When Should Dairy Cows Be Inseminated?

Guide B-117

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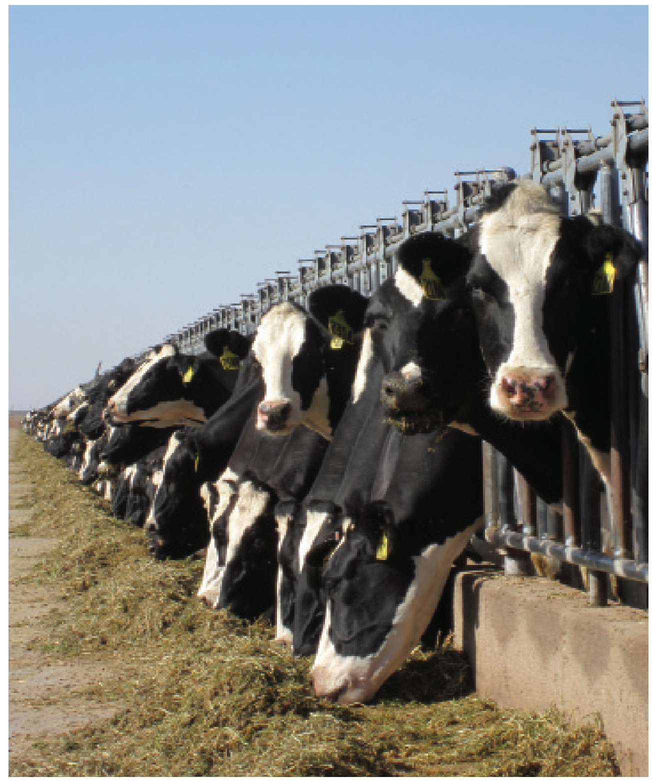
INTRODUCTION

Reproductive efficiency of the dairy herd is important for the economic success of the dairy operation. One of the most important reproductive technologies of the dairy industry is artificial insemination (AI). Artificial insemination reduces the incidence of sexually transmitted diseases among cattle and increases the use of genetically superior sires to improve performance of the herd. Standing estrus, or "heat," is the most reliable indication that a cow is going to ovulate and release an ovum or "egg." Estrous behavior is used to determine when a cow should be inseminated. A brief window of opportunity exists to fertilize the ovum and impregnate the cow.

Senger (1994) estimated that the U.S. dairy industry loses more than $300 million annually due to failure and/or misdiagnosis of estrus. De Vries (2007) reported that a one percentage point increase in pregnancy rate (PR; defined as the number of eligible cows that become pregnant in each 21-day cycle) is valued between $22 and $35 per cow per year when PR varied from 15 to 19%, respectively. The average value of a new pregnancy was $278 in a simulated herd based generally on Holstein cow performance and prices in the United States (De Vries, 2006). The value of a pregnancy changes with different levels of production and with changing milk prices; the value goes up with higher milk prices and at higher milk production levels. Thus, efficiently and accurately detecting estrus and inseminating at the proper time are of utmost importance if dairy producers want to increase reproductive efficiency of the herd.

ESTRUS OR "HEAT"

Estrous behavior, or heat, is due to the actions of the steroid hormone estrogen (E2) on the brain of cattle. Early research by Trimberger (1948) found the duration of estrus in dairy cows ranged from 2.5 to 28 hours, with a mean of 18 hours, in cows visually observed three times daily. With the recent advent of continuous observation of estrous behavior by radiotelemetric systems (HeatWatch, DDx, Inc., Denver, CO), duration of estrus averaged 7 hours (range of 33 minutes to 36 hours; Dransfield et al., 1998).



Several factors related to dairy management affect estrous behavior in dairy cattle. Increasing the number of cows penned together increases the intensity (number of mounts) and duration of estrus (Hurnik et al., 1975). Dairy cows observed for estrus on a dirt surface had greater intensity and duration of estrus compared with cows on concrete surfaces (Britt et al., 1986; Vailes and

