PEER REVIEWED

Beef Heifer and Cow Estrous Synchronization Programs

G.C. Lamb, *PhD*
North Florida Research and Education Center, University of Florida, Marianna, FL 32446

Abstract

Recent estrous synchronization research has aimed to develop reliable protocols that: 1) rely solely on fixed-timed artificial insemination (TAI); 2) require a maximum of three animal handlings; and 3) are successful in estrous-cycling and non-cycling females. In cows, insertion of an intravaginal progesterone insert during the seven-day interval between the initial gonadotropin-releasing hormone (GnRH) and prostaglandin injections of the CO-Synch protocol enhanced pregnancy rates by 9 to 10%. Recent research has shown that TAI protocols yield pregnancy rates similar to a protocol involving detection of estrus plus a fixed-time cleanup AI for females not detected in estrus. Initiation of estrous cycles in non-cycling cows is likely the primary manner in which beef producers may improve fertility in response to estrus synchronization and TAI protocols. Treatment of non-cycling females with progesterone and GnRH increases the percentage of cycling females and improves fertility to a TAI, but inducing cyclicity with human chorionic gonadotropin (hCG) fails to enhance fertility in TAI protocols. Supplementing progesterone after TAI fails to increase pregnancy rates in beef cattle. In contrast, administration of hCG seven days after TAI induced an accessory corpus luteum, increased progesterone, and tended to enhance pregnancy rates. Use of TAI protocols reduces the hassle factors associated with ovulation synchronization and AI, and provides cattle producers efficient and effective tools for capturing selective genetic traits of economic consequences. Location variables, however, such as differences in pasture and diet, breed composition, body condition, postpartum interval, climate, and geographic location, affect the success of TAI protocols.

Key words: estrous synchronization, ovulation, beef cow, beef heifer, artificial insemination

Résumé

Les travaux de recherche récents sur la synchronisation de l'œstrus ont mis l'accent sur le développement de protocoles fiables qui: 1) dépendent exclusivement de l'insémination artificielle sur rendez-vous; 2) requièrent un maximum de trois manipulations des animaux; et 3) ont du succès avec les femelles cycliques et non-cycliques en œstrus. Chez la vache, l'insertion d'un dispositif intra-vaginal de progestérone durant l'intervalle de sept jours entre le début de l'injection de gonadolibérine d'origine hypothalamique et l'injection de prostaglandine dans le protocole CO-Synch peut augmenter le taux de conception de 9 à 10%. Des travaux récents ont montré que les protocoles d'insémination artificielle sur rendez-vous permettent d'avoir des taux de conception similaires à ceux obtenus avec le protocole de détection des chaleurs avec insémination artificielle sur rendez-vous des femelles dont les chaleurs n'ont pas été détectées. L'initiation du cycle œstral chez les vaches non-cycliques est probablement la méthode la plus simple à la portée des producteurs de boucherie pour accroître la fertilité suite à la synchronisation de l'œstrus dans un protocole d'insémination artificielle sur rendez-vous. Le traitement des femelles non-cycliques avec des injections de progestérone et de gonadolibérine permet d'accroître le pourcentage de femelles cycliques et d'augmenter la fertilité dans les protocoles d'insémination artificielle sur rendez-vous. Toutefois, l'induction de la cyclicité avec l'hormone gonadotrophine chorionique humaine (hCG) ne permet pas d'augmenter la fertilité dans ces protocoles sur rendez-vous. L'apport supplémentaire de progestérone après l'insuccès du protocole d'insémination artificielle sur rendez-vous n'augmente pas le taux de conception chez les bovins de boucherie. Au contraire, l'injection de l'hCG sept jours après l'insémination artificielle sur rendez-vous peut induire un corps jaune accessoire, accroître la progestérone et tend à augmenter le taux de conception. L'utilisation de protocoles d'insémination artificielle sur rendez-vous réduit les inconvénients associés à la synchronisation de l'ovulation et à l'insémination artificielle et fournit des outils efficaces aux producteurs de bovins de boucherie pour cibler des caractéristiques génétiques avec potentiel économique. Néanmoins, les variables locales, comme par exemple les différences dans le pâturage et le régime alimentaire, la composition des races, l'indice corporel, l'intervalle postpartum, le climat et la localisation géographique, influencent le succès des protocoles d'insémination artificielle sur rendez-vous.

Introduction

Estrous synchronization and artificial insemination (AI) are reproductive management tools available to beef producers for over 30 years. Synchronization of the estrous cycle can potentially shorten the calving season, increase calf uniformity, and enhance the possibilities for utilizing AI. Artificial insemination offers producers the opportunity to infuse superior genetics into their operations at costs far below the cost of purchasing a herd sire of similar standards. These tools remain the most important and widely applicable reproductive biotechnologies available for beef cattle operations.[28] However, beef producers have been slow to utilize or adopt these technologies into their production systems.

