conception rates of timed breeding versus conventional breeding in heifers with synchronized estrus by prostaglandin $F_{2\alpha}$. J. Dairy Sci. 63 (Suppl. 1):65 (Abstr.).

Denamur, R. 1974. Luteotropic factors in the sheep. J. Reprod. Fertil. 38:251.

Dobson, H., M. J. Cooper, and B. J. A. Farr. 1975. Synchronization of oestrous with I.C.I. 79,939 an analogue of $PGF_{2\alpha}$ and associated changes in plasma progesterone, oestradiol 17-β and LH in heifers. J. Reprod. Fertil. 42:141.

Donaldson, L. E. 1976. Artifical insemination of beef cattle. Australian Vet. J. 52:565.

Donaldson, L. E. 1977a. Some causes of wastage in beef cattle artificial breeding. Australian Vet. J. 53:78.

Donaldson, L. E. 1977b. Synchronization of oestrus in beef cattle artificial breeding programs using prostaglandin $F_{2\alpha}$. Australian Vet. J. 53:72.

Donaldson, L. E. 1980. The development and marketing of estrus synchronization in cattle in Australia using prostaglandins. Theriogenology 14:391.

Doornbos, D. E. and D. C. Anderson. 1979. Bovine estrous synchronization systems and resulting fertility using $PGF_{2\alpha}$. Proc. West. Sec. Amer. Soc. Anim. Sci. 30:201.

Dufour, J., H. L. Whitmore, O. J. Ginther and L. E. Casida. 1972. Identification of the ovulating follicle by its size on different days of the estrous cycle in heifers. J. Anim. Sci. 34:85

Drew, S. B., C. M. Gould and D. C. Bulman. 1978. The effect of treatment with a progesterone releasing intravaginal device on the fertility of spring calving Friesian dairy cows. Vet. Rec. 102:259.

Eley, R. M., W. W. Thatcher, F. W. Bazer and M. J. Fields. 1979. Metabolism of progesterone and androstenedione in vitro by bovine endometrium and conceptus. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 294.

Ellicott, A. R., J. R. Hill and C. E. Thompson. 1975. Appointment of the hour of mating in the cow. J. Anim. Sci. 41:1975 (Abstr.)

Erb, R. E., R. D. Randel and C. J. Callahan. 1971. Female sex steroid changes during the reproductive cycle. J. Anim Sci. 32 (Suppl. 1):80.

Espey, L. L. 1974. Ovarian proteolytic enzymes and ovulation. Biol. Reprod. 10:216.

Esslemont, R. J., R. C. Eddy and P. R. Ellis. 1977. Planned breeding in autumn calving dairy herds. Vet. Rec. 100:426.

Fogwell, R. L., G. S. Lewis, R. L. Butcher and E. K. Inskeep. 1977. Effects of ovarian bisection and response to intrafollicular injection of $PGF_{2\alpha}$ and on follicular development in ewes. J. Anim. Sci. 45:328.

Fogwell, R. L., C. W. Weems, G. S. Lewis, R. L. Butcher and E. K. Inskeep. 1978. Secretion of steroids after induced luteal regression in beef heifers: Effects of $PGF_{2\alpha}$ and removal of corpora lutea. J. Anim. Sci. 46:1718.

Foote, R. H. 1978. General principles and Basic Techniques involved in synchronization of estrus in cattle. Proc. VII Tech. Conf. on A.I. and Reprod., p. 74.

Ford, S. P., L. J. Weber, W. H, Kennick and F. Stormshak. 1977. Response of bovine ovarian arterial smooth muscle to prostaglandin $F_{2\alpha}$ and neurotransmitter. J. Anim. Sci. 45:1091.

Ford, S. P., J. R. Chenault and S. E. Echternkamp. 1979. Uterine bloodflow of cows during the oestrous cycle and early pregnancy: Effect of the conceptus on the uterine blood supply. J. Reprod. Fertil. 56:53.

Freeman, A. E. 1980. Impact of sire evaluation on dairy cattle breeding. Proc. 1980 Beef Imprvmt. Fed., Denver, CO. p. 81.

Fulka, J., J. Motlik and A. Pavlok. 1975. Fertilization rate after synchronization of the oestrous cycle in heifers with prostaglandin $F_{2\alpha}$. Theriogenology 3:107.

Fulka, J., J. Motlik and A. Pavlok. 1978. Heat and conception rate after synchronization of oestrus with cloprostenol. Vet. Rec. 103:52.

Garverick, H. A., R. E. Erb, G. D. Niswender and C. J. Callahan. 1971. Reproductive steroids in the bovine III. Changes during the estrous cycle. J. Anim. Sci. 32:946.

Geschwind, I. I. 1972. Dynamics of pituitary gonadrotropin secretion. J. Anim. Sci. 34 (Suppl. 1):19.

Ginther, O. J. and P. E. Meckley. 1972. Effect of intrauterine infusion on length of diestrus in cows and mares. Vet. Med. Sm. Anim. Clin. 67:751.

