Anim Reprod, v.9, n.3, p.370-387, Jul./Sept. 2012

Economic aspects of applying reproductive technologies to dairy herds

E.S. Ribeiro[1], K.N. Galvão[2], W.W. Thatcher[1], J.E.P. Santos[1,3]

[1]Department of Animal Sciences, University of Florida, Gainesville, FL, USA.
[2]Department of Large Animal Clinical Sciences, University of Florida, Gainesville, FL, USA.

Abstract

Reproduction continues to be a critical component to maintain a dairy farm economically viable. For every farm and for every cow, there is an optimum time for pregnancy, which is mostly influenced by level of production, persistency of lactation, and parity. In general, as production decreases, lactation number increases, and persistency of lactation decreases, cows should be bred sooner postpartum and pregnancy obtained early in lactation. The voluntary waiting period is determined based on the desired interval postpartum to pregnancy and the pregnancy rate of the farm. As pregnancy rates increase, the voluntary waiting period can be delayed, particularly when milk production is high. Studies in the literature have compared several breeding strategies to obtain a pregnant cow. In general, pregnancies obtained by artificial insemination are cheaper than those originated by natural service. The major reason is that AI programs result in similar or better reproductive performance and are cheaper to implement than natural service programs because of the high costs of acquiring and feeding bulls. Within the AI program, those that incorporate timed AI for first insemination followed by detection of estrus result in lowest median days open and more profit per cow, and the benefits of improving reproduction are greater when milk prices are low. The use of embryo technologies as a breeding program for lactating dairy cows, with the aim to improve reproductive performance, is only attractive when the differential in fertility relative to AI is large. In most cases, AI programs have to result in very poor fertility (<15%) for the typical results from embryo transfer (40-45% pregnancy) to be economically attractive at current costs. For dairy heifers, there is little justification to incorporate timed AI programs when detection of estrus is excellent, above 70%; however, for farms with detection of estrus below 60%, either timed AI for first AI followed by detection of estrus or timed AI alone improve reproductive performance and reduce the cost per pregnancy.

Keywords: dairy cow, economics, embryo transfer, reproduction.

Introduction

As any other business enterprise, the sustainability of a dairy farm is highly dependent on economics. There is a constant need to maximize outputs and, oftentimes, to minimize inputs, in order to obtain a profitable return on assets. In a conventional dairy farm, most of the cash receipts (~88%) come from sales of milk, and a smaller portion (~12%) results from sales of animals, including those destined for dairy production (Santos *et al*., 2010). On the other hand, feed cost of lactating dairy cows accounts for 48 to 50% of total cost of production, whereas rearing replacements accounts for almost 23% of the cost of producing milk. Reproduction influences both, milk production and number of replacement heifers available on a farm. Therefore, reproductive efficiency becomes one of the key components to optimize the economic success of dairy herds.

The goal of this review article is to evaluate the importance of reproduction to the economy of a dairy farm and evaluate the use of different breeding strategies and reproductive technologies to achieve a pregnancy in lactating dairy cows and replacement heifers in an economic manner.

The importance of reproduction to the economy of the dairy farm

Reproduction can have a multitude of impacts on a farm, from altering culling policies, increasing retention of better replacements, moving primiparous cows into a more productive 2nd lactation, and improving milk production. Because production accounts for more than 88% of the gross income of a dairy farm (Santos *et al*., 2010), it is no surprise that most attention paid to improvements in reproduction evolve around altering milk production during the productive life of cows. In most cases, altering milk production has to be considered per day of calving interval, as improvements in reproduction increase the time a cow spends in the dry period, which is considered a nonproductive stage of the lactation cycle.

Shortening the calving interval reduces the average days in milk of the herd and, consequently, a greater proportion of cows would be in earlier stages of lactation when peak of milk production and greater income over feed cost (IOFC) occurs, whereas a smaller proportion of cows would be in later stages of lactation producing low amounts of milk with low IOFC (Fig. 1). However, shortening the calving interval also results in a greater proportion of the adult herd dry, which imposes limitations to distribution of cows and requires planning on space availability. Improving reproduction oftentimes results in greater availability of replacement animals, which increases herd turnover.

[3]Corresponding author: jepsantos@ufl.edu
Received: July 3, 2012
Accepted: August 15, 2012

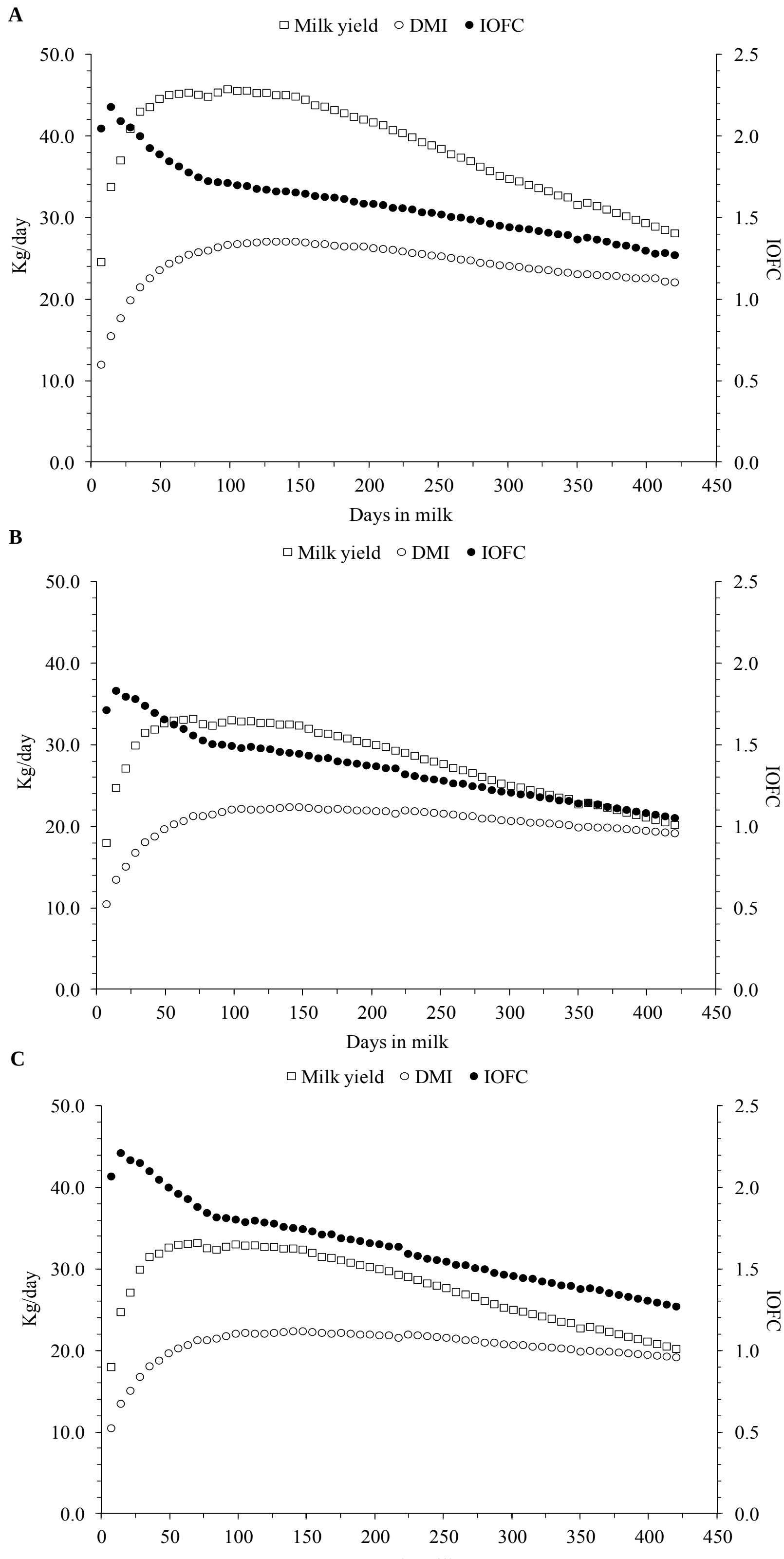


Figure 1. Milk yield (kg/day; □), dry matter intake (DMI, kg/day; ○), and milk income over feed cost (IOFC, $ of income/$ of feed consumed; ●) according to days in milk. Milk price was set at 0.35/kg in all scenarios. Panel A depicts a high-producing herd (12,500 kg/305 days of lactation) with feed price at $0.35/kg of dry matter. Panel B depicts a moderate-producing herd (9,000 kg/305 days of lactation) and feed price at $0.35/kg of dry matter. Panel C depicts a moderate-producing herd (9,000 kg/305 days of lactation) and feed price at $0.29/kg of dry matter.