Several factors, especially during early development of estrous synchronization programs, may have contributed to the poor adoption rates. Initial programs failed to address the primary obstacle in synchronization of estrous, which was to overcome puberty or postpartum anestrus. Additionally, these programs failed to manage follicular waves, resulting in more days during the synchronized period in which detection of estrus was necessary. This ultimately precluded fixed-time AI with acceptable pregnancy rates. More recent developments focused on both corpus luteum (CL) and follicle control in convenient and economical protocols to synchronize ovulation. These developments facilitated fixed-time AI (TAI) use, and should result in increased adoption of these important management practices.[24] Current research has focused on development of methods that effectively synchronize estrous in postpartum beef cows and replacement beef heifers by decreasing the period of time over which estrous detection is required, thus facilitating the use of TAI.[11,13,14] This new generation of estrous synchronization protocols uses two strategies which are key factors for implementation by producers because they: 1) minimize the number and frequency of handling cattle through a cattle-handling facility, and 2) eliminate detection of estrus by employing TAI.

Alas, the extensive nature of most beef cattle operations and labor intensity associated with reproductive technologies, such as AI and synchronization, tends to drive people away from utilizing this technology, yet the financial and genetic advantages have been extensively documented. Ultimately, the single largest reason for the failure of an AI program is poor management, resulting in poor reproductive performance, which causes poor responses to reproductive management. Therefore, producers should use synchronization and AI to enhance the profitability of a well-managed operation, but should not use synchronization and AI to obtain a well-managed operation. Focusing on details such as health, nutrition, and other management factors are critical to the success of an AI program.

Cattle producers should be aware that numerous short- and long-term factors contribute to females conceiving to an AI, maintaining the embryo/fetus to term, delivering the calf without assistance, and raising and weaning a healthy calf.

Effects of Postpartum Anestrus on Fertility

The proportion of cows not cycling is the primary factor that limits the conception of suckled beef cows to synchronization and AI.[30] Continual presence of a suckling calf prolongs and delays the re-initiation of estrous cycles.[38] Insufficient nutrient intake and poor body condition are also limiting factors, but temporary or permanent calf removal usually initiates estrus within a few days.[38] Young cows generally are more prone to prolonged anestrus because of additional growth requirements.[29,30] The first priority is maintenance of essential body functions to preserve life. Once maintenance is met, remaining nutrients accommodate growth. Finally, lactation and the initiation of estrous cycles are supported. Older cows have no growth requirement, thus nutrients are more likely to be available for milk production and initiation of estrous cycles. Because of this priority system, young, growing cows generally produce less milk and are anestrus longer after calving. When the incidence of cyclicity was determined in 3,269 cows at the beginning of the breeding season, the major limiting factors found to affect the rate of cyclicity at the beginning of the breeding season included age of the cow, body condition, and days postpartum.[34]

Generally, beef cows do not experience a period of negative energy balance because they fail to produce the quantity of milk that dairy cows produce; however, beef cows need to be in good enough body condition to resume estrous cycles after parturition and overcome general infertility, anestrus, short estrous cycles, and uterine involution just to maintain a yearly calving interval. For producers with shorter calving intervals with cows in good condition, the probability of a pregnancy is generally very good. But in herds that utilize calving seasons of greater than 60 days, maintaining a 365-day calving interval becomes increasingly more difficult (Figure 1).[30]

Nutritional Management Considerations

Body condition score as an indicator of reproductive efficiency

Body condition scoring (BCS) is a reliable method to assess the nutritional status of cows. A visual body condition scoring system developed for beef cattle uses a scale from 1 to 9, with 1 representing emaciated and 9 obese cattle.[39] A linear relationship exists between body weight change and body condition score, where an approximate 88 lb (40 kg) weight change is associated

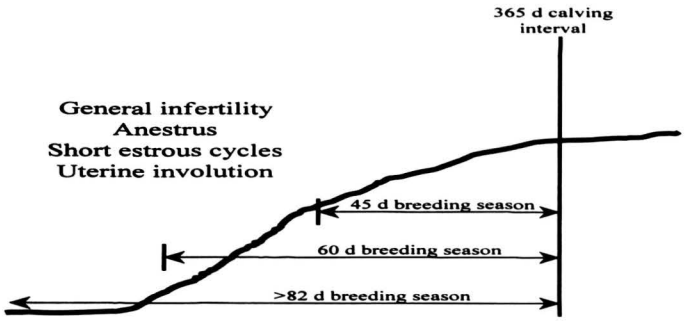


Figure 1. Relationship of length of breeding season to fertility during the postpartum period.[30]

with each unit change in BCS (using the 1 to 9 scale). Managers of breeding-age females should understand when cows can be maintained on a decreasing plane of nutrition, when they should be maintained on an increasing plane of nutrition, or when they can be kept on a maintenance diet. Understanding the production cycle of the cow and how to manipulate the diet will improve the conception rate to AI.[1,13,14,19]

Body condition score at calving has been shown to be a more predictable indicator of the duration of postpartum anestrus than prepartum change in either weight or BCS.[9,39] When cows were thin at calving or had a BCS of 4 or less, increased postpartum level of energy increased the percentage of females exhibiting estrus during the breeding season. Body condition score at parturition and breeding are the dominant factors influencing pregnancy success, although body weight changes during late gestation modulate this effect. However, altering poor body condition after parturition may reduce the negative impact on reproduction, but seldom overcomes or eliminates those negative effects. A recent study[34] using blood samples at initiation of the breeding season to determine estrous cycling status demonstrated that only 47.2% of the cows were cycling at the onset of the breeding season. However, as BCS increased, the percentage of cows cycling also increased. It is important to note that when cows had a body condition of less than 4 at the beginning of the breeding season, only 33.9% had resumed estrous cycles.