Glencross, R. G., I. B. Munro, B. E. Senior and G. S. Pope. 1973. Concentrations of oestradiol-17β, oestrone, and progesterone in jugular venous plasma of cows during the oestrous cycle and in early pregnancy. Acta Endocrinologica 73:374.

Godkin, J. D., C. Cote and R. T. Duby. 1978. Embryonic stimulation of ovine and bovine corpra lutea. J. Reprod. Fertil. 54:375.

Godkin, J. D., F. W. Bazer and R. M. Roberts. 1980. Protein synthesis by the ovine conceptus in vitro. Abstr. 72nd Annu. Meetings Amer. Soc. Anim. Soc., p. 281.

Goldberg, V. J. and R. W. Ramwell. 1975. Role of prostaglandins in reproduction. Physiol. Rev. 55:325.

Gonzales-Mencio, F., B. D. Murphy and J. Mawns. 1977. Failure of exogenous LH to prevent $PGF_{2\alpha}$-induced luteolysis in beef cows. Prostaglandins 14:535.

Graves, N. W., T. G. Dunn, C. C. Kaltenbach, R. E. Short and J. B. Carr. Estrus and ovulation with $PGF_{2\alpha}$, SC21009 and GN-RH. J. Anim. Sci. 41:354 (Abstr.).

Greene, W. M. 1977. Fertility of beef cattle after $PGF_{2\alpha}$ controlled estrus in two breeding management systems. M.S. thesis, Montana State University, Bozeman.

Greene, W. M., D. K. Han, P. W. Lambert and E. L. Moody. 1977. Effect of two consecutive years in a $PGF_{2\alpha}$ or conventional AI breeding system. Proc. West. Sec. Amer. Soc. Anim. Sci. 28:163.

Gregory, K. E. 1966. The impact of artificial insemination on the beef cattle industry. AI Digest 14:3.

Hafez, E. S. E. and M. R. Jainudeen. 1974. Gestation, Prenatal Physiology and Parturition. Chap. 8 in Reproduction in Farm Animals, E. S. E. Hafez (Ed.), Lea & Febiger, Philadelphia.

Hafs, H. D., T. M. Louis, P. A. Noden and W. D. Oxender. 1974. Control of the estrous cycle with prostaglandin $F_{2\alpha}$ in cattle and horses. J. Anim. Sci. 39 (Suppl. 1):10.

Hafs, H. D., J. G. Manns and B. Drew. 1975a. Onset of oestrus after prostaglandin $F_{2\alpha}$ in cattle. Vet. Rec. 96:134.

Hafs, H. D., J. G. Manns and G. E. Lamming. 1975b. Fertility of cattle from AI after $PGF_{2\alpha}$. J. Anim. Sci. 41:355 (Abstr.).

Hans, D. K. and E. L. Moody. 1979. Comparisons of estrous synchronization management systems using prostaglandin $F_{2\alpha}$. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 190.

Hanks, D. R., D. A. Phelps, J. H. Hay and W. D. Foote. 1980. Conception synchronization in beef cows. Proc. West. Sec. Amer. Soc. Anim. Sci. 31:184.

Hansel, W. 1959. The estrous cycle of the cow. In H. H. Cole and P. T. Cupps (Ed.) Reproduction in Domestic Animals. Vol 1, Academic Press, N.Y.

Hansel, W. 1967. Control of the ovarian cycle in cattle - a review. Australian Vet. J. 43:441.

Hansel, W. and P. V. Malven. 1960. Estrous cycle regulation in beef cattle by orally active progestational agents. J. Anim. Sci. 19:1324 (Abstr.).

Hansel, W. and W. C. Wagner. 1960. Luteal inhibition in the bovine as a result of oxytocin injections, uterine dilatation, and intrauterine infusions of seminal and preputial fluids. J. Dairy Sci. 43:796.

Hansel, W., P. V. Malven and D. L. Black. 1961. Estrous cycle regulation in the bovine. J. Anim. Sci. 20:621.

Hansel, W., L. E. Donaldson, W. C. Wagner and M. A. Brunner. 1966. A comparison of estrous cycle synchronization methods in beef cattle under feedlot conditions. J. Anim. Sci. 25:497.

Hansel, W. and S. E. Echternkamp. 1972. Control of ovarian function in domestic animals. Amer. Zoologist 12:225.

Hansel, W. and R. E. Schecter. 1972. Biotechnical procedures for control of the estrous cycles of domestic animals. Proc. VIIth Inter. Congr. Anim. Reprod. and A.I., Munich, p. 78.

Hansel, W., P. W. Concannon and J. H. Lukasze ska. 1973. Corpora lutea of the large domestic animals. Biol. Reprod. 8:222.

Hansel, W., J. Hixon, M. Shemesh and D. Tobey. 1976. Concentrations and activities of prostaglandins of the F series in bovine tissue, blood and milk. Symposium: Prostaglandins in Bovine Reproduction. J. Dairy Sci. 59:1353.

Hardin, D. R., A. C. Warnick and M. J. Fields. 1980. Artificial insemination of subtropical commercial beef cattle following synchronization with cloprostenol (ICI 80,996):II. Estrous Response. Theriogenology 14:259.