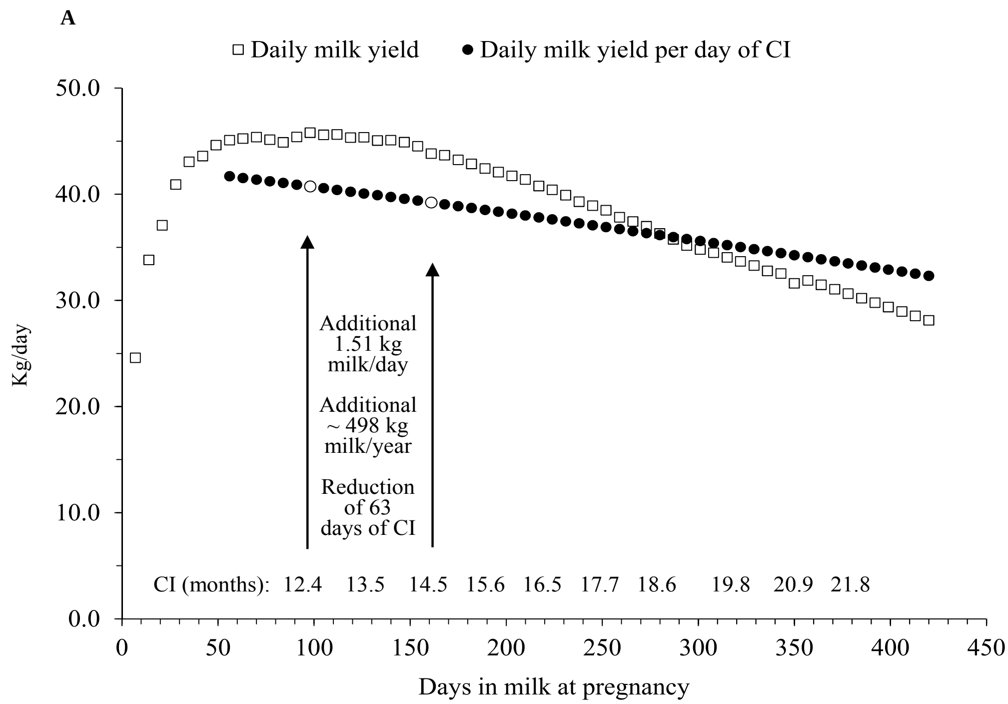
The IOFC reduces as days in milk increases, which seems to be independent of milk production per cow (Fig. 1A and 1B) and scenarios of feed cost per kg of dry matter (Fig. 1B and 1C), except if major changes in lactation persistence occur. It is also clear that in moderate-producing herds, it is difficult to justify expensive rations, particularly when reproduction is poor and more cows are in the later stages of lactation (Fig. 1B). Considering a high-producing herd averaging 12,500 kg of milk/305 days of lactation, reducing the average calving interval by 63 days (from 440 to 377) would represent an increase of 7% in the IOFC and 1.51 kg/cow/day of calving interval or 498 kg of milk/cow/year (Fig. 2A). Considering the same reduction in calving interval in a moderate-producing herd averaging 9,000 kg/cow/305 days of lactation, it would represent an increase of 8% in the IOFC and 1.11 kg of milk/cow/day of calving interval or approximately 366 kg/cow/yr (Fig. 2B). The increment in daily milk production as a result of reducing the calving interval is negatively related with lactation curve persistency. As persistency increases, the benefit to improving reproduction diminishes (DeVries, 2011). Thus, the lower the milk production persistency the higher is the daily milk increment with improvements in reproductive performance.

Culling and replacement policies also have a tremendous impact on profitability of the herd, and both are associated with reproductive efficiency. Improvements in reproduction result in greater flexibility in these policies and allow managers to take programmed decisions based on economic aspects rather than biological considerations (Groenendaal *et al*., 2004). Reproductive inefficiency increases cost per pregnancy, increases retention of low-producing cows because of their pregnancy status, and reduces the number of replacements, which diminishes the gain in genetic merit of the herd. Maintaining the same replacement pressure when reproduction is poor becomes, in many cases, costly and risky as it requires purchase of heifers that may be of lower genetic merit and results in breaks of biosecurity.

Reducing rearing costs of replacement heifers is another important consideration in many farms; however, such a strategy cannot compromise rearing efficiency and future milk production. Optimal growth rates of heifers are critical for future animal performance. In order to maximize lifetime production, Holstein heifers should calve at approximately 23 to 24 months of age with ~85% of adult body weight (Gabler *et al*., 2000; Ettema and Santos, 2004). In order to achieve adequate age and size at first calving, growth rates should ideally allow puberty at 10 to 11 months of age with 40 to 45% of the mature body weight and first breeding at 13 to 14 months of age with 50 to 55% of mature body weight. Heifers calving at younger age (i.e. <22 months) have reduced productive and reproductive performances in the first lactation, whereas those calving at older age (i.e. >25 months) have no improvements in productivity at first lactation (Gabler *et al*., 2000; Ettema and Santos, 2004), with additional days of unproductive life and feed costs. For instance, typical rations fed to pregnant heifers to achieve average daily gains of 0.8 to 0.9 kg in the United States cost today approximately $0.24 to 0.26/kg of dry matter. A typical pregnant heifer at 23 months of age consumes 11 to 13 kg of dry matter per day, resulting in additional feed costs of $2.50 to $3.00 per day. Such implications will impinge on the attractiveness for use of reproductive strategies such as insemination with sexed semen, which results in more valuable calves, but also reduces pregnancy to artificial insemination (AI; Norman *et al*., 2010) and can extend the age at first calving.

Given a specific type of dairy cow and production system, there is an optimal interval from calving to pregnancy at which profitability is maximized. Cows pregnant beyond this optimal time become economically less attractive. The cost of a day open varies from $0 at the optimal day postpartum at pregnancy to as much as $6.00 according to several factors such as the days postpartum, culling policies, availability of replacement heifers, milk production, persistency, and lactation number (De Vries, 2011). The cost of a day open increases as calving interval increases and has been estimated to average $1.25, $2.10 and $2.75 at 90, 150 and 210 days in milk, respectively (Groenendaal *et al*., 2004). Nonetheless, as days postpartum extends beyond a certain maximum, replacement is economically more desired than breeding the cow and thus the cost of an extra day open becomes $0. This window of time in which breeding a cow is economically attractive varies primarily with milk production, lactation number, and profitability during the late stages of lactation. Typically, this interval is shorter in seasonally calving herds and in low-producing and low lactation persistency cows. Therefore, the cost of a day open is, in general, greater for low- than for high-producing cows, and for multiparous than primiparous cows (De Vries, 2011), because the latter present a flatter, more persistent lactation curve (Groenendaal *et al*., 2004).

Similar trends are also observed for the value of a new pregnancy, which increases as days in milk increases until late stages in lactation when it begins to diminish (De Vries, 2006). The economic explanation is also based on profitability of milk production at late stages of lactation and replacement policies that combined dictate future profits. The value of a new pregnancy is higher for low-producing cows at early stages of lactation but the peak is lower and earlier than that for high-producing cows (De Vries, 2011). The cost of pregnancy loss follows similar patterns and increases as lactation progresses or stage of gestation increases. However, in general, the cost of pregnancy loss is greater for high- than low-producing cows unless it occurs very early in lactation (De Vries, 2006). The average value of a new pregnancy for a Holstein cow in the United States has been estimated at $278, whereas the cost of a pregnancy loss was $555 (De Vries, 2006).



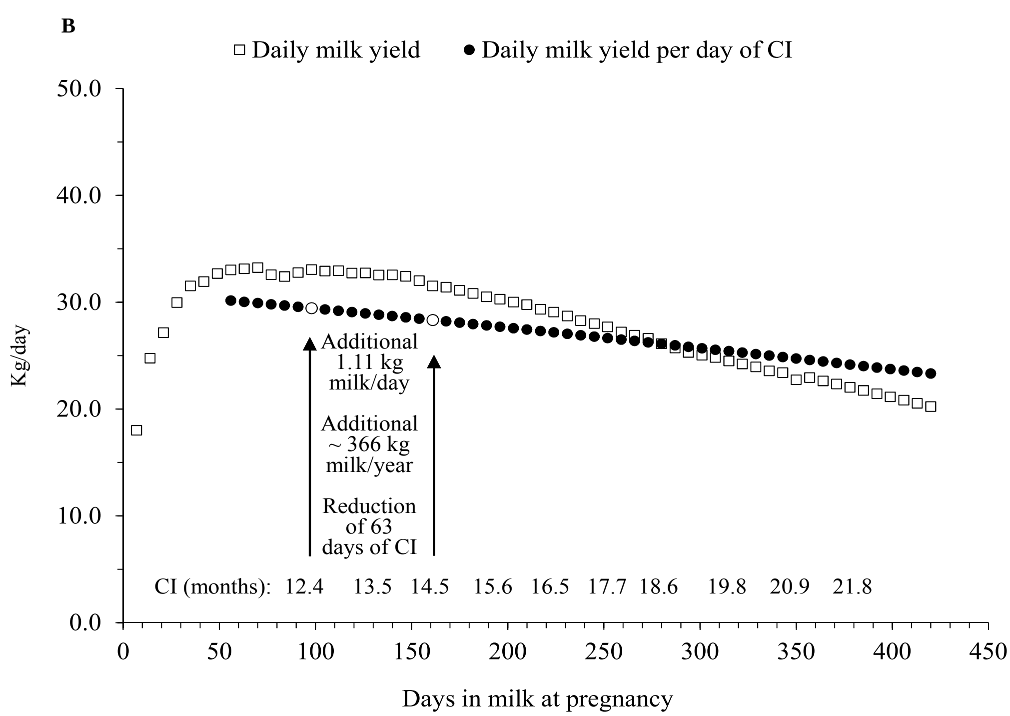


Figure 2. Lactation curve and resulting milk production per day of calving interval (CI) according to days in milk at pregnancy in a high-producing herd (12,500 kg in 305 days of lactation; panel A) and in a moderate-producing herd (9,000 kg of milk in 305 days of lactation; panel B). Reducing the calving interval from 161 to 98 days increases milk production per day of CI by 1.51 and 1.11 kg/day for the high- and moderate-producing herds, respectively.

Economics of reproductive programs for lactating dairy cows

In the past, most dairy herds used reproductive programs that relied solely on observation of estrus and intervention was only implemented in cows with advanced days postpartum and no insemination. Typically, interventions were based on palpation per rectum of the reproductive tract and decisions were made based upon detection of ovarian structures and uterine discharges, focusing on finding the problem cow to "fix" her. Currently, reproductive programs have taken a different approach, in which the main goal is to be proactive and work with groups of cows by the use of systematic breeding programs that allow optimal breeding decisions. Ultimately, the goals are to minimize the variation in the interval from calving to first AI and increase the rate at which eligible cows become pregnant in an optimal timely manner (Santos, 2008).

Four main factors affect reproductive efficiency in dairy herds and are commonly monitored to evaluate reproduction: the voluntary waiting period, insemination rate, pregnancy per AI, and pregnancy loss (Santos, 2008). For insemination rate and pregnancy per AI, only eligible cows to become pregnant are used for calculations, and eligibility is defined as a cow that the producer wants to inseminate, has passed the voluntary waiting period, and is not pregnant. The voluntary waiting period and insemination rate determine the interval postpartum to first AI. Pregnancy per AI is the probability of a cow to become pregnant at a given insemination. Finally, pregnancy loss is defined as the proportion of pregnant cows that have experienced either an embryonic or fetal loss. Because not all cows are inseminated immediately after the end of the voluntary waiting period, and not all inseminated cows become pregnant, a more comprehensive measure of reproduction is often used, pregnancy rate. The latter is the ultimate measure of reproductive efficiency as it comprises both insemination rate and pregnancy per AI, and determines the interval from the end of the voluntary waiting period to pregnancy. Pregnancy rate is a true rate, which changes daily, although it is measured on individual cows or on a herd basis every 21 days.

