Reproductive Systems for North American Dairy Cattle Herds

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KEYWORDS

- Dairy cattle • Reproductive efficiency • Reproductive management • Economics

KEY POINTS

- Reproductive inefficiency compromises the health and longevity of individual cows and the profitability of herds.
- In the average dairy herd, the combination of estrous detection and ovulation synchronization protocols yields the best economic return.
- Genomic selection of animals is particularly profitable in situations in which little is known about their genetic background.
- Biosensor systems in milking parlors may allow for the design of reproductive strategies tailored for cows according to their physiologic needs while optimizing economic return.

INTRODUCTION

Reproductive management of dairy animals has been marked by extensive progress in the past 50 years, from the creation of prostaglandin drugs (prostaglandin F2 alpha [$PGF_{2\alpha}$]) that allow the synchronization of estrus in the 1970s to the implementation of on-farm *in vitro* embryo production programs and the use of genomic selection to aid in breeding strategies. Such progress has been realized because reproductive efficiency has long been identified as critical for the profitability of dairy herds. Herds with efficient reproductive programs benefit from having a large proportion of cows in the most productive phase of lactation,[1] greater availability of replacement animals, greater genetic progress,[2,3] reduced proportion of reproduction culls,[4,5] reduced

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cost of reproductive programs,[2,4] and improved health. Furthermore, improved reproductive performance might reduce emission of greenhouse gases because of the reduced number of animals per unit of production and the reduced retention of replacement animals.[6,7]

For years, fertility in dairy cows has declined in multiple regions of the world and diverse production systems.[8–11] Changes in cow physiology associated with greater milk production, nutritional management, housing, increased herd size, reduced expression of estrus, and genetic makeup of the dairy cattle population have been identified as reasons for the decrease in reproductive efficiency.[8,12,13] Nonetheless, the downward trend in reproductive efficiency has been virtually halted because of the extensive progress in the knowledge of reproductive biology, physiology, and management.[14] For example, calving interval (CI) has declined significantly in the past 10 years (**Fig. 1**A), most likely because of reduced calving to first artificial insemination (AI) interval (**Fig. 1**B, C).[14] The positive trend in daughter pregnancy rate (DPR) observed in the past 10 years (**Fig. 1**D)[14] may be a result of more controlled voluntary waiting periods (VWPs) and shorter calving to first AI intervals. However, the importance of modern genetic selection programs that have focused on milk yield, productive life, reproduction, and health should not be disregarded.[3,6,13]

REPRODUCTIVE EFFICIENCY AND DAIRY HERD PROFITABILITY

The income of dairy herds is mainly originated from sales of milk (88% of gross income), cows for dairy purposes, cull animals, and calves (12% of gross income),[15] whereas the largest expenses are associated with feeding the herd (60% of total operating costs) and rearing replacement animals (25% of total operating costs).[15] Reproductive efficiency affects the profitability of dairies in several ways that are not always easy to account for. Improved reproductive performance has many beneficial effects: increased efficiency of milk production by shifting the milking herd to a more productive phase of the lactation[1]; improved income over feed cost (IOFC) and milk yield per day of CI[16]; reduced reproductive culls,[5] reduced need for replacement animals and increased percentage of the lactating herd that is multiparous[4,15]; improved genetic gain because of more selective culling of lactating cows and more stringent selection of replacement animals[13,15]; and, reduced cost of reproductive interventions.[2,4] However, significant improvement in reproductive performance results in a greater proportion of the adult herd dry,[4] demanding proper planning to accommodate dry cows and maternity needs.

The lactation curve and the dry matter intake (DMI) of mature cows determine that the efficiency of milk production is significantly greater during early versus late lactation (**Fig. 2**).[16] Consequently, the highest efficiency of milk production is achieved when most of the cows in a herd conceive within the first 100 days in milk (DIM). For example, consider 2 herds that have a VWP of 50 days, an average DIM at first AI of 60 days, and cows that are eligible to become pregnant for 13 consecutive cycles (from 50 to 312 DIM). In the herd with average milk yield of 12,500 kg per 305 days of lactation, improving 21-day pregnancy rates (PR; i.e., the percentage of eligible cows that become pregnant every 21 days) from 12% to 33% would reduce the average CI by 63 days (from 440 to 377 days) and result in an increase of 7% in the IOFC and 1.51 kg of milk per cow per day of CI (551 kg of milk per cow per year; **Fig. 3**A).[16] If the same improvements in 21-day PR are achieved in the herd with average milk yield of 9000 kg per 305 days of lactation, IOFC would increase 8% and milk yield would increase by 1.11 kg per cow per day of CI (405 kg of milk per cow per year;