Prepartum nutritional effects on reproduction

The general belief is that cows maintained on an increasing plane of nutrition prior to parturition usually have a shorter interval to first ovulation than cows on a decreasing plane of nutrition. Energy restriction during the prepartum period results in a low BCS at calving, prolonged postpartum anestrus, and a decrease in the percentage of cows exhibiting estrus during the breeding season.[25] Pregnancy rates and intervals from parturition to pregnancy also are affected by level of prepartum energy.[25] Conversely, when prepartum nutrient restriction was followed by increased postpartum nutrient intake, the negative effect of prepartum nutrient restriction was partially overcome; however, the effectiveness of elevated postpartum nutrient intake depended on the severity of prepartum nutrient restriction.[9,25] The effect of BCS prior to calving also has implications for calf birth and weaning weights. When cows were fed to achieve a BCS of either 4 or 6 prior to calving, body weights were greater and calf birth and weaning weights (with similar genetics) were also greater for cows in a BCS of 6.[32] Despite greater birth weights, there was no difference in calving difficulty, demonstrating the added advantage for recipients to wean calves with greater weaning weights. In addition, there tended to be an increased number of cows calving with a medium BCS that were cycling at the beginning of breeding season and after a 60-day breeding season than cows in poor condition, resulting in a greater proportion of cycling cows at various stages of the breeding season.[32]

Postpartum nutrition

Numerous studies document that increasing nutritional levels following parturition increases conception and pregnancy rates in beef cows.[39,40] Increasing the postpartum dietary energy density increased body weight and BCS and decreased the interval to first estrus.[9] However, suckled beef cows in relatively poor body condition gaining in excess of 2.2 lb (1 kg)/day while consuming an 85% concentrate diet did not resume cyclic ovarian activity before 70 days postpartum.[9] Therefore, although an enhanced plane of nutrition after calving may partially overcome the negative effects of poor prepartum nutrition, the added stress and negative impact of suckling and lactation also must be considered.

A major impact on postpartum fertility is the length of the breeding season. Having a restricted breeding season has many advantages, such as a more uniform, older calf crop, but most importantly a breeding season of 60 days or less increases the percentage of females cycling during the next breeding season. If the breeding season is shortened, then all cows have a higher probability for pregnancy during the next breeding season. Strategic feeding to obtain ideal BCS can be achieved by understanding the production cycle of the cow. The period of greatest nutritional need occurs shortly after calving; a cow is required to produce milk for a growing calf, regain weight lost shortly before and after parturition, and repair her reproductive tract to become pregnant within three months after calving. During this stage, a cow usually is consuming as much feed as she can and adjusting BCS at this time is often futile. Cows usually are grazing and tend to consume full protein, vitamin and mineral requirements; however, the grass is often lush with a high percentage of moisture which occasionally can cause a deficiency in energy.[21]

Control of the Estrous Cycle by Synchronization

Overview of estrous synchronization protocols

Gonadotropin-releasing hormone (GnRH) is widely used as an integral component of estrous and ovulation synchronization programs for both beef and dairy cattle. Combinations of GnRH, prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$), and two progestins (melengesterol acetate (MGA), and a controlled internal drug release insert (CIDR)) comprise the majority of estrous and ovulation synchronization protocols in the United States.

Briefly, GnRH ovulates a dominant follicle via luteinizing hormone (LH) release which results in subsequent CL formation and follicular wave emergence (via follicle stimulating hormone (FSH)).[36] Prostaglandin $F_{2\alpha}$ is used to lyse a CL, either spontaneously formed[16] or induced via GnRH administration.[31] Upon lysis of the CL, estrus ensues as follicular maturity dictates, usually occurring within four days.[10,14] Progestins may prevent the occurrence of estrus and premature ovulation,[14] and initiate cyclicity in a portion of prepubertal heifers and postpartum anestrous cows.[17] Figures 2 and 3 demonstrate estrous synchronization protocols mentioned in subsequent sections for beef cows and beef heifers, respectively.

Advances in protocols for beef cows

Preliminary studies identified significant improvements in fertility among cows that received MGA prior to the administration of $PGF_{2\alpha}$ compared to cows that received only $PGF_{2\alpha}$.[22] When cows received a CIDR for seven days and an injection of $PGF_{2\alpha}$ the day before CIDR removal, estrus synchrony and pregnancy rates were improved.[17] When GnRH was given six or seven days prior to $PGF_{2\alpha}$, 70 to 83% of cows were in estrus within a four-day period.[36]