Voluntary waiting period

The voluntary waiting period is the standard postpartum interval in which cows are not inseminated with the ultimate goal of avoiding breeding at a time in which fertility is poor because of uterine regression and clearance, recovery to a favorable nutrient balance, and resumption of estrous cyclicity. Cows inseminated very early postpartum typically have depressed fertility (Tenhagen *et al.*, 2003), and as the voluntary waiting period is extended, fertility to first AI improves (Chebel and Santos, 2010). Thus, an extension in the voluntary waiting period does not necessarily result in an increase in calving interval if this is followed by an improvement in pregnancy at first AI.

In general terms, the voluntary waiting period is established based on the anticipated optimum time of pregnancy. Because most dairy farms cannot control when every cow becomes pregnant, the end of the voluntary waiting period occurs several weeks or months before the ideal day of pregnancy. Invariably, many cows will become pregnant before their optimum day, thereby resulting in a short lactation and dry off when milk production is still profitable. Figure 3A illustrates the desired voluntary waiting period for a herd according to the ideal day postpartum at pregnancy and pregnancy rate of the herd. Two calculations are depicted, one for an ideal day at pregnancy of 110 and another of 130 days postpartum. Herds with poor pregnancy rates, usually below 13%, cannot achieve any of those days open even if they begin insemination immediately after calving. For herds with pregnancy rates of 15% or greater, those values of median days open can be achieved but, in some cases, the voluntary waiting period has to be of fewer than 30 days, which is physiologically not indicated. For herds with good to excellent pregnancy rates (>22.5%), then median days open of 110 and 130 days can be achieved with a voluntary waiting period ranging from 60 to 98 days. Because pregnancy rate in lactating cows in herds in the United States averages 16 to 17%, it is no surprise that the average dairy farm uses a voluntary waiting period of 55 days, with almost no variation with herd size (NAHMS, 2009). Indeed, a recent survey by the National Animal Health and Monitoring System (NAHMS, 2009) observed that 75% of all dairy herds have a voluntary waiting period that ranges between 41 and 60 days postpartum (Fig. 3B).

Because level of production and persistency of lactation determines the ideal day of pregnancy for a cow or herd, it is no surprise that the voluntary waiting period would change in similar fashion. Therefore, this period should be shorter for low producers or low milk persistency cows, whereas the same should be longer for high producers and high milk persistency cows. Similarly, for a given level of production, the voluntary waiting period should also be altered according to the fertility of the herd. As pregnancy rate increases, the voluntary waiting period can be extended (Fig. 3A). In fact, delaying the voluntary waiting period and first AI usually improves fertility (Chebel and Santos, 2010; Tenhagen *et al*., 2003). When timed AI is incorporated to precisely control interval to first insemination, then programs that improve fertility should be used to allow later insemination in high-producing herds, but to achieve high pregnancy per AI. This minimizes the proportion of cows that become pregnant too early and reduces costs to obtain a pregnancy in places in which semen and labor are more expensive than hormonal treatments. Santos (2008) calculated the necessary increase in pregnancy per AI at first AI to compensate for by a delay in voluntary waiting period. In order to maintain the same days open, each 21-day delay in first AI after 60 days postpartum required an increment of 8 to 10 percentage units (e.g. from 30 to 38%; Santos, 2008).

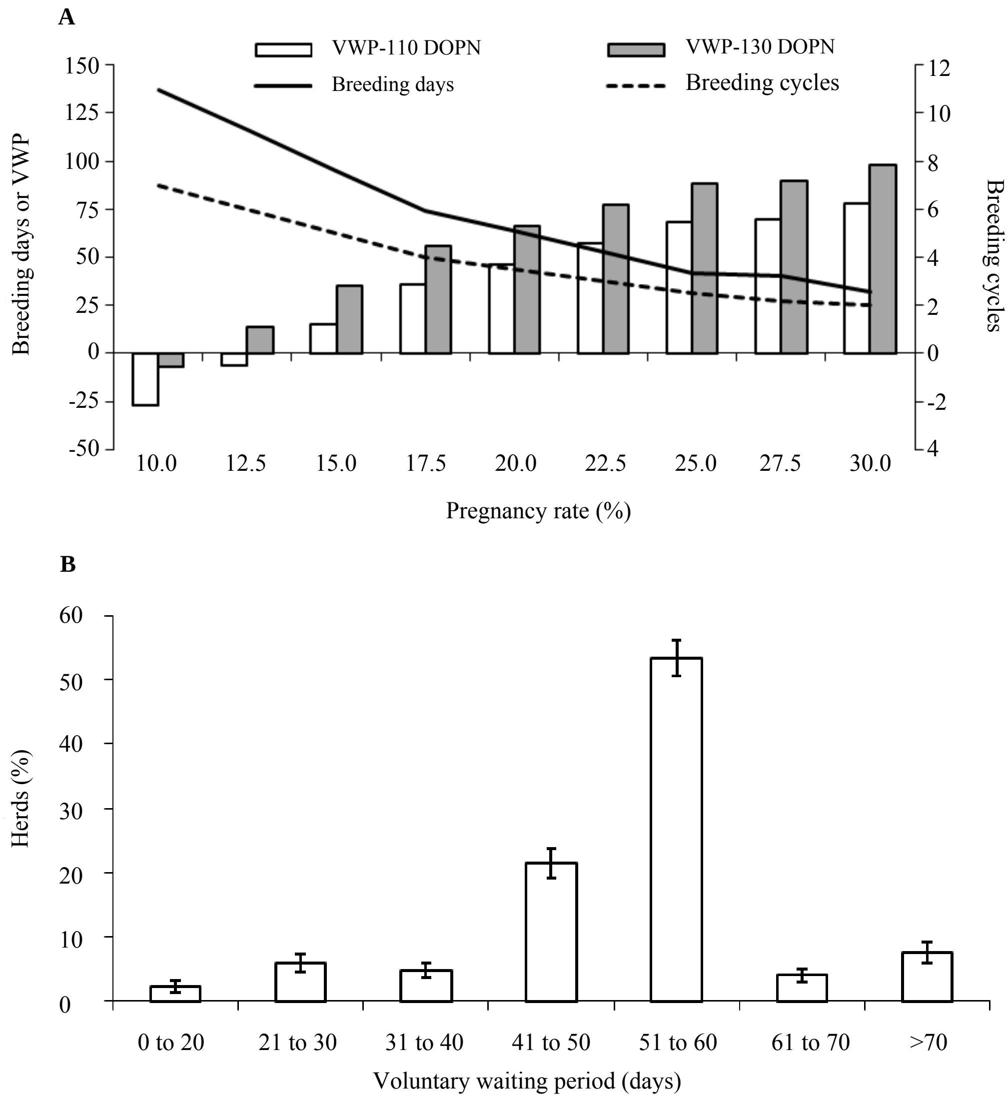


Figure 3. Estimated voluntary waiting period (VWP) to achieve median days open (DOPN) of a herd of either 110 (VWP-110DOPN) or 130 days (VWP-130DOPN) according to the 21-day cycle pregnancy rate of the herd (panel A). The resulting breeding days and 21-day breeding cycles to achieve the respective DOPN are also calculated. Negative values on both primary and secondary Y axes are the result of calculations and not possible to achieve. For instance, if the ideal DOPN is 130 days, and pregnancy rate is 17.5%, then the number of breeding days and cycles to achieve the desired DOPN would be 74 and 4, respectively. Under those circumstances, the VWP would have to be 56 days. Observed voluntary waiting period in dairy farms in the United States according to a recent survey (National Animal Health Monitoring System, 2009; panel B).

Day postpartum at first AI and interval to pregnancy

In addition to the voluntary waiting period, interval to first breeding also depends on breeding submission. In herds using detection of estrus, interval to first breeding is highly dependent on the ability to detect cows in heat. Accuracy and efficiency of estrous detection are variable and depend upon animal, environmental, and management factors (Lucy, 2006). Estrous detection can be compromised by increased herd size, animal density and time standing on concrete (Vailes and Britt, 1990). Moreover, smaller concentrations of circulating estradiol in high-producing cows have been associated with reduced duration and intensity of estrus (Wiltbank *et al*., 2006), which affects detection. Also, 13 to 48% of the postpartum cows are anovular at the end of the voluntary waiting period, which further limits submission to AI after estrous detection (Santos *et al*., 2009).

Low estrous detection rates and consequent low breeding submission result in more variable and longer time to first insemination and pregnancy, reduced pregnancy rates, and increased calving interval. A reasonable alternative to enhance submission rate and the proportion of cows pregnant early after the end of the voluntary waiting period is the incorporation of timed AI programs, either alone or in combination with estrous detection. Timed AI programs are particularly beneficial in farms with low detection of estrus (Tenhagen *et al*., 2004), typically in herds with 21-day cycle insemination rates below 55% (Santos, 2008). Because of the poor detection of estrus in most farms, the success of synchronized ovulation schemes, as a systematic breeding program, has been remarkable, becoming an integral portion of reproductive management in North American herds (Caraviello *et al*., 2006). LeBlanc (2007) reported that implementation of timed AI resulted in an increase of $30 yearly profit per cow compared with estrous detection alone. Similarly, De Vries (2011) reported $80 to $148 lower cost per pregnancy for timed AI compared with estrous detection programs.

Initially, timed AI programs were considered "submission protocols", but increased knowledge of the reproductive biology of the cow and how hormonal manipulation influences oocyte and embryo quality have now led to the development of methods that also optimize pregnancy per AI. In many cases, pregnancy per AI achieved with timed AI programs has surpassed 45% in high-producing cows and 55% in grazing dairy cows (Bisinotto and Santos, 2011; Wiltbank *et al*., 2011). The combined control of first insemination, ability to improve fertility of anovular cows, and adequate pregnancy per AI has optimized pregnancy rates to first AI in dairy herds incorporating timed AI programs.

According to De Vries (2011), the optimal interval to first breeding in Holstein herds in the United States is on average 70 days, but a delay of 1 to 2 weeks for primiparous and high-producing cows within the same herd is attractive, whereas shortening this interval by 1 to 2 weeks for low-producing herds also is beneficial. The author described that optimal interval postpartum to pregnancy is, on average, 133 and 112 days for 1st and 2nd lactations, respectively. These respective values are reduced to 91 and 77 days for low-producing cows, 105 and 99 days for cows with low lactation persistency, and 63 and 51 days for low producers with low lactation persistency. All these values can be used as set-points in systematic breeding programs to optimize profitability.