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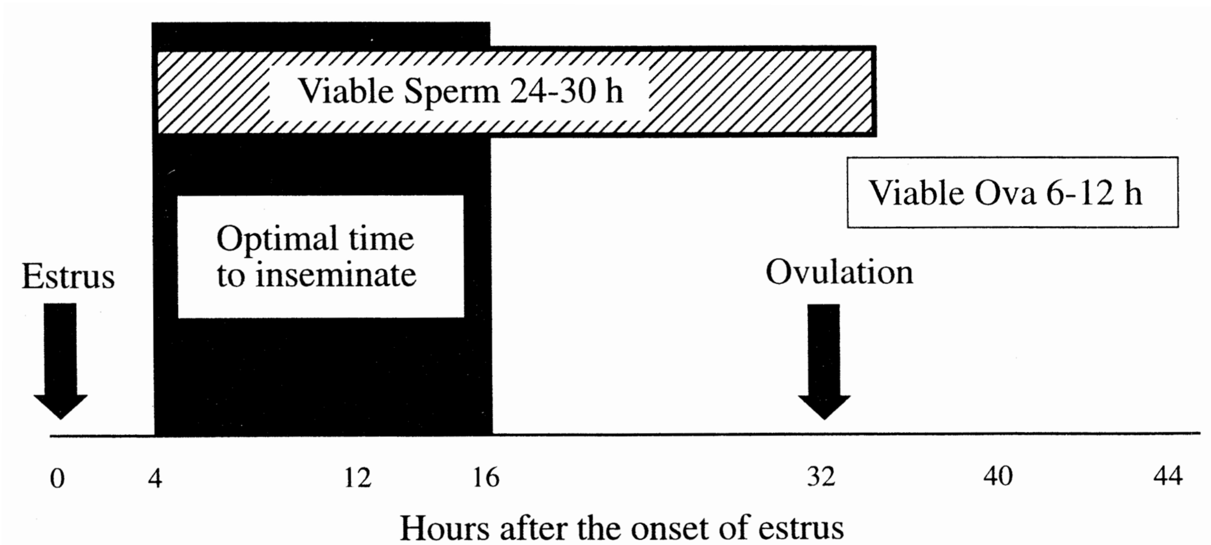

Figure 1. **Optimal time to inseminate dairy cows.**

Britt, 1990). Environmental factors such as high temperatures decrease estrous activity. Estrous behavior was greatest in dairy cows observed twice daily when ambient temperatures were less than 77°F (25°C) compared to temperatures above 86°F (30°C) (Gwazdauskas et al., 1983; Gwazdauskas, 1985).

Proper estrus detection is critical to the success of AI. Approximately 75 to 80% of cows in estrus will be identified when the herd is visually observed twice daily (30 minutes each time). When estrus detection is increased to three times daily, 85% of cows in estrus may be detected, while four daily observations identify more than 90% of cows in estrus. Several aides have been developed to help producers detect estrus, including pedometers, Kamar patches, tail paint, chin-ball markers, and radiotelemetric systems. A combination of visual observation and one or more of the detection aides increases the efficiency of estrus detection compared to visual observation or detection aides alone.

OVULATION IN DAIRY COWS

Ovulation is initiated by a surge of luteinizing hormone (LH) from the brain of cattle. This surge of LH results in the rupture of the follicle and the release of the ovum from the ovary (Espey, 1994). In dairy cows, ovulation usually occurs approximately 28 to 32 hours after the onset of estrus (Trimberger, 1948; Walker et al., 1996). After ovulation, there is only a short period when ova can be fertilized (Figure 1). Optimal fertility of ova is projected to be between 6 and 12 hours after ovulation (Brackett et al., 1980). The viable lifespan of sperm in the reproductive tract is estimated to be 24 to 30 hours (Trimberger, 1948).

ARTIFICIAL INSEMINATION RELATIVE TO ESTRUS

For the past 50 years, researchers have investigated the optimal time at which to inseminate cows relative to the stage of estrus. Trimberger (1948) found that conception rates were highest when cows were inseminated between 6 and 24 hours before ovulation. This early work led to the establishment of the "a.m.–p.m." recommendation, which says that cows in estrus during a.m. hours should be inseminated during the p.m. hours, and cows in estrus in the p.m. should be bred the following a.m. However, research with large numbers of cows indicates that maximum conception rates may not be achieved using the a.m.–p.m. rule. A large field trial (44,707 cows) found no difference in the percentage of non-return rates at 150 and 180 days (which would indicate pregnancy) between cows bred either the same morning as observed estrus, between noon and 6 p.m. on the day of observed estrus, or the following morning after observed estrus the previous evening (Foote, 1979). This indicates that a single mid-morning insemination for all cows observed in estrus the night before or the same morning should give near maximum conception. Also, cows bred once daily (between 8 and 11 a.m.) had similar non-return rates as cows bred according to the a.m.–p.m. rule (Nebel et al., 1994). Research from Virginia suggests that cows should be bred earlier than the a.m.–p.m. rule. Highest conception rates for AI occurred between 4 and 12 hours after the onset of estrus (Table 1; Dransfield et al., 1998). Cows inseminated 16 hours after the onset of estrus had lower conception rates than cows bred between 4 and 12 hours after the onset of estrus.

