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Possibilities with today's reproductive technologies

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Abstract

Reproductive efficiency is critical to economic viability for cow/calf producers; however, very few producers take advantage of available reproductive technologies that can increase profitability. Today, more opportunities are available for producers who want to capture value from known genetics. Through the use of artificial insemination (AI), the average producer has access to a wide range of high-accuracy sires that can be selected to match production goals. Systems to synchronize estrus and ovulation can now produce pregnancy rates to a single fixed-timed AI that are 10–15% greater than those of the previous generation. Increased age and weight of calves at weaning is sufficient in some situations to pay for the cost of synchronization and AI. As a result of synchronization, more cows calve early the next year and in subsequent years of synchronization. The breeding season can be shortened without reducing end-of-season pregnancy rates, since synchronized cows have one more chance to conceive than unsynchronized cows in a 22–25 day interval. Cow nutrition can be more economically and precisely managed with a shorter breeding period. Producers that establish AI programs now will be prepared to take advantage of newly identified superior genetics or other technologies, e.g. sexed semen, when they become available. Trends towards more value-based marketing and improvements in pregnancy rates from synchronization systems, make this a key time to be aware of the possibilities using reproductive technologies.

Keywords: Artificial insemination; Synchronization of estrus; Reproductive management; Pregnancy rates; Beef cattle

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1. Introduction

The U.S. beef industry continues to undergo changes and experience growing pains. Targeting consumer demands and new product development have helped to reverse the decline in beef demand experienced in the 1980s and 1990s. Tools available to assist in genetic selection are increasing, as are the breadth of traits evaluated. Thus producers who want to target particular markets with genetic programs can do so, and if successful, be rewarded for their efforts. A lower risk way to get specific, high-accuracy genetics, particularly for smaller producers, is through the use of estrus synchronization and AI. The protocols available to synchronize estrus and ovulation are better than ever, and many are not aware of what can be accomplished with the new systems. The combination of demand, better genetic tools and better reproductive management tools, makes this an ideal time for commercial producers to re-evaluate how these options might fit in their operations. Veterinary practitioners are in an excellent position to advise clients regarding the use of reproductive management techniques that can improve total herd management.

2. Genetic opportunities

The 2004 Alliance Yellow Pages in BEEF magazine [1] lists 30 consumer-based alliances focused on meeting predefined consumer product specifications and six calf-based alliances concerned with procuring calves that fit certain value requirements. The oldest, Certified Angus Beef (CAB) has been around since 1978. In 2000, annual grid premiums for CAB reached US$ 25 million [2]. Angus registrations numbered 222,608 (40% of the British breed total) in 1978 and declined to a low of 133,475 registrations in 1986. Registrations have increased every year since then, to the current level of 281,734 [3]. In 2001, Angus registrations represented 65.9% of all British breed registrations. The USDA lists 55 beef programs they have certified to meet specific carcass characteristics and, in some cases, management and phenotype requirements as well [4]. Of those listed in October 2004, less than 25% were in place before 1999.

The choice/select spread plays an important role in determining carcass value, although yield grade cannot be overlooked. The average boxed beef values from 1995 to 1997 of Angus sires ($n = 1087$) with 10 or more carcass data points is shown in Table 1 [5]. The average progeny value, assuming an average choice/select spread, was US$ 206/head different between the top 10% of the sires and the bottom 10%. Most opportunities to collect value on carcass-related genetic traits occur when ownership is retained to harvest, or proof of previous performance can be documented. Although change has come slowly, cow/calf producers now have more opportunities to take part in the value chain. Premiums averaged US$ 40 per head for those calf-based programs listed in the 2004 Alliance Yellow Pages. These opportunities seem likely to expand in the future. Trends toward more sales of feeder calves and replacement heifers that are genetically tied to a particular breeder or breed of cattle are further indications of expanding prospects for commercial producers to get paid for investments in genetics.

Breed associations have been working hard to develop new and better tools to aid in selection decisions. Economic indexes tie value to expected progeny differences (EPDs) and

Table 1
Characterization of boxed beef values in 1995–1997 for progeny of Angus sires with 10 or more carcass records

Traits	Top 10% of sires	Bottom 10% of sires	Difference
No. progeny	2728	1751	
No. sires	109	110	
%CAB	47.4	0.7	+46.7
%Choice and above	93.7	48.1	+45.6
%Select	6.1	35.0	−28.9
%Standard	0.2	16.9	−16.7
%YG 1 and 2	60.0	38.2	+21.8
%YG 4 and 5	1.4	18.2	−16.8
Carcass price (US$/cwt)	110.19	94.15	16.04
Carcass value (US$/cwt)	822.27	616.36	205.91

can help producers deal with the challenges of multi-trait selection. Some breeds have added EPDs for fertility and longevity. A new type of EPD, marker-assisted EPDs, blends the outcomes from DNA marker tests with traditional EPDs. The Simmental Association published the first of these in their 2004 Fall Sire Summary. The combination of information from shear-force tests and a marker associated with tenderness provides slightly more accurate information, especially for low-accuracy animals. Several other gene marker tests have been developed that can be used in conjunction with traditional selection information.

The groundwork has been laid for a national individual animal ID system. While the purpose of the system is to track animal disease, it will establish the components that can allow information to transfer to various segments of the industry. Consumer demands for information on age, origin, and animal husbandry practices may drive the capture and transfer of data beyond that needed to track diseases. However this works out, the likelihood is that more data from individual animal performance will be collected and used to improve selection decisions. More data means higher accuracy EPDs to reduce risk in selection decisions.

As more is learned about the bovine genome and more performance information is use in traditional estimates of breeding value, the more incentive there will be for producers to take advantage of as much of this information as possible. A producer that uses AI will be able to take advantage of high-value sires much sooner than a herd dependent on natural service. The economic advantage of using new technology and perhaps newly valued genetics is usually with the early adopters.

3. A new era for synchronization of estrus and ovulation

The development and application of methods to control the estrous cycle of beef cattle have been reviewed [6–8]. Historically, four distinct phases in this development process have been identified [6] and recently two more [8]. Phase I was the era of progesterone to prolong or create an artificial luteal phase. In Phase II, estrogens and gonadotropins were combined with progesterone. Phase III used prostaglandins to synchronize luteal regression and Phase IV the combination of progestins with $PGF_2\alpha$. Phase V brought the understanding of the need for control of follicular waves, with GnRH as a primary tool.

In Phase VI, progestins, $PGF_2\alpha$ and GnRH have been used together for what is currently the most precise control of estrus and ovulation to date.

