Advancing Genetic Gain in Dairy Cattle through Genomics and Reproductive Technologies

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Take Home Messages

- Routine genomic testing of all female calves is now a common management practice on many commercial dairy farms, and these tests can provide accurate predictions of future production, type, health, and fertility at a very young age.
- Use of sexed semen and beef semen for artificial insemination (AI) in dairy herds has reached unprecedented levels in a short period of time, and many producers have implemented customized plans to create the desired number of replacement heifers and value-added crossbred calves.
- Use of embryo transfer (ET) and in vitro fertilization (IVF) has increased at a slower rate because of costs and logistical considerations, but these technologies can lead to remarkable rates of genetic progress when implemented effectively.
- The aforementioned reproductive technologies and breeding strategies can be implemented with or without genomic testing, but significant synergies exist, and farms that use routine genomic testing will sort their cows and heifers more accurately and achieve greater gains.

Genomic Testing and its Impact on Genetic Progress

Genomic testing of dairy cattle with low-density single nucleotide polymorphism (SNP) arrays, followed by imputation to medium-density using ancestral genotypes and computation of genomic predicted transmitting abilities (PTA) for use in selection decisions, has become the norm in genetic improvement programs for dairy cattle worldwide (Bengtsson et al., 2020). More than 3,000,000 dairy bulls, cows, heifers, and calves have been genotyped to date in the United States and Canada, along with 2,500,000 more in France, Germany, Austria, The Netherlands, and New Zealand (VanRaden, 2020). Ear punch samples represent the predominant DNA source, due to simplicity and error resistance, followed by hair and blood samples, respectively. Current genomic tests feature approximately 40,000 to 70,000 SNP markers, which are sufficient to capture the genetic variation present in common dairy cattle breeds and track inheritance from one generation to the next, as shown in Figure 1.

