Fertility associated economic losses of farms

V. E. Cabrera

Department of Dairy Science, University of Wisconsin-Madison, 1675 Observatory Dr., Madison, WI 53706, U. S. A.

Introduction

Herd net return is strongly associated with reproductive performance (Giordano et al., 2012; Galvao et al., 2013). Efficient reproductive programs regulate herd population dynamics and herd structure allowing cows to take advantage of the most efficient part of the lactation curve (Ferguson and Galligan, 1999), while maximizing production of on-farm replacements (Giordano et al., 2012), minimizing costs associated with replacements and mortality (Giordano et al., 2011; 2012; Galvao et al., 2013), and minimizing the relative costs associated with reproduction (Giordano et al., 2012). Most of high-yielding dairy farms in the US use a combination of synchronization / ovulation control protocols and estrous detection for their reproductive management (Caraviello et al., 2006; Giordano et al., 2012; Galvao et al., 2013). Although there are a number of metrics for reproductive performance (e.g., herd days open or calving interval), the 21-day pregnancy rate (21-d PR; Ferguson and Galligan, 1999), which measures the rate at which eligible cows become pregnant in successive 21-day periods, integrates many other reproductive performance parameters and seems to be the best single parameter to measure, standardize, and benchmark reproductive performance among herds (Giordano et al., 2011; 2012; Galvao et al., 2013). Managers of modern US commercial dairy farms monitor their herd's reproductive performance using the 21-d PR index. However, it is difficult for them to assess the overall economic impacts of reproductive programs. A series of simulation studies in recent years (Giordano et al., 2011; 2012; 2013; Galvao et al., 2013) attempt to provide responses to these difficult questions. These were summarized in Cabrera (2014) and this is an excerpt of such study. Some of reviewed studies in Cabrera (2014) also provided decision support tools that could be customized for herd specific economic assessments related to reproduction. New technologies such as estrous detection devices or early blood chemical pregnancy diagnosis tests, are being adopted by modern high-yielding herd operations, and could make significant differences on the management and outcomes of reproductive programs. Therefore, these should also be included in the economic analysis of reproductive program (Giordano et al., 2013). Once the dairy farm manager finds the best reproductive program for the herd, there are still opportunities to further fine-tune reproductive performance by executing cow-level reproductive decisions. The concept of the economic value of a cow (Cabrera, 2012) or its equivalent retention pay-off (RPO; De Vries, 2006) and all their associated metrics (e.g., the value of a new pregnancy, the cost of a pregnancy loss, and the cost of a day open) could be used to differentiate and optimize cow-specific reproductive management, which will ultimately determine optimal herd value (Kalantari and Cabrera, 2012).

The economic value of improving reproductive performance

A series of studies demonstrate consistently that improving reproductive performance improves the cow and the herd economic net returns (Giordano et al., 2011; 2012; Kalantari and Cabrera, 2012; Cabrera, 2012; Galvao et al., 2013). These gains follow the law of diminishing returns and, therefore, economic gains are greater with a lower initial 21-d PR. A curve of reproductive performance (i.e., 21-d PR) versus economic net return (i.e., US$/cow per year) can be described as a quadratic function with diminishing net returns at higher 21-d PR. Nonetheless, economic gains still exist even above 40% 21-d PR (Figure 1).

Reproductive performance indicating a 21-d PR of between 30% and 40% are outstanding (Ferguson and Skidmore, 2013) considering that the US average might be below 16% (Raleigh DRMS, 2012). Increasing the 21-d PR by 1percentage point increases the economic net return (US$/cow per year) between $14.4, $10, $7.4, $5.4, $4.2, and $3.2 when the 21-d PR increases within 10 to 15%, 15 to 20%, 20 to 25%, 25 to 30%, 30 to 35%, and 35 to 40%, respectively (Figure 1). These values are highly dependent on economic variables (e.g., milk price or reproductive costs), however, gains with increased reproductive performance and the decreasing trend at lower reproductive capacity are consistent among studies (Giordano et al., 2011; 2012; Cabrera, 2012; Kalantari and Cabrera, 2012; Galvao et al., 2013). Variability in the net return gain (US$/cow per year per 1% increased 21-d PR) was between $18 and $7 for reproductive programs between 10 to 26% 21-d PR (Galvao et al., 2013); $9 and $7 for reproductive programs between 14 and 20% 21-d PR (Giordano et al; 2012); $17 and $13 for programs between 14 and 20% 21-d PR (Kalantari and Cabrera, 2012); and $9 and $6 for programs between 15 and 25% 21-d PR (Giordano et al., 2011).