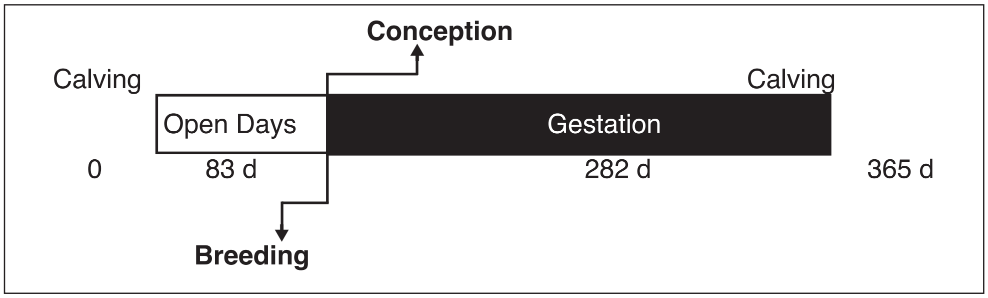

Figure 2. **Target calving interval of 365 days, or one calving per year.**

WHEN SHOULD DAIRY COWS BE INSEMINATED?

Using the traditional a.m.–p.m. rule may not provide the best conception rates because cows probably will be bred too long after the onset of estrus, so the chance for successful fertilization may be missed. The exact onset of estrus is usually unknown. For example, according to the a.m.–p.m. rule, a cow beginning estrus at 1 a.m. and observed in estrus at 6 a.m. would be bred approximately 17 to 18 hours after the onset of estrus. Breeding cows at this time would limit the number of cows that become pregnant (Table 1).

The herd should be observed twice daily, usually 30 minutes each time, to identify a majority (75–80%) of cows in estrus. Influences of the environment and managerial practices on behavioral estrus must be recognized so that failure or misdiagnosis of estrus is minimized. Cows should be inseminated within 4 to 16 hours of observed estrus when the precise onset of estrus is unknown (Figure 1). If estrous detection is conducted twice daily, most cows should be detected within this time period. A single mid-morning insemination of cows that have been observed in estrus the same morning or the previous evening should provide the best conception rates.

Table 1. Conception Rates of Dairy Cows Inseminated at Different Times After the Onset of Estrus

Interval from onset of estrus to AI (hours)[1]	Number of inseminations	Conception rate (%)
0 to 4	327	43.1
>4 to 8	735	50.9
>8 to 12	677	51.1
>12 to 16	459	46.2
>16 to 20	317	28.1
>20 to 24	139	31.7
>24 to 26	7	14.3

[1]Onset of estrus determined by HeatWatch system (DDx, Inc., Denver, CO).

CALVING INTERVAL, VOLUNTARY WAITING PERIOD, AND TIMED ARTIFICIAL INSEMINATION

Reproductive performance is determined by how quickly a heat can be detected postpartum along with successful insemination that leads to a pregnancy. Calving interval (CI) is the time from one calving to the next, and is dependent on how quickly a cow conceives after calving. The longer a cow is open (not pregnant), the longer the calving interval. Ideally, with a 12-month calving interval, a cow would become pregnant approximately 90 days after calving (Figure 2). Calving interval is primarily determined by the time open between calving and conception, and is affected by estrous cycles, estrous detection, breeding, and conception.

Detection of estrus is one of the major challenges in the reproductive management of dairy cows. Higher-producing dairy cows have reduced expression and duration of estrus (Lopez et al., 2004). An inverse relationship between milk yield and reproductive performance has been documented (Washburn et al., 2002). Genetic selection for greater milk yield in dairy cows now favors lactation at the expense of reproductive performance (Lopez et al., 2004). As a result, high-producing cows tend to have poor estrous expression, which is exacerbated by poor estrous detection by personnel, especially in larger herds.