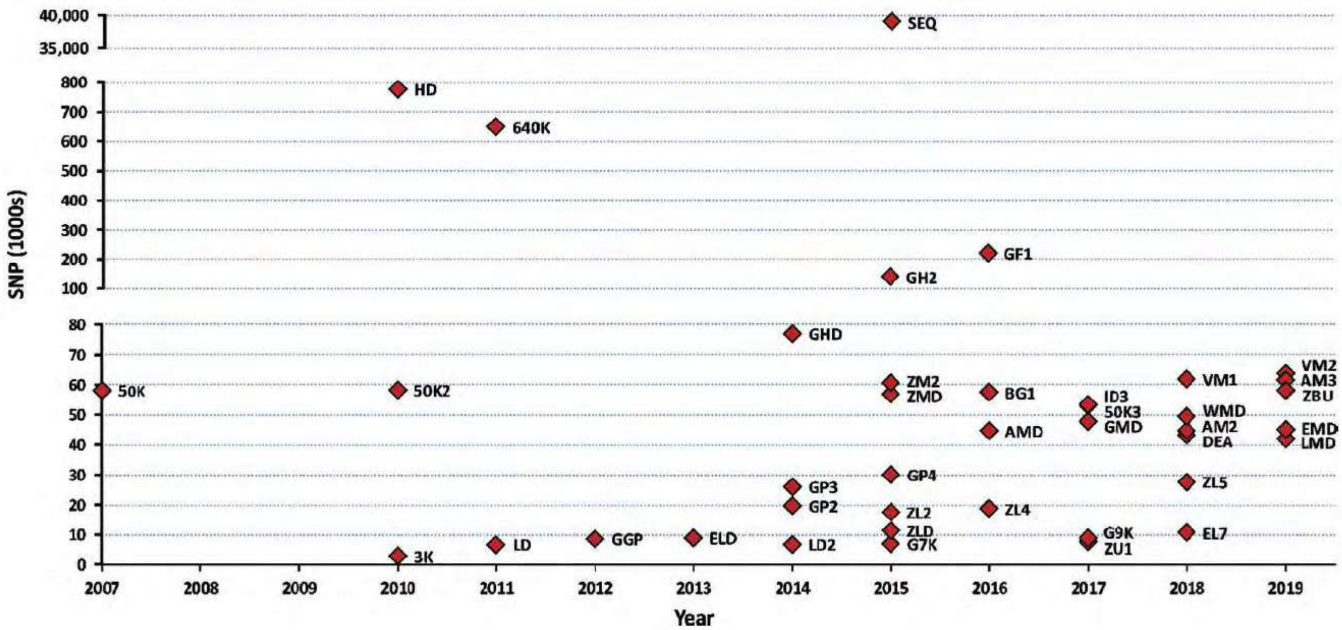

Figure 1. Introduction of genotyping arrays for dairy cattle by number of SNP markers and year (from VanRaden, 2020).

Young, genome-tested bulls with no milking daughters now represent more than 75% of the AI semen market, and information regarding the genomic PTA of heifers and cows is used routinely for selection, culling, and mating decisions. Generation intervals have decreased dramatically, and this has led to rapid increases in genetic progress for most important dairy traits over the past decade (García-Ruiz et al., 2016), as shown in Figure 2.

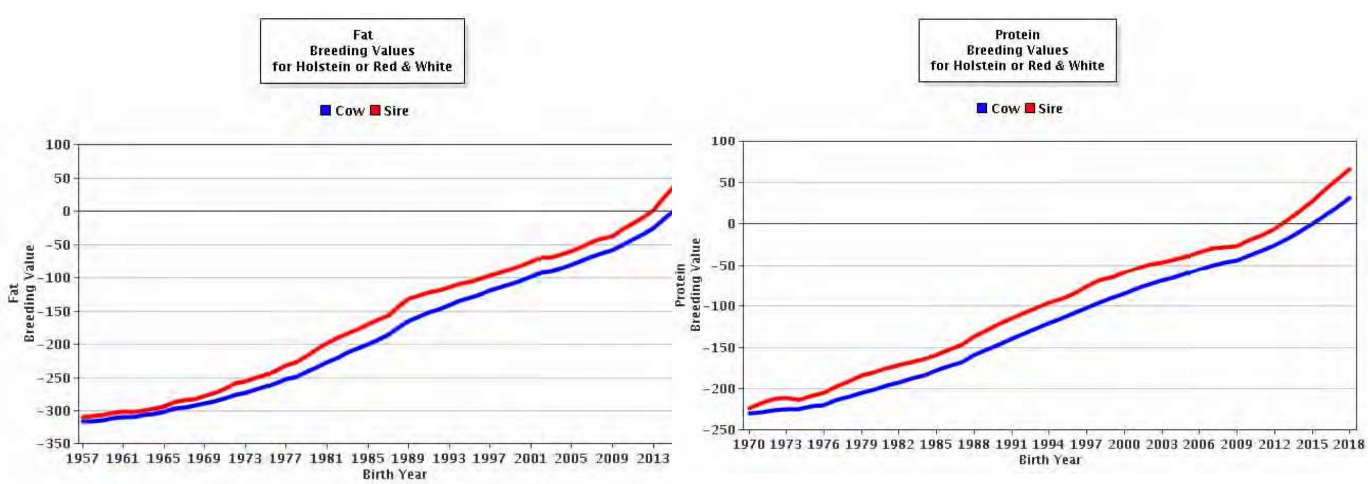

Figure 2. Genetic trends in breeding values for Holstein bulls and cows in the United States from 1957 to present: a) fat yield (left) and b) protein yield (right) (Council on Dairy Cattle Breeding, Bowie, MD).

▪ Potential Synergies with Reproductive Technologies

Dairy producers have a broad array of genetic and reproductive technologies at their disposal, and this allows many new opportunities to create and sort prospective replacement heifers and optimize the genetic make-up of the next generation, as shown in Figure 3.