The use of GnRH to control follicular wave emergence and ovulation and $PGF_{2\alpha}$ to induce luteolysis led to development of the Ovsynch protocol for dairy cows.[27] Combining the second injection of GnRH with TAI (CO-Synch) proved to be more practical than estrus detection for beef producers because it had no negative effects on fertility.[7] However, a disadvantage of this protocol is that approximately 5 to 15% of suckled beef cows exhibit estrus prior to, or immediately after the $PGF_{2\alpha}$ treatment.[13] Unless these cows are detected in estrus and inseminated, they will fail to become pregnant to TAI. Therefore, we hypothesized that the addition of a CIDR to a GnRH-based protocol would prevent the premature occurrence of estrus and result in enhanced fertility following TAI. Overall pregnancy rates were enhanced by the addition of a CIDR to a GnRH-based TAI protocol (59 vs 48%, respectively). The CIDR delayed the onset of ovulation, resulting in more synchronous ovulation, and induced cyclicity in non-cycling cows.[13] However, the efficacy of these CIDR-based TAI protocols had not been evaluated concurrently with AI protocols requiring detection of estrus in suckled beef cows. Therefore, we implemented and coordinated a multi-state, multi-location experiment to discern whether a GnRH-based + CIDR protocol for TAI could yield pregnancy rates similar to protocols requiring detection of estrus.[14] Results demonstrated that the TAI protocol yielded pregnancy rates that were similar to the estrus detection protocol, even though 35% of the cows were in postpartum anestrous at the time of treatment. Utilizing a similar protocol on recipients using fixed-time embryo transfer would be practical and effective for yielding high pregnancy rates in recipients.[1] For best results producers should consider utilizing protocols recommended by the Beef Reproduction Task Force. These protocols can be found in AI manuals and through the Beef Reproduction Task Force website (http://westcentral.unl.edu/beefrepro/).

Advances in protocols for beef heifers

Early studies in beef heifers demonstrated that feeding MGA for 14 days followed by $PGF_{2\alpha}$ 17 days later was an effective method of estrous cycle control in heifers.[2,23] However, when heifers were treated with $PGF_{2\alpha}$ 19 days after the 14 days MGA feeding period, there was no difference in fertility but estrus was more synchronous.[12] Following the success of this protocol, researchers began to include GnRH in estrus synchronization protocols for TAI. However, addition of GnRH to the above protocol failed to increase pregnancy rates following TAI in heifers.[41] Estrus synchronization using GnRH followed by $PGF_{2\alpha}$ successfully synchronized heifers, but the above MGA-$PGF_{2\alpha}$ protocol led to greater synchrony of estrus and, therefore, tended to be more effective.[10]

Development of a TAI protocol in beef heifers has not been as straightforward as in cows, especially considering that at the time of estrus synchronization, a majority (greater than 85%) of heifers have attained puberty.[11] The primary reason for failure of TAI in heifers appears to be the inability to synchronize follicular waves with GnRH. After an injection of GnRH at random stages of the estrous cycle, 75 to 90% of postpartum beef cows ovulated,[6,35] whereas only 48 to 60% of beef and dairy heifers ovulated in response to the same treatment.[18,20,27] We have found no difference in synchrony of estrus or pregnancy rate in CIDR-treated heifers whether or not GnRH is administered at CIDR insertion, suggesting that response to GnRH in heifers at CIDR insertion may be of limited value.[10]

In a large, 12-location study using GnRH, $PGF_{2\alpha}$, and CIDR, GnRH did not enhance pregnancy rates following estrus detection, but the addition of a CIDR to a GnRH-based TAI protocol yielded similar pregnancy rates to those utilizing estrus detection.[11] Nevertheless, a bewildering fact remains that the average pregnancy

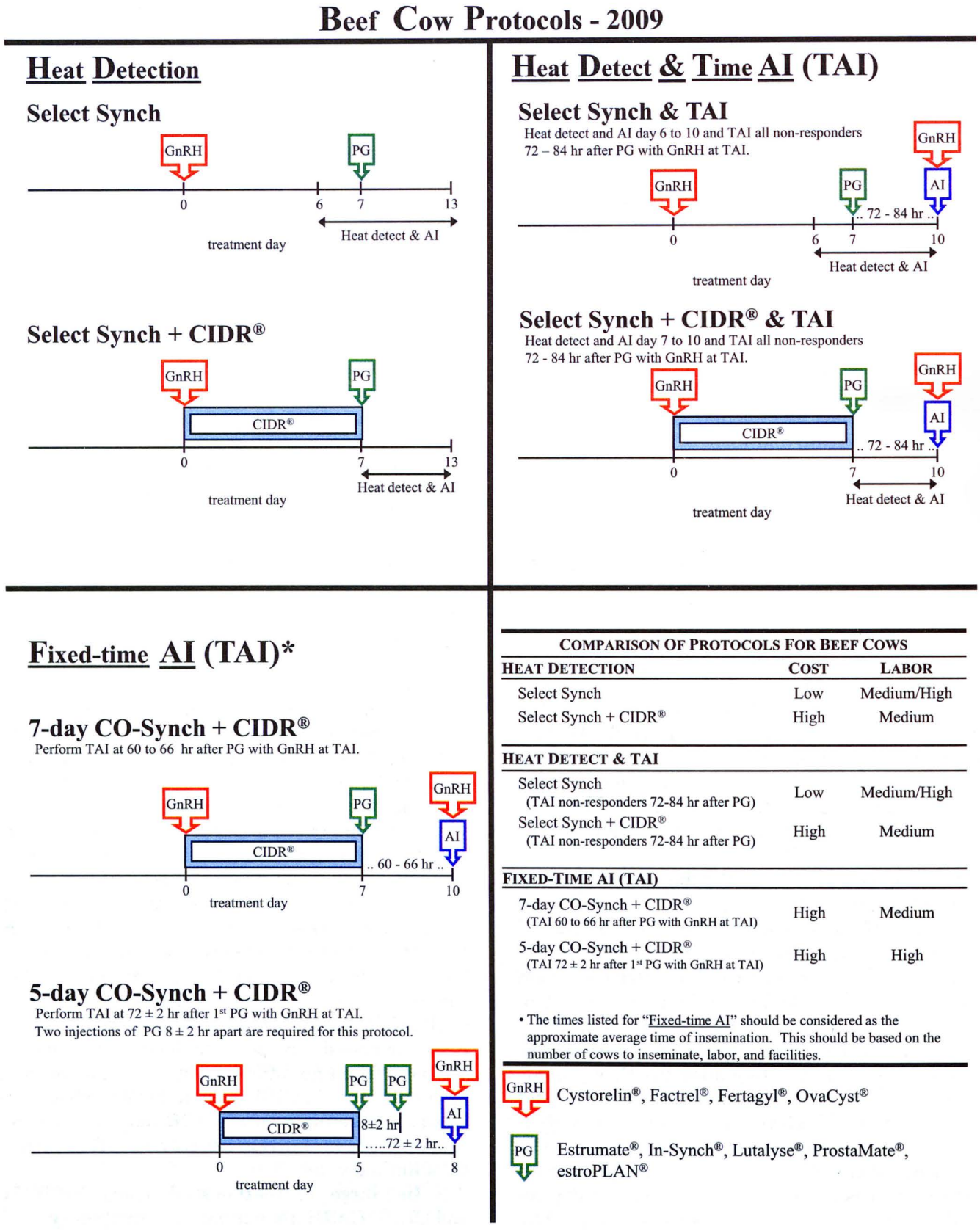
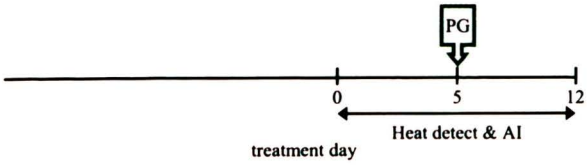