Hawk, H. W. 1968. Effect of intrauterine devices on corpus luteum function. J. Anim. Sci 22 (Suppl. 1):119.

Henderson, K. M. and K. P. McNatty. 1975. A biochemical hypothesis to explain the mechanims of luteal regression. Prostaglandins 9:779.

Henderson, K. M. and K. P. McNatty. 1977. A possible interrelationship between gonadotropin stimulation and prostaglandin $F_{2\alpha}$ inhibition at steroidogenesis by granulosa-luteal cells *in vitro*. J. Endocrinol. 73:71.

Henderson, K. M., R. J. Scaramuzzi and D. I. Baird. 1977. Simultaneous infusion of Prostaglandin $F_{2\alpha}$ antagonizes the luteolytic action of Prostaglandin $F_{2\alpha}$ *in vitro*. J. Endocrinol. 72:379.

Henricks, D. M., J. F. Dickey and J. R. Hill. 1971. Plasma estrogen and progesterone levels in cows prior to and during estrus. Endocrinol. 89:1350.

Henricks, D. M., J. T. Long, J. R. Hill and J. F. Dickey. 1974. The effect of prostaglandin $F_{2\alpha}$ during various stages of the oestrous cycle of beef heifers. J. Reprod. Fertil. 41:113.

Herbst, J. H. 1976. Farm Management-Principles, Budgets, Plans. Stipes Pub. Co., Champaign, Ill. p. 54.

Herman, H. A. 1967. Report of National Association of Animal Breeders at 20th Convention, Hershey, PA. p. 8.

Hichens, M., D. L. Grinwich and R. R. Behriman. 1974. $PGF_{2\alpha}$ induced loss of corpus luteum gonadotropin receptors. Prostaglandins 7:457.

Hill, J. R. Jr., D. R. Lamond, D. M. Henricks, J. F. Dickey and G. D. Niswender. 1971. The effect of melengestrol acetate (MGA) on ovarian function and fertilization in beef heifers. Biol. of Reprod. 4:16.

Hopper, L. D., W. D. Humphrey, P. Clemente, T. G. Dunn and C. C. Kaltenbach. 1977. Fertility of beef cows following estrous synchronization and calf removal, controlled ovulation with GNRH and timed insemination. Proc. West. Sec. Amer. Soc. Anim. Sci. 28:171.

Humphrey, W. D., L. D. Hopper, P. Clemente, T. G. Dunn and C. C. Kaltenbach. 1977. Estrus and conception in heifers treated with norgestomet and estradiol-valerate vs. norgestomet alone. Proc. West. Sec. Amer. Soc. Anim. Sci. 28:173.

Inskeep, E. K. and R. L. Butcher. 1966. Local component of utero-ovarian relationships in the ewe. J. Anim. Sci. 25:1164.

Inskeep, E. K. 1973. Potential uses of prostaglandins in control of reproductive cycles of domestic animals. J. Anim. Sci. 36:1149.

Inskeep, E. K., J. A. Welch, M. R. McClung, E. A. Linger and J. O. Heishman. 1975. Control of estrus by $PGF_{2\alpha}$ and estradiol benzoate. J. Anim. Sci. 40:187 (Abstr.).

Inskeep, E. K. and W. J. Murdoch. 1980. Relation of ovarian functions to uterine and ovarian secretion of prostaglandins during the estrous cycle and early pregnancy in the ewe and cow. Inter. Rev. Physiol. 22:325.

Ireland, J. J. , P. B. Coulson and R. L. Murphee. 1979. Follicular development during four stages of the estrous cycle of beef cattle. J. Anim. Sci. 49:1261.

Johnson, C. T. 1978. Time to onset of oestrus after the injection of heifers with cloprostanol. Vet. Rec. 103:204.

Kaltenbach, C. C., G. P. Niswender, D. R. Zimmerman and J. N. Wiltbank. 1964. Alteration of ovarian activity in cycling, pregnant, and hysterectomised heifers with exogenous estrogens. J. Anim. Sci. 23:995.

Kaltenbach, C. C. and T. G. Dunn. 1979. Effect of 24 vs. 48 hour calf removal in progestagen synchronized beef cows. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 307.

Karim, S. M. M. 1975. Prostaglandins and Reproduction. Univ. Park Press, Baltimore, MD.

Kesner, J. S. and E. M. Convey. 1979. Mechanism of the estradiol-17β (E_2)-induced LH surge using the steer as a model. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 308.

Kimball, F. A. and J. W. Lauderdale. 1975. Prostaglandin E_1 and $F_{2\alpha}$ specific binding in corpora lutea: Comparison with luteolytic effect. Prostaglandins 10:313.

Kiser, T. E., S. E. Dunlap and L. L. Benyshek. 1979. The effect of calf removal on estrous response and pregnancy of beef cows after synchro-mate-β treatment. Abstr. 71st Annu. Meeting Amer. Soc. Anim. Sci., p. 309.

Kindahl, H., E. Granstrom, L. Edgvist, B. Gustafsson, G. Astrom and G. Stabenfeldt. 1977. Progesterone and 15-Keto-13, 14-Dihydroprostaglendin $F_{2\alpha}$ levels in peripheral circulation after intrauterine iodine infusions in cows. Acta. Vet. Scand. 18:274.