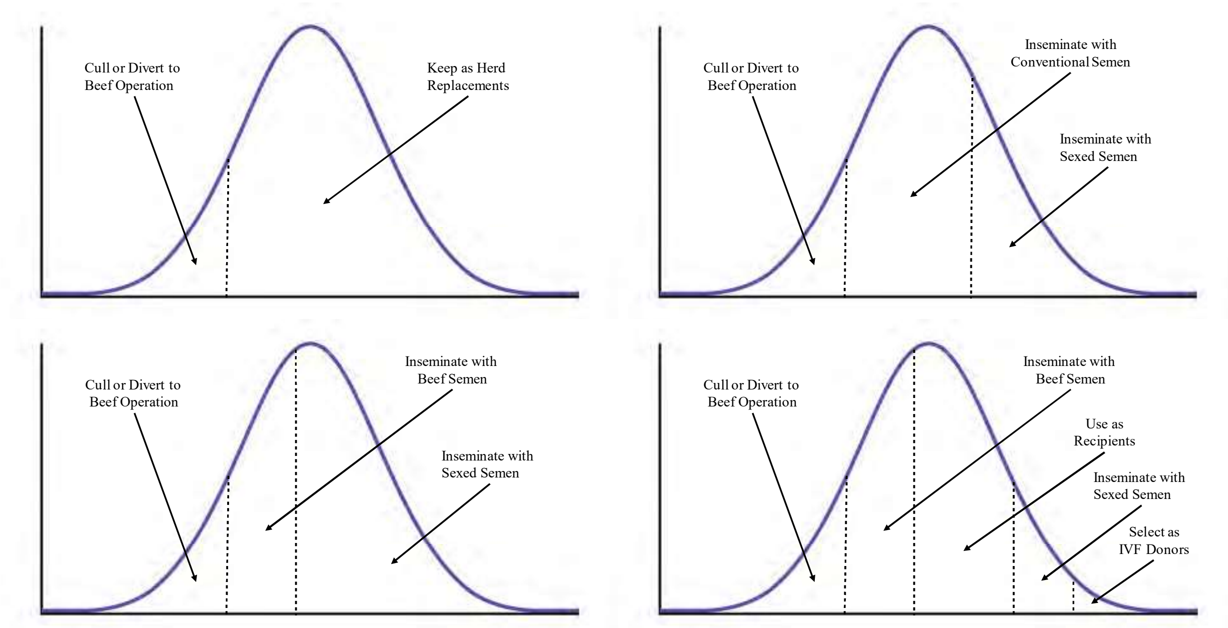

Figure 3. Potential strategies for combining genomic selection and advanced reproductive technologies to enhance the genetic level of replacement heifers on a commercial dairy farm: a) early culling (upper left); b) early culling and sexed semen (upper right); c) early culling, sexed semen, and beef semen (lower left), and d) early culling, sexed semen, beef semen, and IVF (lower right).

The simplest strategy, in Figure 3a, involves culling the poorest heifers based on genomic PTA and health history, which can lead to modest financial gains (Weigel et al., 2012; Calus et al., 2015), particularly in herds where pedigree data are incomplete. This strategy was common in the early years of genomic testing, as the savings in feed costs and income from calf sales could help offset the cost of genomic testing. Dairy producers quickly began searching for additional ways to leverage genomic testing to enhance genetic progress and increase farm profitability, and sexed semen was an obvious focus (Ettema et al., 2011; Sørensen et al., 2011). In Figure 3b, sexed semen is used for the heifers and cows with highest genomic PTA values, while the remaining females that are retained are inseminated with conventional semen. Studies such as Hjortø et al. (2015) suggested that herds with good reproductive performance should use sexed semen at a rate of 40 to 60% in yearling heifers and 20 to 40% in first lactation cows, whereas herds with poor reproductive performance should use sexed semen in roughly 80% of yearling heifers and avoid its use in lactating cows. Sexed semen usage on commercial dairy farms has increased rapidly, starting with heavy usage of sexed semen for first and second services in yearling heifers. In herds with good reproductive performance, sexed semen usage began to increase steadily in lactating cows as well. As expected, this led to a surplus of female dairy calves, and their market value plummeted.