Artificial insemination vs. natural service programs

Natural service has been used as an alternative breeding scheme to avoid problems with detection of estrus. In fact, a considerable portion of dairy producers in the United States still uses natural service in at least part of their breeding program (De Vries *et al*., 2005; NAHMS, 2009). Approximately 25% of the dairy calves born in the United States are from cows sired by natural service (NAHMS, 2009). Epidemiological studies comparing natural service with AI after detected estrus or a combination of detection of estrus and timed AI demonstrated that, in general, reproductive performance was not altered (De Vries *et al*., 2005), or worsened for natural service (Overton and Sischo, 2005). In many dairy farms using a combination of AI and natural service, cows initially are inseminated one or more times and then moved to bull breeding groups (Overton and Sischo, 2005); however, it is unclear how many inseminations cows should receive before exposed to bulls to maximize pregnancy rate. This is particularly important in herds managing reproduction without the aid of estrous detection, as the interval between inseminations is determined by when a cow can be resynchronized for AI.

Few studies have directly evaluated reproductive performance of lactating dairy cows exposed to natural service or AI with randomly allocated cows. In a recent study comparing natural service and timed AI, the 21-day cycle pregnancy rate and interval to pregnancy were modestly influenced by the breeding program (Lima *et al*., 2009). One of the problems with only timed AI is the long inter-AI interval. Cows can only be subjected to another insemination once a nonpregnancy diagnosis is performed. In a subsequent study, cows were subjected to 1 compared with 3 timed AI before exposure to natural service (Lima *et al*., 2012a). Increasing the number of AI improved reproductive performance of dairy cows. Therefore, despite the long inter-AI interval, replacing natural service with timed AI improves reproductive performance of dairy cows, and exposing cows to natural service does not seem to be a valid strategy to improve reproductive performance.

In Lima *et al*. (2009), resynchronization for AI in cows subjected to the timed AI program was initiated 7 days before the nonpregnancy diagnosis, which increases costs associated with insemination as pregnant cows receive a portion of the treatment for resynchronization. Nevertheless, this strategy reduces the interval between inseminations by approximately 7 days. Economic evaluation favored those receiving timed AI (Lima *et al*., 2010). The economic advantage of timed AI was even greater when genetic progress was considered, and when marginal feed cost and milk price increased. The major component of natural service that increases costs with breeding is feeding bulls. The feeding cost of a Holstein bull is approximately 70% of that of a lactating dairy cow. According to Lima *et al*. (2009), exposing cows to natural service was $32.7 more expensive/cow/yr compared with timed AI. This economic advantage to AI compared with natural service would likely increase if the insemination program incorporated both timed AI and insemination upon detection of estrus in nonpregnant cows to reduce the interval between inseminations (Galvão *et al*., 2012).

Artificial insemination by detection of estrus or timed AI

Few studies evaluated the economic benefits of different AI programs in lactating dairy herds (Tenhagen *et al*., 2004; Giordano *et al*., 2011). Tenhagen *et al*. (2004) demonstrated that incorporation of timed AI programs such as Ovsynch improved reproductive performance and resulted in economic advantage over only estrous detection when the efficiency of detection of estrus was low. Giordano *et al*. (2001) evaluated three reproductive programs for lactating dairy cows: AI based on detection of estrus (DE), the double Ovsynch program for first AI followed by resynchronization of nonpregnant cows with Ovsynch starting on day 32 after the previous AI (DO-Res), and the double Ovsynch program for first and subsequent AI (DO-DO). Although the timed AI programs were $17 (DO-Res) and $21 (DO-DO) more expensive/cow/yr to implement than the estrous detection program, they resulted in $45 and $69 more income per cow/yr, respectively. In Giordano *et al*. (2011), the authors used pregnancy per AI of 45, 45, and 33% at first AI and, for subsequent AI, 30, 39, and 30% for DO-Res, DO-DO, and DE, respectively. When timed AI programs offer such increments in fertility, it is expected that they become more profitable than insemination following detection of estrus. The reason for that is because the benefits of getting a cow pregnant, in general, outweigh potential expenses with more costly AI programs when fertility is improved. However, fertility and reproductive performance in timed AI programs are not always superior to that of cows inseminated at detected estrus (Santos *et al*., 2004a; Tenhagen *et al*., 2004; Santos *et al*., 2009; Chebel and Santos, 2010). Therefore, it is important to consider which timed AI program to use and select the one that offers the highest fertility when detection of estrus is completely eliminated (Giordano *et al*., 2011).

In most farms in the United States, timed AI is utilized concurrently with insemination following synchronized or spontaneous estrus. In fact, more than 55% of the farms rely primarily on detection of estrus as the major method to inseminate cows (NAHMS, 2009). Because cows inseminated on estrus have similar fertility to that of cows inseminated following timed AI (Santos *et al*., 2004a; Tenhagen *et al*., 2004; Santos *et al*., 2009; Chebel and Santos, 2010), it is contentious to suggest a delay in insemination of cows that spontaneously return to estrus to enroll them in a timed AI program as economically advantageous. Except when efficacy and accuracy of detection of estrus are poor or labor for daily detection is expensive, it is anticipated that rebreeding cows that spontaneously return to estrus should complement the benefits of timed AI programs.

Galvão *et al*. (2012) recently modeled reproductive performance and economics of dairy farms that adopt one of ten breeding programs during the course of 1 yr. Simulation was performed until steady-state was reached, then average daily values for the subsequent 5 yr were used to calculate profit/cow/yr. Authors evaluated breeding programs (detection of estrus or timed AI), altered efficiency (40 *vs*. 60%) and accuracy (85 *vs*. 95%) of detection of estrus, compliance with each injection of the synchronization protocol (85 *vs*. 95%), and milk price ($0.33 *vs*. $0.44/kg). The programs proposed were: 1) detection of estrus at 40% with 85% accuracy; 2) detection of estrus at 40% with 95% accuracy; 3) detection of estrus at 60% with 85% accuracy; 4) detection of estrus at 60% with 95% accuracy; 5) timed AI for all AI with 85% compliance of treatments; 6) timed AI for all AI with 95% compliance of treatments; 7) timed AI for first AI with 85% compliance of treatments followed by detection of estrus at 40% with 85% accuracy; 8) timed AI for first AI with 95% compliance of treatments followed by detection of estrus at 40% with 85% accuracy; 9) timed AI for first AI with 85% compliance of treatments followed by detection of estrus at 60% with 85% accuracy; and 10) timed AI for first AI with 95% compliance of treatments followed by detection of estrus at 60% with 95% accuracy. The authors assumed the following: pregnancy to first AI was 33.9%, and then decreased by 2.6% for every subsequent insemination. Pregnancy loss was set at 11.3%. Cows were not inseminated after 366 days postpartum and nonpregnant cows were culled after 450 days postpartum. Culled cows were immediately replaced to maintain a herd of 1,000 cows, including lactating and dry cows, with a dry period of 60 days. The model accounted for all incomes and costs. The authors assumed that replacements would be obtained by purchasing a pregnant heifer at $1,600. Feeding costs were $0.25/kg of lactating cow diet dry matter and $0.15/kg of dry cow diet dry matter; breeding cost was $0.10/cow/day for detection of estrus; prostaglandin F2α was $2.65/dose; GnRH was $2.4/dose; hormonal administration was $0.25/injection; pregnancy diagnosis was $3.0/pregnancy; and other costs were $2.5/cow/day to account for labor, veterinary costs, and fixed costs. Income was calculated based on daily milk yield with milk priced at $0.33 or $0.44/kg, cow sale at $0.65/kg of live weight, and calf sale at $140/calf. Figure 4 depicts the profit per cow/yr when milk price is $0.33/kg (Fig. 4A) or 0.44/kg (Fig. 4B). Under the assumptions of Galvão *et al*. (2012), the highest 21-day cycle pregnancy rate was obtained when cows were subjected to program 10 (Fig. 4A), timed AI for first

AI with 95% compliance of treatments followed by detection of estrus at 60% with 95% accuracy. This same program resulted in the shortest median days (113) to pregnancy (Fig. 4B) and the greatest profit per cow/yr with both milk price scenarios, \$0.33/kg of milk (profit of \$375/cow) or \$0.44/kg of milk (profit of \$1,616/cow).

Therefore, incorporating a timed AI program for first AI with very high compliance that results in the highest fertility should improve profits. Following first AI, having an aggressive and accurate estrous detection program to reinseminate cows that spontaneously return to estrus, concurrent with routine nonpregnancy diagnosis to resynchronize nonpregnant cows, usually improves pregnancy rate, reduces days open, and increases profit per cow.