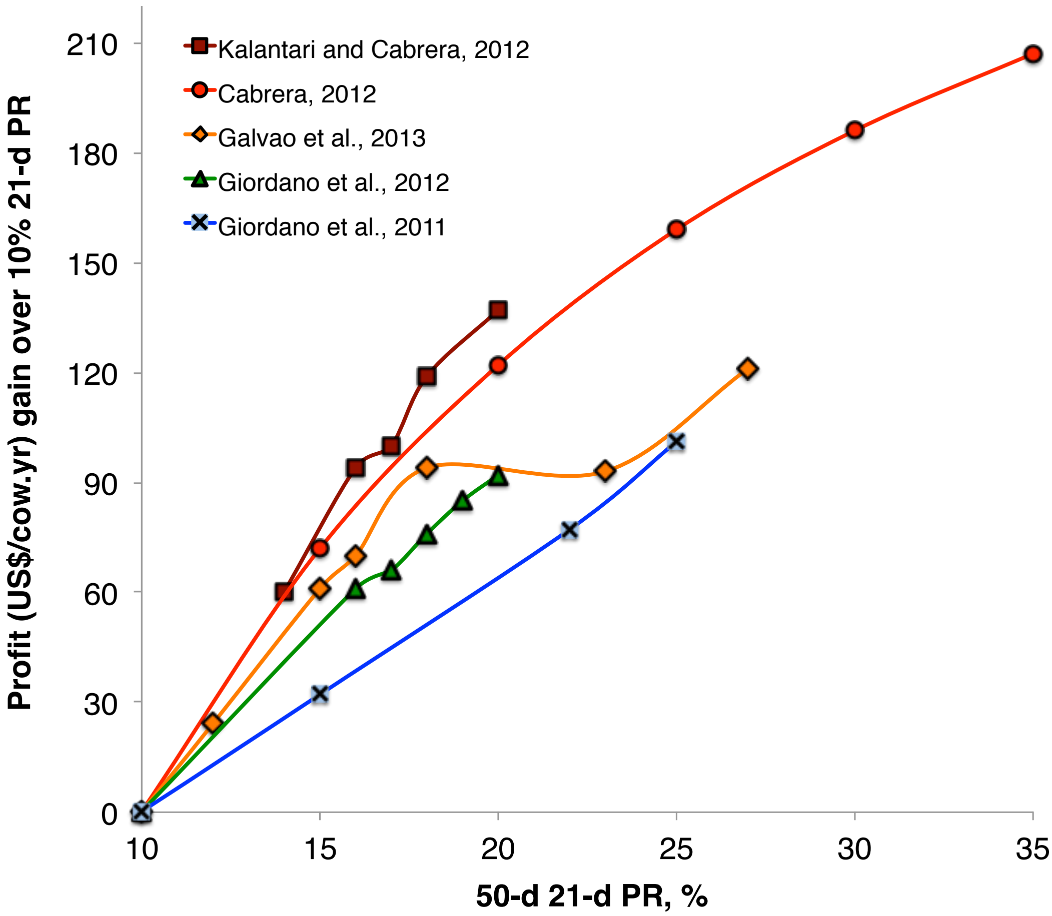

Figure 1. Approximate economic net return gain (US$/cow per year) of improving reproductive efficiency by 10 percentage points of a 21-day pregnancy rate (21-d PR) compiled from different studies. Quadratic fit on Cabrera (2012) was net return gain (US$) = -0.1881(21-d PR^2) + 16.783(21-d PR) -143.36 (R^2 = 0.995).

Components of reproductive economic value

Economic gains of improving reproductive performance occur because of higher milk productivity and consequent increase in milk sales and potentially higher milk income over feed cost, greater calf sales, lower replacement and mortality costs, and lower relative reproductive costs. These factors seem to be the most important determinants of economic reproductive efficiency (Giordano et al., 2012; Galvao et al., 2013). However, the overall value of improving reproductive efficiency is a combination of all economic factors interacting with no single factor being defined as the most important in all situations. For example at low reproductive performances (e.g., between 10 and 15% 21-d PR), the most important factor could be the savings of decreasing culling (reproductive or involuntary culling) and mortality, but at higher reproductive performances (e.g., between 25 and 30% 21-d PR) the most important factors could be milk and calf sales. Nonetheless, large variations occur among studies and specific conditions of studied herds. The dairy herd is a complex interrelated system, which is dynamically affected by changes in reproductive performance.