Producers began to ask the logical question – why create extra heifer calves that we don't expect to be successful due to their pedigrees or genomic test results? Studies in Europe, where premiums for calves sired by beef bulls are large, began to emerge in the scientific literature. Hjortø et al. (2015) noted the opportunities associated with using beef semen on genetically inferior cows, suggesting that a herd's 'excess reproductive capacity' should be diverted to the creation of value-added crossbred calves. Subsequent studies, such as Ettema et al. (2017), found that net economic returns per 'slot' in the herd were maximized when the top 50 to 75% of yearling heifers and top 30 to 40% of lactating cows were mated with sexed semen, with the remaining females mated to beef bulls. Not surprisingly, returns were greater in herds with above average calf survival, cow longevity, and cow fertility. The use of beef semen has increased rapidly in the past few years, as noted by McWhorter et al. (2020), though reporting of 'beef on dairy' inseminations to the national database is incomplete. Sexed semen is now widely available from many top AI bulls, albeit with a modest reduction in conception rate relative to conventional semen, and most producers can capture at least a small premium for crossbred beef calves. Furthermore, this strategy allows farmers to 'have their cake and eat it too', in terms of accelerating genetic progress by mating their genetically modern (and on average, superior) yearling heifers and young cows with sexed semen, while using beef semen to allow genetically outdated (and on average, inferior) older cows to remain in the herd and produce large volumes of milk without contributing to next generation of replacement heifers. So, what will be the role of conventional AI semen in the future, other than to introduce unnecessary and random variation into your herd's replacement heifer inventory? The answer is unclear, and for this reason the proportion of inseminations with conventional semen is in steady decline.

▪ Supercharging Genetic Progress with IVF Programs

As noted above, the optimal strategy for most commercial herds seems to involve breeding roughly the top two-thirds of yearling heifers and the top one-third of lactating cows with sexed semen, while mating the remaining females with beef semen. Angus is the overwhelmingly popular choice for the latter, due to breed popularity, coat color, and calving ease (McWhorter et al., 2020). However, some producers are interested in maximizing genetic progress by increasing the reproductive capacity of elite females using IVF, and they have strategies to offset the extra costs through added sales of milk and breeding stock.

Advanced reproductive technologies, specifically ET and IVF, have been available for many years, but their use has largely been limited to highly selected females whose offspring can be marketed at premium prices via public auction or private sale. Only recently have herds implemented large-scale IVF programs that involve routine collection from top donors on a weekly basis.

In a series of papers, Kaniyamattam et al. (2016, 2017, 2018) evaluated the genetic and economic consequences of implementing IVF systems, denoted in the papers as in vitro-produced embryo transfer (IVP-ET), for creating large numbers of pregnancies on commercial dairy farms. In Kaniyamattam et al. (2016), the authors found that selection for lifetime net merit (NM$) using sexed semen would yield greater genetic progress than conventional AI, with a difference of $74 per cow in average PTA for NM$ over a 15-year time horizon. In the same study, net profit was $64 greater per cow per year with sexed semen than conventional semen, after accounting for differences in semen price and conception rate, as shown in Figure 4. Sexed semen resulted in 33% surplus females compared with 18% for conventional semen.

In a subsequent paper, Kaniyamattam et al. (2017) compared the performance of breeding systems based on IVF with those based on AI with sexed semen. As shown in Figure 5, incorporation of IVF led to rapid genetic gains in NM$ that far outpaced the rate of genetic progress achieved using sexed semen. After 15 years of selection, herds that used a routine IVF system to propagate their best females achieved an average genetic superiority of $294 per cow, relative to herds that used sexed semen without IVF. The system with IVF produced 54% surplus heifer calves compared with 31% with sexed semen.