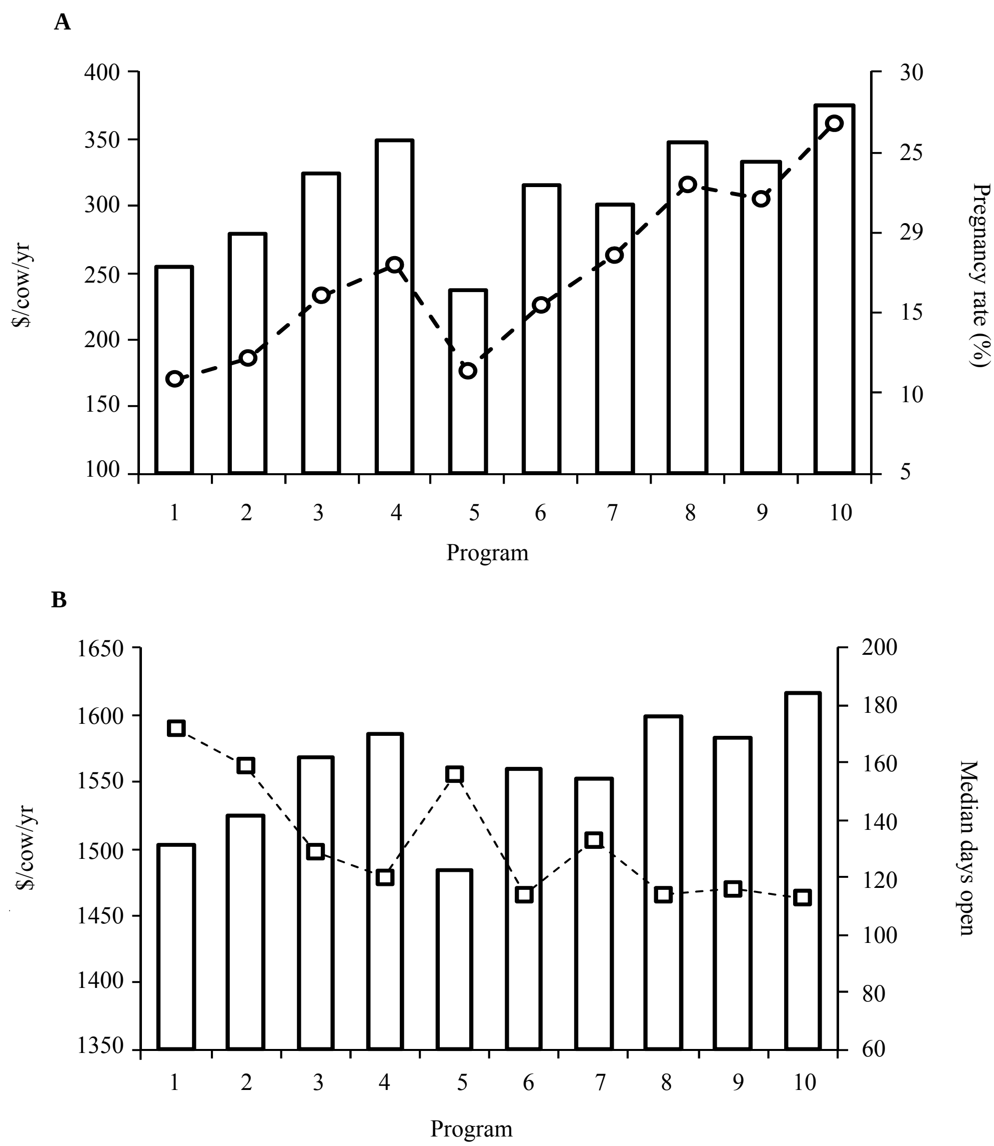


Figure 4. Profits per cow per yr (\$/cow/yr) of cows subjected to one of ten breeding programs: 1) detection of estrus at 40% with 85% accuracy; 2) detection of estrus at 40% with 95% accuracy; 3) detection of estrus at 60% with 85% accuracy; 4) detection of estrus at 60% with 95% accuracy; 5) timed AI for all AI with 85% compliance of treatments; 6) timed AI for all AI with 95% compliance of treatments; 7) timed AI for first AI with 85% compliance of treatments followed by detection of estrus at 40% with 85% accuracy; 8) timed AI for first AI with 95% compliance of treatments followed by detection of estrus at 40% with 85% accuracy; 9) timed AI for first AI with 85% compliance of treatments followed by detection of estrus at 60% with 85% accuracy; and 10) timed AI for first AI with 95% compliance of treatments followed by detection of estrus at 60% with 95% accuracy. Bars represent the profit/cow/yr according to each reproductive program calculated using milk price at \$0.33/kg (panel A) or \$0.44/kg (panel B). Dashed lines represent either the 21-day cycle pregnancy rate (panel A) or median days open (panel B). Adapted from Galvão *et al*. (2012).

Economics of embryo technologies to optimize fertility in dairy herds

The use of embryo technologies has been described as an alternative to improve pregnancy in dairy cows, especially during periods of heat stress (Ambrose *et al*., 1999; Al-Katanani *et al*., 2002; Stewart *et al*., 2011). The transfer of a blastocyst to a synchronized recipient has the potential to improve fertility because it bypasses fertilization and early embryo development, which are stages of increased thermosensitivity (Hansen, 2007) and of increased losses of pregnancy (Santos *et al*., 2004b). Nevertheless, in addition to fertility, several other factors need to be considered to determine if the use of embryo technologies is economically sound. The cost of an embryo, labor, recipient utilization, genetic progress, and fertility to AI programs are all additional important factors that cannot be ignored.

We calculated and compared the costs of five breeding programs for lactating dairy cows including embryo transfer (ET) from superovulated (SOV) cows; *in vitro* produced embryos from ovum pick up (IVP-OPU) or from oocytes of dairy cows from slaughterhouse (IVP-S); timed AI; and timed AI combined with insemination after detection of estrus (timed AI + DE). Conventional or sexed semen were used in all programs and both lactating and nonlactating donor cows were considered for ET and IVP-OPU programs. Assumptions were based on previous published work (Sartori *et al*., 2004; Schenk *et al*., 2006; Chebel *et al*., 2008; Steward *et al*., 2011) and on data from two large commercial dairy farms in California that both milk approximately 5,000 dairy cows and transfer more than 3,000 embryos/yr (D. Demétrio, 2012, Maddox Dairy; personal communication). For the ET program, each SOV used either 2 doses of conventional or 6 doses of sexed semen that resulted in 5 and 2.6 transferable embryos, respectively. The same embryo production was considered for lactating and dry cow donors because of the conflicting results in the literature (Hasler *et al*., 2006; Chebel *et al*., 2008). When the embryo donor was a lactating cow, a single collection was used and an additional 30 days open was added to the cost because of the delay in first postpartum insemination. When the embryo donor was a dry cow, then interval between collections was 50 days. For IVP-OPU, 8 good quality oocytes were recovered per OPU and 20% of them developed into blastocysts in both conventional and sexed semen, which resulted in 1.6 embryos/OPU session (Merton *et al*., 2003). Interval between OPU sessions was 5 to 7 days, which was included in the cost of maintenance of nonlactating oocyte donor cows. For lactating cows, oocytes were aspirated only from pregnant animals, so no additional costs were incurred. Cost of IVP-S embryos was based on market values in the United States, approximately $60 per embryo. For timed AI and synchronization of recipients, the first breeding in the lactation used a presynchronized Ovsynch protocol, whereas for subsequent AI or timed embryo transfer, the Ovsynch with a progesterone insert was used. Recipient use following synchronization for timed embryo transfer was 79%. Cost of one straw of semen was $6 for conventional and $18 for sexed semen, based on values for high net merit ($500 to $600) genomic sires marketed in the United States. Costs with labor were $10/h for farm employee and $150/h for veterinary services. A dose of PGF2α and GnRH were both $2 and progesterone insert was $4 for 7-day use, whereas FSH treatment for SOV was $75.

Two analyses were performed. The first assumed that only the cows at first breeding postpartum received either AI or an embryo. A second analysis assumed a reproductive program that lasted 120 days of breeding (e.g. starting at 80 and finishing at 200 days postpartum) using one of the five programs with either conventional or sexed semen. The combination of timed AI and detection of estrus included observation of estrus starting immediately after the second PGF2α of the presynchronization program until the end of the program, lasting 138 days. Estrous detection was 50% between the presynchronization and the first timed AI, and 40% for each 21-day cycle after the first AI. The interval between AI for cows diagnosed nonpregnant that were not observed in estrus was 40 days because they would be automatically enrolled in a synchronization protocol for rebreeding. The cost of a day open for lactating cows was assumed to be $2, which was applied to lactating ET donor cows as well as lactating cows receiving AI or embryos. When the embryo donor was a dry cow, the daily maintenance cost was set at $3.5, corresponding to feeding and maintenance costs. Genetic gain and culling decisions were not considered. Responses evaluated were cost/breeding, cost/pregnancy and cost/pregnancy carrying a female calf assuming scenarios for pregnancy per AI or ET at first breeding varying from 15 to 65%. It was assumed that pregnancy per AI would decline 6% for each subsequent service after the first, and that the proportion of female pregnancies would be 50% for conventional and 89% for sexed semen for both timed AI and ET programs, and 40% for conventional and 79% for sexed semen for IVP programs.

The cost per breeding was highest ($258.9) for ET when the embryo donor was a nonlactating cow inseminated with sexed semen and lowest ($16.3) when timed AI + DE using conventional semen was used (Table 1). As expected, using sexed semen increased cost per breeding, but the increment was proportionally greater when used for insemination than for production of embryos. This is because semen represents a larger portion of the breeding costs with AI than embryo production and transfer.

Table 1. Cost per breeding (US$) for lactating cows according to breeding program, semen utilized and embryo donor cow.

Breeding program[1]	Semen	Type of donor	Cost/breeding[2]
ET	Conventional	Lactating	$112.5
		Nonlactating	$135.5
	Sexed	Lactating	$214.6
		Nonlactating	$258.9
IVP-OPU	Conventional	Lactating	$125.2
		Nonlactating	$140.5
	Sexed	Lactating	$145.8
		Nonlactating	$158.9
IVP-S	Conventional	---	$96.9
	Sexed	---	$101.9
TAI	Conventional	---	$18.8
	Sexed	---	$30.8
TAI + DE	Conventional	---	$16.3
	Sexed	---	$28.3

[1]ET= embryo transfer from superovulated cows; IVP-A= *in vitro* produced embryos from aspirated oocytes from donors cows; IVP-S= *in vitro* produced embryos from slaughterhouse oocytes; TAI= timed artificial insemination; TAI + DE= timed artificial insemination and detection of estrus during 11 days before timed AI. [2]Includes all costs to have a cow breed: embryo or semen, labor, equipment, synchronization, days open for lactating cows and recipients, and feed for nonlactating donor cows.

When these five programs were evaluated for first breeding only, the costs per pregnancy were lowest for timed AI + DE with conventional semen and highest for ET with sexed semen at all fertility levels evaluated (Table 2). As pregnancy per AI or embryo transfer declined, the cost per pregnancy increased regardless of the program used. For the embryo programs, the cost to generate a pregnancy was lowest for embryos produced from slaughterhouse oocytes (IVP-S) and highest for IVP-OPU. Compared with TAI + DE when pregnancy per AI is 35%, embryo transfer from ET, IVP-OPU and IVP-S would have to achieve more than 65% fertility to generate a pregnancy of similar value. When lactating cows are inseminated with sexed semen, fertility is usually 75 to 80% of that observed with conventional semen (Norman *et al*., 2010). Using 25% pregnancy per AI in TAI + DE with sexed semen, use of embryo technologies with sexed semen would have to result in approximately 43% pregnancy when a sexed embryo is originated from IVP-S or 52% when originated from IVP-OPU or >65% with *in vivo* production of embryos with sexed semen (Table 2). A similar picture was observed when costs were calculated to produce a female calf. The programs followed a similar pattern, except the use of sexed semen which, as expected, reduced the cost to produce a female calf compared with conventional semen in all breeding programs (Table 3).