Kinkie, R. A. 1976. Breeding heifers by appointment with $PGF_{2\alpha}$ and GnRH. M. S. Thesis, Montana State University, Bozeman.

Lambert, P. W. 1977. AI beef management with prostaglandin $F_{2\alpha}$ controlled estrus. M. S. Thesis. Montana State University, Bozeman.

Lambert, P. W., D. R. Griswold, V. A. Lavoie and E. L. Moody. 1975. AI Beef management with $PGF_{2\alpha}$ controlled estrus. J. Anim. Sci. 41:364 (Abstr.).

Lambert, P. W., W. M. Greene, J. D. Strickland, D. K. Han and E. L. Moody. 1976. $PGF_{2\alpha}$ controlled estrus in beef cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. 27:211.

Lamming, G. E. 1973. The synchronization of estrus and the hormonal control of ovulation in cattle. Beef Cattle Sci. Handbook 10:326.

Lamming, G. E., J. P. Foster and D. C. Buhlman. 1979. Pharmacological control of reproduction cycles. Vet. Rec. 104:156.

Lamond, D. R., J. F. Dicken, D. M. Henricks, J. R. Hill, Jr. and T. M. Leland. 1971. Effect of a progestin on the bovine ovary. J. Anim. Sci. 33:77.

Lamond, D. R., R. V. Tomlinson, M. Drost, D. M. Henricks and W. Jochle. 1973. Studies of $PGF_{2\alpha}$ in the cow. Prostaglandins 4:269.

Lamothe, P., D. Bosquet and P. Guay. 1977. Cyclic variation of F prostaglandins in the uterine fluids of cows. J. Reprod. Fertil. 50:381.

Lantz, W. B., C. W. Kasson, A. L. Slyter and D. R. Zimmerman. 1968. Synchronization of ovulation in beef heifers. J. Anim. Sci. 27:1198 (Abstr.).

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

Lauderdale, J. W. 1974. Distribution and biologic effects of prostaglandins. J. Anim. Sci. 38 (Suppl. 1):22.

Lauderdale, J. W., J. R. Chenault, B. E. Seguin and W. W. Thatcher. 1973. Fertility of cattle after $PGF_{2\alpha}$ treatment. J. Anim. Sci. 37:319 (Abstr.).

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

Lavoie, V. A., G. R. Poncelet, D. K. Ham, C. L. Soliday, P. W. Lambert and E. L. Moody. 1975. Effect of prostaglandin $F_{2\alpha}$ on the estrous cycle, corpora lutea, and progesterone levels of hysterectomized cows. J. Anim. Sci. 41:166.

Learmonth, B. 1973. Practical aspects of artificial insemination. Agric. Tech. J. 4:5

Lehninger, A. L. 1977. Biochemistry. Worth Pub. Co., New York, N.Y.

Lewis, G. S., P. E. Jenkins, R. L. Fogwell and E. K. Innskeep. 1978. Concentrations of prostaglandins E_2 and $F_{2\alpha}$ and their relatinoship to luteal function in early pregnant ewes. J. Anim. Sci. 47:1314.

Lewis, G. S., S. M. M. Basha, F. W. Bazer, R. M. Roberts and W. W. Thatcher. 1979. Proteins originating from bovine and porcine blastocysts. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci. p. 313.

Lewis, G. S., W. W. Thatcher, L. A. Guilbault, F. W. Bazer and F. F. Bortol. 1980. Prostaglandin production by bovine blastocysts and endometrium. Abstr. 72nd Annu. Meetings Amer. Soc. Anim. Sci., p. 298.

Liehr, R. A., G. B. Marion and H. H. Olson. 1972. Effects of prostaglandin on cattle estrus cycles. J. Anim. Sci. 35:247 (Abstr.).

Louis, T. M., H. D. Hafs and D. A. Morrow. 1972. Estrus and ovulation after $PGF_{2\alpha}$ in cows. J. Anim. Sci. 35:1121 (Abstr.).

Louis, T. M., J. N. Stellflug, H. A. Tucker and H. F. Hafs. 1974. Plasma prolactin, growth hormone, luteinizing hormone, and glucocorticoids after prostaglandin $F_{2\alpha}$ in heifers. Proc. Soc. Exp. Biol. Med. 147:128.

Loy, R. G., R. G. Zimbelman and L. E. Casida. 1960. Effects of injected ovarian hormones on the corpus luteum of the estrual cycle in cattle. J. Anim. Sci. 19:175.

Macmillan, K. L., A. M. Day and J. F. Smith. 1980. Onset of oestrus and fertility in lactating dairy cows injected with an analogue of prostaglandin $F_{2\alpha}$ Cloprostenol. Anim. Reprod. Sci. 3:171.

Manns, J. G. and H. D. Hafs. 1976. Controlled breeding in cattle: a review. Can. J. Anim. Sci. 56:121.

Mares, S. E., J. A. Peterson, E. A. Henderson and M. E. Davenport. 1979. Ovulation control with synchromate-B (SMB) in beef cattle classified by ovarian palpation. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 317.