USDA (2007) reported that the average calving interval increased from 12.8 months in 1991 to 13.2 months in 2007, and 40.5% of operations had a calving interval of over 13 months (Figure 3). If we want to reduce calving intervals, we must detect estrus and successfully breed cows without a conception loss within a reasonable period of time; however, many cows fail to present detectable estrous behavior within the first 90 days postpartum. In fact, research reports have estimated that 20 to 30% of lactating cows were not cycling by 60 days in milk (Pursley et al., 2001; Gümen et al., 2003). Because detection of estrus is insufficient to ensure high insemination rates, timed AI following

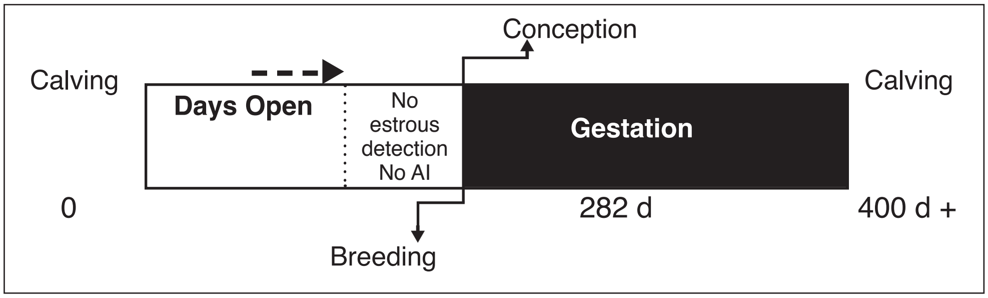

Figure 3. **Typical calving interval in U.S. dairy herds**

protocols for synchronization of ovulation (Pursley et al., 1995; Pancarci et al., 2002) has become common practice for reproductive management in dairy herds (Caraviello et al., 2006).

The development of timed artificial insemination (TAI) programs allows for reduced emphasis on detection of estrus since all cows are inseminated at a specific time relative to the timing of the GnRH (gonadotropin-releasing hormone) injection (Galva et al., 2007). Timed artificial insemination has become crucial in herds in which detection of estrus is difficult, especially in large dairy herds (Melendez et al., 2006).

How long do we need to wait before using TAI protocols? The voluntary waiting period (VWP) is a key management decision wherein the herd manager designates a target number of days postpartum after which cows will be inseminated (Figure 2). The interval from calving to first insemination provides time for uterine shrinkage. Within a herd, the VWP may be flexible (e.g., cows that were observed in estrus a few days before a fixed VWP might be inseminated before the target date). Also, some herds may have a variable VWP that may be longer by choice for high producers or for first-parity cows (Miller et al., 2007). One factor in choosing a VWP for lactating cows is that the conception rate (CR) is expected to increase as days postpartum increase (Tenhagen et al., 2003), which may be partly related to milk yield. Reducing the VWP is tempting because of associated reductions in calving interval. Williamson et al. (1980) reported that a 1-day reduction in days to first service (DFS) decreased calving interval by 0.86 days.

Protocols that allow for fixed-time insemination, such as Ovsynch (synchronization regimen using sequential injections of GnRH and PGF2 α hormones to control ovulation for TAI; Pursley et al., 1995), help overcome the pitfalls of poor detection and expression of estrus in lactating cows (Sterry et al., 2006). Farms adopting synchronization exclusively for first postpartum TAI and subsequent AI services have the opportunity to precisely determine the duration of the voluntary waiting period and improve AI service rate over time (Fricke et al., 2003). Because the 21-day pregnancy rate is a function of service risk (risk of detecting estrus) and conception risk (risk associated with a breeding), the only strategy to increase pregnancy rate over a 21-day period using this management scheme is to improve fertility to TAI (Sterry et al., 2006). Subsequent studies have reported various hormone injection protocols that allow for fixed-time insemination for improving pregnancy rates obtained with a single TAI (Portaluppi and Stevenson, 2005). Using the Ovsynch protocol has shown pregnancy rates (PR) between 30 and 40% (Pursley et al., 1995; Burke et al., 1996; Stevenson et al., 1999).

TAI has become crucial in herds in which detection of estrus is difficult, especially in large dairy herds (Miller et al., 2007). The Ovsynch protocol can be started at any time in the estrous cycle of the cow. It involves administering one dose of GnRH, followed in 7 days by PGF2 α , a second dose of GnRH 2 days after PGF2 α , and subsequent TAI 12 to 24 hours later. The protocol synchronizes ovarian follicular waves and time of ovulation (Pursley et al., 1995). This protocol would reduce days open and improve calving intervals (Figure 4).