Many protocols are available today, but protocols that seem to be most reliable for a wide range of production situations in the United States are shown in Fig. 1 (cows) and Fig. 2 (heifers). This short list of recommended protocols was developed by the Beef Cattle Reproduction Leadership Team. This team consists of practicing veterinarians, representatives from the AI and pharmaceutical industries, and academic personnel with active research programs in this area. The primary goals of the team are to promote wider adoption of reproductive technologies among cow-calf producers and to educate cow-calf producers in management considerations that will increase the likelihood of successful AI programs. Consistent nomenclature and protocol diagrams are considered important in this process. Because heifers do not respond to all treatments in the same way as cows, different recommendations exist.

Protocols that include estrogens are not recommended because estradiol cypionate (ECP®, Pfizer Animal Health, Kalamazoo, MI, USA) is no longer being manufactured and no other estrogen products are approved for use in cattle in the United States. The use of estradiol or estradiol benzoate for synchronization of estrus is not extra-label use, it is illegal. Currently consumer demand for beef is strong, but could easily be damaged over media-inflated fears that consumers have regarding estrogen, cancer, and food safety in general.

Protocols can be grouped into three categories based on amount of heat detection: (1) heat detection and AI for 6 days; (2) heat detection and AI up to the time point prescribed in the schedule, followed by mass insemination of cattle not previously detected in heat (clean-up fixed-timed AI); and (3) a strict fixed-time AI. For mature cows, the strict fixed-time AI will often produce pregnancy rates equal to those involving more heat detection. Studies conducted by one lab in Missouri have shown similar pregnancy rates to AI with use of the MGA-Select system either with AI after observed estrus, 63.6% (234/368) [9–12] or after a single, fixed-timed AI, 64.4% (261/368) [10,13,14]. In GnRH-based systems, pregnancy rates have been higher with CO-Synch (fixed-timed AI) than Select Synch (estrus AI) [15,16] or were similar for anestrous cows, but higher in cycling cows for Select Synch than CO-Synch [17]. That pregnancy rates from systems with 6 days of estrus AI, with good heat detection, do not necessarily exceed single fixed-timed AI systems is a testament to the ability of systems to effectively synchronize ovulation in a majority of cows. Producers are very conscious that more semen is used to get the same number of pregnancies with fixed-timed AI. If heat detection is difficult and the value of AI pregnancies is high, this may be an acceptable trade off. An advantage to AI after observed estrus, or a combination of estrus AI and clean-up fixed-time AI, is that in situations where for whatever reason synchronization response was poor or delayed, the early heat detection provides some assessment of response. If the early response is low, plans for fixed-time AI could be abandoned in favor of estrus AI. Those just starting a synchronization program and lacking confidence may wish to refine management techniques with an estrus AI program before the use of a timed-AI system.

The single injection of $PGF_2\alpha$ protocol does not produce tight synchrony like some of the newer systems and only works on females with a CL, but remains on the list of recommend protocols for heifers because it is a low-cost, low-risk way of getting females bred to AI sires.

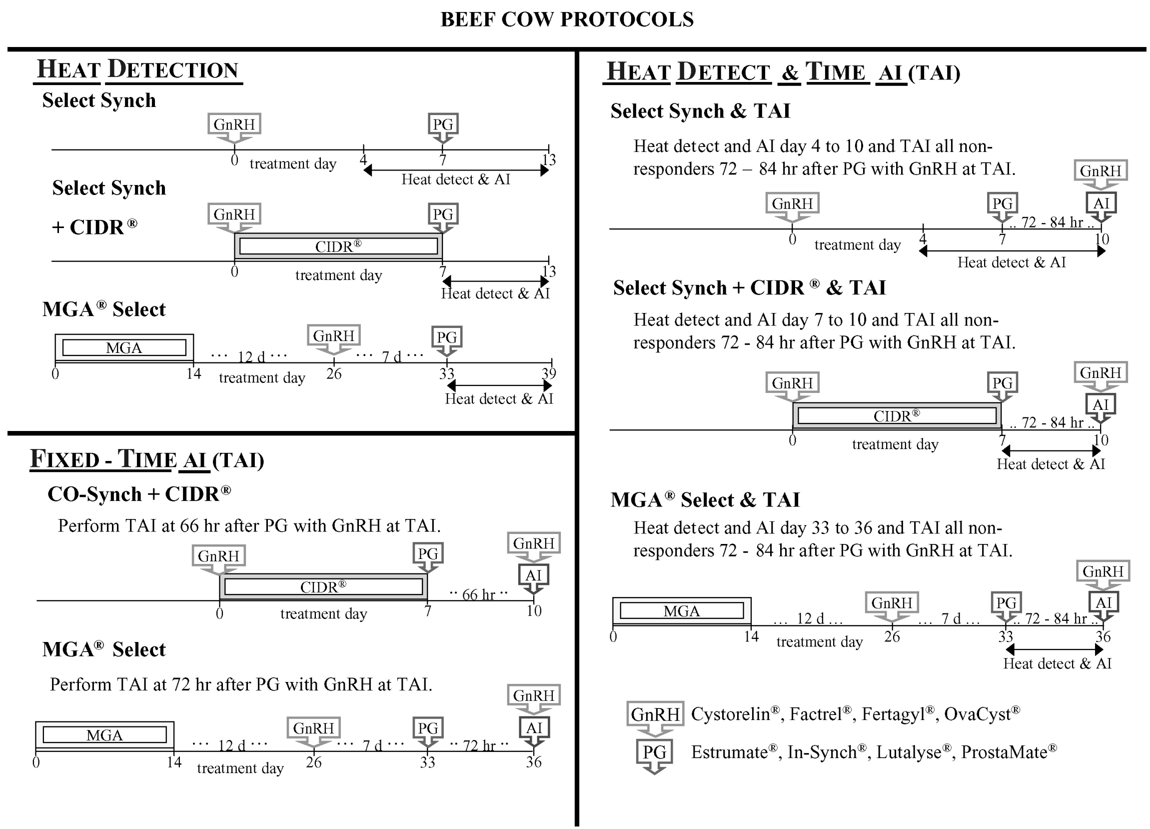

Fig. 1. Recommended protocols for synchronization of estrus and ovulation in cows.