McClellan, M. C., J. H. Abel, Jr. and A. D. Niswender. 1977. Function of lysosomes during luteal regression in normally cycling and $PGF_{2\alpha}$-treated ewes. Biol. Reprod. 16:499.

McCraken, J. A., J. C. Carlson, M. E. Glew, J. R. Goding, D. T. Baird, K. Green and B. Samuellson. 1972. Prostaglandin $F_{2\alpha}$ identified as a luteolytic hormone in sheep. Nature New Biol. 238:129.

Meacham, T. N., W. D. Lamm and R. G. Saache. 1979. Influence of breed and winter feed level on response of beef cows to $PGF_{2\alpha}$. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci. p. 196.

Melampy, R. M. and L. L. Anderson. 1968. Role of the uterus in corpus luteum function. J. Anim. Sci. 27 (Suppl. 1):77.

Miller, S. J. 1979. Proc. Aust. Vet. Assoc., Queensland Division (1979).

Milvae, R. A. and W. Hansel. 1980. Concurrent uterine venous and ovarian arterial prostaglandin F concentrations in heifers treated with oxytocin. J. Reprod. Fertil. 60:7.

Montgomery, R. 1977. Biochemistry - A Case Oriented Approach. C. V. Mosby Co., New York, N. Y.

Moody, E. L. 1980. Prostaglandin $F_{2\alpha}$ systems of synchronization of estrus. In Synchronizing Estrus in Beef Cattle. Mont. Agr. Exp. Sta. Bull. No. 730.

Moody, E. L. and J. W. Lauderdale. 1977. Fertility of cattle following $PGF_{2\alpha}$ controlled ovulation. Abstr. 69th Annu. Meetings Amer. Soc. Anim. Sci., p. 189

Moody, E. L., D. G. Cameron, R. E. Short, D. K. Han, R. P. Ansotegui and C. K. Higgins. 1980. Comparisons of estrous synchronization management systems using $PGF_{2\alpha}$ and progesterone plus $PGF_{2\alpha}$. Abstr. 72nd Annu. Meetings Amer. Soc. Anim. Sci., p. 151.

Moor, R. M. and L. E. A. Rowson. 1966. The corpus luteum of the sheep: effect of removal of embryos on luteal function. J. Endocrinol. 34:497.

Mosher, R. 1964. Experiences with artificial insemination. Proc. 9th Mont. Beef Prod. School, Montana State University Cooperative Extension Service p. 71.

Nakahara, T., I. Doneki and M. Yamanchi. 1971. Local effect of intr uterine injection of iodine solution on the life-span of the corpus luteum of the cow. J. Reprod. Fertil. 26:423.

Nancarrow, C. D., H. Hearnshaw, P. E. Mattner, P. J. Connell and B. J. Restall. 1974. Hormonal changes occurring in cattle following administration of prostaglandin $F_{2\alpha}$. J. Reprod. Fertil. 36:484.

Nellor, J. E. and H. H. Cole. 1956. The hormonal control of estrus and ovulation in the beef heifers. J. Anim. Sci. 15:650.

Niswender, A. D., T. J. Reimers, M. A. Diekman and T. A. Neff. 1976. Blood flow: A mediator of ovarian function. Biol. Reprod. 14:64.

O'Farrell, K. J. 1977. Calving rate of dairy cows and heifers following a 12-day progesterone and estradiol benzoate synchronization treatment. Ir. J. Agr. Res. 16:131.

Osland, R. B., J. J. Reeves and E. F. Ellington. 1970. Estrous cycle regulation with spaced hormone injections. Proc. West. Sec. Amer. Soc. Anim. Sci. 21:15.

Oxender, W. D. 1974. Prostaglandin $F_{2\alpha}$ control of ovulation in cows and mares. Proc. V. Tech. Conf. A.I. and Reprod. 5:36.

Pancake, J. 1963. A rancher's view on the use of artificial insemination on beef cows. Proc. 8th Mont. Beef Prof. School, Montana State University Coop. Ext. Serv., p. 60.

Perry. E. J. 1968. The Artificial Insemination of Farm Animals. Rutgers Univ. Press, Quinn and Boden, Rahway. N.J.

Peters, J. B., J. A. Welch, J. W. Lauderdale and E. K. Inskeep. 1977. Synchronization of estrus in beef cattle with $PGF_{2\alpha}$ and estradiol benzoate. J. Anim. Sci. 45:230.

Peterson, A. J., R. J. Fairclough and E. Payne. 1974. Hormonal changes around bovine luteolysis. Prostaglandins 10:675.

Peterson, L. A., S. E. Mares, E. A. Henderson and M. E. Davenport. 1979. Effect of calf separation time on pregnancy rates of cows synchronized with synchro-mate-β (SMB). Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 326.

Pexton, J. E. 1980. The Syncro-Mate-B system for estrus synchronization. In Synchronizing Estrus in Beef Cattle, Montana Agr. Exp. Sta. Bull. No. 730.