When breeding was extended to 120 days, from 80 to 200 days in milk, timed AI + DE again resulted in the cheapest pregnancy, whereas embryo transfer with embryos from IVP-OPU was the most expensive (Table 4). For instance, with pregnancy per AI at 35% and use of conventional semen, the cost to generate a pregnancy was $145.8. With current costs for embryo technologies, the three methods evaluated to produce an embryo resulted in more expensive pregnancies. If pregnancy per embryo transfer is 40%, then fertility in the AI program has to be very poor, below 15% to justify use of any embryo technology with the objective to improve reproductive performance in a cost-effective manner. When producers value obtaining female calves over having a pregnant cow, then cost to generate a female pregnancy with IVP-S would be attractive if fertility is maintained at 50% compared with timed AI + DE using sexed semen with fertility at 20% (Table 5).

Data from Stewart *et al*. (2011) were also used to calculate the cost per pregnancy, per female pregnancy, per live calf born, and per live female calf born based on the fertility obtained when either timed AI or timed embryo transfer were used in cows under heat stress. The assumptions were that heat stress limits fertilization and early embryo development; therefore, bypassing those stages would benefit fertility (Ambrose *et al*., 1999; Hansen, 2007). Embryos were produced by IVP-S with sexed semen and conventional semen was used for AI. The proportions of pregnant cows on day 40 and term were 18.3 and 14.6% for timed AI and 42.1 and 31.2% for timed embryo transfer. Because heat stress impaired fertility in inseminated cows compared with embryo transfer, the cost to produce a pregnancy was $93.8 cheaper for IVP-S (Table 6). Nonetheless, because IVP-S results in greater pregnancy losses, and each lost pregnancy costs $550

(De Vries, 2006), the cost/live calf born was $60.4 cheaper for timed AI than IVP-S. However, the IVP-S resulted in more female calves, so the cost/live female calf born was less for IVP-S, which might benefit producers in need of additional replacements.

These data reinforce the concept that for embryo technologies to be economically attractive to replace AI programs, they have to offer major increments in fertility. When pregnancies per AI are below 15%, then timed embryo transfer with embryos produced in an affordable manner becomes attractive. Moreover, as embryo technologies become more efficient and cheaper, their use as a tool to improve reproductive efficiency in dairy herds will come to be more attractive and justifiable economically. However, it is important to remember that fertility below 15% in AI programs is a major concern and requires reevaluation of management practices to identify the reasons for such mediocre results.

Table 2. Cost per pregnancy (US$) at first breeding according to breeding program, semen utilized and pregnancy per AI or embryo transfer.[1]

		Pregnancy per AI or embryo transfer (%)										
Program[2]	Semen	65.0	60.0	55.0	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0
ET	Conventional	216.2	240.9	270.0	305.0	347.8	401.3	470.1	561.7	690.1	882.6	1,203.5
	Sexed	373.3	411.0	455.7	509.2	574.7	656.5	761.8	902.1	1,098.5	1,393.1	1,884.1
IVP-OPU	Conventional	235.6	261.9	293.0	330.3	375.9	432.9	506.2	603.9	740.7	945.8	1,287.8
	Sexed	267.4	296.3	330.5	371.6	421.8	484.5	565.1	672.6	823.2	1,048.9	1,425.3
IVP-S	Conventional	192.2	214.9	241.7	273.8	313.2	362.3	425.5	509.7	627.7	804.6	1,099.5
	Sexed	199.9	223.2	250.8	283.8	324.3	374.8	439.8	526.4	647.7	829.6	1,132.8
TAI	Conventional	72.0	84.7	99.6	117.6	139.6	167.0	202.3	249.3	315.2	414.0	578.7
	Sexed	90.5	104.7	121.5	141.6	166.2	197.0	236.6	289.3	363.2	474.0	658.7
TAI + DE	Conventional	68.1	80.4	95.0	112.5	133.9	160.6	195.0	240.8	305.0	401.3	561.7
	Sexed	86.5	100.4	116.8	136.5	160.6	190.6	229.3	280.8	353.0	461.3	641.7

[1]Nonpregnant cows had an additional 40 days for rebreeding, which was considered in the cost per pregnancy. [2]ET= embryo transfer from superovulated cows; IVP-A= *in vitro* produced embryos from aspirated oocytes from donors cows; IVP-S= *in vitro* produced embryos from slaughterhouse oocytes; TAI= timed artificial insemination; TAI + DE= timed artificial insemination and detection of estrus during 11 days before timed AI.

Table 3. Cost per female pregnancy (US$) at first breeding according to breeding program, semen utilized and pregnancy per AI or embryo transfer.[1]

		Pregnancy per AI or embryo transfer (%)										
Program[2]	Semen	65.0	60.0	55.0	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0
ET	Conventional	432.4	481.7	540.1	610.1	695.7	802.6	940.1	1,123.5	1,380.2	1,765.2	2,407.0
	Sexed	419.4	461.8	512.0	572.2	645.7	737.7	855.9	1,013.5	1,234.2	1,565.3	2,117.0
IVP-OPU	Conventional	589.1	654.8	732.6	825.8	939.8	1,082.3	1,265.5	1,509.7	1,851.6	2364.5	3,219.4
	Sexed	338.4	375.1	418.4	470.4	533.9	613.3	715.3	851.4	1042.0	1327.8	1,804.1
IVP-S	Conventional	480.5	537.2	604.2	684.6	782.9	905.8	1,063.7	1,274.4	1,569.2	2,011.5	2,748.7
	Sexed	253.0	282.5	317.4	359.3	410.5	474.4	556.7	666.3	819.9	1,050.1	1,434.0
TAI	Conventional	144.0	169.3	199.3	235.2	279.1	334.0	404.6	498.7	630.4	828.0	1,157.3
	Sexed	101.6	117.6	136.5	159.1	186.8	221.3	265.8	325.1	408.1	532.6	740.1
TAI + DE	Conventional	136.2	160.8	190.0	225.0	267.8	321.3	390.0	481.7	610.0	802.5	1123.3
	Sexed	97.2	112.8	131.3	153.4	180.4	214.2	257.6	315.5	396.6	518.3	721.0

[1]Nonpregnant cows had an additional 40 days for rebreeding, which was considered in the cost per pregnancy. [2]ET= embryo transfer from superovulated cows; IVP-A= *in vitro* produced embryos from aspirated oocytes from donors cows; IVP-S= *in vitro* produced embryos from slaughterhouse oocytes; TAI= timed artificial insemination; TAI + DE= timed artificial insemination and detection of estrus during 11 days before timed AI.

Table 4. Average cost per pregnancy (US$) during 120 days of breeding period according to breeding program, semen utilized and pregnancy per AI or embryo transfer.[1]

		Pregnancy per AI or embryo transfer (%)										
Program[2]	Semen	65.0	60.0	55.0	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0
ET	Conventional	223.2	249.1	279.5	315.6	359.3	413.6	482.8	574.5	702.1	892.7	1,209.1
	Sexed	385.2	478.1	531.3	594.8	672.0	768.0	890.8	1,053.7	1,281.0	1,620.9	2,185.9
IVP-OPU	Conventional	243.3	271.0	303.4	342.0	388.9	447.0	521.2	619.5	756.4	960.8	1,300.2
	Sexed	276.0	306.6	342.5	385.2	437.1	501.5	583.8	692.9	844.8	1,071.8	1,449.0
IVP-S	Conventional	198.5	222.2	249.9	282.9	322.8	372.3	435.4	519.0	635.2	808.6	1,096.5
	Sexed	206.4	230.8	259.4	293.4	334.5	385.6	450.6	536.8	656.6	835.6	1,132.6
TAI	Conventional	74.5	87.2	102.0	119.3	140.2	165.8	198.2	240.9	300.0	387.8	533.1
	Sexed	93.6	108.0	124.7	144.4	168.2	197.5	234.7	283.6	351.5	452.4	619.6
TAI + DE	Conventional	62.8	70.5	79.7	90.8	104.7	122.4	145.8	177.8	223.7	293.8	412.7
	Sexed	81.9	89.9	99.4	111.1	125.7	144.5	169.4	203.5	252.3	327.3	454.3

[1]Nonpregnant cows had an additional 40 days for rebreeding, unless inseminated following detected estrus, which was considered in the cost per pregnancy. [2]ET= embryo transfer from superovulated cows; IVP-A= *in vitro* produced embryos from aspirated oocytes from donors cows; IVP-S= *in vitro* produced embryos from slaughterhouse oocytes; TAI= timed artificial insemination; TAI + DE= timed artificial insemination and detection of estrus during 11 days before timed AI.

Table 5. Average cost per female pregnancy (US$) during 120 days of breeding period according to breeding program, semen utilized and pregnancy per AI or embryo transfer.[1]

		Pregnancy per AI or embryo transfer (%)										
Program[2]	Semen	65.0	60.0	55.0	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0
ET	Conventional	446.5	498.2	558.9	631.2	718.7	827.2	965.6	1,149.0	1,404.2	1,785.3	2,418.1
	Sexed	432.8	478.1	531.3	594.8	672.0	768.0	890.8	1,053.7	1,281.0	1,620.9	2,185.9
IVP-OPU	Conventional	608.2	677.4	758.5	855.1	972.2	1,117.5	1,303.0	1,548.7	1,890.9	2,401.9	3,250.6
	Sexed	349.4	388.1	433.5	487.6	553.3	634.8	739.0	877.1	1,069.4	1,356.8	1,834.2
IVP-S	Conventional	496.2	555.4	624.8	707.3	807.1	930.8	1,088.6	1,297.4	1,588.0	2,021.6	2,741.4
	Sexed	261.3	292.2	328.3	371.4	423.5	488.0	570.4	679.4	831.2	1,057.7	1,433.7
TAI	Conventional	149.1	174.5	203.9	238.6	280.3	331.6	396.5	481.9	600.0	775.6	1,066.1
	Sexed	105.1	121.3	140.1	162.3	189.0	221.9	263.7	318.7	394.9	508.4	696.2
TAI + DE	Conventional	125.7	141.1	159.4	181.6	209.3	244.8	291.6	355.6	447.3	587.6	825.5
	Sexed	92.0	101.0	111.7	124.8	141.3	162.4	190.3	228.6	283.5	367.7	510.5

[1]Nonpregnant cows had an additional 40 days for rebreeding, unless inseminated following detected estrus, which was considered in the cost per pregnancy. [2]ET= embryo transfer from superovulated cows; IVP-A= *in vitro* produced embryos from aspirated oocytes from donors cows; IVP-S= *in vitro* produced embryos from slaughterhouse oocytes; TAI= timed artificial insemination; TAI + DE= timed artificial insemination and detection of estrus during 11 days before timed AI.