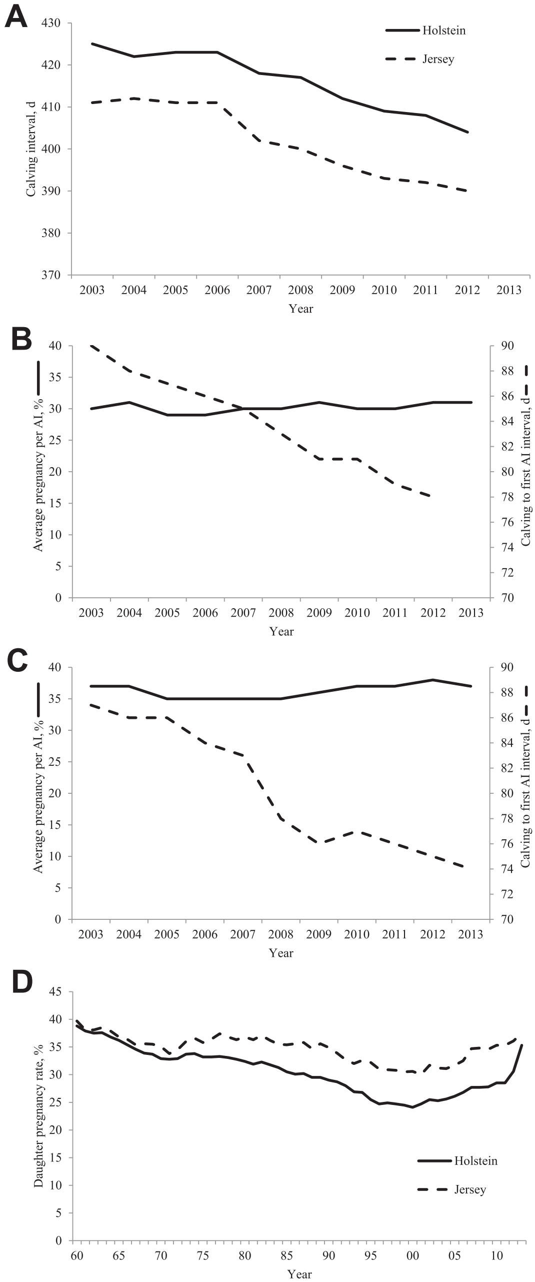


Fig. 1. (*A*) Average calving interval in Holstein (*solid line*) and Jersey (*dashed line*) cows in dairy herd improvement programs in the United States. (*B*) Average pregnancy per AI (*solid line*) and interval from calving to first postpartum AI (*dashed line*) among Holstein cows enrolled in dairy herd improvement programs in United States. (*C*) Average pregnancy per AI (*solid line*) and interval from calving to first postpartum AI (*dashed line*) among Jersey cows enrolled in dairy herd improvement programs in United States. (*D*) Average DPR of Holstein (*solid line*) and Jersey (*dashed line*) sires. (*Data from* Norman HD, Walton LM, Durr J. Reproductive status of cows in dairy herd improvement programs and bred using artificial insemination. Council on Dairy Cattle Breeding; 2013. Available at: https://www.cdcb.us/publish/dhi/current/reproall.html.)

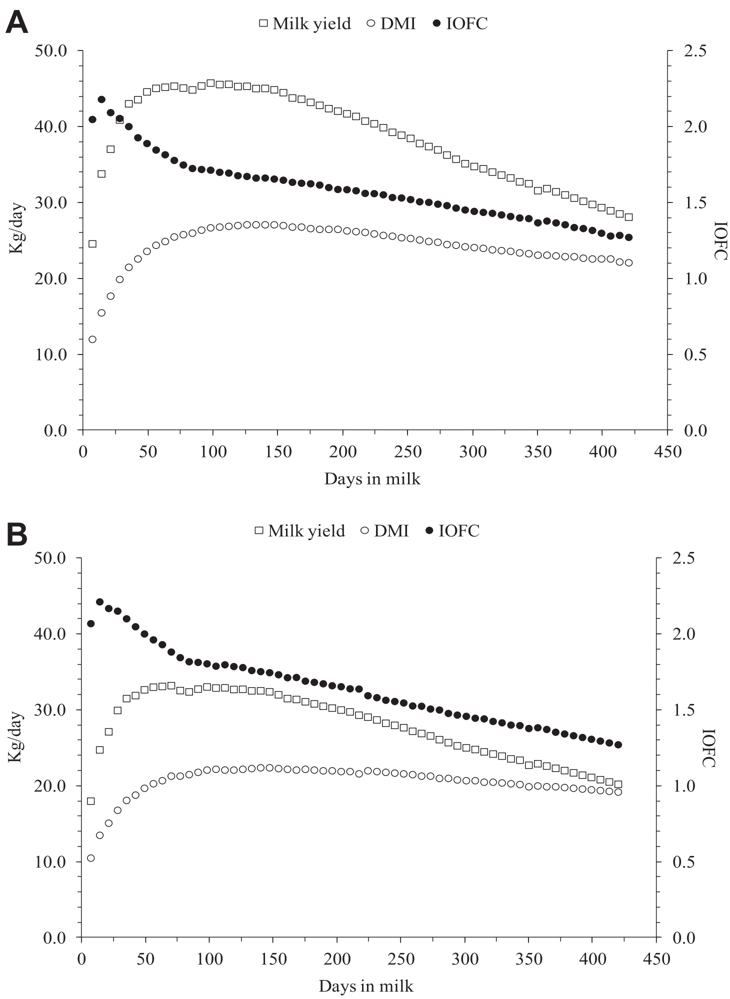


Fig. 2. Milk yield (kg/d; □), DMI (kg/d; ○), and milk IOFC (dollars of income per dollars of feed consumed; •) according to days in milk. Milk price was set at $0.35/kg in all scenarios. (*A*) High-producing herd (12,500 kg per 305 days of lactation) with feed price at $0.35/kg of dry matter. (*B*) A moderate-producing herd (9000 kg per 305 days of lactation) and feed price at $0.29/kg of dry matter. (*From* Ribeiro ES, Galvão KN, Thatcher WW, et al. Economic aspects of applying reproductive technologies to dairy herds. Anim Reprod 2012;9:370–87.)