Phariss, B. B., S. A. Tillson and R. R. Erickson. 1972. Prostaglandins in luteal function. Rec. Prog. Horm. Res. 28:51.

Powell, R. L., H. D. Norman and F. N. Dickinson. 1977. Trends in breeding value and production. J. Dairy Sci. 60:1316.

Rajakoski, E. 1960. The ovarian follicular system in sexually mature heifers with speical reference to seasonal, cyclical, and left-right variations. Acta Endocrinologica 52:7.

Ray, D. E., M. A. Emmerson and R. M. Melampy. 1961. Effect of exogenous progesterone on reproductive activity in the beef heifer. J. Anim. Sci. 20:373.

Refsal, K. R. and B. E. Seguin. 1980. Effect of stage of diestrus and number of cloprostenol (ICI 80,996) injections on intervals to estrus, LH peak and ovulation in heifers. Theriogenology 14:47.

Renegar, R. H., H. D. Hafs, J. H. Britt and T. D. Carruthers. 1978. Luteolysis, growth hormone, glucocorticoids, prolactin, and milk production in lactating diary cows given $PGF_{2\alpha}$. J. Anim. Sci. 47:532.

Roberts, S., D. L. LeFever and J. N. Wiltbank. 1970. Increasing reproductive efficiency in a cow herd. Proc. West. Sec. Amer. Soc. Anim. Sci. 21:33.

Robertson, H. A. 1972. Sequential changes in plasma progesterone in the cow during the estrous cycle, pregnancy, at parturition, and post-partum. Can. J. Anim. Sci. 52:645.

Robinson, T. J. 1967. The control of the ovarian cycle in the sheep. Sydney, Sydney University Press.

Robinson, T. J. 1977. Reproduction in Cattle. In Reproduction in Domestic Animals, H. H. Cole and P. T. Cupps (Eds.), Academic Press, New York.

Roche, J. F. 1974. Effect of short term progesterone treatment on heifers. J. Reprod. Fertil. 40:433.

Roche, J. F. 1976c. Fertility in cows after treatment with a prostaglandin analogue with or without progesterone. J. Reprod. Fertil. 46:341.

Roche, J. F. 1976a. Retention rate in cows and heifers of intravaginal silastic coils impregnated with progesterone. J. Reprod. Fertil. 46:253.

Roche, J. F. 1976b. Calving rate of cows following insemination after a 12 day treatment with silastic coils impregnated with progesterone. J. Anim. Sci. 43:164.

Roche, J. F. 1977. Control of estrus in dairy cows with a synthetic analogue of prostaglandin $F_{2\alpha}$ (Estrumate). Abstr. 69th Annu. Meetings Amer. Soc. Anim. Sci., p. 202.

Roche, J. R. 1978. Control of oestrus in cattle using progesterone coils. Anim. Reprod. Sci. 1:145.

Roche, J. F., K. O'Farrell, D. Prendiville, W. Davis and T. Condon. 1976. Fixed time insemination of cows following a 12-day progesterone treatment with silastic coils. Proc. VIII Inter. Cong. on Anim. Reprod. and A.I., p. 503.

Roche, J. F., D. J. Prendiville and W. D. Davis. 1977. Calving rate following fixed time insemination after a 12 day progesterone treatment in dairy cows, beef cows and heifers. Vet. Rec. 101:417.

Rogers, L. F. 1973. Economics of artificial insemination and cross-breeding on commercial cattle ranches in Washington. Montana State University Coop. Ext. Serv. Bull. No. 1075.

Rondell, P. 1970. Biophysical aspects of ovulation. Biol. Reprod. 6(Suppl. 2):64.

Rowson, L. E. A., R. Tervit and A. Brand. 1972. Synchronization in cattle by means of prostaglandin $F_{2\alpha}$. Proc. VII Intern. Congr. Anim. Reprod. and A.I., p.856.

Ruttle, J. L. and T. G. Dunn. 1980. Management for AI and estrous synchronization. In Synchronizing Estrus in Beef Cattle, Mont. Agr. Exp. Sta. Bull. No. 730, p. 14.

Sawyer, C. H. 1964. Control of secretion of gonadotropins, in Gonadotropins: Their chemical and biological properties and secretory control (H.H. Cole, Ed.) W. H. Freeman & Co., San Francisco.

Scanlon, P. F., W. J. Neville, T. D. Burgess and J. W. Macpherson. 1971. Synchronization of estrus in cattle by intravaginal application of progesterone with estrogen administration. Can. J. Anim. Sci. 51:250.

Schultz, R. H., D. R. Beerwinkle, C. J. Bierschwal, M. J. Fields, R. A. Godke, D. C. Kraemer, J. G. Manns, B. E. Seguin, and R. J. Vatthauer. 1977. Synchronizing beef cows with cloprostenol. Abstr. 69th Annu. Meetings Amer. Soc. Anim. Sci. 513:206.

Seguin, B. E., D. A. Morrow and T. M. Louis. 1974. Luteolysis, luteostasis, and the effect of prostaglandin $F_{2\alpha}$ in cows after endometrial irritation. Amer. J. Vet. Res. 35:57.