Table 6. Estimated costs per pregnancy and live born calf for timed AI with detection of estrus using conventional semen and *in vitro* production of embryo using slaughterhouse ovaries with sexed semen based on fertility data from Stewart *et al*. (2011).

Item	Program		Difference (timed AI - IVP-S)
	TAI + DE	IVP-S	
Pregnant (%)			
Day 40	18.3	42.1	-23.8
Term	14.6	31.2	-16.6
Pregnancy loss and stillborn (%)	20.2	34.7	-14.5
Cows delivering live calves (%)	14.6	27.5	-12.9
Cost (US$)			
Per pregnancy	446.0	352.1	93.8
Female pregnancy	891.9	445.7	446.2
Live calf	559.0	539.1	19.9
Pregnancy loss per live calf	112.2	192.5	-80.3
Total cost/live calf (US$)	671.2	731.5	-60.4
Total cost/live female calf (US$)	1,342.4	926.0	416.4

TAI + DE= timed artificial insemination and detection of estrus during 11 days before timed AI; IVP-S= *in vitro* produced embryos from slaughterhouse oocytes.

Economics of reproductive programs for dairy heifers

According to a survey conducted by the National Animal Health Monitoring System, approximately 63% of the dairy farms in the United States use AI following detection of spontaneous or induced estrus in dairy heifers (NAHMS, 2009). The main advantages of this program are the ease of implementation, relatively low costs and high pregnancy per AI. However, success of programs for detection of estrus is highly dependent on efficiency and accuracy of detection, which requires daily observation. Low estrous detection rates result in low pregnancy rates and a large variation in age at first breeding and pregnancy, and consequently age at first calving, which are economically undesired (Ettema and Santos, 2004). Administration of PGF2α when heifers are moved to the breeding pens is a very common strategy to induce luteolysis and formation of sexually active groups, thereby facilitating detection of estrus by concentrating estrous expression in fewer days that improves pregnancy rates (Stevenson *et al*., 2008).

Approximately 33% of dairy farms in the United States still use natural service as the main method for breeding heifers (NAHMS, 2009). Although natural service programs require less labor and personnel commitment, reproductive efficiency is not improved (Overton and Sischo, 2005; Lima *et al*., 2009; Lima *et al*. 2012a). Increments in age at pregnancy and the expenses to maintain bulls can markedly increase the costs of rearing a pregnant heifer. Additionally, maintaining service sires poses additional problems such as risk of transmission of venereal diseases, trauma during breeding, inability to select for less dystocia, impairment of genetic improvement and, more importantly, risk to personnel. According to a report from the Center for Diseases Control, Morbidity and Mortality Weekly Report, of 21 deaths associated with handling of cattle in the states of Iowa, Missouri, and Nebraska, 10 of them were caused by attacks by bulls (Morbidity and Mortality Weekly Report - MMWR, 2009). Of the fatalities in dairy farms reported, all of them were caused by bulls. A recent study reported 287 serious accidents or deaths caused by bulls in the United States, and most victims had considerable experience handling bulls (Sheldon *et al*., 2009). Therefore, in general, infertility, genetic inferiority, disease transmission, and risk to personnel are common problems with natural service programs.

A survey completed in 2007 indicated that fewer than 4% of dairy operations used timed AI programs for breeding dairy heifers (NAHMS, 2009). The low utilization was justified by reduced pregnancy per AI (30 to 40%) obtained with standard Ovsynch protocol compared with AI at detected estrus (50 to 60%). Another reason was the perception by producers that reproductive management of dairy heifers is not a concern. Nonetheless, novel timed AI programs for dairy heifers have been developed and resulted in adequate pregnancy per AI (50 to 60%; Rabaglino *et al*., 2010; Lima *et al*., 2011, 2012b). With adequate fertility, the major advantage of implementing timed AI protocols for dairy heifers is to maximize the number of pregnant animals immediately after they become eligible for breeding, which is expected to result in younger age at pregnancy and calving that reduces costs for feeding dairy heifers (Ettema and Santos, 2004). Nevertheless, it is important to mention that these programs require compliance, and have additional labor and costs associated with hormone administration.

A simulation was performed to calculate pregnancy rates, average time to pregnancy, total costs per AI (including labor, drugs, semen and equipment required), and total costs per pregnancy for four reproductive programs when the duration of the breeding period was 84 days, approximately four estrous cycles. Heifers were eligible to be bred starting at 400 days of age (day 0) and subjected to one of the four breeding protocols: 1) timed AI for first and subsequent inseminations; 2) detection of estrus only; 3) timed AI for first breeding and detection of estrus for the remaining period; and 4) timed AI for first breeding followed by insemination upon detected estrus or resynchronized insemination after nonpregnancy diagnosis. Four estrous detection rates were considered: 50, 60, 70 and 80%. Detection of estrus program included an injection of PGF2α on day 0 in all heifers and a second injection 14 days later for those not inseminated. Pregnancy per AI for those inseminated in estrus was assumed to be 60% for the first breeding and 54% for the remaining inseminations (Norman *et al*., 2010). For timed AI, nonpregnant heifers were reinseminated every 40 days for up to 3 AI, and pregnancies per AI were 59, 55, and 51% for the first, second and third breedings, respectively (Lima *et al*., 2011, 2012b). For detection of estrus, costs with labor were calculated for daily tail chalking and observation of heifers. Costs per pregnancy included costs incurred to implement the breeding program and feed costs associated with the interval from beginning of breeding to pregnancy. It was assumed that each extra day to pregnancy after 400 days of age would increase feed costs $2. Therefore, nonpregnant heifers at the end of the simulation, day 84, had an additional cost of $168 for feed.

As expected, results of programs using detection of estrus were highly dependent on insemination rates (Table 7). As efficiency of estrous detection increased from 50 to 80%, more heifers were pregnant early in the breeding period, which reduced age at pregnancy. These improvements in reproduction also affected the cost per AI and the feed cost per pregnancy, which decreased the total cost per pregnancy with higher detection of estrus. Incorporation of timed AI for first AI reduced cost per pregnancy compared with estrous detection alone, although the benefits declined at the high estrous detection rates (Table 7). When additional timed AI were incorporated in the breeding program to resynchronize nonpregnant heifers that had not been detected in estrus, it further benefited simulations with low estrous detection efficiency (50 to 60%), but had negligible effects when estrous detection was at least 70%. Timed AI only was equivalent to a program based on detection of estrus when efficiency of detection was at least 70%. Incorporation of detection of estrus after one timed AI was superior to only timed AI when estrous detection rate was >50%. Most of the changes in costs per pregnancy resulted from feed costs associated with heifers becoming pregnant later in the breeding period.

In summary, most dairy farms breed heifers using detection of estrus. When efficiency of estrous detection drops below 70%, the cost of obtaining a pregnancy is similar to that of using timed AI alone. Nevertheless, incorporating detection of estrus in between timed AI reduces costs associated with rearing heifers to calving, which decreases the cost per pregnancy.

Table 7. Reproductive efficiency and costs of four breeding programs for dairy heifers according to estrous detection rate.

	Breeding program[1]												
	TAI only	Detection of estrus only				TAI + DE on remaining AI				TAI + DE between TAI			
Estrous detection rate (%)	----	50	60	70	80	50	60	70	80	50	60	70	80
Pregnant (%)													
Day 20	59.0	45.0	50.4	54.6	57.6	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0
Day 40	81.6	59.9	66.5	71.8	75.9	70.1	72.3	74.5	76.7	81.4	81.4	81.3	81.3
Day 84	91.0	78.6	84.7	89.1	92.2	84.1	87.3	90.1	92.5	91.1	91.2	91.2	91.3
Age at pregnancy (days)	418.2	426.6	425.0	423.6	422.4	414.4	415.3	415.9	416.3	416.8	416.5	416.2	415.9
Labor days	12	84	84	84	84	68	68	68	68	68	68	68	68
Labor (h/AI)	0.18	0.57	0.49	0.43	0.39	0.37	0.34	0.32	0.30	0.23	0.22	0.21	0.20
Cost/AI (US$)	20.8	14.9	13.9	13.3	12.8	18.9	18.3	17.8	17.4	19.1	18.5	17.9	17.4
Number of AI/pregnancy	1.75	1.75	1.74	1.74	1.74	1.74	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Feed cost/pregnancy (US$)	53.1	98.9	80.5	67.8	58.9	60.6	55.0	50.2	46.2	49.9	45.3	48.6	48.0
Total cost/pregnancy (US$)	89.5	125.0	104.7	90.9	81.1	93.5	86.9	81.4	76.7	83.3	81.7	80.0	78.4

[1]TAI= timed artificial insemination; TAI + DE= timed artificial insemination for first AI followed by detection of estrus for remaining AI; TAI + DE between TAI= timed AI for first AI followed by detection of estrus and resynchronization of nonpregnant heifers for timed AI following nonpregnancy diagnosis.

Conclusions

Reproduction continues to be a critical component to maintain a dairy farm economically viable. It allows heifers to reach production at a proper age and lactating dairy cows to return to production at the desirable interval. According to level of production and efficiency of getting cows pregnant, producers need to establish goals to initiate insemination and obtain a pregnancy. As control of interval to first AI and fertility increase, the voluntary waiting period can be delayed. Similarly, although obtaining a timely pregnancy is attractive to low- and high-producing herds, as production increases, the loss with delay in pregnancy becomes smaller. Low-producing cows or cows in low-producing herds should receive the first breeding early in lactation, usually between 40 and 60 days postpartum, whereas high-producing cows or cows in high-producing herds this interval can be delayed several weeks. In general, incorporating timed AI for first AI followed by detection of estrus with resynchronization of cows that are nonpregnant and not reinseminated is the most profitable breeding strategy. When embryo technologies are incorporated into the breeding program with the aim to improve reproductive performance, the differential in fertility has to be large compared to AI to be justified. In many cases, AI programs have to result in very poor fertility (<15%) for the typical results from embryo transfer (40-45% pregnancy) to be economically attractive. As embryo technologies become more efficient and cheaper, then their use as a tool to improve reproductive efficiency in dairy herds will come to be more attractive and economically justifiable. For dairy heifers, in farms with excellent estrous detection rates, above 70%, incorporation of timed AI programs is not attractive when the objective is to improve reproductive performance or reduce the cost per pregnancy. Incorporation of timed AI followed by detection of estrus or timed AI alone become attractive when detection of estrus in heifer breeding programs is 60% or less.