Fig. 3B).[16] The economic gains of improving reproductive performance in herds with higher productivity and more persistent lactation curve may not be as dramatic.[17]

The economic value of improved reproductive performance is not easily determined, is particular for given production systems, and is affected by several factors. Several researchers have created models to estimate the value of increasing 21-day PR or reducing the calving to pregnancy interval (days open) according to different scenarios. De Vries[17] suggested that the cost of a day open varies from $0 to $6.00 depending on DIM, milk production and price, feeding costs, persistency of lactation curve, lactation number, culling policies, and availability of replacement heifers. Groenendaal and colleagues[18] estimated the cost of a day open to be $1.25, $2.10, and

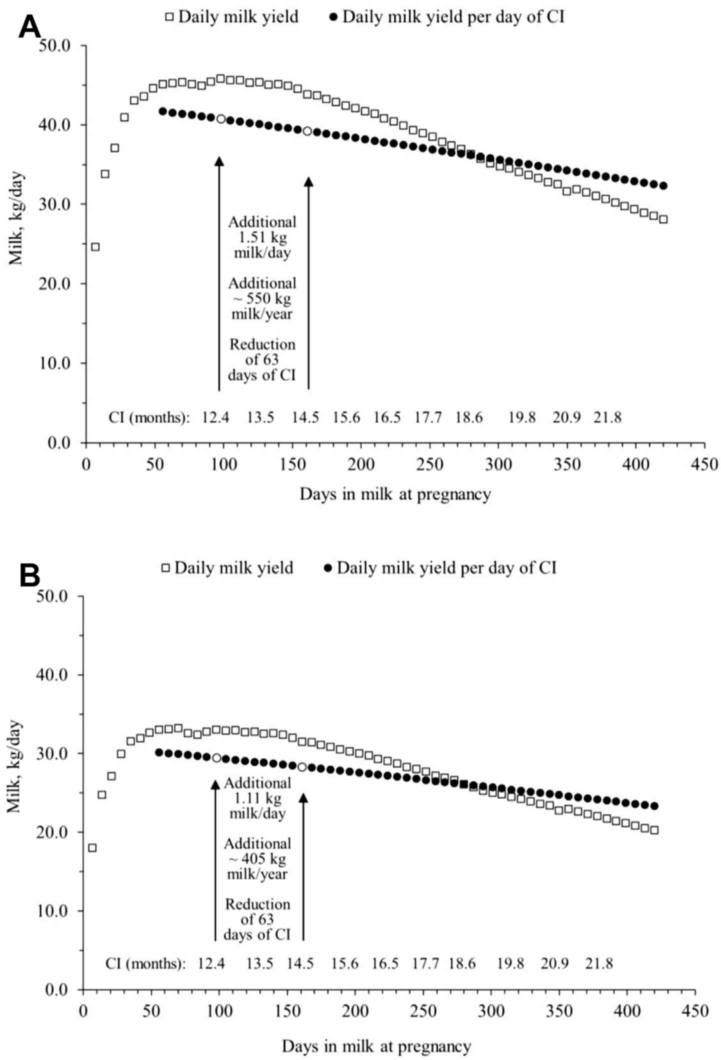


Fig. 3. Lactation curve and resulting milk production per day of CI according to DIM at pregnancy in a high-producing herd (12,500 kg in 305 days of lactation [*A*]) and in a moderate-producing herd (9000 kg of milk in 305 days of lactation [*B*]). (*From* Ribeiro ES, Galvão KN, Thatcher WW, et al. Economic aspects of applying reproductive technologies to dairy herds. Anim Reprod 2012;9:370–87.)

$2.75 up to 90, 150, and 210 DIM, respectively. Researchers have also created models to estimate the value of newly established pregnancies and the cost of pregnancy losses. De Vries[17] proposed that the difference in retention pay off (RPO; the economic benefit of keeping a cow in the herd vs. culling and replacing it with a replacement heifer) of pregnant and nonpregnant cows provides an estimate of the value of a new pregnancy (assuming equal milk yield, DIM, lactation curve persistency, and lactation number).[19] According to this theory, the value of a pregnancy is less early postpartum because there is little difference in RPO between pregnant and nonpregnant cows. The value of a pregnancy increases dramatically in later stages of lactation. For example, when evaluating 2 cows in later stages of lactation with equal milk yield, lactation curve persistency, and lactation number, it is more profitable to replace the nonpregnant cow for a replacement heifer, whereas it is profitable to keep the pregnant cow.[19] According to De Vries,[17] establishing a new pregnancy in the early stages of lactation is highly valuable for low-producing cows and cows with low persistency of the lactation curve but establishing a new pregnancy too early postpartum in high-producing cows and cows with high persistency of the lactation curve may result in economic losses.[19] The value of a new pregnancy has been estimated to range from −$100 to $500[19] and from $128 to $232.[20] In contrast, the cost of a pregnancy loss ($0 to $1373[19]; $128 to $897[20]) increases as stage of lactation, stage of gestation, and milk yield increase.[19]

The aforementioned research may lead to the suggestion that reproductive management should be tailored to the individual to optimize economic return. Although this may be possible in small herds, and in the future in large herds, the present reality of large herds demands reproductive management systems that are robust and meet the needs of most cows in a group. With that in mind, many herds adopt robust reproductive strategies for first postpartum AI and reinsemination of all cows,[21] and some herds adopt different VWP according to parity. The average VWP is approximately 55 days in US dairy herds, with nearly 75% of dairies having a VWP of 41 to 60 DIM (**Fig. 4**),[22] and the average interval from calving to first AI is 78 ± 0 and 74 ± 0.1 days for Holstein and Jersey cows, respectively.[14] The VWP should be established based on the anticipated optimum time for establishment of pregnancy and on the reproductive efficiency of the herd. In most herds it is not possible to precisely control when a cow becomes pregnant and it is necessary to adopt a short VWP. **Fig. 5** shows the estimated VWP for herds according to the desired interval from calving to pregnancy and 21-day PR, maintaining a maximum of 13 reproductive cycles. To achieve an average days open of 110 days, herds with 21-day PR less than 25% need to have VWPs less than 50 DIM, which is often associated with reduced