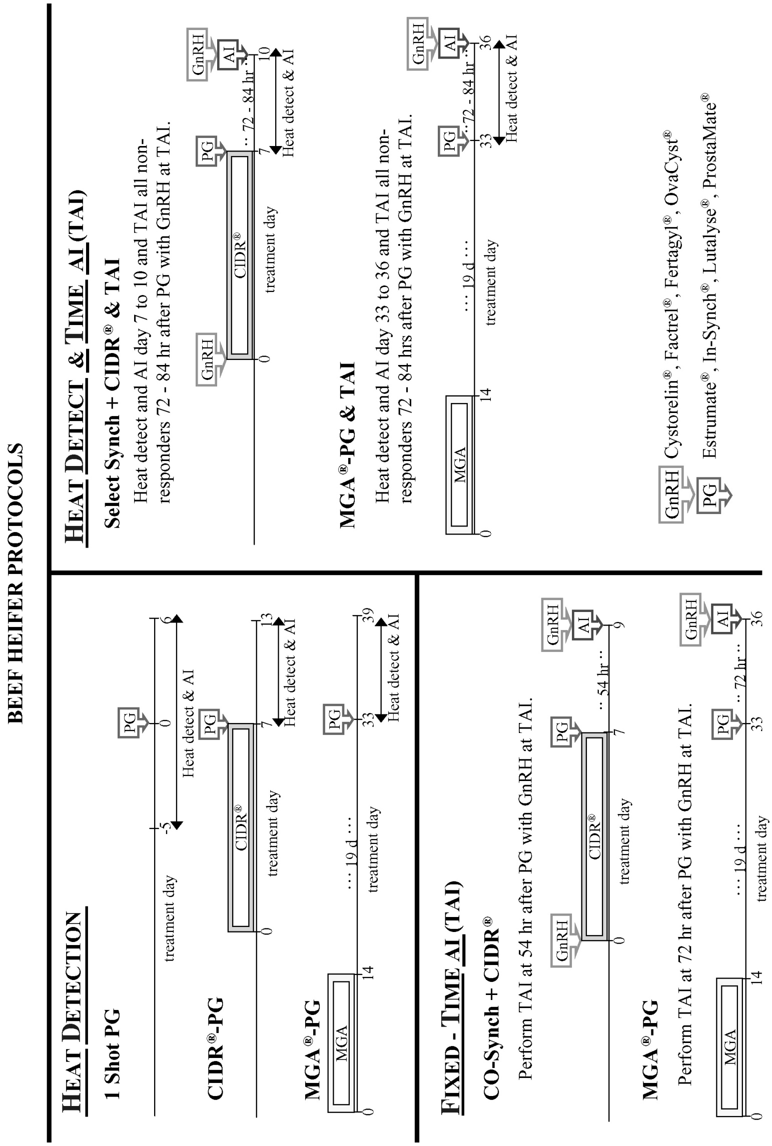

Fig. 2. Recommended protocols for synchronization of estrus and ovulation in heifers.

A summary of some of the published reports involving larger numbers of animals that are associated with the protocols shown in Figs. 1 and 2, are listed in Tables 2 and 3. A review [7] of synchronization systems in 1990 reported pregnancy rates from single or double injections of $PGF_2\alpha$ and 5–9 days of AI averaged 33% (range 17–46%). Pregnancy rates from Syncro-Mate B systems and estrus AI averaged 39% (range 30 to 64%) and for timed AI 45% (range 26 to 62%). Most of the reports in Tables 2 and 3 meet or exceed those reported by Odde [7] and pregnancy rates reported for some average more than 60%. Of summary data from the recommended protocols in cows, only four report pregnancy rates in the 20–30% range and two of the four are from *Bos indicus* cows.

In most breeding situations, a proportion of females are anestrus so most of the recommended systems include a progestin, either MGA or a CIDR. Where there are fewer anestrus animals, protocols without a progestin can be given more consideration. The MGA-Select protocol requires MGA feeding to begin 33 days before the start of the breeding season. Even with a 60-days breeding season, some cows may not have calved at the time this treatment needs to begin. For best results, the herd should average 40–45 days postpartum at the start of MGA feeding. Successful use of MGA also requires each animal receives their daily dose. It will not work in all management situations.

One of the biggest challenges of helping producers apply synchronization systems is to make sure they understand what needs to be done each day. With at least four different $PGF_2\alpha$ products (Estrumate®, In-Synch®, Lutalyse®, and ProstaMate®) and four different GnRH products (Cystorelin®, Factrel®, Fertagyl®, and OvaCyst®) on the market, someone who does not use these terms and products daily can easily get them confused. The large number of systems available and inconsistent nomenclature adds to the confusion. There is an improved tool available to help select a synchronization system and apply it correctly; it is the Estrus Synchronization Planner, Version Synch04, available from the Iowa Beef Center (http://www.iowabeefcenter.org/content/ibcproducts.htm). The CD contains general resource material, details 22 different synchronization systems, estimates costs of treatment and perhaps most importantly, will provide a daily calendar that shows what should happen each day. It is intended to serve as a tool to evaluate different synchronization options, outline strengths and weaknesses, and helps ensure that, whatever system is selected, it is properly applied.

A typical assessment of costs associated with AI usually accounts for synchronization treatment costs, semen and a per-head insemination charge to determine cost per AI pregnancy. Value of AI-sired calves is not considered, nor is any long-term genetic gain from retaining replacements from AI sires; both are substantial economic incentives to use AI. Johnson and Jones [18] have evaluated breeding system costs associated with synchronization of estrus and AI for the first service and natural service for the remainder of the breeding season. If AI-sired calves are valued at US$ 25 per head more than natural service calves (10 day older × 0.91 kg/day heavier at weaning @ US$ 1 per 45.4 kg plus US$ 5 for "genetic value") then there are several synchronization systems that produce pregnancies at a lower cost than exclusively natural service programs (Table 4). If a premium for genetic value is applied to AI-sired calves based on the average premium paid per head in the calf-based alliance yellow pages programs (US$ 40 per day), the synchronization system with the highest costs (CO-Synch + CIDR) produces pregnancies for US$ 0.24 per 45.4 kg less than natural service for a herd size of 100.