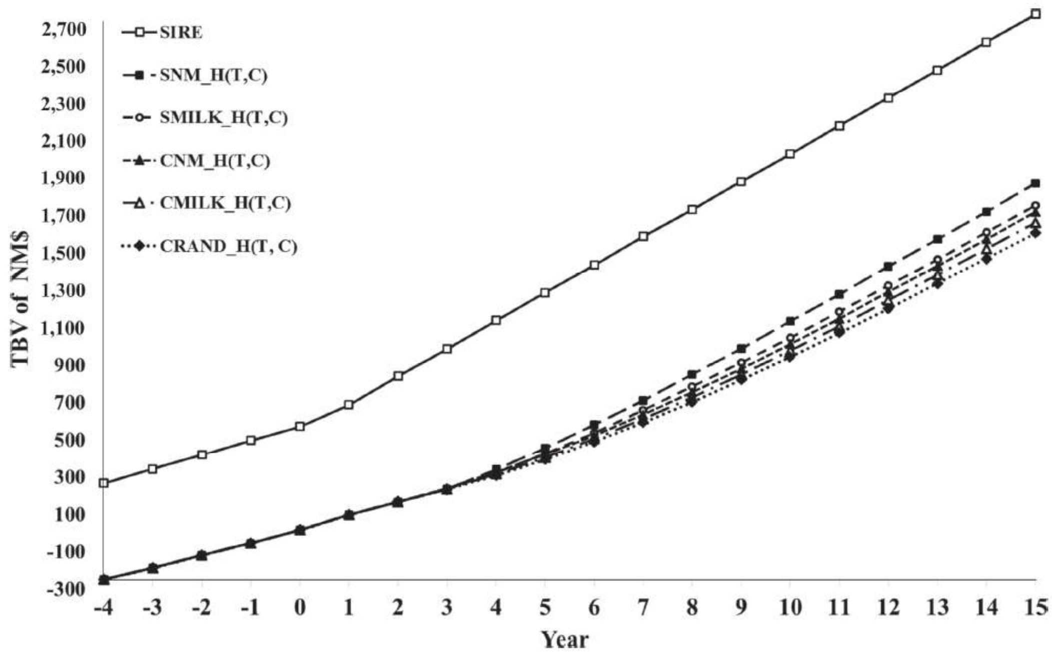

Figure 4. Genetic trends of cows in true breeding value (TBV) for NM$ when selection was random (CRAND) or based on milk yield (CMILK) or NM$ (CNM) with conventional semen compared with selection for milk yield (SMILK) or NM$ (SNM) using sexed semen, and with breeding values of sires (SIRE) as a reference (from Kaniyamattam et al., 2016).