Figure 2. Estrous synchronization protocols for use in beef cows. From the Beef Reproductive Task Force; available at http://westcentral.unl.edu/beefrepro/resources.html

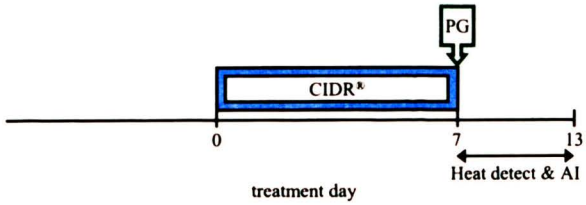
Beef Heifer Protocols - 2009

Heat Detection

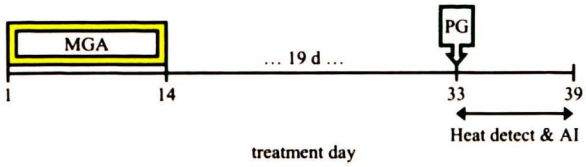
1 Shot PG



CIDR®-PG



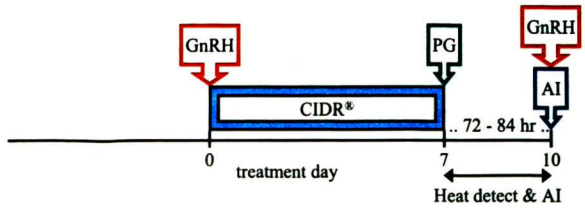
MGA®-PG



Heat Detect & Time AI (TAI)

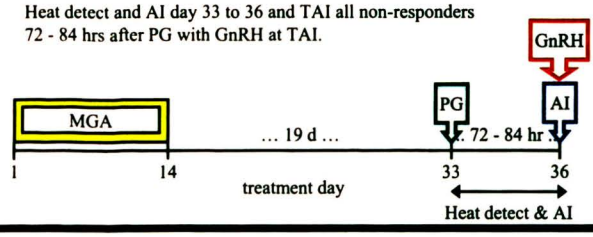
Select Synch + CIDR® & TAI

Heat detect and AI day 7 to 10 and TAI all non-responders
72 - 84 hr after PG with GnRH at TAI.



MGA®-PG & TAI

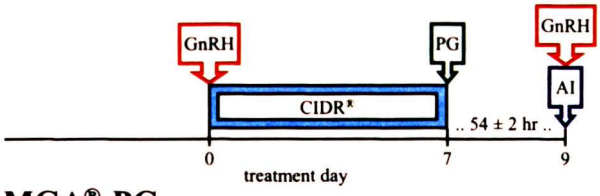
Heat detect and AI day 33 to 36 and TAI all non-responders
72 - 84 hrs after PG with GnRH at TAI.



Fixed-time AI (TAI)*

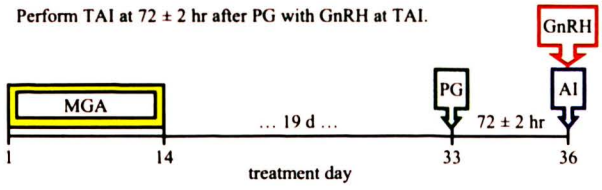
CO-Synch + CIDR®

Perform TAI at 54 ± 2 hr after PG with GnRH at TAI.