Table 2
Summary of pregnancy rates from published reports on recommended systems for synchronizing cows

Reference	Pregnancy rate (n)		
	Select Synch	Select Synch + CIDR®	MGA®-Select
Heat detection[a]			
Geary et al.[35]	68 (56)		
Kojima et al. [36]	47 (45)		
Patterson et al. [11]			70 (56)
Stevenson et al. [17]	38 (289)	42 (289)[b]	
	44 (184)	54 (78)[b]	
Dejarnette et al. [37]	70 (27)		
	52 (77)		
Patterson et al. [9]			65 (103)
Lemaster et al. [16]	21 (197)[c]		
Patterson et al. [10]			67 (100)
Stegner et al. [12]			56 (109)
Total	*40 (875)*	*45 (367)*	*64 (368)*
Heat detection and time AI			
Stevenson et al. [17]	34 (177)	59 (86)[b]	
Dejarnette et al. [38]	44 (45)		
	47 (632)		
Lemaster et al. [16]	36 (200)[c]		
Larson et al. [39]	53 (507)	58 (497)	
Dejarnette et al. [40]	51 (102)[d]		65 (85)[d]
	55 (287)[e]		64 (157)[e]
			54 (70)[d]
			55 (336)[e]
Total	*48 (1950)*	*58 (583)*	*58 (648)*

Reference	CO-Synch + CIDR®[f]		MGA®-Select[f]	
Fixed-time AI				
Johnson et al. [41]	45 (266)	48 h		
Lamb et al. [42]	59 (273)	48 h		
Bader et al. [13]			67 (213)	72 h
Stegner et al. [14]			64 (108)	72 h
Larson et al. [39]	54 (539)	60 h		
Perry et al. [43]			61 (115)	72 h
Martinez et al. [44]	43 (77)	48 h		
Stevenson et al. [45]	66 (95)	48 h	46 (309)	48 h
	51 (92)[b]	48 h		
	55 (291)	48 h		
	44 (178)	48 h		
	48 (181)	60 h		
Kojima et al. [46]	55 (105)	48 h		
Bremer et al. [47]	56 (78)	48 h		
	74 (76)	54 h		
	74 (72)	66 h		

Table 2 (*Continued*)

Reference	CO-Synch + CIDR®[f]		MGA®-Select[f]	
Johnson et al. [48]			43 (180)	72 h
Schafer et al. [49]	66 (323)	66 h	61 (327)	72 h
Total	*56 (2380)*		*56 (1252)*	

[a] 5–6 Days of AI following observed estrus.
[b] Norgestomet.
[c] Bos Indicus.
[d] Primiparous.
[e] Multiparous.
[f] Interval from $PGF_2\alpha$ to TAI.

More difficult to estimate is the value of incorporating genetics available via AI into the herd as replacements. Baker et al. [19] estimated the net present value of semen from bulls available from the major AI studs in 2003. The net present value of semen is the difference between the value of the discounted net income earnings from genetic improvement and the cost of the semen. In one scenario, net present value was determined for a multi-generation planning horizon, with a portion of the AI-sired heifer calves kept as replacements and the remaining calves sold at weaning. Averaged across all breeds and sires, the net present value was US$ 3.23 and the top 20 bulls averaged US$ 22.51. It is clear that a producer using one of the top 20 AI sires can benefit from substantial genetic and economic improvement.

Pregnancy rates achieved in response to synchronization programs will reflect the many aspects of management. Many of the illustrated results come from research performed on commercial herds; therefore, operations with above-average management could achieve similar results. Producers should use their own costs and marketing plans to determine the potential value received from the use of estrous synchronization and AI.

4. Interactions with other management practices

The result of a successful synchronization program is that all females have an opportunity to become pregnant on the first day of the breeding season. Theoretically, all females would have three opportunities to conceive by the end of a 45-days breeding season, given an average estrous cycle length of 21 days. More than 60 days are required without synchronization.

Moderate breeding-season lengths (60–70 days) have been suggested [20–22]. However, others [23,24] indicated that the optimal length depended on conception rates at first service. When conception rates were high (70–80%) there was little difference in net income due to breeding season length. A breeding season of 45 days or less ensures all cows have a high probability of pregnancy at the beginning of the breeding season [25]. An example of reproductive performance in one herd (multiparous cows; research herd at the Agricultural Research Center – Hays; ARCH) over a 5-year period is shown in Table 5 and Fig. 3. Each year, this group of cows was used for research projects pertaining to synchronization of estrus, which may have moderated pregnancy rates, because not all

Table 3
Summary of pregnancy rates from published reports on recommended systems for synchronizing heifers

Reference	Pregnancy rate (*n*)	
	CIDR®-PG	MGA®-PG
Heat detection[a]		
Deutscher [50]		57 (119)
		61 (686)
Lucy et al. [51]	45 (121)[b,c]	
	28 (105)[c,d]	
	49 (116)[c,e]	
Richardson et al. [52]	41 (64)	
	59 (83)[b]	
Dejarnette et al. [40]		44 (75)
Salverson et al. [53]		49 (181)
		40 (96)
		71 (209)
		66 (216)
Johnson and Day [54]		63 (253)
		64 (401)
Lamb et al. [55]		56 (301)
Larson et al. [56]	45 (517)[c]	
Total	*44 (1006)*	*60 (2537)*

Reference	Select Synch + CIDR® and TAI	MGA®-PG and TAI
Heat detect and time AI		
Larson et al. [57]		48 (634)[f]
Salverson et al. [53]		58 (292)
Johnson and Day [54]		64 (460)
Larson et al. [56]	57 (504)	
Total	*57 (504)*	*55 (1386)*

Reference	CO-Synch + CIDR®[g]		MGA®-PG[g]	
Fixed-time AI				
King et al. [58]			41 (116)	72[f] h
Larson et al. [57]			36 (289)	72[f] h
Kojima et al. [59]			49 (88)	72 h
Martinez et al. [60]	65 (103)	48 h		
Martinez et al. [44]	68 (25)	48 h		
Johnson and Day [54]			47 (158)	60 h
Larson et al. [57]	53 (531)	56 h		
Total	*56 (659)*		*42 (651)*	

[a] 5–6 Days of AI following observed estrus.
[b] Dairy heifers.
[c] Estrus AI for 3 days only.
[d] Prepubertal.
[e] Cyclic.
[f] Interval between last MGA feeding and $PGF_{2}\alpha$ of 17 days.
[g] Interval from $PGF_{2}\alpha$ to TAI.