Milk productivity, milk sales, and milk income over feed cost

As milk productivity increases, feed costs also increase and although some studies found that the milk income over feed cost increased with reproductive performance (Giordano et al., 2012; Kalantari et al., 2012), other studies reported that the milk income over feed cost could, at times, decrease slightly as reproductive performance increases (Cabrera, 2012; Galvao et al., 2013). The relationship between milk production and feed consumption is complex and interacts with many factors such as the herd structure, feeds prices, and the shape and persistence of lactation curves. Cabrera (2012) and Galvao et al (2013) reported a combined synergistic and antagonistic effect of reproductive performance and milk income over feed cost at varying levels of 21-d PR. The gain in income over feed cost (US$) varied between +$9 (Giordano et al., 2011) and -$2.4 (Galvao et al., 2013) per 1% increase in 21-d PR. It is difficult to identify the specific reasons for these differences, but it can be speculated that they are due to a series of factors interacting as discussed below. In all cases, milk production was simulated as a function of the state of the cow's lactation following a standard lactation curve, which determined the feed requirements. Therefore, the main driver of milk production and milk income over feed cost was the herd structure, which responded to reproductive performance. The understanding is that better reproductive programs will determine that cows, and therefore, more cows in a herd, spend more time in the best part of their milk production curve, in which the ratio between milk produced and feed consumed is greater, generating greater milk income over feed costs. However, this relationship depends on the level and persistence of the lactation curves. Using the Cabrera (2012) model at different levels of production, and, therefore, different shapes and persistence of lactation curves, it was demonstrated that milk income over feed costs could remain static, decrease, or increase with increased reproductive performance. Highly persistent lactation curves, as they are common in high-yielding dairy farms in confined systems using TMR, could indicate that there is an opportunity, in some cases, to slightly delay the voluntary waiting period (the time to start breeding postpartum) to improve milk income over feed cost. Indeed, this fact was earlier detected and reported by De Vries (2006), who indicated that the value of a pregnancy could become negative if established early in lactation if the lactation curve is highly persistent. Galvao et al., (2013) offered additional insights in this dilemma, indicating that another factor with an important role in the milk income over feed costs is the herd structure related to the number of cows producing milk in the herd in relationship to the reproductive program and its associated reproductive performance. Galvao et al., (2013) argued that in their study of a herd of 1,000 cows, there were between 36 and 39 fewer cows producing milk (dry cows) in the best reproductive performance program (26.8% 21-d PR) compared to the worst program (10.9% 21-d PR), which counteracted the increased productivity in milk on a per cow basis.

Calf sales

Greater reproductive performance determines faster rate of pregnancy establishment and, therefore, greater production of calves, which is translated into greater net return. Previous research consistently agreed that greater calf sales or greater value of offspring are a consequence of improved reproductive efficiency (Giordano et al., 2012; Kalantari and Cabrera, 2012; Cabrera, 2012; Galvao et al., 2013). Cabrera (2012) used a combined value per calf (weighted average of male and female offspring) of $100. Results from Cabrera (2012) conforms to the following quadratic function: Net return gain (US$/cow per year) = $-0.0352 \text{ (21-d PR)}^2 + 2.8476 \text{ (21-d PR)} + 18.93$ ($R^2 = 0.996$). This function indicates a net return gain (US$/cow per year) of between $3 and $1 per 1% increase in 21-d PR for low and high initial 21-d PR, between 10 and 40%, respectively. Galvao et al., (2013) using a weighted average calf value of $140 also reported a net return (US$) of between $1 and $3 per 1% increase in 21-d PR. However, the correlations of higher gains for lower 21-d PR and lower gain for higher 21-d PR reported by Galvao et al., (2013), were not identified. This probably happened due to the specific reproductive programs that were defined in that study. Giordano et al., (2012) using a weighted calf value of $90, reported net return gains (US$) of between $2 and $1 per 1% increase in 21-d PR for the levels of 21-d PR with a range of 14 and 20%.