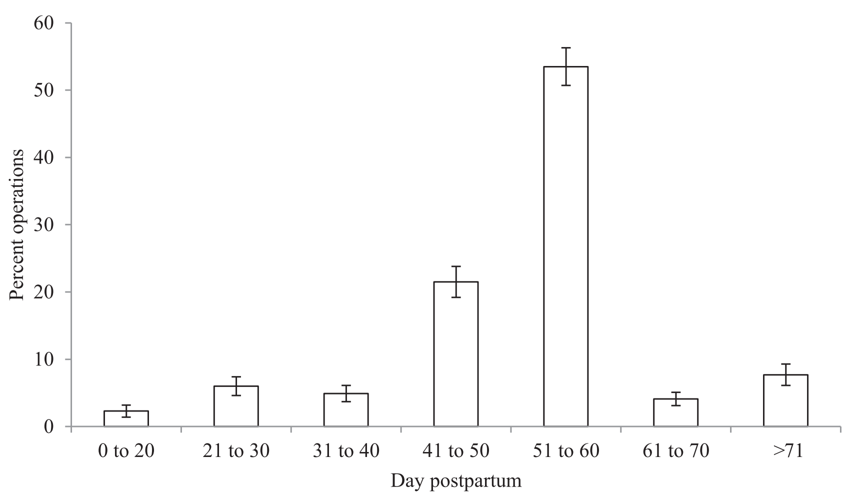


Fig. 4. Observed VWP in dairy farms in the United States according to a recent survey. (*Data from* Norman HD, Walton LM, Durr J. Reproductive status of cows in dairy herd improvement programs and bred using artificial insemination. Council on Dairy Cattle Breeding; 2013. Available at: https://www.cdcb.us/publish/dhi/current/reproall.html.)

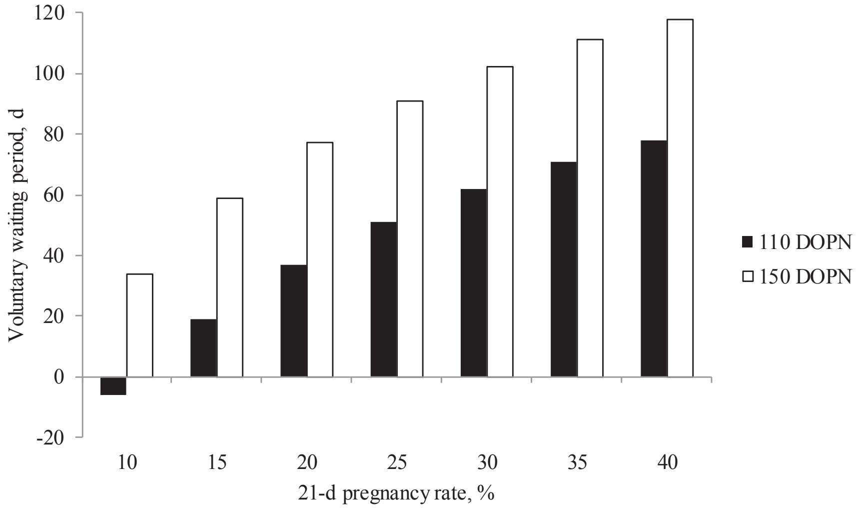


Fig. 5. Estimated VWP to achieve median days open (DOPN) of 110 or 150 days according to the 21-day pregnancy rate (breeding cycles kept constant = 13). Negative VWP values are the result of calculations and are not possible to achieve.

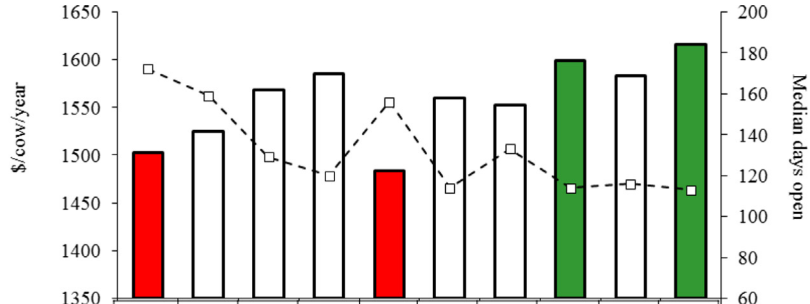
fertility. In contrast, herds that need to achieve 150 days open and have 21-day PR greater than 25% may have VWPs greater than 80 DIM. De Vries[17] suggested that the ideal interval from calving to pregnancy is, on average, 133 days for first-lactation cows and 112 days for second-lactation cows, but could be reduced to 63 and 51 days for cows with low production and low lactation persistency. In summary, herds with reduced milk yield, poor lactation curve persistency, and low 21-day PR must have short VWP and aggressive reproductive management. In contrast, herds with persistent lactation curves, high milk yield, and increased 21-day PR may benefit from extending the VWP.

Greater reproductive efficiency reduces the number of reproductive culls, which affects replacement policies because dairy managers may make culling decisions based on economic aspects rather than biological considerations.[18] In most scenarios, reduced reproductive efficiency forces managers to either reduce selection pressure, otherwise number of lactating cows may be reduced, affecting cash flow, or purchase replacement heifers to replace cows culled for reproduction failure, jeopardizing genetic improvement and the biosecurity of the herd. Dairies that have efficient reproductive management often have a surplus of replacement heifers.[4] Rearing replacement heifers accounts for approximately 25% of the total cost of dairy operations,[15] but herds with good reproductive performance may be more selective in replacement selection and may profit from the sale of heifers for dairy purposes.