It has been demonstrated that ovulation was synchronized more precisely and fertility was improved when the Ovsynch protocol was started between day 5 and day 12 of the estrous cycle (Vasconcelos et al., 1999; Cartmill et al., 2001). Variations of these original protocols have been developed during the last few years; it was shown that administering two doses of PGF2 α 14 days apart (Presynch) placed a large proportion of cows between day 5 and day 12 of the estrous cycle when the Ovsynch program was started 12 days after the second dose of PGF2 α (Moreira et al., 2001). Also, an intravaginal insert containing progesterone (P4) administered for 7 days between the first dose of GnRH and the administration of PGF2 α of the Ovsynch protocol showed an improved conception rate compared to TAI

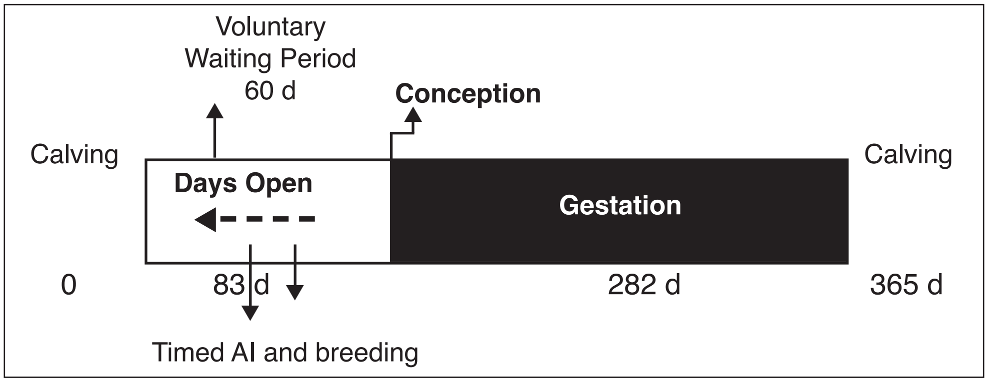

***Figure 4*. Target calving interval of 365 days with a voluntary waiting period of 60 days before timed AI. This allows for a second service on time.**

(El-Zarkouny et al., 2004; Ambrose et al., 2005; Stevenson et al., 2006).

To achieve success with any hormonal protocol, each dairy must develop a system to correctly administer all five injections to all cows enrolled in the program on the correct days required, and finally inseminate all of these cows. Failure anywhere along the line of this protocol dramatically or completely reduces the success of TAI. It is important to understand that a protocol accuracy or compliance rate of even 95% means that the final outcome is that one in four cows will not complete the five injections of the the Presynch/Ovsynch protocol (e.g., 0.95 x 0.95 x 0.95 x 0.95 x 0.95 = 0.77) (Fricke et al., 2003). Therefore, if 100% protocol compliance cannot be achieved, other methods to improve reproductive service performance, including heat detection and heat detection aids, should be considered.

NATURAL SERVICE BULL VERSUS TIMED ARTIFICIAL INSEMINATION

Timed artificial insemination using estrous synchronization and natural service (NS) using bulls are two programs that aim to overcome low estrous detection efficiency (Lima et al., 2010). The use of TAI is widespread in the U.S. USDA (2009) reported that 58% of all surveyed dairy farms used TAI programs to manage reproduction in heifers, cows, or both. Natural service by bulls is also widely used throughout the U.S. (Smith et al., 2004; De Vries et al., 2005; Caraviello et al., 2006). USDA (2009) reported that natural service was used for first service for heifers by 33% of the surveyed dairy farms and for cows by 22% of the farms. Many dairy farms use a mixture of TAI and natural service by utilizing bulls to impregnate cows still open after TAI (“cleanup bulls”).

Once cows are cleared for breeding, the bull’s job is to detect cows/heifers in estrus and breed them. With natural service, estrous detection is considered to be easy since it is the bull’s job. However, great differences exist among bulls in terms of libido. Libido refers to a bull’s desire to mate, and is thought to be a highly heritable trait. Libido has a direct effect on pregnancy rate and, as such, can influence reproductive success (Perry et al., 2010). Libido is affected by many variables, including the bull’s age, health status, and nutritional status; climate; or conditioning. Artificial insemination has many advantages compared with natural service, such as eliminating venereal diseases, more accurate dry-off dates, reduced incidence of dystocia, increased safety for farm employees (Vishwanath, 2003), and greater genetic improvement resulting in daughters that are more productive and profitable (Norman and Powell, 1992).