Table 4
Breeding system costs and 227 kg equivalent weaned calf breeding cost per 45.4 kg

System[a]	Days worked	Preg. rate (%)	Total labor hours			No.of bulls[b]			Cost (US$) per pregnancy			227 kg Equivalent weaned calf breeding cost (US$) per 45.4 kg[c]					
			Herd size														
			30	100	300	30	100	300	30	100	300	30	Diff[d]	100	Diff[d]	300	Diff[d]
Natural Service						2	4	12	58	35	35	**13.27**	–	**8.01**	–	**8.01**	–
MGA + PGF	6	50	37	67	116	1	2	6	62	41	37	11.61	1.65	6.83	1.17	5.93	2.08
MGA Select	7	50	40	72	125	1	2	6	66	45	41	12.67	0.60	7.79	0.22	6.84	1.17
Select Synch	9	50	45	82	142	1	2	6	68	46	41	12.94	0.33	7.88	0.13	6.83	1.17
7–11 Synch	8	50	42	77	133	1	2	6	70	48	44	13.47	(0.21)	8.50	(0.49)	7.50	0.51
CO-Synch	3	50	26	47	82	1	2	6	70	51	47	13.43	(0.17)	9.02	(1.01)	8.30	(0.29)
MGA-Select–TAI	3	50	26	47	82	1	2	6	70	51	48	13.56	(0.30)	9.15	(1.14)	8.43	(0.43)
CIDR + PGF	7	50	40	72	125	1	2	6	73	51	47	14.06	(0.79)	9.18	(1.17)	8.22	(0.22)
Select Synch & TAI[e]	7	50	40	72	125	1	2	6	73	52	47	14.13	(0.86)	9.24	(1.24)	8.12	(0.12)
Select Synch + CIDR	7	50	40	72	125	1	2	6	76	55	51	14.90	(1.63)	10.01	(2.01)	9.06	(1.06)
CO-Synch + CIDR	3	50	26	47	82	1	2	5	80	61	55	15.79	(2.52)	11.37	(3.36)	9.99	(1.98)

[a] Descriptions of these systems are shown in Fig. 1.
[b] Costs: bull purchase price US$ 2300, annual bull cost US$ 952, semen US$ 14/unit, $PGF_2\alpha$ US$ 2.54/dose, GnRH US$ 3.21/dose, CIDR US$9.02.
[c] 500 lb Equivalent weaned calf breeding cost (US$) per hundred.
[d] Diff = difference between natural service and breeding system, US$ per 45.4 kg.
[e] Assumes 40% of cows bred based on observed estrus (no GnRH at AI).

Table 5
Characteristics of calving and breeding seasons for multiparious cows in a single herd with five consecutive years of synchronization and AI

Year	n	Calving season duration (days)[a]	Calved by 42nd day (%)	Proportion >40 DPP[b] At AI (%)	Average PPI[c] At AI (days)	Type of AI[d]	AI preg rate[d]	Breeding season duration (days)	Final preg. rate (%)
1999	240	98	77.5[e]	89.2	59	TAI	45	71	97
2000	262	87	77.6[e]	93	73	EAI	39.2	70	95.4
2001	214	80	78.1	85.5	60	TAI	48.1	51	93.9
2002	154	71	85	98.3	75	TAI	53.9	46	94.8
2003	162	69	87.6[f]	93.2	70	TAI	55.1	53	96.3

[a] No AI during 1998.
[b] DPP = days postpartum.
[c] PPI = postpartum interval-average of days from calving to AI.
[d] TAI = single fixed-timed AI; EAI = 5 days of heat detection and AI following observed estrus.
[e,f] Proportions differ ($P < 0.05$).

treatments were expected to be equal. In addition, to accurately determine AI pregnancy rates, clean-up bulls were not turned in until 10 days after AI, which most likely delayed conception in a percentage of the cows. Fig. 3 shows a gradual increase in the cumulative proportion of cows calving in the first 3 weeks of the calving season. By 2003, more ($P < 0.05$) cows had calved by the 42nd day of the calving season compared to 1999. No synchronization was used in 1998.

Cows that calve early in the calving season have more time to reinitiate cyclicity before the breeding season begins, and predictably a higher proportion are cycling at the start of the breeding season (Fig. 4) and their conception rates are higher [17,26]. Shortening the breeding period to 50 days means that the last cow to calve will theoretically be at least 30 days postpartum at the start of the breeding season and the majority will be more than 45 days postpartum. This puts a majority of the cows beyond the effects of uterine involution, short estrous cycles, and the major effects of anestrus if the cows are in good body condition [25]. The breeding season of the ARCH herd was shortened from 70 to 50 days with no measurable change in final pregnancy rate, given an existing high pregnancy rate. As a general rule, reductions in breeding-season lengths should be made gradually.

Other benefits from a shorter breeding period include a shorter range in gestation lengths. This should reduce the number of days late-calving cows have precalving nutrition increased before they really need it and that early calving cows do not have the increase when they do need it. Body condition score tended to be higher for spring-calving cows calving late in the calving season [26], which may reflect increased time on higher-energy diets. Regardless of breeding method, a long breeding period makes targeting nutrition for cows more difficult, resulting in either increased feed costs or reduced performance. Synchronization can be used to tighten the breeding period, better target nutritional changes, and maintain reproductive performance.

Calves born as the result of a synchronized breeding were 10 days older and 70 lbs heavier than calves born after a non-synchronized breeding [27]. In another report [20], a 30-day breeding season alone did not increase weaning weights compared to a 70-day breeding season. However the single injection of $PGF_2\alpha$ system did not induce any non-

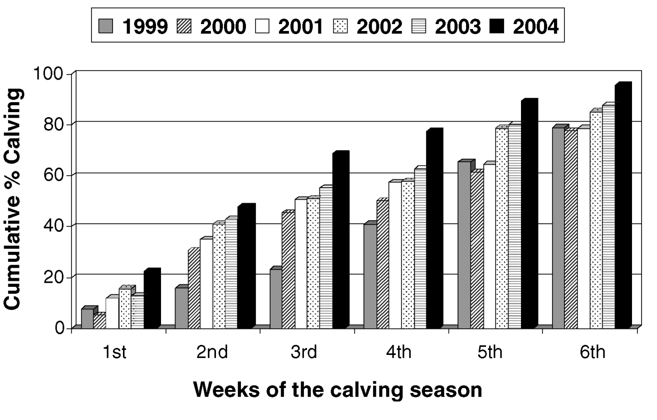

Fig. 3. Calving distribution for the same multiparous herd over five calving seasons. Estrus was not synchronized in 1998, single fixed-timed AI each following year except 2000 which was 5 days of estrus AI.