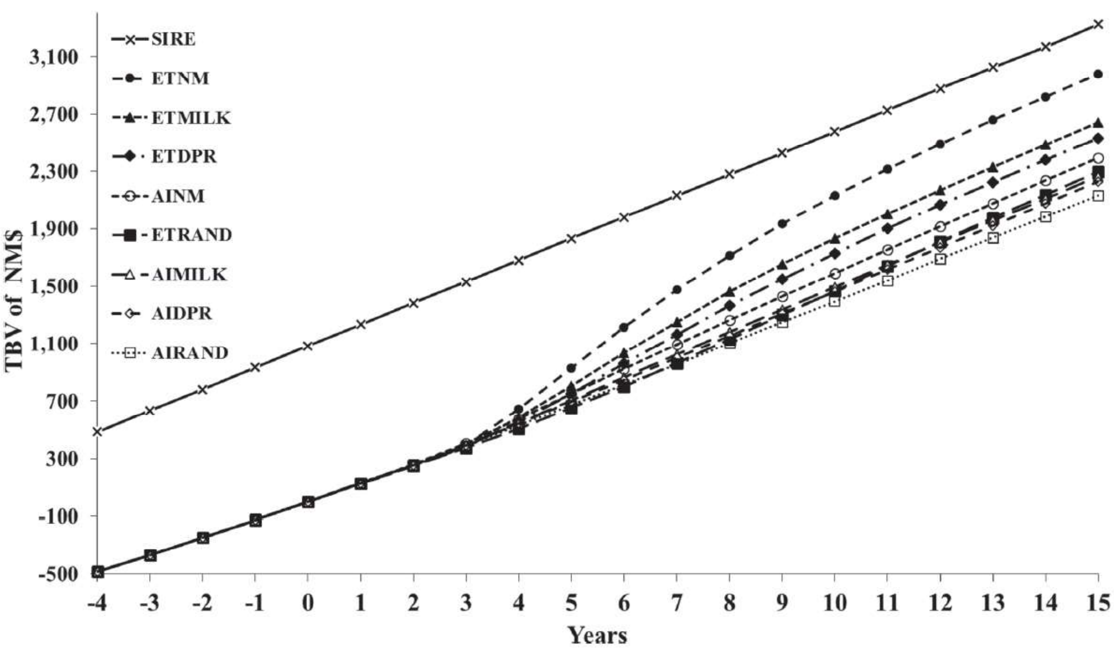

Figure 5. Genetic trends of cows in TBV for NM$ when selection was random (AIRAND) or based on milk yield (AIMILK), daughter pregnancy rate (AIDPR), or NM$ (AINM) using sexed semen compared with trends using IVF and selection that was random (ETRAND) or based on milk yield (ETMILK), daughter pregnancy rate (ETDPR) or NM$ (ETNM), and with breeding values of sires (SIRE) as a reference (from Kaniyamattam et al., 2017).

In the same paper (Kaniyamattam et al., 2017) the authors computed net profit per cow per year in IVF-based breeding systems compared with systems based on sexed semen. After 15 years of selection, net profit was $8 per cow per year greater with routine use of IVF than with sexed semen, as shown in Figure 6. This indicates that the genetic progress achieved using IVF can translate into greater net profit, even after accounting for the substantial initial investment and ongoing costs of IVF, but on average the profit margin is slim, and focus on operational efficiency and attention to detail is critical in IVF systems.

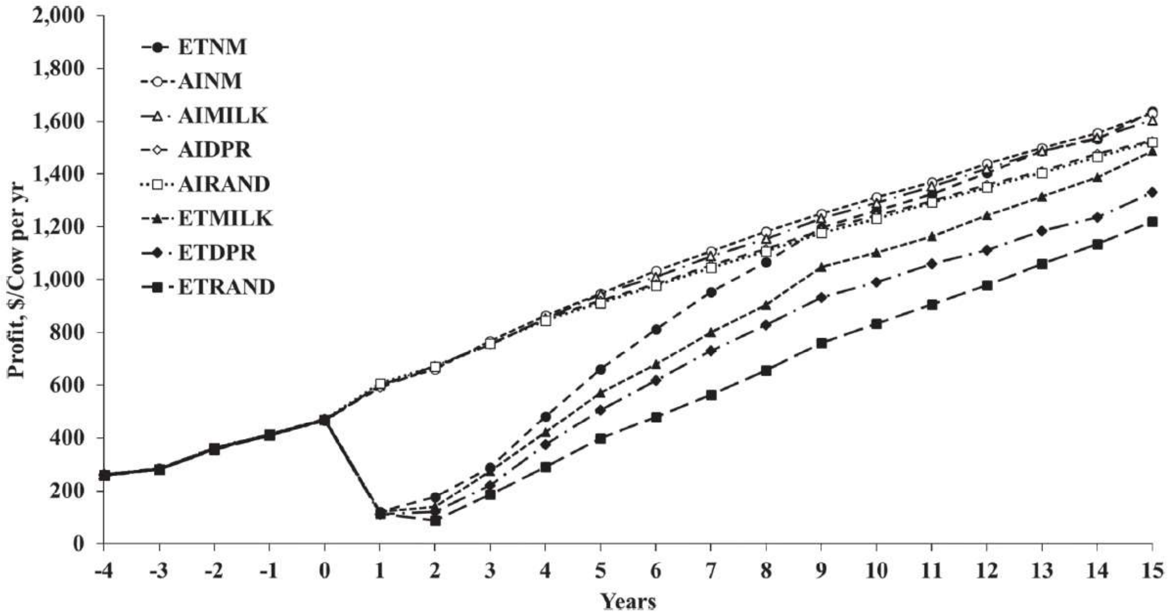

Figure 6. Net profit per cow per year when selection was random (AIRAND) or based on milk yield (AIMILK), daughter pregnancy rate (AIDPR), or NM$ (AINM) using sexed semen compared with trends using IVF and selection that was random (ETRAND) or based on milk yield (ETMILK), daughter pregnancy rate (ETDPR) or NM$ (ETNM) (from Kaniyamattam et al., 2017).