The number and availability of replacements (a function of calves produced) on a farm could impact the farm management with regards to replacement decisions. For example, in a closed herd, farmers having a large influx of replacements (because of improved reproductive performance) might decide to aggressively cull cows more to balance the relationship between replacement demand and supply. Indeed, there are some indications that farmers might perform more aggressively with more selective culling in a herd with better reproductive performance (Souza et al., 2013). Also, farmers might try to balance the replacement demand and supply by decreasing the opportunities of breeding more eligible cows. This would imply the culling of non-pregnant cows sooner when the overall reproductive performance is better, as it was proposed by Giordano et al. (2012). The baseline scenario in Giordano et al., (2012) stopped breeding at 300 days postpartum (DIM; cut-off) in all reproductive programs examined. As expected, superior reproductive programs had a surplus of heifers and vice versa, with the highest surplus related to the best reproductive program. They manipulated the cut-off in an attempt to mimic a reasonable farmer decision to balance demand and supply of replacements: decrease it (< 300 DIM) if there was a surplus and increase it (> 300 DIM) if there was a deficit. Simulations in Giordano et al. (2012) showed that all reproductive programs having a 21-d PR ≥ 16% had a surplus of heifer replacements when the cut-off was 300 DIM, which varied (for a herd size of 1,000 adult cows) between 11 at 16% 21-d PR and 48 at 20% 21-d PR. These superior reproductive programs were simulated to balance their heifer supply and demand resulting in about 281 and 235 DIM cut-off time for 16 and 20% 21-d PR, respectively. Interestingly, the overall net return (US$/cow per year) yet increased in all the cases in which a replacement heifer surplus originally existed (21-d PR ≥ 16% 21-d PR) and a more aggressive cut-off (lower cut-off DIM for services) was required to balance the heifer replacement demand and supply. The opposite was also true, lower performing reproductive programs (< 16% 21-d PR) that required an increased cut-off DIM to balance the heifer supply and demand, decreased even more their estimated net returns. It is clear that best reproductive performance farms could have additional means to further improve herd economic gains.

Replacement and mortality costs

Replacement and mortality costs are an integral part of the dairy farm business. Sooner or later cows are replaced whether they are culled for involuntary reasons, culled for reproductive failure, or died. Improved reproductive efficiency will ensure that fewer animals are culled earlier for reproductive failure. Cows becoming pregnant earlier have a significantly lower culling risk than their non-pregnant herd mates. Indeed, pregnant cows could have about 25% the culling risk compared to similar non-pregnant cows (De Vries et al., 2010). Involuntary culling risk follows a typical pattern in which there is slightly higher culling risk early in lactation, decreases to a lower plateau after the transition period, increases slowly between mid and late lactation, and then increases dramatically later in lactation (> 250 DIM). Therefore, it is clear that the longer the cow remains open in lactation, the higher the risk of the cow of being culled. Mortality risk follows a similar curve and can be expressed as a proportion of the culling risk (e.g., 17% of culling risk as used in Giordano et al., 2012) and, therefore, it has a similar pattern with reproduction. Earlier culling and mortality are expensive events in a dairy herd as these include the cost of replacing the animal. Immediate replacement is a standard assumption (De Vries, 2006; Giordano et al., 2012; Galvao et al., 2013). The transaction cost of a discarded animal is the difference between the cost of a replacement (heifer at or about at first calving) and the salvage value of the discarded cow. This cost was estimated in Cabrera (2012) to be about US$1,300 - US$496 = U$804 for a cow weighing 596 kg live weight and receiving US$0.83/ kg live weight salvage value. The cost of mortality is even higher as dead cows have no salvage value. In the above example, this would be US$1,300. Using those values for culling and salvage, Cabrera (2012) reported a lower cost of culling and mortality of between $4 and $1 per 1% increase of 21-d PR between 10 and 40% 21-d PR, respectively. Consistently, Giordano et al., (2012) using a replacement cost of $1,302 and a salvage value of $1.16/kg live weight found a decrease in costs of replacement and mortality of between $4 and $3 for 1% change in 21-d PR between 14 and 18%, respectively. A much higher cost decrease was reported in Galvao et al., (2013) of between $27 and $4 for each 1% change in 21-d PR. Results from Galvao et al., (2013) were not consistent showing the trend of higher benefits with lower initial 21-d PR. For example, the greater gains occurred at between 19 and 20% 21-d PR. Possible causes of differences between studies can be attributed to: 1) substantially higher salvage value and replacement cost set in Galvao et al., (2013) at US$1.65/kg live weight and US$1,600/heifer, respectively, and 2) significant differences in probabilities used to simulated culling and mortality. Galvao et al., (2013) used a fixed daily culling and death rate of 0.1% and 0.05% for the first 60 DIM and 0.03% and 0.0076%, for the remainder of the lactation, respectively.