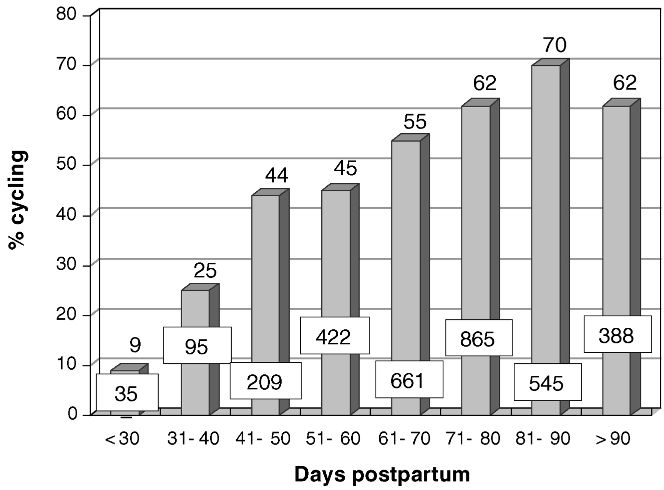

Fig. 4. Percentage of cows that had resumed estrous cycles before initiation of treatments regressed on days postpartum at the beginning of the breeding season. Values in boxes are numbers of cows per category. From Stevenson et al. [26].

cycling cows to cycle, and the AI period was extended 10 days. In a separate ARCH herd, 105 cows were bred by fixed-timed AI to a single sire for four consecutive years. The AI sire and two half siblings were used for natural service. The average weaning weight by week born for the AI sired calves was 248, 243 and 239 kg. Calves born the first week were heavier ($P < 0.05$) than calves born the 4th week. Overall, AI-sired calves were heavier than natural-service-sired calves (235 versus 227 kg, respectively).

To estimate the effect of calving distribution on average weaning weight, the proportion of cows calving each week was multiplied by the weaning weight corresponding to that week and summed to get a calving distribution adjusted weaning weight (Fig. 5). More, older and heavier calves gradually increased the average weaning weight each successive year. While there will still be variation in calf weights, the reduction in age variation should help improve uniformity and marketability.

Pregnant females bred to AI-sires or calves from AI sires can be accurately marketed as such when pregnancy is confirmed with early ultrasound. Detection of embryonic vesicles has been reported as early as 9 days of gestation [28], but is not practical before 25 days of gestation, because it is less accurate and requires more time to verify at this early stage [29]. By 26–30 days, the determination can be made very rapidly and accurately for an experienced technician. If pregnancy determination via ultrasound is used 26–30 days after bulls are removed in a 50-day breeding season, AI-sired calves could be fetal sexed (60–80 days) and a pregnancy diagnosis could be made on all cows. In the future, other tests may be practical for early pregnancy diagnosis [30].

The basic technology to produce sexed semen has been developed and has many applications in the beef industry [31,32]. Replacement heifers could be produced from select cows and sires that meet the specifications for the maternal herd. The remainder of the herd could be bred to terminal sires that excel at growth and feed efficiency and meet the necessary carcass requirements. The process of making this technology widely

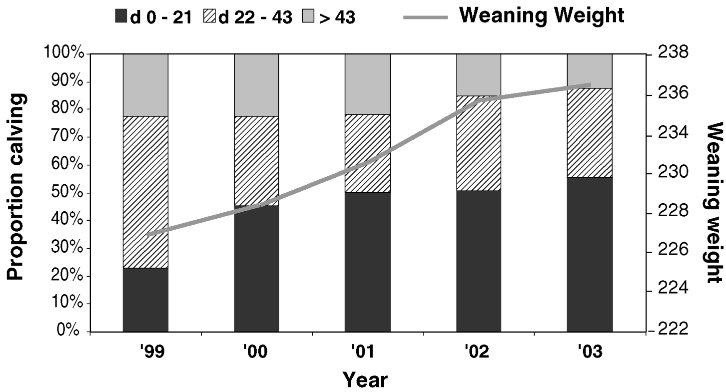

Fig. 5. Proportion of calves born during the first 21 days, the second 21 days, or later in the same herd from 1999 to 2003. Average weaning weight (unadjusted) was determined by calving week over a 4-year period in a companion herd using a single AI sire at a fixed-time AI. Weaning weight shown reflects the calving distribution (Fig. 3) weighted average weaning weight.

available for use by commercial producers seems agonizingly slow, but hopefully it will become available in the future.

Since synchronization and AI will require a minimum of two handlings and often three, producers will strive to combine those activities with other activities that require cows to pass through the chute. Combining prebreeding vaccinations with synchronization treatments is not recommended. Modified live vaccines for BVD and IBR given to females prebreeding can reduce fertility from oophoritis and damage to the CL [33]. A practitioner working with a client on a new synchronization program should consider reviewing the herd's vaccination program and making any necessary changes to prevent problems. Refinements to the vaccination program could provide benefits beyond cow reproduction.

Compared to the hours dedicated to study of the control of the estrous cycle, relatively little has been done on the male side. While differences in male fertility are known to exist, less is known about the relationship of timing of insemination and fertility as it relates to individual male/inseminate differences [34]. As more work is done in the area, it is conceivable the existing systems may be capable of producing higher results from specific sires. An established AI program will be able to take advantage of advances in male fertility as they become available.

5. Summary

In the past, a strict commodity marketing system where groups of calves were sold on averages made it difficult for producers to get paid for investments in genetics. Today, there are a number of avenues available for producers who want to share in the value of the high-quality cattle they produce. The information to aid selection decisions is growing and will continue, perhaps even more rapidly than in the past. Through the use of AI, the average producer has access to a wide range of high-accuracy sires that can be selected to match production goals. Systems to synchronize estrus and ovulation are capable of producing pregnancy rates to a single fixed-timed AI of 60% or greater. Synchronization of estrus and AI do require more planning and management; however, there are many opportunities to increase profitability from increased weaning weights, more uniformity in the cowherd and the calf crop, and marketing targeted genetics. As commercial producers recognize these changes, they will benefit from the assistance of a knowledgeable professional to successfully incorporate these practices into their herds.

References

[1] Alliance Yellow Pages. Beef Magazine. August 2004. Accessed Jan 4, 2005 http://beef-mag.com/mag/2004-alliance/.

[2] Suther S. CAB at 25. Angus Journal. November 2003: 98. Accessed Jan 8, 2005 http://www.angusjournal.com/ArticlePDF/ACF5606.pdf.

[3] National Pedigreed Livestock Council. Registrations NPLC Beef Breed 65–99. Accessed Jan 11, 2005 http://www.nplc.net/history.html.

[4] Certified Beef Programs. 2004. Accessed Jan 10, 2005 http://www.ams.usda.gov/lsg/certprog/certbeef.htm.

[5] Suther S. What's ''High Quality'' Worth? Angus Beef Bulletin. January 2000. Accessed Jan 8, 2005 http://www.angusbeefbulletin.com/ArticlePDF/01abb_highquality.pdf.

[6] Hansel W, Beal WE. Ovulation control in cattle. In: Hawk HW (Ed.). Anim Reprod, BARC Beltsville Symp Agr Res, Symposium 3. Allanheld, Osmun & Co., Montclair, NJ, 1979. pp. 91–110.