In a third paper, Kaniyamattam et al. (2018), considered hybrid systems in which varying proportions of replacement females were generated using IVF on the top females, with the top 50% of remaining heifers bred with sexed semen and all remaining heifers and cows bred with conventional semen. As shown in Figure 7, genetic progress was greatest when IVF was used to create 100% of pregnancies each year, but the marginal gain in average NM$ started to diminish significantly at roughly 60% IVF.

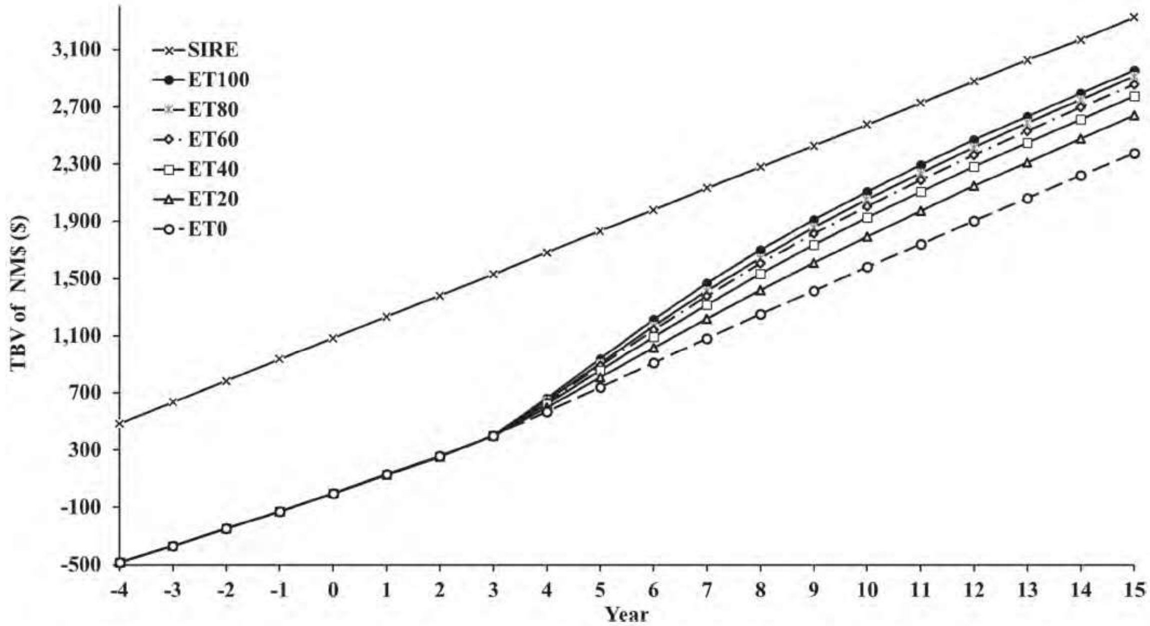

Figure 7. Genetic trends of cows in TBV for NM$ when selection used IVP-ET to generate 0% (ET0), 20% (ET20), 40% (ET40), 60% (ET60), 80% (ET80), or 100% (ET100) of pregnancies, and with breeding values of sires (SIRE) as a reference (from Kaniyamattam et al., 2018).

Lastly, and in the same study (Kaniyamattam et al., 2018), the authors considered the costs of implementing partial or full IVF systems and computed net profit per cow per year in each scenario. As shown in Figure 8, net profit was greatest for a system in which the top 40% of females were selected as IVF donors, the top 50% of remaining yearling heifers were mated with sexed semen, and the remaining heifers and cows were mated with conventional semen. This system achieved break-even status in year 8 and produced positive net returns in subsequent years.