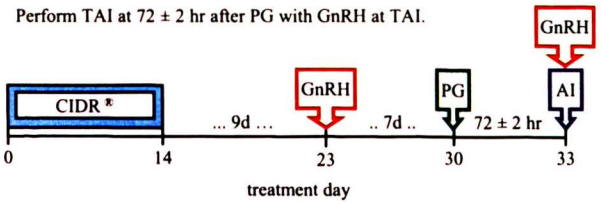
MGA®-PG

Perform TAI at 72 ± 2 hr after PG with GnRH at TAI.



CIDR® Select

Perform TAI at 72 ± 2 hr after PG with GnRH at TAI.



COMPARISON OF PROTOCOLS FOR BEEF HEIFERS

HEAT DETECTION	COST	LABOR
1 Shot PG	Low	High
CIDR®-PG	Medium	Medium
MGA®-PG	Low	Low/Medium
HEAT DETECT & TAI		
Select Synch + CIDR® (TAI non-responders 72-84 hr after PG)	High	Medium
MGA®-PG (TAI non-responders 72-84 hr after PG)	Medium	Medium
FIXED-TIME AI (TAI)		
CO-Synch + CIDR® (TAI 54 ± 2 hr after PG with GnRH at TAI)	High	Medium
MGA®-PG (TAI 72 ± 2 hr after PG with GnRH at TAI)	Medium	Medium
CIDR® Select (TAI 72 ± 2 hr after PG with GnRH at TAI)	High	Medium/High

• The times listed for "Fixed-time AI" should be considered as the approximate average time of insemination. This should be based on the number of heifers to inseminate, labor, and facilities.

GnRH Cystorelin®, Factrel®, Fertagyl®, OvaCyst®

PG Estrumate®, In-Synch®, Lutalyse®, ProstaMate®, estroPLAN®

Beef Reproduction Task Force

Figure 3. Estrous synchronization protocols for use in beef heifers. From the Beef Reproductive Task Force; available at http://westcentral.unl.edu/beefrepro/resources.html

rate for these protocols ranged from 53 and 58%, whereas pregnancy rates in MGA (with $PGF_{2\alpha}$ administered 19 days after MGA removal) or a long-term CIDR (with $PGF_{2\alpha}$ administered 16 days after MGA removal) protocol followed by $PGF_{2\alpha}$ range from 60 and 75%.[5,8,10,12,24,41] Further research is required to understand methods of estrous cycle control in heifers to develop estrus synchronization protocols for TAI.

Re-synchronization of estrus

Re-insemination of non-pregnant cows at the first eligible estrus can be facilitated by re-synchronization of the estrous cycle,[37] which would have wide application in intense embryo transfer (ET) programs. To most effectively condense the calving season, the second round of estrus synchronization must begin before the pregnancy status of the animals is known. Although re-synchronization with a progestin increased synchronized return rates of non-pregnant females,[4,33] re-synchronization with CIDR devices and estradiol cypionate or estradiol benzoate decreased subsequent conception rates to AI.[33] In contrast, further studies did not note a decrease in fertility when estrogens were utilized for re-synchronization with a CIDR.[3] Furthermore, insertion of a CIDR for 13 days on the day of ET seven days after estrus[26] or from five days after TAI until day 21[15] was effective in re-synchronizing estrus in non-pregnant cows, but insertion of a CIDR failed to enhance fertility compared to controls.

Additional Considerations for a Successful AI Program

Recordkeeping

Maintaining a sound recording keeping system is a key to success in any reproductive management system. For synchronization to work, producers need to know when their cows calved, whether the cow had a difficult birth, and birth weights of all calves. We aim at starting a synchronization protocol when cows are greater than 45 days from calving; however, if a cow had a difficult birth or large calf, it may be wise to wait an extra few weeks. Without accurate records, these decisions can be extremely subjective.

Facilities

With synchronization, many more females will be in heat at a single time than without synchronization. Plus, females will need to be pushed through the chute for injections more frequently than usual; therefore, working facilities must accommodate the extra work. This requires reliable holding and sorting pens, and a good solid alley and chute system. Anticipating an increase in facility use will certainly ensure a successful synchronization program. Utilizing facility designs proven to make cattle handling less stressful for animals will enhance fertility. Well designed facilities and the use of breeding barns also reduces the stress level on producers and AI technicians.

Labor

Reliable labor is an issue often neglected when planning a synchronization program. Detecting when cows are in heat is important for success of a synchronization program. Any labor associated with this process needs to know exactly how cows act when in heat. In many cases, this is when a program fails. Some producers feel they have more important things to do than spend time heat checking. They will often leave for the "more important" job or leave heat checking to a less competent individual. The end result is poor estrus response or poor conception rates.

Many more factors need to be considered, such as using a proficient AI technician. Many AI companies can now provide full services that reduce the need for producers to inject, insert implants, and AI. Utilizing these resources provides the potential to enhance the overall success of the program. Regardless of the system used, directions on the drug label must be followed and shortcuts must be avoided.

Conclusion

For synchronization and AI programs to be effective, numerous factors must be in place to ensure success. Nutrition, estrous cycle control, and female management all contribute to success or failure in a given program. Producers, AI technicians, veterinarians, and all members of the reproductive management team must be aware of the short- and long-term factors that influence females conceiving to AI, maintaining the embryo/fetus to term, delivering the calf without assistance, and raising and weaning a healthy calf.

Acknowledgements

This manuscript was presented at the American Association of Bovine Practitioners Conference in Omaha, Nebraska, September, 2009.