REPRODUCTIVE EFFICIENCY AND BREEDING STRATEGIES

Development of $PGF_{2\alpha}$ in the 1970s produced significant advancements in reproductive management of dairy cattle. Although $PGF_{2\alpha}$ treatment causes luteolysis and induces estrus in a large proportion of cyclic animals, accuracy and efficiency of estrous detection are variable and depend on animal, environmental, and management factors.[23–25] In the late 1990s, ovulation synchronization protocols (OVSPs; eg, Ovsynch[26]) were developed, allowing the fixed-time AI of cows while producing acceptable pregnancy per AI (P/AI; number of cows pregnant divided by the number of cows inseminated). Implementation of OVSP for timed AI increases yearly profit per cow by $30 compared with AI on detected estrus (DE) alone[27] and reduces the cost per pregnancy by 80 to $148 compared with AI on DE alone.[17]

The use of OVSP for timed AI of lactating dairy cows has become popular to the point of some producers using it exclusively to manage their herds. However, questions arise concerning what is the most profitable reproductive management strategy (eg, 100% OVSP, 100% AI on DE, combination of OVSP and AI on DE). To answer this question, it is important to consider a few facts. One of the most important is that identification of nonpregnant cows following AI may be done by observed return to estrus or by nonpregnancy diagnosis. In most herds that adopt estrous detection, 40% to 60% of nonpregnant cows are observed in estrus and reinseminated between 3 and 28 days after a previous AI (average 22 days). In contrast, nonpregnancy diagnosis by transrectal ultrasonography may be done as early as 26 days after AI with proper accuracy and efficiency and, if an aggressive OVSP for timed AI is adopted, cows could be reinseminated as early as 29 days after previous AI. Thus, the interval to reinsemination in herds that adopt estrous detection may be reduced by 4 or more days when compared with herds that do not reinseminate cows based on signs of estrus. Although this may lead to the suggestion that adopting estrous detection is advisable, this is not always the case. In herds in which efficiency of estrous detection is high but accuracy is low, it may be deleterious to increase the number of cows inseminated in estrus. Giordano and colleagues[28] indicated that when P/AI of cows inseminated in estrus is 25%, increasing the percentage of cows inseminated in estrus from 30% to 80% decreases net return per cow per year from −$7.91 to −$14.84 per cow per year compared with 100% OVSP and timed AI. Tenhagen and colleagues[29] showed that when P/AI of cows inseminated in estrus is adequate (35%–40%) and the estrous detection rate is approximately 55%, herds may rely more heavily on AI on DE but when estrous detection rate is extremely low (<30%) it may be more advantageous to implement aggressive OVSP for timed AI. Galvão and colleagues[4] simulated in a herd of 1000 cows the best economic outcomes of reproductive programs that used 100% OVSP and timed AI with differing levels of compliance (85% and 95%), 100% AI on DE with differing levels of efficiency (40% and 60%) and accuracy (85% and 95%), and a combination of OVSP and timed AI and AI on DE. Pregnancies per AI of the different protocols were estimated from the literature. According to this simulation, the reproductive programs that resulted in the best return per cow per year, the greatest 21-day PR, and the shortest average DIM were programs that combined OVSP for timed AI and AI on DE.[4] As expected, poor compliance with OVSP and poor estrous detection efficiency and accuracy had important detrimental effects on the profitability of the herds (**Fig. 6**).[4] According to Kalantari and Cabrera[30] the best economic return was obtained when 80% of cows were inseminated on DE, P/AI of cows inseminated on DE was 35%, and P/AI of cows inseminated at fixed time following OVSP were 30% and 28% for first AI and reinseminations, respectively. This finding raises an important topic that is often overlooked when discussing reproductive management of lactating dairy cows and heifers: labor force. Proper training and education of the labor involved in all aspects of reproductive management is fundamental for the success of such programs. Veterinarians and consultants have a prime opportunity to make themselves indispensable to dairy producers when they become involved in training, educating, and monitoring the performance of the labor involved in these tasks. In conclusion, no single reproductive management strategy fits all dairy herds in North America. Before a reproductive management strategy is recommended, it is important to evaluate facilities (eg, freestall, open lots, tie stalls) and management (eg, severe overstocking), personnel (eg, training, education),



Reproductive program	1	2	3	4	5	6	7	8	9	10
Characteristics of the reproductive programs										
Compliance TAI, %	---	---	---	---	85	95	85	95	85	95
ED, %	40	40	60	60	---	---	40	40	60	60
ED accuracy, %	85	95	85	95	---	---	85	95	85	95

Fig. 6. Mean profit per cow per year ($/cow/y; bars) and median days open (dashed line) according to 10 breeding programs. Milk price set at $0.44/kg. Red bars represent the breeding programs with the lowest profit per cow per year and the green bars represent the breeding programs with the highest profit per cow per year. ED, estrous detection; TAI, timed artificial insemination. (*Data from* Galvão KN, Federico P, De Vries A, et al. Economic comparison of reproductive programs for dairy herds using estrous detection, timed artificial insemination, or a combination. J Dairy Sci 2013;96:2681–93.)

herd composition (eg, breed, percentage of first lactation cows), adoption of new technologies, record keeping, and cow health.