Reproductive costs

Reproductive costs can be defined as all those management costs incurred with the purpose of getting cows pregnant. Those would normally include labor for OD or pro-rated investment on OD devices, labor for synchronization treatment, cost of hormones, labor for insemination, cost of semen, and cost of first and repeated pregnancy diagnosis tests. With the exception of repeated pregnancy diagnosis, all other costs only apply to presumed non-pregnant and breeding eligible cows and are lower when they shorten the interbreeding interval. Therefore, improving reproductive efficiency without additional investments will reduce reproductive costs per cow and per herd. However, improved reproductive efficiency may require additional investments. The relationship between additional investments and cost of reproduction seems to be inconsistent. It will depend on the economic association between the gains from reproductive efficiency and the amount of additional investment required to achieve these gains. All the costs listed above were included in both Giordano et al., (2012) and Galvao et al (2013) studies. In both studies prices for $PGF_{2\alpha}$ and GnRH hormones were similar between US$2.3 and US$2.65 and US$2.4 and US$2.6/cow treated, respectively. Also the labor cost was similar at US$15/hr. However, the cost incurred in labor for OD and hormone treatment differed because this was set on a per cow basis in Galvao et al., (2013), whereas it depended on the population dynamics in the study of Giordano et al., (2012). The cost of pregnancy diagnosis that was set at US$3/pregnancy diagnosis in Galvao et al., (2013), whereas it was $105/hr in Giordano et al., (2012). Finally, the cost of AI was set to US$15 in Galvao et al., (2013) whereas it was set to $10 in Giordano et al., (2012). Results of these studies show increases and decreases in the overall reproductive costs (US$/cow per yr) as a response to different reproductive programs and different reproductive performances. Overall, changes per 1% increase in 21-d PR varied between $-4 and $4/cow per year. It is important to note that important differences in reproductive programs were defined in these studies and, therefore, it is not possible to generalize these impacts, which would depend on the interaction among current reproductive program, proposed changes, and farm specific conditions including productive and economic parameters. A tool, based on the study of Giordano et al., (2012) that performs farm-specific assessments within a daily Markov chain structure - the Wisconsin-Cornell Dairy Repro tool - is available at the University of Wisconsin Dairy Management Website (http://DairyMGT.info) and could be used effectively to perform these assessments according to farm specific conditions in a rapid and efficient way.

The value of a cow

In simple terms the value of a cow is the expected long-term net return of the cow compared with an imminent replacement. Therefore, factors such as: 1) cow's productivity level in relation to herd mates, 2) replacement's genetic improvement in relation to herd mates, and 3) current conditions of the evaluated cow all play a critical role in determining the value of the cow for a particular farm at a specific cow state. The value of a cow can also be expressed as RPO (De Vries, 2006). The value of a cow can be calculated using Markov chains (Cabrera, 2012) and the RPO using dynamic programming (De Vries, 2006). Either way, results are consistent indicating that: 1) the value of a non-pregnant cow decreases from its maximum in early postpartum (e.g., < 30 days postpartum (DIM)) to negative values in late lactation (e.g., >270 DIM) (Figure 2), 2) it increases to a higher value when the cow becomes pregnant and remains higher than its contemporary non-pregnant mates, and 3) re-aligns to a similar value at the end of the gestation in spite of when the pregnancy occurred during the lactation (not shown). Obviously, the value of a cow responds to herd productive and reproductive variables such as culling risk or herd productivity level and also to economic variables such as milk price or replacement costs. Nonetheless, the most important factors in determining the value of a cow are the cow's expected productive performance and the replacement's expected genetic value. There is certainly an interaction between the cow's productivity, the replacement's genetic value, and herd structure, which determine the value of a cow. This value has been normally used to help farmers and managers in the decisions to keep (positive) or replace (negative) cows. This value could also be used effectively and efficiently for reproductive decisions complementing already established herd-level reproductive programs. For a herd's average cow, it will vary between $900 in early lactation to $70 at 240 DIM and to negative after 270 DIM. Consequently, decisions for the same cow could dramatically change at different times. Decisions will depend on those values and their relationship with the cost benefit that the farmer would estimate from a specific reproductive management strategy. A valid question from a herd manager would be, for example, should an investment still be made in reproduction if the value of a cow is only $70? Another valid question would be: should a different reproductive management strategy be followed depending on the value of the cow? Certainly, answers to these questions require herd managerial skills, but individual cow value estimates could help perform best-informed decisions.