Shemesh, M., N. Ayalon and H. R. Lindner. 1972. Oestradiol levels in the peripheral blood of cows during the oestrous cycle. J. Endocrinol. 55:73.

Shemesh, M. and W. Hansel. 1975. Levels of prostaglandin F (PGF) in bovine endometrium, uterine venous, ovarian arterial and jugular plasma during the estrous cycle. Proc. Soc. Exp. Biol. Med. 148:123.

Short, R. E. and G. H. Kriacoffe. 1980. Other potential methods of synchronizing estrus. In Synchronizing Estrus in Beef Cattle, Mont. Agr. Exp. Sta. Bull. No. 730, p. 33.

Short, R. V. 1972. Role of hormones in sex cycles. In Hormones in Reproduction, C. R. Austin and R. V. Short (Ed.), Cambridge Univ. Press.

Singleton, W. L. and D. C. Petritz. 1975. Management and economics of a beef cow herd AI program. Purdue Univ. Coop. Ext. Serv. Bull. ID-100.

Smith, J. F., R. J. Fairclough, E. Payne and A. J. Peterson. 1975. Changes in progesterone and estrogen during the normal oestrous cycle. New Zealand J. Agr. Res. 18:123.

Smith, J. F. and K. L. Macmillan. 1978. The applied and economic aspects of oestrus synchronization in cattle. New Zealand Vet. J. 26:173.

Smith, J. F., A. O. Peterson and R. J. Fairclough. 1979. Plasma hormone levels in the cow. II. Changes in progesterone and oestrogen after the intra-uterine administration of prostaglandin $F_{2\alpha}$ or benzyl alcohol. New Zealand J. Agr. Res. 22:227.

Snook, R. B., M. A. Brenner, R. R. Sustman and W. Hansel. 1969. The effect of anisera to bovine LH in hysterectomized and intact heifers. Biol. of Reprod. 1:49.

Sorensen, A. M., Jr. 1979. Animal Reproduction - Principles and Practices. McGraw-Hill, Inc., New York, N.Y.

Spicer, L. J., J. J. Ireland and J. F. Roche. 1980. Serum LH, progesterone, and specific binding of I^{125}-HCG to luteral cells during regression and development of corpora lutea. Abstr. 72nd Annu. Meetings Amer. Soc. Anim. Sci., p. 331.

Sprague, E. A., M. L. Hopwood, G. D. Niswender and J. N. Wiltbank. 1971. Progesterone and luteinizing homrone levels in peripheral blood of cycling beef cows. J. Anim. Sci. 33:99.

Sreenan, J. M. 1975. Effect of long- and short-term intravaginal progestagen treatments on synchronization of oestrus and fertility in heifers. J. Reprod. Fertil. 45:479.

Stabenfeldt, G. H., L. E. Edqvist, H. Kindahl, B. Gustafson and A. Bane. 1978. Practical implications of recent physiologic findings for reproductive efficiency in cows, mares, sows and mares. J. Amer. Vet. Med. Assoc. 172:667.

Staigmiller, R. B., R. Webb, B. G. England, R. A. Bellows and R. E. Short. 1979. Steroidogenic function of individual bovine follicles during estrus. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci., p. 339.

Stauffer, G. D., E. F. Ellington and M. K. Nielsen. 1976. Estrous cycle control with progestagen-prostaglandin treatment. Proc. West. Sect. Amer. Soc. Anim. Sci. 27:201.

Stellflug, J. N., T. M. Louis, B. E. Seguin and H. D. Hafs. 1973. Luteolysis after 30 or 60 mg $PGF_{2\alpha}$ in heifers. J. Anim. Sci. 37:330 (Abstr.).

Stellflug, J. N., T. M. Louis, H. Hafs and B. Seguin. 1975. Luteolysis, estrus, and ovulation and blood prostaglandin F after intramuscular administration of 15, 30, or 60 mg prostaglandin $F_{2\alpha}$. Prostaglandins 9:609.

Stevens, D. M. and T. Mohr. 1969. Artificial insemination of range cattle in Wyoming - an economic analysis. University of Wyoming Agr. Exp. Sta. Bull. No. 496.

Syntex, Agribusiness Corporation. 1976. The Cowpedia.

Thatcher, W. W. and J. R. Chenault. 1976. Reproductive physiological responses of cattle to exogenous prostaglandin $F_{2\alpha}$. J. Dairy Sci. 59:1366.

Thibault, C. and M. Levasseur. 1974. Reproductive Life Cycle. In Reproduction in Farm Animals. E. Hafez (Ed.), Lea & Febiger, Philadelphia, PA.

Tilton, J. E., L. J. Johnson and W. D. Eide. 1973. Managing the AI program. Great Plains Beef Cattle Hdbk. GPE-8455.

Toby, P. M. and W. Hansel. 1975. Insemination at a predetermined time after prostaglandin $F_{2\alpha}$, estradiol, and luteinizing hormone releasing hormone treatments. J. Dairy Sci. 58:769 (Abstr.).

Trimberger, G. W. and W. Hansel. 1955. Conception rate and ovarian function following estrous control by progesterone injections in dairy cattle. J. Anim. Sci. 14:224.