Acknowledgments

The authors thank Dr. Daniela Demétrio of Maddox and Ruaan Dairies, California, for sharing data of their embryo transfer program for this manuscript.

References

Al-Katanani YM, Drost M, Monson RL, Rutledge JJ, Krininger CE, Block J, Thatcher WW, Hansen PJ. 2002. Pregnancy rates following timed embryo transfer with fresh or vitrified in vitro produced embryos in lactating dairy cows under heat stress conditions. *Theriogenology*, 58:171-182.

Ambrose JD, Drost M, Monson RL, Rutledge JJ, Leibfried-Rutledge ML, Thatcher MJ, Kassa T, Binelli M, Hansen PJ, Chenoweth PJ, Thatcher WW. 1999. Efficacy of timed embryo transfer with fresh and frozen in vitro produced embryos to increase pregnancy rates in heat-stressed cattle. *J Dairy Sci*, 82:2369-2376.

Bisinotto RS, Santos JEP. 2011. The use of endocrine treatments to improve pregnancy rates in cattle. *Reprod Fertil Dev*, 24:258-266.

Caraviello DZ, Weigel KA, Fricke PM, Wiltbank MC, Florent MJ, Cook NB, Nordlund KV, Zwald NR, Rawson CL. 2006. Survey of management practices on reproductive performance of dairy cattle on large US commercial farms. *J Dairy Sci*, 89:4723-4735.

Chebel R, Santos JEP. 2010. Effect of inseminating cows in estrus following a presynchronization protocol on reproductive and lactation performances. *J Dairy Sci*, 93:4632-4643.

De Vries A, Steenholdt C, Risco CA. 2005. Pregnancy rates and milk production in natural service and artificially inseminated dairy herds in Florida and Georgia. *J Dairy Sci*, 88:948-956.

De Vries A. 2006. Economic value of pregnancy in dairy cattle. *J Dairy Sci*, 89:3876-3885.

De Vries A. 2011. Economics of reproductive performance. *In*: Risco CA, Melendez P (Ed.). *Dairy Production Medicine*. Hoboken, NJ: Wiley-Blackwell. pp. 139-151.

Ettema J, Santos JEP. 2004. Impact of age at calving on lactation, reproduction, health, and income in first-parity Holsteins on commercial farms. *J Dairy Sci*, 87:2730-2742.

Gabler MT, Tozer PR, Heinrichs AJ. 2000. Development of a cost analysis spreadsheet for calculating the costs to raise a replacement dairy heifer. *J Dairy Sci*, 83:1104-1109.

Giordano JO, Fricke PM, Wiltbank MC, Cabrera VE. 2011. An economic decision-making support system for selection of reproductive management programs on dairy farms. *J Dairy Sci*, 94:6216-6232.

Groenendaal H, Galligan DT, Mulder HA. 2004. An economic spreadsheet model to determine optimal breeding and replacement decisions for dairy cattle. *J Dairy Sci*, 87:2146-2157.

Galvão KN, Federico P, De Vries A, Schuenemann GM. 2012. Economic comparison of reproductive programs for dairy herds using estrus detection, Ovsynch, or a combination of both. *J. Dairy Sci*. (submitted).

Hansen PJ. 2007. Exploitation of genetic and physiological determinants of embryonic resistance to elevated temperature to improve embryonic survival in dairy cattle during heat stress. *Theriogenology*, 68:S242-S249.

Hasler, JF. 2006. The Holstein cow in embryo transfer today as compared to 20 years ago. *Theriogenology*, 65:4-16.

LeBlanc S. 2007. Economics of improving reproductive performance in dairy herds. *WCDS Adv Dairy Technol*, 19:201-214.

Lima FS, Risco CA, Thatcher MJ, Benzaquen ME, Archbald LF, Santos JEP, Thatcher WW. 2009 Comparison of reproductive performance in lactating dairy cows bred by natural service or timed artificial insemination. *J Dairy Sci*, 92:5456-5466.

Lima FS, De Vries A, Risco CA, Santos JEP, Thatcher WW. 2010. Economic comparison of natural service and timed artificial insemination breeding programs in dairy cattle. *J Dairy Sci*, 93:4404-4413.

Lima FS, Ayres H, Favoreto MG, Bisinotto RS, Greco LF, Ribeiro ES, Baruselli PS, Risco CA, Thatcher WW, Santos JEP. 2011. Effects of the GnRH at initiation of the 5-d timed AI program and timing of induction of ovulation relative to AI on ovarian dynamics and fertility of dairy heifers. *J. Dairy Sci*, 94:4997-5004.

Lima FS, Bisinotto RS, Ribeiro ES, Ayres H, Greco LF, Galvão KN, Risco CA, Thatcher WW, Santos JEP. 2012a. Effect of one or three timed artificial inseminations before natural service on reproductive performance of lactating dairy cows not observed for detection of estrus. *Theriogenology*, 77:1918-1927.

Lima FS, Ribeiro ES, Bisinotto RS, Martinez N, Greco LF, Galvão KN, Risco CA, Thatcher WW, Amstalden M, Santos JEP. 2012b. Effects of GnRH and administering number of PGF2α doses in the 5-d timed AI program on ovarian responses and fertility of dairy heifers. *J Dairy Sci*, 95(suppl 2):576-577. (abstract).

Lucy MC. 2006. Estrus: basic biology and improving estrous detection. *In*: *Proceedings of DCRC Annual Meeting*, 2006, Denver, CO. Hartland, WI: Dairy Cattle Reproduction Council. pp. 29-37.

Merton JS, de Roos AP, Mullaart E, de Ruigh L, Kaal L, Vos PL, Dieleman SJ. 2003. Factors affecting oocyte quality and quantity in commercial application of embryo technologies in the cattle breeding industry. *Theriogenology*, 59:651-674.

Morbidity and Mortality Weekly Report (MMWR). 2009. Fatalities caused by cattle - Four states, 2003-2008. *MMWR Morb Mortal Wkly Rep*, 58:800-804

National Animal Health Monitoring System (NAHMS). 2009. Dairy 2007. Part IV: Reference of Dairy Cattle Health and Management Practices in the United States, 2007. #N494.0209. Fort Collins, CO: Centers for Epidemiology and Animal Health/USDA/APHIS/VS

Norman HD, Hutchison JL, Miller RH. 2010. Use of sexed semen and its effect on conception rate, calf sex, dystocia, and stillbirth of Holsteins in the United States. *J Dairy Sci*, 93:3880-3890.

Overton MW, Sischo WM. 2005. Comparison of reproductive performance by artificial insemination versus natural service sires in California dairies. *Theriogenology*, 64:603-613.

Rabaglino MB, Risco CA, Thatcher MJ, Kim IH, Santos JEP, Thatcher WW. 2010. Application of one injection of prostaglandin F2α in the five-day Co-Synch+CIDR protocol for estrous synchronization and resynchronization of dairy heifers. *J Dairy Sci*, 93:1050-1058.

Sartori R, Souza AH, Guenther JN, Caraviello DZ, Geiger LN, Schenk JL, Wiltbank MC. 2004. Fertilization rate and embryo quality in superovulated Holstein heifers artificially inseminated with X-sorted or unsorted sperm. *Anim Reprod*, 1:86-90.

Santos JEP, Juchem SO, Cerri RL, Galvão KN, Chebel RC, Thatcher WW, Dei CS, Bilby CR. 2004a. Effect of bST and reproductive management on reproductive performance of Holstein dairy cows. *J Dairy Sci*, 87:868-881.

Santos JEP, Thatcher WW, Chebel RC, Cerri RL, Galvão KN. 2004b. The effect of embryonic death rates in cattle on the efficacy of estrus synchronization programs. *Anim Reprod Sci*, 82/83:513-535.

Santos JEP. 2008. Implementation of reproductive programs in dairy herds. *Cattle Pract*, 16:5-14.

Santos JEP, Rutigliano HM, Sá Filho MF. 2009. Risk factors for resumption of postpartum estrous cycles and embryonic survival in lactating dairy cows. *Anim Reprod Sci*, 110:207-221.

Santos JEP, Bisinotto RS, Ribeiro ES, Lima FS, Greco LF, Staples CR, Thatcher WW. 2010. Applying nutrition and physiology to improve reproduction in dairy cattle. *Soc Reprod Fertil Suppl*, 67:387-403.

Schenk JL, Suh TK, Seidel Jr GE. 2006. Embryo production from superovulated cattle following insemination of sexed sperm. *Theriogenology*, 65:299-307.

Sheldon KJ, Deboy G, Field WE, Albright JL. 2009. Bull-related incidents: their prevalence and nature. *J Agromedicine*, 14:357-369.

Stevenson, JL, Dalton JC, Santos JEP, Sartori R, Ahmadzadeh A, Chebel RC. 2008. Effect of synchronization protocols on follicular development and estradiol and progesterone concentrations of dairy heifers. *J Dairy Sci*, 91:3045-3056.

Stewart BM, Block J, Morelli P, Navarette AE, Amstalden M, Bonilla L, Hansen PJ, Bilby TR. 2011. Efficacy of embryo transfer in lactating dairy cows during summer using fresh or vitrified embryos produced *in vitro* with sex-sorted semen. *J Dairy Sci*, 94:3437-3445.

Tenhagen BA, Vogel C, Drillich M, Thiele G, Heuwieser W. 2003. Influence of stage of lactation and milk production on conception rates after timed artificial insemination following Ovsynch. *Theriogenology*, 60:1527-1537.

Tenhagen BA, Drillich M, Surholt R, Heuwieser W. 2004. Comparison of timed AI after synchronized ovulation to AI at estrus: Reproductive and economic considerations. *J Dairy Sci*, 87:85-94.

Vailes LD, Britt JH. 1990. Influence of footing surface on mounting and other sexual behaviors of estrual

Holstein cows. *J Anim Sci*, 68:2333-2339.
Wiltbank M, Lopez H, Sartori R, Sangsritavong S, Gumen A. 2006. Changes in reproductive physiology of lactating dairy cows due to elevated steroid metabolism. *Theriogenology*, 65:17-29.
Wiltbank MC, Sartori R, Herlihy MM, Vasconcelos JL, Nascimento AB, Souza AH, Ayres H, Cunha AP, Keskin A, Guenther JN, Gumen A. 2011. Managing the dominant follicle in lactating dairy cows. *Theriogenology*, 76:1568-1582.