The value of a new pregnancy, the cost of a pregnancy loss, and the cost of a day open

Estimates of economic value of a cow or the RPO can be effectively used to deduct the value of a new pregnancy, the cost of a pregnancy loss, and the cost of a day open. The value of a new pregnancy in a specified time period (e.g., at 30 days in pregnancy) is the difference of the value of a 30-day pregnant cow and the value of the same cow, but not pregnant (Figure 4). The cost of a pregnancy loss is the difference in the value of the cow losing the pregnancy (non-pregnant) and the value of the same cow remaining pregnant (Figure 4).

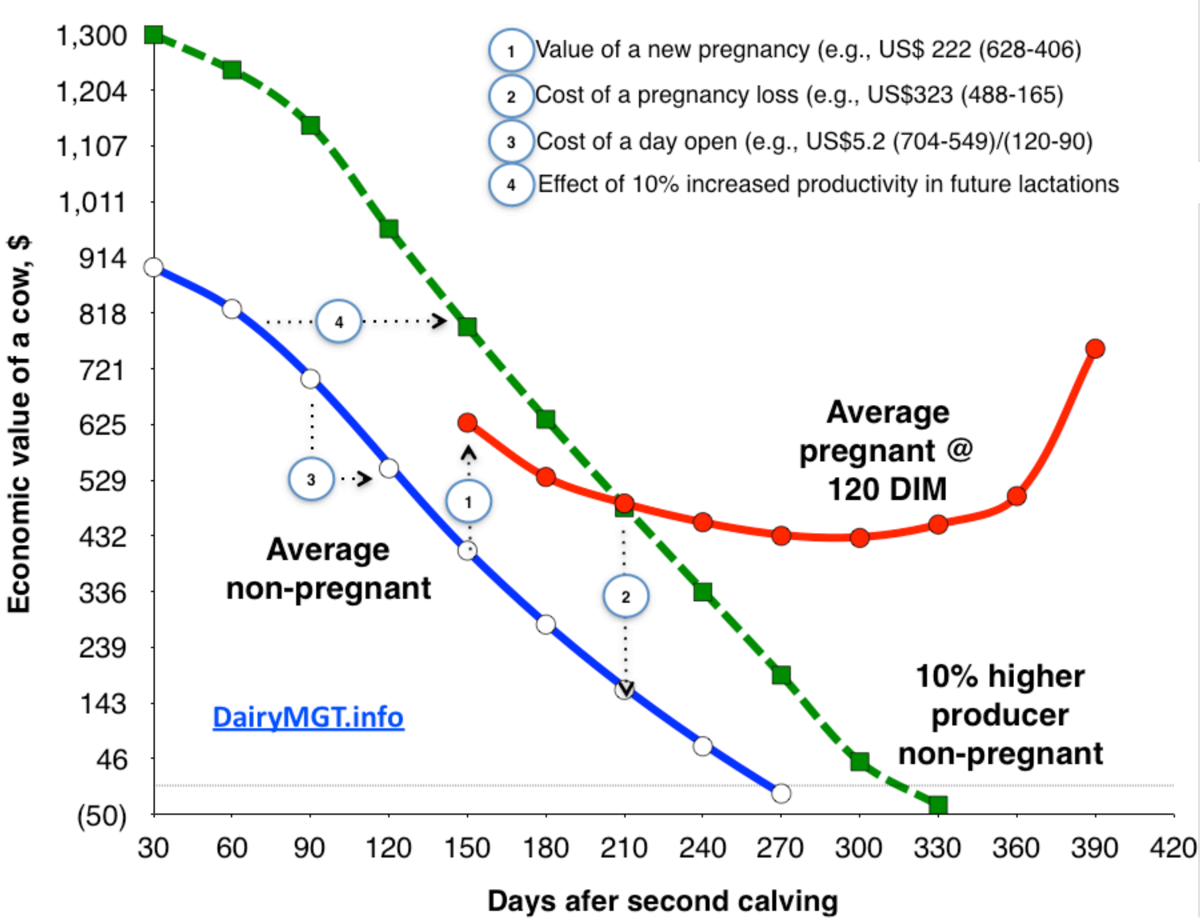

Figure 4. Estimated economic value of an average producing cow (US$) remaining non-pregnant (empty circles) or becoming pregnant at 120 days postpartum (DIM; solid circles) and economic value of a 10 percentage points higher than average producing (in future lactations) cow (solid squares). Calculations performed using the tool Economic Value of a Dairy Cow available at http://DairyMGT.info/tools and described in Cabrera (2012).

The cost of a day open is the difference in the value of a non-pregnant cow between an earlier and a later day in lactation divided by the number of days in that period. In the examples presented in Figure 4, the value of a 30-day gestation new pregnancy at 120 DIM for an average cow was calculated as the difference between: 628 - 406 = US$ 222, the cost of 90-day gestation pregnancy loss occurring at 210 DIM for an average cow was the difference between: 488 - 165 = US$ 323, and the cost of a day open for an average cow between 90 and 120 DIM was calculated as: (704 - 549) / (120 - 90) = US$ 5.2/day. Also, inform Figure 4 note that the effect of 10% expected productivity of a cow had important impacts in the economic value of a cow, shifting the curve to the right. The same calculated economic values (at the same states) for the 10% higher producing cow was: value of a new pregnancy = US$456, cost of a pregnancy loss = US$491, and cost of an extra day open = US$6.0. It is also clear that it is justifiable to give more breeding service opportunities to the 10% higher producing cow. It would justify breeding the higher producing cow at least until 300 DIM (value is still positive at 300 DIM) compared to less than 270 DIM for the average cow (value becomes negative even before 270 DIM) (Figure 4).

Knowing the specific value of a cow, its pregnancy value, its cost of pregnancy loss, and the cost of an additional day open, would provide farmers with a better guide in the quest for improved economic efficiency related to herd reproductive management. Since the value of the whole herd or the herd value is the combination of the individual values of the cows on the herd according to the herd structure (Kalantari and Cabrera, 2012), the rationale of improving the herd value by cow-specific decisions will depend on making the best decisions for individual cows. For example, giving extra attention to cows that have a higher value by becoming pregnant will improve the whole