Ulberg, L. C., R. E. Christian and L. E. Casida. 1951. Ovarian response in heifers to progesterone injections. J. Anim. Sci. 10:752.

United States Department of Agriculture. 1979. Econ. Res. Serv. Rept. 8-107.

Van Vleck, D. and C. Henderson. 1963. Measurement of genetic trend. J. Dairy Sci. 46:976.

Wagner, J. F., E. L. Veenhuizer, R. P. Gregory and L. V. Tonkinson. 1968. Fertility in the beef heifer following treatment with 6-chloro Δ^6-17-acetoxy progesterone. J. Anim. Sci. 27:1627.

Wallace, R. 1980. Using sire evaluation data. Proc. 1980 Beef Imprvmt. Fed., Denver, CO. p. 96.

Warren, J. E., Jr., P. E. Lewis and D. O. Kiesling. 1979. Inhibition by indomethacin of estrogen-induced luteal regression in heifers. Abstr. 71st Annu. Meetings Amer. Soc. Anim. Sci. p. 346.

Watson, J. S., L. F. Archbald and R. A. Godke. 1980. The use of cloprostenol and estradiol cypionate to induce luteal regression in intact and hysterectomized beef heifers. Abstr. 72nd Annu. Meetings Amer. Soc. Anim. Sci., p. 336.

Welch, J. A., A. J. Hockett, C. J. Cunningham, J. O. Heishman, S. P. Ford, R. Nadaraja, W. Hansel and E. K. Inskeep. 1975. Control of estrus in lactating beef cows with prostaglandin $F_{2\alpha}$ and estradiol benzoate. J. Anim. Sci. 41:1686.

Wetteman, R. P., H. D. Hafs, L. A. Edgerton and L. V. Swanson. 1972. Estradiol and progesterone in blood serum during the bovine estrous cycle. J. Anim. Sci. 34:1020.

Whitman, R. W., J. N. Wiltbank, D. C. LeFever, and A. H. Denham. 1972. Ear implant (SC21009) for estrous control in cows. Proc. West. Sec. Amer. Soc. Anim. Sci. 32:280.

Wideman, D., D. G. LeFever, L. C. Faulkner and J. N. Wiltbank. 1969. Subcutaneous implants for control of estrus. Proc. West. Sect. Amer. Soc. Anim. Sci. 20:13

Willett, E. L. 1950. The fertility of heifers following administration of progesterone to alter the estrual cycle. J. Dairy Sci. 33:381 (Abstr.).

Wiltbank, J. N. 1970. Short breeding periods with the aid of estrous cycle synchronization. Proc. III Conf. A.I. and Reprod. p. 85.

Wiltbank, J. N. 1974. Management programs to increase reproductive efficiency of beef herds. J. Anim. Sci. 38 (Suppl. 1):58.

Wiltbank, J. N. and L. E. Casida. 1956. Alteration of ovarian activity by hysterectomy. J. Anim. Sci. 15:93.

Wiltbank. J. N., J. E. Engalls and W. W. Rowden. 1961. Effects of various forms and levels of estrogens alone or in combinations with gonadotropins on the estrous cycle of beef heifers. J. Anim. Sci. 20:341.

Wiltbank, J. N., D. R. Zimmerman, J. E. Engalls and W. W. Rowden. 1965. Use of progestational compounds alone or in combination with estrogen for synchronization of estrus. J. Anim. Sci. 24:990.

Wiltbank, J. N., R. P. Shumway, W. R. Parker and D. R. Zimmerman. 1967. Duration of estrus, time of ovulation, and fertilization rate in beef heifers synchronized with dyhydroxy progesterone acetophenide. J. Anim. Sci. 26:764.

Wiltbank, J. N., J. C. Sturges, D. Wideman, D. G. LeFever and L. C. Faulkner. 1971. Control of estrus and ovulation using subcutaneous implant and estrogens in beef cattle. J. Anim. Sci. 33:600.

Wiltbank, J. N. and J. C. Spitzer. 1978. Recent research on controlled reproduction in beef cattle. World Anim.Rev. 27:30

Wise, T. H., D. Caton, W. W. Thatcher, D. H. Barrow, C. J. Wilcox, A. R. Lehres and M. J. Fields. 1980. Ovarian blood flow and progesterone during the bovine estrous cycle. Abstr. 72nd Annu. Meetings Amer. Soc. Anim. Sci., p. 338.

Wishart, D. F. and B. D. Hoskin. 1968. Estrus synchronization with vaginal pessaries. J. Reprod. Fertil. 17:285.

Woodward, R. R. 1963. The impact of artificial breeding on the beef industry. Proc. 8th Mont. Beef Prod. School, Montana State Univ. Coop. Ext. Serv. 8:34.

Zimbelman, R. G. and L. W. Smith. 1966. Control of ovulation in cattle with melengestrol acetate. J. Reprod. Fertil. 11:185.

Zolman, J., E. M. Convey and J. H. Britt. 1974. Relationships between the luteinizing hormone response to gonadotropin releasing hormone and endogenous steroid. J. Anim. Sci. 39:355.

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