[7] Odde KG. A review of synchronization of estrus in postpartum cattle. J Anim Sci 1990;68:817–30.

[8] Patterson DJ, Kojima FN, Smith MF. A review of methods to synchronize estrus in replacement beef heifers and postpartum cows. J Anim Sci 2003;81(E. Suppl 2):E166–77.

[9] Patterson DJ, Bader JF, Graham KK, Kojima FN, Perry GA, Kerley MS, et al. Addition of GnRH to a melengestrol acetate (MGA)-prostaglandin $F_2\alpha$ (PG) estrus synchronization protocol in postpartum beef cows. J Anim Sci 2001;79(Suppl 1):250.

[10] Patterson DJ, Stegner JE, Kojima FN, Smith MF. MGA Select improves estrus response in postpartum beef cows in situations accompanied with high rates of anestrus. Proc West Sec Anim Soc Anim Sci 2002;53:418–20.

[11] Patterson DJ, Wood SL, Kojima FN, Smith MF. Improved synchronization of estrus with a progestin-GnRH-prostaglandin $F_2\alpha$ (PG) protocol. J Anim Sci 2000;78(Suppl 1):218.

[12] Stegner JE, Kojima FN, Ellersieck MR, Lucy MC, Smith MF, Patterson DJ. A comparison of progestin-based protocols to synchronize estrus in postpartum beef cows. J Anim Sci 2004;82:1016–21.

[13] Bader JF, Kojima FN, Schafer SJ, Stegner JE, Ellersieck MR, Smith MF, et al. A comparison of progestin-based protocols to synchronize ovulation and facilitate fixed-time artificial insemination in postpartum beef cows. J Anim Sci 2005;83:36–143.

[14] Stegner JE, Bader JF, Kojima FN, Ellersieck MR, Smith MF, Patterson DJ. Fixed-time artificial insemination of postpartum beef cows at 72 or 80 h after treatment wit the MGA Select protocol. Theriogenology 2004;61:1299–305.

[15] Grieger DM, Lamb GC, Rozell TG, Thompson KE, Stevenson JS. Site of semen deposition and fertility in beef cows inseminated according to estrus or at a fixed time after synchronization with GnRH-$PGF_2\alpha$. J Anim Sci 1998;76(Suppl. 1):279.

[16] Lemaster JW, Yelich JV, Kempfer JR, Fullenwider JK, Barnett CL, Fanning MD, et al. Effectiveness of GnRH plus prostaglandin $F_2\alpha$ for estrus synchronization in cattle of *Bos indicus* breeding. J Anim Sci 2001;79:309–16.

[17] Stevenson JS, Thompson KE, Forbes WL, Lamb GC, Grieger DM, Corah LR. Synchronizing estrus and(or) ovulation in beef cows after combinations of GnRH, norgestomet, and prostaglandin $F_2\alpha$ with or without timed inseminations. J Anim Sci 2000;78:1747–58.

[18] Johnson SK, Jones RD. Costs and comparisons of estrous synchronization systems. In: Johnson SK, editor. Proceedings: Applied Reproductive Strategies in Beef Cattle, North Platte, NE, September 5–6, 2004. p. 103–15.

[19] Baker DA, Shumway CR, Gaskins CT, Linton AC. Selecting AI beef sires for maximum profit. Prof Anim Sci 2004;20:336–43.

[20] Deutscher GH, Stotts JA, Nielsen MK. Effects of breeding season length and calving season on range beef cow productivitiy. J Anim Sci 1991;69:3453–60.

[21] Dziuk PJ, Bellows RA. Managment of reproduction in beef cattle, sheep and pigs. J Anim Sci 1983;57(Suppl 2):355–79.

[22] Werth LA, Azzam SM, Nielsen MK, Kinder JE. Use of a simulation model to evaluate the influence of reproductive performance and management decisions on net income in beef production. J Anim Sci 1991;69:4710–21.

[23] Fiske DA. Economic consequences of alternative reproductive management practices for beef cow herds in Nebraska [thesis]. Lincoln: University of Nebraska; 1987.

[24] Pritchard SM. Simulated economic efficiency of beef production for different breeding season lengths [thesis]. Lincoln: University of Nebraksa; 1987.

[25] Short RE, Bellows RA, Staigmiller RB, Berardinelli JG, Custer EE. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. J Anim Sci 1990;68:799–816.

[26] Stevenson JS, Johnson SK, Milliken GA. Incidence of postpartum anestrus in suckled beef cattle: Treatments to induce estrus, ovulation, and conception. Prof Anim Sci 2003;19:124–34.

[27] Anderson L, Deaton P. Economics of estrus synchronization and artificial insemination. In: National Association of Animal Breeders Reproduction Symposium, Lexington, KY; 2003, http://www.beefimprovement.org/03proceedings/Anderson.pdf.

[28] Boyd JS, Omran SN, Ayliffe TR. Use of a high frequency transducer with real time B-mode ultrasound scanning to identify early pregnancy in cows. Vet Rec 1988;123:8–11.

[29] Fricke PM, Lamb GC. Practical applications of ultrasound for reproductive management of beef and dairy cattle. In: Johnson SK, editor. Proceedings: Applied Reproductive Strategies in Beef Cattle, Manhattan, KS, September 5–6, 2002. p. 228–45.

[30] Youngquist RS. Emerging Technologies in Bovine Pregnancy Diagnosis. Society for Theriogenology Annual Conference, Columbus, OH, 2003. p. 162–71.

[31] Hohenboken WD. Applications of Sexed Semen in Cattle Production. Theriogenology 1999;52:1421–33.

[32] Seidel GE, Schenk JL, Herickhoff LA, Doyle SP, Brink Z, Green RD, et al. Insemination of heifers with sexed sperm. Theriogenology 1999;52:1407–20.

[33] Randle RF. Timing of vaccinations in estrous synchronization programs. In: Funston RN, Meyer TL, editors. Proceedings: Applied Reproductive Strategies in Beef Cattle, North Platte, NE, September 1–2, 2004. p. 100–1.

[34] Saacke RG. Insemination related factors affecting fertilization in estrous-synchronized cattle. In: Funston RN, Meyer TL, editors. Proceedings: Applied Reproductive Strategies in Beef Cattle, North Platte, NE, September 1–2, 2004. p. 173–83.

[35] Geary TW, Whittier JC. Effects of a timed insemination following synchronization of ovulation using the Ovsynch or CO-Synch protocol in beef cows. Prof Anim Sci 1998;14:217–20.