A common conception among dairy producers is that natural service is less expensive and an easy strategy to overcome problems with estrous detection (Lima et al., 2010). Overton (2005) compared the costs of a well-managed natural service program with that of a modified Presync-Ovsynch TAI program in conjunction with AI based on estrous detection. Reproductive performance of both programs was assumed to be the same. The cost of the natural service program was on average $10 per cow per year greater compared to the TAI program. Lima et al. (2009) compared the reproductive efficiency of natural service and TAI without estrous detection on a large commercial dairy farm in Florida and found that reproductive performance was similar for both programs, with a pregnancy rate of 25.7% and 25.0%, respectively. Lima (2010) reports that unadjusted net cost for differences in voluntary waiting period for first insemination and pregnancy rates was $100.49 per cow per year for natural service and $67.80 per cow per year for the TAI program. After adjusting for the differences in VWP and PR, the economic advantage of the TAI program was $9.73 per cow per year. Increasing semen costs could change that advantage compared to natural service. However, if increased marginal feed costs and greater genetic advantage of semen were considered, the economic advantage of the TAI program increased, and this advantage was even larger when opportunity costs for the replacement of cows by bulls was taken into consideration (Lima et al., 2010), not to mention employee safety.

CONCLUSION

Pregnancy in dairy cows is a function of both successful service and conception. Correct timing of service is easily manipulated by implementing estrus or ovulation synchronization protocols. Conception is less easily manipulated or improved, and ultimately no management program can compensate for poor protocol compliance.

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LITERATURE CITED

Ambrose, J.D., J.P. Kastelic, R. Rajamahendran, M. Aali, and N. Dinn. 2005. Progesterone (CIDR)-based timed AI protocols using GnRH, porcine LH or estradiol cypionate for dairy heifers: Ovarian and endocrine responses and pregnancy rates. *Theriogenology*, 64, 1457–1474.

Brackett, B.G., Y.K. Oh, J.F. Evans, and W.J. Donawick. 1980. Fertilization and early development of cow ova. *Biology of Reproduction*, 23, 189–205.

Britt, J.H., R.G. Scott, J.D. Armstrong, and M.D. Whitacre. 1986. Determinants of estrous behavior in lactating Holstein cows. *Journal of Dairy Science*, 69, 2195–2202.

Burke, J.M., R.L. de La Sota, C.A. Risco, C.R. Staples, E.J.P. Schmitt, and W.W. Thatcher. 1996. Evaluation of timed insemination using a gonadotropin-releasing hormone agonist in lactating dairy cows. *Journal of Dairy Science*, 79, 1385–1393.

Caraviello, D.Z., K.A. Weigel, P.M. Fricke, M.C. Wiltbank, M.J. Florent, N.B. Cook, K.V. Nordlund, N.R. Zwald, and C.L. Rawson. 2006. Survey of management practices on reproductive performance of dairy cattle on large US commercial farms. *Journal of Dairy Science*, 89, 4723–4735.

Cartmill, J.A., S.Z. El-Zarkouny, B.A. Hensley, G.C. Lamb, and J.S. Stevenson. 2001. Stage of cycle, incidence, and timing of ovulation, and pregnancy rates in dairy cattle after three timed breeding protocols. *Journal of Dairy Science*, 84, 1051–1059.

De Vries, A. 2006. Economic value of pregnancy in dairy cattle. *Journal of Dairy Science*, 89, 3876–3885.

De Vries, A. 2007. Economic value of a marginal increase in pregnancy rate in dairy cattle. *Journal of Dairy Science*, 90(Suppl. 1), 423.

De Vries, A., C. Steenholdt, and C.A. Risco. 2005. Pregnancy rates and milk production in natural service and artificially inseminated dairy herds in Florida and Georgia. *Journal of Dairy Science*, 88, 948–956.

Dransfield, M.B.G., R.L. Nebel, R.E. Pearson, and L.D. Warnick. 1998. Timing of insemination for dairy cows identified in estrus by a radiotelemetric estrus detection system. *Journal of Dairy Science*, 81, 1874–1882.