Automated estrous detection systems (eg, pedometers or activity monitors) have had greater penetration in the US dairy industry in the past 10 years. These systems predict estrus with 70% to 80% accuracy based on changes in behavioral patterns[31] and their performance is comparable with that of mount detection devices.[32] Although it has often been suggested that the adoption of automated estrous detection systems in the management of dairy herds may eliminate the need for OVSP for timed AI and reduce hormone use in dairy herds, this is not necessarily true. Unquestionably, herds with poor estrous detection efficiency and accuracy may benefit significantly from the use of automated estrous detection systems. However, the automated estrous detection systems do not detect in estrus cows that do not display estrus (eg, anovular cows). In recent experiments, 7% to 44% of cows were not detected in estrus by such systems.[32–34] Therefore, most herds that adopt automated estrous detection systems still need to implement OVSP for timed AI of cows that do not display estrus. The cost of the automated estrous detection systems may easily be compensated for by significant improvements in estrous detection efficiency and accuracy, which lead to improved 21-day PR. Thus, it may be assumed that herds with low estrous detection efficiency and poor P/AI of cows inseminated on DE would realize economic gains when adopting automated estrous detection systems, particularly when such systems have long durability. Furthermore, automated estrous detection systems may help to optimize the timing of insemination of heifers and lactating cows with sex-sorted semen and improve their P/AI,[35,36] which may be an attractive strategy for herds that desire a larger pool of replacement heifers.

According to the NAHMS (2009)[22], 25% of the dairy calves born in the United States are from cows sired by natural service.[22] Although many producers defend the use of natural service with the belief that reproductive performance may be improved compared with AI systems, epidemiologic studies have shown that reproductive performance is not altered[37] or worsened[38] for natural service compared with AI based on DE or OVSP systems. Lima and colleagues[39,40] compared reproductive performance and economic return of reproductive management based on 100% OVSP for timed AI versus 100% natural service. The OVSP for timed AI was aggressive to ensure timely reinsemination of cows that failed to conceive to a previous AI. Similarly, sires were aggressively managed and underwent a breeding soundness examination every 3 months (including trichomoniasis screening), the bull to open cow ratio was 1:20, exposure period to rest period pattern was 14:14 days, and bulls were evaluated weekly for health problems and replaced if necessary. The median interval to pregnancy was slightly shorter for the natural service (111 vs 116 days) but, because of the cost of feeding sires and gains in genetic merit by using semen for timed AI, the economic return was approximately $32.47 per cow per year greater for the 100% OVSP for timed AI versus the 100% natural service.[39,40] In summary, natural service may be a reproductive strategy for managers who do not have the ability to manage the activities necessary for AI (estrous detection or OVSP, labor, semen inventory, inventory of AI consumables); however, natural service is not a strategy to improve the reproductive performance or genetic composition of the herd, and it is more costly than AI programs.

REPRODUCTIVE EFFICIENCY AND HEALTH

Although constantly overlooked, reproductive efficiency also is associated with overall health of dairy herds and individual cow health. As mentioned earlier, improved reproductive efficiency reduces both the number of reproductive culls[5] and the need for replacement heifers,[4] whereas the availability of replacement heifers increases.[4] Therefore, herds with efficient reproductive management that are not expanding do not need to purchase replacement heifers to maintain a constant number of lactating cows in the herd, reducing the risk of a breach in biosecurity and introduction of contagious and infectious diseases.

Improved reproductive performance is also expected to improve the health of individual cows. Success of the reproductive program and gestation length determine the CI. In most herds the dry period is constant (45–60 days in most US dairy herds)[22] and extending the CI results in cows spending a larger amount of time in the less efficient stages of lactation.[1] Therefore, cows that do not conceive promptly after the VWP tend to gain a significant amount of body fat reserves during the final stages of lactation, even when herds adjust rations according to milk yield. According to a large data set (8989 lactations from 2 CA herds), body condition score (BCS) at dry-off was mainly explained by 305-day mature equivalent milk yield, interval from calving to establishment of pregnancy, and number of lactations (**Fig. 7**; Chebel and Mendonça, unpublished data, 2012). In general, there was a positive correlation between interval from calving to conception and BCS at dry-off and a negative correlation between 305-day mature equivalent milk yield and BCS at dry-off.

Excessive accumulation of fat poses a significant risk for the health of periparturient dairy cows because obese cows have more dramatic immunosuppression during this period than thinner cows.[41,42] Predisposing factors for reduced innate immune function during the prepartum period are hormonal alterations associated with parturition,[43] reduced DMI,[44] increased concentrations of nonesterified fat acids and beta-hydroxy butyrate,[44–47] and decreased concentration of insulin-like growth factor-1.[48,49] Consequently, conditions that limit DMI and exacerbate negative energy balance during the periparturient period increase the risk of infectious diseases.[50]

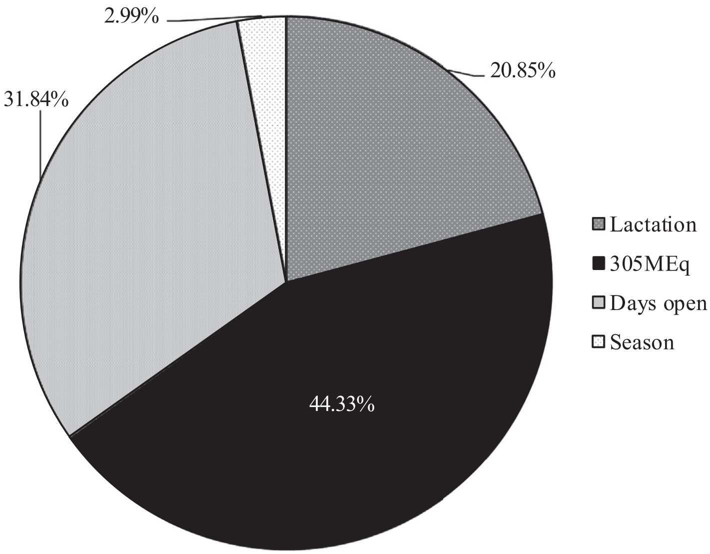


Fig. 7. Proportion of variation in BCS at dry-off accounted for by 305-day mature equivalent milk yield, interval from calving to pregnancy (days open), lactation, and season (winter vs summer). R^2 of multivariate model = 0.184 (Chebel and Mendonça, unpublished data, 2012).