References

1. Beal WB: Streamlining embryo transfer. *Proc AETA 18th Annual Convention*, Colorado Springs, CO, pp 78-85, 1999.
2. Brown LN, Odde KG, LeFever DG, King ME, Neubauer CJ: Comparison of MGA- $PGF_{2\alpha}$ to Syncro-Mate B for estrous synchronization in beef heifers. *Therio* 30:1-12, 1988.
3. Cavalieri J, Hepworth G, Smart VM, Ryan M, Macmillan KL: Reproductive performance of lactating dairy cows and heifers resynchronized for a second insemination with an intravaginal progesterone-releasing device for 7 or 8d with estradiol benzoate injected at the time of device insertion and 24h after removal. *Therio* 67:824-834, 2007.

4. Colazo MG, Kastelic JP, Mainar-Jaime RC, Gavaga QA, Whittaker PR, Small JA, Martinez MF, Wilde RE, Veira DM, Mapletoft RJ: Re-synchronization of previously timed-inseminated beef heifers with progestins. *Therio* 65:557-572, 2006.
5. Dahlen CR, Lamb GC, Zehnder CM, Miller LR, DiCostanzo A: Fixed-time insemination in peripuberal, light-weight replacement beef heifers synchronized with $PGF_{2\alpha}$ and GnRH. *Therio* 59:1827-1837, 2003.
6. El-Zarkouny SZ, Cartmill JA, Hensley BA, Stevenson JS: Pregnancy in dairy cows after synchronized ovulation regimens with or without presynchronization and progesterone. *J Dairy Sci* 87:1024-1037, 2000.
7. Geary TW, Whittier JC, Hallford DM, MacNeil MD: Calf removal improves conception rates to the Ovsynch and CO-Synch protocols. *J Anim Sci* 79:1-4, 2001.
8. Kojima FN, Bader JF, Stegner JE, Schafer DJ, Clement JC, Eakins RL, Smith MF, Patterson DJ: Substituting EAZI-BREED CIDEER inserts (CIDR) for melengestrol acetate (MGA) in the MGA Select protocol in beef heifers. *J Anim Sci* 87(Suppl.1):255, 2004.
9. Lalman DL, Keisler DH, Williams JE, Scholljegerdes EJ, Mallet DM: Influence of postpartum weight and body condition change on duration of anestrus by undernourished suckled beef heifers. *J Anim Sci* 75:2003-2008, 1997.
10. Lamb GC, Cartmill JA, Stevenson JS: Effectiveness of Select Synch (gonadotropin-releasing hormone and prostaglandin F2[alpha]) for synchronizing estrus in replacement beef heifers. *Prof Anim Sci* 20:27-33, 2004.
11. Lamb GC, Larson JE, Geary TW, Stevenson JS, Johnson SK, Day ML, Ansotegui RP, Kesler DJ, DeJarnette JM, Landblom D: Synchronization of estrus and artificial insemination in replacement beef heifers using GnRH, $PGF_{2\alpha}$ and progesterone. *J Anim Sci* 84:3000-3009, 2006.
12. Lamb GC, Nix DW, Stevenson JS, Corah LR: Prolonging the MGA-prostaglandin $F_{2\alpha}$ interval from 17 to 19 days in an estrus synchronization system for heifers. *Therio* 53:691-698, 2000.
13. Lamb GC, Stevenson JS, Kesler DJ, Garverick HA, Brown DR, Salfen BE: Inclusion of an intravaginal progesterone insert plus GnRH and prostaglandin $F_{2\alpha}$ for ovulation control in postpartum suckled beef cows. *J Anim Sci* 79:2253-2259, 2001.
14. Larson JE, Lamb GC, Stevenson JS, Johnson SK, Day ML, Geary TW, Kesler DJ, DeJarnette JM, Schrick FN, DiCostanzo A, Arseneau JD: Synchronization of estrus in suckled beef cows for detected estrus and artificial insemination and timed artificial insemination using gonadotropin-releasing hormone, prostaglandin F2alpha, and progesterone. *J Anim Sci* 84:332-342, 2006.
15. Larson JE, Thielen KN, Funnell BJ, Stevenson JS, Kesler DJ, Lamb GC: Influence of a CIDR after fixed-time AI on pregnancy rates and returns to estrus of non-pregnant cows. *J Anim Sci* 87:914-921, 2009.
16. Lauderdale JW, Seguin BE, Stellflug JN, Chenault JR, Thatcher WW, Vincent CK, Loyancano AF: Fertility of cattle following $PGF_{2\alpha}$ injection. *J Anim Sci* 38:964-967, 1974.
17. Lucy MC, Billings HJ, Butler WR, Ehnis LR, Fields MJ, Kesler DJ, Kinder JE, Mattos RC, Short RE, Thatcher WW, Wettemann RP, Yelich JV, Hafs HD: Efficacy of an intravaginal progesterone insert and an injection of PGF2alpha for synchronizing estrus and shortening the interval to pregnancy in postpartum beef cows, peripubertal beef heifers, and dairy heifers. *J Anim Sci* 70:1904-1910, 2001.
18. Macmillan KL, Thatcher WW: Effects of an agonist of gonadotropin-releasing hormone on ovarian follicles in cattle. *Biol Reprod* 45:883-889, 1991.
19. Mapletoft RJ, Lindsell CE, Pawlyshyn V: Effects of clenbuterol, body condition and non-surgical embryo transfer equipment on pregnancy rates in bovine recipients. *Therio* 25:172 (abstract), 1986.