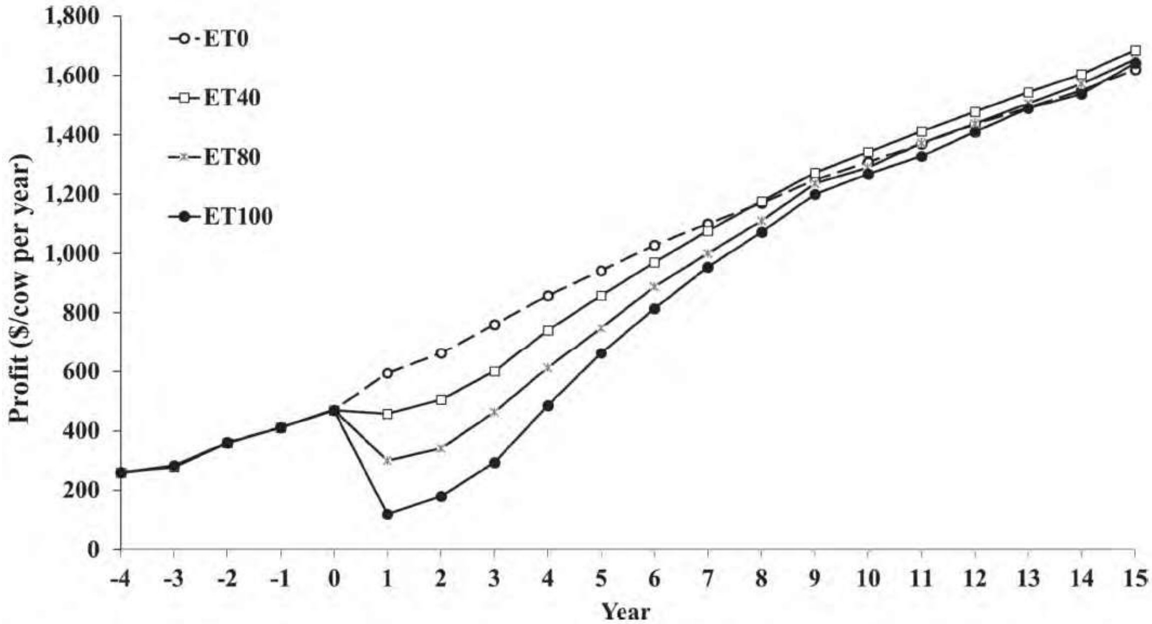

Figure 8. Net profit per cow per year when selection used IVP-ET to generate 0% (ET0), 40% (ET40), 80% (ET80), or 100% (ET100) of pregnancies (from Kaniyamattam et al., 2018).

Final Considerations

Most recently, Bérodier et al. (2019) and Thomasen et al. (2020) investigated the role of farming systems and the impact on inbreeding of breeding schemes, respectively, when combining genomic testing with advanced reproductive technologies. In the latter study, Thomasen et al. (2020) showed that adding more genotyped cows to the genomic reference population could increase genetic gain and reduce the rate of inbreeding in both numerically large (e.g., Holstein) and small (e.g., Jersey) populations. However, they noted inbreeding is more difficult to manage in numerically smaller breeds, due to lower accuracy of genomic predictions and fewer relevant families from which to select influential parents of future generations. In the former study, Bérodier et al. (2019) considered the costs and benefits of genomic testing and reproductive technologies in a conventional herd producing standard milk to be sold at commodity prices compared with an organic herd producing milk to be sold at a modest premium and a herd producing milk that would be sold at a high premium to make cheese with a protected designation of origin. In all cases, the top 80% of yearling heifers and top 30% of first lactation cows were mated with sexed semen, with or without routine genomic testing of all females. Net economic gains using sexed versus conventional semen were roughly twice the magnitude of gains due to genomic testing, though the latter was also profitable in all three farming scenarios. In every case, net returns were maximized when sexed semen was combined with terminal crossbreeding of excess females to beef bulls. Relative net returns were greatest, and break-even costs of sexed semen and genomic testing lowest, in herds that sold specialty cheese, followed by those selling organic milk, and those selling commodity milk. Collectively, the studies cited herein demonstrate the vast potential to increase genetic progress and net farm profitability by combining genomic and reproductive technologies to create customized herd breeding programs.

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