[36] Kojima FN, Salfen BE, Bader JF, Ricke WA, Lucy MC, Smith MF, et al. Development of an estrus synchronization protocol for beef cattle with short-term feeding of melengestrol acetate: 7–11 Synch. J Anim Sci 2000;78:2186–91.

[37] DeJarnette JM, Wallace RW, House RB, Salverson RR, Marshall CE. Attenuation of premature estrous behavior in postpartum beef cows synchronzied to estrus using GnRH and $PGF_2\alpha$. Theriogenology 2001;56:493–501.

[38] Dejarnette JM, Day ML, House RB, Wallace RA, Marshall CE. Effect of GnRH pretreatment on reproductive performance of postpartum suckled beef cows following synchronization of estrus using GnRH and PG $F_2\alpha$. J Anim Sci 2001;79:1675–82.

[39] Larson JE, Lamb GC, Stevenson JS, Johnson SK, Day ML, Geary TW, et al. Synchronization of estrus in suckled beef cows using GnRH, prostaglandin $F_2\alpha$ (PG), and progesterone (CIDR): a multi-location study. J Anim Sci 2004;82(Suppl. 1):368–9.

[40] DeJarnette JM, House RB, Ayars WH, Wallace RA, Marshall CE. Synchronization of estrus in postpartum beef cows and virgin heifers using combinations of melengestrol acetate, GnRH and $PGF_2\alpha$. J Anim Sci 2004;82:867–77.

[41] Johnson SK, Grum DE, Day ML. Addition of GnRH or an intravaginal progesterone insert to a GnRH-PGF synchronization system to enhance response to timed breeding in postpartum beef cows. J Anim Sci 2000;78(Suppl. 1):218.
[42] 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 2001;79:2253–9.
[43] Perry GA, Smith MF, Patterson DJ. Evaluation of a fixed-time artificial insemination protocol for postpartum suckled beef cows. J Anim Sci 2002;80:3060–4.
[44] Martínez MF, Kastelic JP, Adams GP, Cook B, Olson WO, Mapletoft RJ. The use of progestins in regimens for fixed-time artificial insemination in beef cattle. Theriogenology 2002;57:1049–59.
[45] Stevenson JS, Lamb GC, Johnson SK, Medina-Britos MA, Grieger DM, Harmoney KR, et al. Supplemental norgestomet, progesterone, and MGA increases pregnancy rates in suckled beef cows after timed inseminations. J Anim Sci 2003;81:571–86.
[46] Kojima FN, Stegner JE, Bader JF, Schafer DJ, Eakins RL, Smith MF, et al. A comparison of two fixed-time AI programs for postpartum beef cows. J Anim Sci 2003;81(Suppl 1):50.
[47] Bremer VR, Damiana SM, Ireland FA, Faulkner DB, Kesler DJ. Optimizing the interval from PGF to timed AI in the CO-Synch + CIDR and 7–11 Synch estrus synchronization protocols for postpartum beef cows. J Anim Sci 2004;82(Suppl. 2):106.
[48] Johnson SK, Harmoney KR, Stevenson JS. Addition of ECP or calf removal to a modified MGA + CO-Synch protocol for synchronization of ovulation in beef cows. J Anim Sci 2004;82(Suppl. 1):372.
[49] Schafer D, Bader J, Meyer J, Smith M, Patterson D. A Comparison of Two Progestin-Based Protocols to Synchronize Estrus Prior to Fixed-Time AI in Postpartum Beef Cows, Field Day Report: University of Missouri; 2004. http://aes.missouri.edu/greenley/fieldday/report.stm.
[50] Deutscher GH. Extending interval from seventeen to nineteen days in the melengestrol acetate-prostaglandin estrous synchronization program for heifers. Prof Anim Sci 2000;16:164–8.
[51] Lucy MC, Billings HJ, Butler WR, Ehnes LR, Fields MJ, Kesler DJ, et al. Efficacy of intravaginal progesterone insert and injection of PGF:Synchronizing estrus and shortening the interval to pregnancy in postpartum beef cows, peripubertal beef heifers and dairy heifers. J Anim Sci 2001;79:982–95.
[52] Richardson AM, Hensley BA, Marple TJ, Johnson SK, Stevenson JS. Characteristics of estrus before and after first insemination and fertility of heifers after synchronized estrus using GnRH, PGF and progesterone. J Anim Sci 2002;80:2792–800.
[53] Salverson RR, Dejarnette JM, Marshall CE, Wallace RA. Synchronization of estrus in virgin beef heifers using melengesterol acetate and $PGF_2\alpha$: an efficacy comparison of cloprostenol and dinoprost tromethamine. Theriogenology 2002;57:853–8.
[54] Johnson SK, Day ML. Methods to reduce or eliminate detection of estrus in a melengesterol acetate-PGF protocol for synchronization of estrus in beef heifers. J Anim Sci 2004;82:3071–6.
[55] Lamb GC, Cartmill JA, Stevenson JS. Effectiveness of Select Synch (gonadotropin-releasing hormone and prostaglandin $F_2\alpha$) for synchronizing estrus in replacement beef heifers. Prof Anim Sci 2004;20:27–33.
[56] Larson JE, Lamb GC, Geary TW, Stevenson JS, Johnson SK, Day ML, et al. Synchronization of estrus in replacement beef heifers using GnRH, prostaglandin $F_2\alpha$ (PG), and progesterone (CIDR): a multi-location study. J Anim Sci 2004;82(Suppl 1):369.
[57] Larson RL, Corah LR, Peters CW. Synchronization of estrus in yearling beef heifers with the melengestrol acetate/prostaglandin $F_2\alpha$ system: Efficiency of timed insemination 72 h after prostaglandin treatment. Theriogenology 1996;45:851–63.
[58] King ME, Daniel MJ, Teague LD, Schutz DN, Odde KG. Comparison of timed insemination with insemination at estrus following synchronization of estrus with a MGA-prostaglandin system in beef heifers. Theriogenology 1994;42:79–88.
[59] Kojima FN, Smith MF, Kerley MS, Graham KK, Patterson DJ. A comparison of fixed-time insemination protocols for replacement beef heifers. J Anim Sci 2001;79(Suppl. 2):88.
[60] Martinez MF, Kastelic JP, Adams GP, Mapletoft RJ. The use of a progesterone-releasing device (CIDR) or melengestrol acetate with GnRH, LH or estradiol benzoate for fixed-time AI in beef heifers. J Anim Sci 2002;80:1746–51.