El-Zarkouny, S.Z., J.A. Cartmill, B.A. Hensley, and J.S. Stevenson. 2004. Pregnancy in dairy cows after synchronized ovulation regimens with or without presynchronization and progesterone. *Journal of Dairy Science*, 87, 1024–1037.

Espey, L.L. 1994. Current status of the hypothesis that mammalian ovulation is comparable to an inflammatory reaction. *Biology of Reproduction*, 50, 233–238.

Foote, R.H. 1979. Time of artificial insemination and fertility in dairy cattle. *Journal of Dairy Science*, 62, 355–358.

Fricke, P.M., D.Z. Caraviello, K.A. Weigel, and M.L. Welle. 2003. Fertility of dairy cows after resynchronization of ovulation at three intervals after first timed insemination. *Journal of Dairy Science*, 86, 3941–3950.

Galva, K., J. Santos, R. Cerri, R. Chebel, H. Rutigliano, R. Bruno, and R. Bicalho. 2007. Evaluation of methods of resynchronization for insemination in cows of unknown pregnancy status. *Journal of Dairy Science*, 90, 4240–4252.

Gümen, A., J.N. Guenther, and M.C. Wiltbank. 2003. Follicular size and response to Ovsynch versus detection of estrus in anovular and ovular lactating dairy cows. *Journal of Dairy Science*, 86, 3184–3194.

Gwazdauskas, F.C. 1985. Effects of climate on reproduction in cattle. *Journal of Dairy Science*, 68, 1568–1578.

Gwazdauskas, F.C., J.A. Lineweaver, and M.L. McGilliard. 1983. Environmental and management factors affecting estrous activity in dairy cattle. *Journal of Dairy Science*, 66, 1510–1514.

Hurnik, J.F., G.J. King, and H.A. Robertson. 1975. Estrous and related behavior in postpartum Holstein cows. *Applied Animal Ethology*, 2, 55–68.

Lima, F.S, A. De Vries, C.A. Risco, J.E. Santos, and W.W. Thatcher. 2010. Economic comparison of natural service and timed artificial insemination breeding programs in dairy cattle. *Journal of Dairy Science,* 93, 4404–4413.

Lopez, H., L. Satter, and M.C. Wiltbank. 2004. Relationship between level of milk production and estrous behavior of lactating dairy cows. *Animal Reproduction Science*, 81, 209–223.

Melendez, P., G. Gonzalez, E. Aguilar, O. Loera, C. Risco, and L. Archbald. 2006. Comparison of two estrus-synchronization protocols and timed artificial insemination in dairy cattle. *Journal of Dairy Science*, 89, 4567–4572.

Miller, R.H., H.D. Norman, M.T. Kuhn, J.S. Clay, and J.L. Hutchison. 2007. Voluntary waiting period and adoption of synchronized breeding in dairy herd improvement herds. *Journal of Dairy Science*, 90, 1594–1606.

Moreira, F., C. Orlandi, C.A. Risco, R. Mattos, F. Lopes, and W.W. Thatcher. 2001. Effect of presynchronization and bovine somatotropin on pregnancy rates to a time artificial insemination protocol in lactating dairy cows. *Journal of Dairy Science*, 84, 1646–1659.

Nebel, R.L., W.L. Walker, M.L. McGilliard, C.H. Allen, and G.S. Heckman. 1994. Timing of artificial insemination of dairy cows: Fixed time once daily versus morning and afternoon. *Journal of Dairy Science*, 77, 3185–3191.

Norman, H.D., and R.L. Powell. 1992. Genetic change attained and possible. In *Large dairy herd management* (pp. 59–66). Champaign, IL: American Dairy Science Association.

Overton, M.W. 2005. Cost comparison of reproductive performance by artificial insemination versus natural service sires for dairy cattle reproductive management. *Theriogenology*, 64, 589–602.

Pancarci, S.M., E.R. Jordan, C.A. Risco, M.J. Schouten, F.L. Lopes, F. Moreira, and W.W. Thatcher. 2002. Use of estradiol cypionate in a presynchronized timed artificial insemination program for lactating dairy cattle. *Journal of Dairy Science*, 85, 122–131.

Perry, G.A., J.C. Dalton, and T.W. Geary. 2010. Management factors influencing fertility in synchronized and natural breeding programs. In *Proceedings, Applied Reproductive Strategies in Beef Cattle January 28-29, 2010; San Antonio, TX.*

Portaluppi, M.A., and J.S. Stevenson. 2005. Pregnancy rates in lactating dairy cows after presynchronization of estrus cycles and variations of the Ovsynch protocol. *Journal of Dairy Science*, 88, 914–921.