Obese cows (BCS $\sim$ 4.0) had reduced DMI during the last 21 days of gestation and had a more dramatic decrease in DMI from 21 to 1 day before calving.[51] Furthermore, BCS 21 days before calving explained 9.7% of the variability in DMI from 21 to 1 day before calving.[51] Consequently, obese cows are more likely to lose BCS and body weight during the periparturient period than thinner cows.[52,53] In a model that explained 38.7% of the variability in BCS change during the dry period, BCS at dry-off explained 90.6% of its variability (**Fig. 8**; Chebel and Mendonça, unpublished data, 2012). The association between BCS loss during the dry period and incidence of postpartum diseases also was investigated. Loss of BCS during the prepartum period increased the likelihood of diseases such as retained fetal membranes, metritis, and digestive disorders and increased the likelihood of cows being removed from the herd within 30 and 60 DIM (**Table 1**; Chebel and Mendonça, unpublished data, 2012).

In summary, excessive BCS at dry-off reflects poor milk yield and/or poor reproductive efficiency. Obese cows have compromised immune and metabolic functions in the prepartum period and are more likely to present postpartum health disorders. Because the occurrence of metabolic and infectious diseases early postpartum has a negative impact on reproductive performance,[25,54] a so-called revolving-door scenario is established, jeopardizing the lifetime production of cows.

THE ROLE OF GENOMIC SELECTION IN REPRODUCTIVE MANAGEMENT OF DAIRY HERDS

Genetic selection of the Holstein breed was focused mainly on milk yield until approximately 10 years ago. However, a negative correlation exists between genetic traits for milk yield and other traits, including reproductive efficiency.[55,56] Consequently, compared with genetically inferior cows for milk yield, a population of genetically superior cows for milk yield presents important physiologic and behavioral alterations that may, at least in part, be the cause of the reduced reproductive efficiency observed

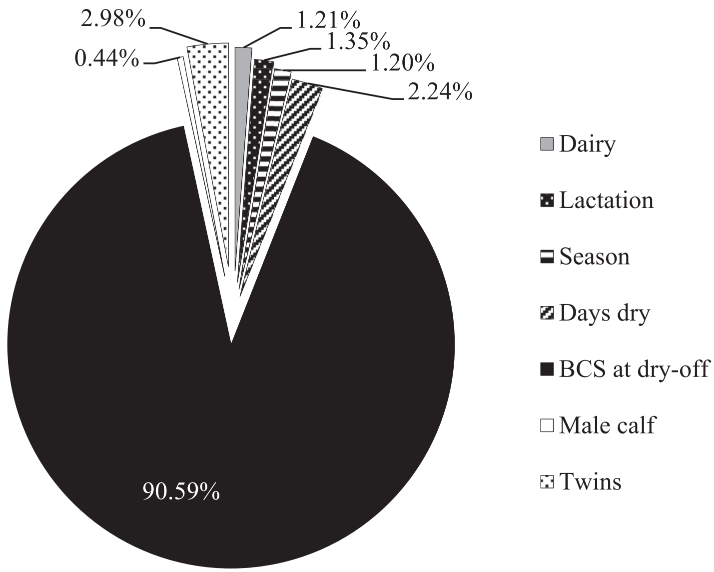


Fig. 8. Proportion of variation in BCS loss accounted for by herd, lactation, season (winter vs summer), length of the dry period, BCS at dry-off, calf sex, and number of calves (singleton vs twins). R^2 of multivariate model = 0.387 (Chebel and Mendonça, unpublished data, 2012).

from the 1950s to the beginning of the current century. A breeding project that started in 1964 at the University of Minnesota provides evidence that genetic selection for high milk yield is associated with physiologic alterations of dairy cows that affect fertility. Cows bred continuously with semen of sires and sons of sires with predicted

Table 1
Association between BCS change during the dry period and incidence of postpartum health disorders, removal from the herd within 30 and 60 DIM, and rate of removal from the herd up to 305 days postpartum (Chebel and Mendonça, unpublished data, 2012)

	BCS Change During the Dry Period				
Items	**≥+0.25**	**0**	**−0.25 to −0.5**	**≤−0.75**	***P* Value**
Cows, n (%)	1384 (15)	3852 (43)	3551 (40)	202 (2)	—
RFM (%)	3.0[a,B]	3.4[a,B]	5.5[b]	7.4[B]	<.01
Metritis (%)	10.0[a]	12.3[a]	15.7[b,A]	20.8[b,B]	<.01
GI disorders, %	2.6[a]	2.4[a]	4.8[b]	9.9[c]	<.01
At least 1 disease (%)	15.0[a,c,A]	17.4[a]	24.7[b,B]	34.2[c]	<.01
Removal by 30 DIM (%)	3.0[a]	2.8[a]	5.1[b]	12.9[c]	<.01
Removal by 60 DIM (%)	5.1[a]	4.5[a]	7.6[b]	15.4[c]	<.01
Culling rate (AHR and 95% confidence interval)	0.88[a] (0.77, 1.01)	Reference[a]	1.14[b] (1.04, 1.25)	1.73[c] (1.36, 2.19)	<.01

Abbreviations: AHR, adjusted hazard ratio; GI, gastrointestinal; RFM, retention of fetal membranes.
[a,b,c] Within a row, values with different superscripts differ ($P < 0.05$).
[A,B] Within a row, values with different superscripts differ ($0.05 < P < 0.10$).