20. Moreira F, de la Sota RL, Diaz T, Thatcher WW: Effects of day of the estrous cycle at the initiation of a timed artificial insemination protocol on reproductive responses in dairy heifers. *J Anim Sci* 78:1568-1576, 2000.
21. National Research Council (NRC): *Nutrient Requirements of Beef Cattle*, ed 7. Washington, DC, National Academy Press, 1996, pp 85-96.
22. Patterson DJ, Hall JB, Bradley NW, Schillo KK, Woods BL, Kearnan JM: Improved synchrony, conception rate, and fecundity in postpartum suckled beef cows fed melengestrol acetate prior to prostaglandin $F_{2\alpha}$. *J Anim Sci* 73:954-959, 1995.
23. Patterson DJ, Kiracofe GH, Stevenson JS, Corah LR: Control of the bovine estrous cycle with melengestrol acetate (MGA): A review. *J Anim Sci* 67:1895, 1989.
24. Patterson DJ, Kojima FN, Smith MF: A review of methods to synchronize estrus in replacement beef heifers and postpartum cows. *J Anim Sci* 81(ESuppl.2):E166-177. Online. Available: http://www.asas.org/symposia/03esupp2/jas2402.pdf, 2003.
25. Perry RC, Corah LR, Cochran RC, Beal WE, Stevenson JS, Minton JE, Simms DD, Brethour JR: Influence of dietary energy on follicular development, serum gonadotropins, and first postpartum ovulation in suckled beef cows. *J Anim Sci* 69:3762-3773, 1991.
26. Purcell SH, Beal WE, Gray KR: Effect of a CIDR insert and flunixin meglumine, administered at the time of embryo transfer, on pregnancy rate and resynchronization of estrus in beef cattle. *Therio* 64:867-878, 2005.
27. Pursley JR, Mee MO, Wiltbank MC: Synchronization of ovulation in dairy cows using $PGF_{2\alpha}$ and GnRH. *Therio* 44:915-923, 1995.
28. Seidel GE Jr: Reproductive biotechnologies for profitable beef production. *Proc Beef Improvement Federation*. Sheridan, WY, pp 28-39, 1995.
29. Short RE, Adams DC: Nutritional and hormonal interrelationships in beef cattle reproduction. *Can J Anim Sci* 68:29-39, 1988.
30. Short RE, Bellows RA, Staigmiller RB, Berardinelli JG, Custer EE: Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. *J Anim Sci* 68:799-816, 1990.
31. Smith VG, Chenault JR, McAllister JF, Lauderdale JW: Response of postpartum beef cows to exogenous progestogens and gonadotropin releasing hormone. *J Anim Sci* 64:540-551, 1987.
32. Spitzer JC, Morrison DG, Wetteman RP, Faulkner LC: Reproductive responses and calf birth and weaning weights as affected by body condition at parturition and postpartum weight gain in primiparous beef cows. *J Anim Sci* 73:1251-1257, 1995.
33. Stevenson JS, Johnson SK, Medina-Britos MA, Richardson-Adams AM, Lamb GC: Resynchrnonization of estrus in cattle of unknown pregnancy status using estrogen, progesterone, or both. *J Anim Sci* 81:1681-1692, 2003.
34. Stevenson JS, Johnson SK, Milliken GA: Symposium Paper: Incidence of postpartum anestrus in suckled beef cattle: Treatments to induce estrus, ovulation, and conception. *Prof Anim Sci* 19:124-134, 2003.
35. Thompson KE, Stevenson JS, Lamb GC, Grieger DM, Loest CA: Follicular, hormonal, and pregnancy responses of early postpartum suckled beef cows to GnRH, norgestomet, and prostaglandin$F_{2\alpha}$. *J Anim Sci* 77:1823-1832, 1999.
36. Twagiramungu HL, Guilbault A, Dufour JJ: Synchronization of ovarian follicular waves with a gonadotropin-releasing hormone agonist to increase the precision of estrus in cattle: A review. *J Anim Sci* 73:3141-3151, 1995.
37. Van Cleef J, Macmillan KL, Drost M, Lucy MC, Thatcher WW: Effects of administering progesterone at selected intervals after insemination of synchronized heifers on pregnancy rates and resynchronization of returns to service. *Therio* 46:1117-1130, 1996.
38. Williams GL: Suckling as a regulator of postpartum rebreeding in cattle: A review. *J Anim Sci* 68:831-852, 1990.
39. Whitman RW: Weight change, body condition and beef-cow reproduction. PhD dissertation. Colorado State Univ, Fort Collins, CO, 1975.
40. Wiltbank JN, Rowden WW, Ingalls JE, Gregory KE, Koch RM: Effect of energy level on reproductive phenomena of mature Hereford cows. *J Anim Sci* 21:219-225, 1962.
41. Wood-Follis SL, Kojima FN, Lucy MC, Smith MF, Patterson DJ: Estrus synchronization in beef heifers with progestin-based protocols. I. Differences in response based on pubertal status at the initiation of treatment. *Therio* 62:1518-1528, 2004.