Pursley, J.R., M.O. Mee, and M.C. Wiltbank. 1995. Synchronization of ovulation in dairy cows using PGF2 α and GnRH. *Theriogenology*, 44, 915–923.

Pursley, J.R., P.M. Fricke, H.A. Garverick, D.J. Kesler, J.S. Ottobre, J.S. Stevenson, and M.C. Wiltbank. 2001. NC-113 Regional Research Project. Improved fertility in anovulatory lactating dairy cows treated with exogenous progesterone during Ovsynch. *Journal of Dairy Science*. (Midwest Branch ADSA Meetings, Des Moines, IA, Abstract 251, p. 63).

Senger, P.L. 1994. The estrus detection problem: New concepts, technologies, and possibilities. *Journal of Dairy Science*, 77, 2745–2753.

Smith, J.W., L.O. Ely, W.D. Gilson, and W.M. Graves. 2004. Effects of artificial insemination vs. natural service breeding on production and reproduction parameters in dairy herds. *Professional Animal Scientist*, 20, 185–190.

Sterry, R.A., M.L. Welle, and P.M. Fricke. 2006. Effect of interval from timed artificial insemination to initiation of resynchronization of ovulation on fertility of lactating dairy cows. *Journal of Dairy Science*, 89, 2099–2109.

Stevenson, J.S., Y. Kobayashi, and K.E. Thompson. 1999. Reproductive performance of dairy cows in various programmed breeding systems including Ovsynch and combination of gonadotropin-releasing hormone and prostaglandin F2 α . *Journal of Dairy Science*, 82, 506–515.

Stevenson, J.S., J.R. Pursley, H.A. Garverick, P.M. Fricke, D.J. Kesler, J.S. Ottobre, and M.C. Wiltbank. 2006. Treatment of cycling and noncycling lactating dairy cows with progesterone during Ovsynch. *Journal of Dairy Science*, 89, 2567–2578.

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

Trimberger, G.W. 1948. *Breeding efficiency in dairy cattle from artificial insemination at various intervals before and after ovulation* [Research Bulletin 153:3]. Lincoln: University of Nebraska Agricultural Experiment Station.

USDA. 2007. Dairy 2007, Part I: Reference of dairy cattle health and management practices in the United States, 2007 USDA-APHIS-VS, CEAH. Fort Collins, CO #N480.1007.

USDA. 2009. Dairy 2007, Part IV: Reference of dairy cattle health and management practices in the United States, 2007 USDA:APHIS:VS, CEAH. Fort Collins, CO #N494.0209.

Vailes, L.D., and J.H. Britt. 1990. Influence of footing surface on mounting and other sexual behaviors of estrual Holstein cows. *Journal of Animal Science*, 68, 2333–2339.

VanRaden, P.M., A.H. Sanders, M.E. Tooker, R.H. Miller, H.D. Norman, M.T. Kuhn, and G.R. Wiggans. 2004. Development of a national genetic evaluation for cow fertility. *Journal of Dairy Science*, 87, 2285–2292.

Vasconcelos, J.L., M.R.W. Silcox, G.J.M. Rosa, J.R. Pursley, and M.C. Wiltbank. 1999. Synchronization rate, size of the ovulatory follicle, and pregnancy rate alter synchronization of ovulation beginning on different days of the estrous cycle in lactating dairy cows. *Theriogenology*, 52, 1067–1078.

Vishwanath, R. 2003. Artificial insemination: The state of the art. *Theriogenology*, 59, 571–584.

Walker, W.L., R.L. Nebel, and M.L. McGilliard. 1996. Time of ovulation relative to mounting activity in dairy cattle. *Journal of Dairy Science*, 79, 1555–1561.

Washburn, S.P., W.J. Silvia, C.H. Brown, B.T. McDaniel, and A.J. McAllister. 2002. Trends in reproductive performance in southeastern Holstein and Jersey DHI herds. *Journal of Dairy Science*, 85, 244–251.

Williamson, N.B., F.W. Quinton, and G.A. Anderson. 1980. The effect of variations in the interval between calving and first service on the reproductive performance of normal dairy cows. *Australian Veterinary Journal*, 56, 477–480.

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