transmitting ability (PTA) milk average for the 1960s (unselected = 6890 ± 403 kg per 305-day lactation) have milk yield ~4000 kg per 305-day lactation less than cows bred continuously to sires with the highest PTA milk from each year (selected = 11,078 ± 329 kg per 305-day lactation).[57,58] Unselected and selected cows had similar body weight, degree of fat depot mobilization during the peripartum period, and energy balance during the postpartum period.[59,60] However, unselected cows had lower growth hormone concentration during lactation and higher insulin like growth factor-1 concentration until 12 weeks of lactation.[59–61] These differences in somatotropic axis are critical for resumption of ovarian cycles following parturition.[62] Consequently, unselected cows resumed ovarian cycles ~10 days sooner and had greater progesterone concentration during the first 3 estrous cycles postpartum compared with selected cows.[60,63] These experiments show that genetic selection for high milk yield alters reproductive physiology of lactating dairy cows directly or indirectly (as suggested by Sangsritavong and colleagues[64]).

Conventional methods of genetic selection (parental average [PA] and PTA) are limited in their ability to improve the genetic progress of traditional fertility traits (eg, DPR, CI) because such traits have low heritability.[3,65–67] Heritability of productive traits ranges from 0.30 (mature equivalent milk, fat, and protein yield) to 0.58 (fat percentage), whereas heritability of reproductive traits ranges from 0.04 (interval from calving to first insemination) to 0.23 (interval from calving to first ovulation). The low heritability of traditional reproductive traits may reflect a dependence on a multitude of cow and managerial factors. For example, DPR is the speed at which animals become pregnant, assuming a 60-day VWP. Consequently, this variable is highly affected by the actual VWP adopted on-farm, use of fixed-time AI, and use of natural service. Similarly, CI depends on the interval from calving to resumption of ovarian cycles, estrous expression, estrous detection efficiency, establishment and maintenance of pregnancies, and length of gestation.[68] Despite the low heritability of traditional reproductive traits, the implementation of genetic evaluation for DPR starting in 2003 is thought to have contributed to increases in reproductive performance of Holstein and Jersey breeds.[3] Physiologic characteristics of cows that depend less on management and affect reproductive performance (eg, postpartum resumption of ovarian cycles and pregnancy loss) may present higher heritability and may be better candidates for genetic selection.[12,69,70]

The generation of PA and PTA data demands large investments of time and resources, which still do not guarantee 100% accurate information because of inherent confounding of some phenotypes (eg, DPR and CI).[71] In recent years, cattle breeders and producers have gained access to more affordable genomic evaluation. Initially (late 2007), only young males and elite females were tested using the 50,000 (50K) bovine single-nucleotide polymorphism probes because cost limited its broader use in the cattle population. Since 2010 a more affordable array (3K probes) has been available to the dairy industry. The low-density array (3K) may be used effectively for imputation of the 50K probes and produces results (genomic PTA [GPTA]) that are almost as accurate as the results produced with the 50K probes.[72,73] The use of GPTA for selection of future sires presents economic advantages because of its higher reliability compared with PA or PTA, because it expedites genetic gains through shortening of generation intervals, and because it allows the elimination of lower GPTA animals soon after birth.[74] In recent years, 90% of young Holstein and Jersey sires have been selected using GPTA.[75] However, questions remain on how commercial producers may use GPTA information in their reproductive programs. The cost of genomic testing is ~$40 per animal, demanding that a clear strategy to use the GPTA information generated be designed to result in profits. Weigel and colleagues[76] simulated lifetime net merit (LNM$) gains that dairy herds may realize by using GPTA for selection of females, taking into consideration reliability of the test and selection strategy. According to this simulation, reliability of selection would be smallest when heifer calves of unknown pedigree are selected based on phenotype alone, and reliability of selection would be maximum when sixth-lactation cows with complete pedigree are selected based on GPTA. According to the investigators, genomic testing is more valuable when less is known about an animal's genetic potential (heifer calves or animals with no pedigree).[76] Use of GPTA for selection of heifer calves with no pedigree resulted in an increase in LNM$ of $66 to $259 per animal, whereas use of GPTA for selection of heifer calves with full pedigree resulted in increase in LNM$ of $19 to $87 per animal.[76] Claus and colleagues[77] also estimated the benefits of using GPTA to select replacement heifers according to different scenarios. In general, an economic advantage was observed when using GPTA to select replacement heifers, particularly when little was known about their genetic potential, replacement heifers were abundant, cost of testing was low, accuracy of GPTA was significantly higher than PTA, and benefits of genetic improvement were higher.[77] In summary, genomic testing may result in significant economic gains when a clear strategy exists to make use of the GPTA data. Increased use of GPTA for selection of replacement heifers will improve the quality of genetic information of herds, increasing the reliability of PTA selection and, possibly, reducing the economic advantage of using GPTA, unless niche markets are explored (stock farms) or the cost of genomic testing is reduced significantly.

FUTURE CONSIDERATIONS

Biosensor systems within the milking parlor (eg, AfiLab system and Herd Navigator) are currently available in Israel, Europe, Canada, and a few select markets of the United States. Such systems allow the daily monitoring of dairy cows for several metabolites and biological markers that are used to estimate energy balance, identify occurrence of metabolic (eg, ketosis) and infectious (eg, mastitis) diseases, and to predict stage of the estrous cycle and pregnancy status (eg, in-line determination of progesterone and pregnancy-associated glycoprotein concentrations). Such systems coupled with technologies currently available (eg, GPTA, activity monitors/pedometers, rumination monitors, ultrasonography, OVSP for timed AI, sex-sorted semen) will facilitate the design of reproductive strategies for specific groups of cows according to their physiologic needs while maximizing profitability.

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