herd value and therefore, the farm profitability will increase. However, these decisions would need to be performed within an existing herd's reproductive program and will depend heavily on the management options available for individual cows. The cost of a pregnancy loss is expensive and is higher as gestation progresses. Following the concept of herd value, keeping the pregnant cows pregnant with an emphasis on later gestation status will certainly increase the net return of reproductive programs. Finally, the cost of a day open is something that could be avoided as much as possible in order to increase herd net returns. Indeed, herd average days open is a common indicator of reproductive performance that is inversely related to profitability. At the cow level, it is possible to estimate dynamically the changing cost of a day open throughout lactation. In general, the lower the days open for a cow, the better. Nonetheless, if a farm needs to prioritize and has the means to do so, cows with a higher cost of day open could be singled out for reproductive treatment. .
Tools to calculate the RPO or the value of a cow exist and are readily available for dairy herd decision makers. Some examples for RPO calculations are the University of Florida DairyVIP tool (http://dairy.ifas.ufl.edu/tools/) or the University of Wisconsin Retention Pay-Off calculator (http://dairymgt.uwex.edu/tools.php). An example of a tool to perform calculations related to the value of a cow is the University of Wisconsin Economic Value of a Dairy Cow (http://dairymgt.uwex.edu/tools.php).

Conclusions

Improved reproductive performance increases overall herd economic net returns. Economic factors that contribute to it are higher milk sales, calf sales, lower replacement costs, and lower relative reproductive costs. Most high-yielding TMR dairy farms use a combined approach that includes synchronization protocols and estrous detection interventions in their reproductive programs. The reproductive performance on these farms can be measured and compared using the standard 21-day PR, which captures the interacting reproductive performance of these combined programs. With an observed 21-day PR of between 10 and 40%, the economic net gain increases as the pregnancy rate increases. Within those reproductive programs, the use of blood chemical pregnancy diagnoses one-week earlier that a conventional pregnancy diagnosis, can be economically effective as long the test is more than 94% accurate and the herd records indicate that the early pregnancy losses do not exceed 10%. Using the economic value of a cow or its equivalent RPO to perform individual cow fine-tuning of reproductive decisions within defined herd reproductive programs would improve reproductive performance and in turn net returns. Decision support tools to evaluate the economic outcomes of reproductive programs and cow-level reproductive decisions in high-yielding dairy farms are available at the University of Florida (http://dairy.ifas.ufl.edu/tools/) and at the University of Wisconsin (http://dairymgt.uwex.edu/tools.php).

References

Cabrera VE 2014. Economics of fertility in high-yielding dairy cows on confined TMR systems. Animal 8, 211-221.

Cabrera VE 2012. A simple formulation and solution to the replacement problem: A practical tool to assess the economic cow value, the value of a new pregnancy, and the cost of a pregnancy loss. Journal of Dairy Science 95, 4683-4698.

Caraviello DZ, Weigel KA, Fricke PM, Wiltbank MC, Florent MC, Cook NB, Nordlund KV, Zwald NR and Rawson CL 2006. Survey of management practices on reproductive performance of dairy cattle on large US commercial farms. Journal of Dairy Science 89, 4723–4735.

Chebel RC and Santos JE 2010. Effect of inseminating cows in estrus following presynchronization protocol on reproductive and lactation performances. Journal of Dairy Science 93, 4632–4643.

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

De Vries A, Olson JD and Pinedo PJ 2010. Reproductive risk factors for culling and productive life in large dairy herds in the eastern United States between 2001 and 2006. Journal of Dairy Science 93, 613–623.

Ferguson JD and Galligan DT 1999. Veterinary reproductive programs. In Proc. 32nd Annual Convention of the American Association of Bovine Practitioners (AABP), Nashville, TN. pp. 133–137. American Association of Bovine Practitioners, Opelika, AL, US.

Ferguson JD and Galligan DT 2011. The value of pregnancy diagnosis—A revisit to an old art. Paper presented at the 2011 Theriogenology Annual Conference Symposium, August 9-13, 2011, Milwaukee, USA.

Ferguson JD and Skidmore A 2013. Reproductive performance in a select sample of dairy herds. Journal of Dairy Science 96, 1269-1289.

Galvao KN, Federico P, De Vries A and Schuenemann G 2013. Economic comparison of reproductive programs for dairy herds using estrus detection, timed artificial insemination, or a combination. Journal of Dairy Science 96, 2681-2693.

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

Giordano JO, Kalantari A., Fricke PM, Wiltbank MC and Cabrera VE 2012. A daily herd Markov-chain model to study the reproductive and economic impact of reproductive programs combining timed artificial insemination and estrous detection. Journal of Dairy Science 95, 5442-5460.

Giordano JO, Fricke PM and Cabrera VE 2013. Economics of resynchronization strategies including chemical tests to identify non-pregnant cows. Journal of Dairy Science 96, 949-961.

Kalantari, AS and Cabrera VE 2012. The effect of reproductive performance on the dairy cattle herd value assessed by integrating a daily dynamic programming with a daily Markov chain model. Journal of Dairy Science 95, 6160–6170.

Lima JR, Rivera FA, Narciso CD, Oliveira R, Chebel RC and Santos JE 2009. Effect of increasing amounts of supplemental progesterone in a timed artificial insemination protocol on fertility of lactating dairy cows. Journal of Dairy Science 92, 5436–5446.

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

Pursley JR, Mee MO and Wiltbank MC. 1995. Synchronization of ovulation in dairy cows using PGF2α and GnRH. Theriogenology 44, 915–923.

Raleigh DRMS 2012. Dairy Metrics. Retrieved on September 2013 from http://www.drms.org/dairymetricsinfo.aspx?node_id=Dflt6. Raleigh DRMS, Raleigh, NC.

Souza AH, Carvalho PA, Shaver RD, Wiltbank MC and Cabrera VE. 2013. Impact of timed AI use on reproductive performance and culling rate in Wisconsin dairy herds. Journal of Animal Science 91 (E-Suppl. 2), W303.

Vasconcelos JLM, Silcox RW, Lacerda JA, Pursley JR and Wiltbank MC 1997. Pregnancy rate, pregnancy loss, and response to estrous stress after AI at two different times from ovulation in dairy cows. Biology Reproduction 56(Suppl. 1), 140.