Economics of Improving Reproductive Performance in Dairy Herds

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Take Home Messages

- The objective of reproductive management is to optimize the profit per slot (stall) per year by maximizing the proportion of a cow's life in the most profitable part of the lactation curve
- On average, the value of making an open cow pregnant is $300 to $600 CDN
- For herds with 21-day pregnancy rates (PR) < 16%, implementation of a systematic synchronized insemination program that improves PR to > 17 to 20% is very likely to be profitable, across a wide range of reasonable costs for days open, insemination, and replacements. Herds with lower PR and/or higher production have the most to gain from improved reproductive performance.

Concepts

The economics of reproductive performance are driven substantially by the lactation curve of dairy cows, and in particular the fact that production efficiency, and therefore income over feed cost, is greatest around peak production. For this discussion, it is assumed that the herd is at a stable size, such that there is a fixed number of slots or cow-spaces (corresponding roughly to the number of stalls). Efficiency and profitability are gained or lost by the status of the average cow filling a slot in the herd. If reproductive performance improves, the average cow will be closer to peak than to late lactation, and therefore the average slot will be filled by a cow that is producing more milk per day.

In general terms, reproductive performance economics are a function of two main opportunity costs: the forgone profit as cows remain open beyond approximately 120 DIM, and therefore spend a more-than-optimal proportion of their lifetime in later lactation; and the failure to realize all the profit potential in otherwise profitable cows that are replaced sooner-than-optimally because of the inability to make them pregnant.

The direct costs of delayed pregnancy or failure to achieve pregnancy are concrete and obvious to producers, and include extra semen, labour, veterinary and drug costs, and the difference between revenue for a cow culled for non-pregnancy and the cost of her replacement. What is not obvious to many managers and their advisors is that the opportunity costs of prolonged non-pregnancy or culling may be greater than the obvious direct costs.

The magnitude and the source of payback from improved reproductive performance vary among herds, but generally the greatest single component is marginal milk. Marginal milk is additional production without additional capital cost. Even though extra feed is required to make extra milk, there is still net profit, because maintenance costs are diluted into more production. In fact, marginal milk from existing cows is generally the most efficient means to increase profit through management. This is true even under the quota system. Although the net price for marginal milk must account for purchase and financing of additional quota to sell the extra milk, this does not change the fundamental profitability of marginal milk under realistic price ranges. Marginal milk is a result of having a more productive, nearer-peak cow filling in the average slot on the farm. This is reflected in lower herd average DIM, and over time, increased milk per day per lactating cow in the herd, even though the barn, nutrition, and genetics have not changed.

Additional benefits of improved reproductive performance include more selective and therefore more optimal culling. As more pregnant cows are produced in a fixed herd, more selection pressure can be applied and lower producing cows can be removed, which contributes to increased milk revenue per slot as the herd distribution for production shifts as the lower tail is removed.

For example, in a 100-cow herd with average 305ME production of 11800 kg (~10,600 kg herd average 305 Milk), this lactation curve indicates that at 200 DIM, average production is 35 L/d. If the herd pregnancy rate is improved such that the average slot is occupied by a cow at 180 DIM, the lactation curve is such that this cow will produce 36.4 L/d. If milk revenue net of quota purchase is $0.40 and marginal feed cost is $0.10/kg, then $0.30/extra kg of milk x 1.4 kg = $0.42 kg/cow/d x 365 days x 100 cows = $15,300 per year (Adapted from Overton, 2006).

An important consideration is that there is a delay in the return on investments to improve reproductive performance. Costs of, for example, implementing a systematic timed artificial insemination (TAI) program occur immediately, but the returns from having cows pregnant sooner do not accrue until these cows reach the peak of their next lactation. Therefore the returns are estimates of improved profits that will be gained 9 to 18 months in the future. Success must be measured accordingly, and future improved earnings must be discounted to their net present value. When a new systematic TAI program is implemented, there are immediate increases in cash costs for hormones, labour, semen, and often, veterinary costs. As pregnancy rate (PR) begins to improve, cash flow may be reduced somewhat as fewer open cows are culled. Starting 9 months after successful implementation of a program, there will be more transition cows per unit of time, which may strain facilities, and more feed will be required for these cows. However, as early as 9 months, and by 12 months after PR is improved, milk revenue rises substantially as the gains from improved reproductive performance are realized and paid in a larger milk cheque because of increased milk revenue per slot.

Insemination rate (IR) is the starting place for intervention to improve reproductive management, because cows cannot become pregnant unless they are inseminated, and because there are numerous tools (reproduction management programs – i.e. Ovsynch and its variants) that will reliably and efficiently increase IR. Conversely, while conception risk (CR) is important, it only becomes a consideration once a cow is inseminated. Moreover, current reproduction management tools have limited ability to increase CR.

The power of systematic TAI programs is their ability to increase IR with minimal change in CR, by greatly reducing the variability in time to first insemination and to re-insemination. However, it is important to evaluate and correct constraints on reproduction other than low IR, such as transition period health, which is associated with uterine health, anovular condition, and therefore with the ability of cows to respond successfully to synchronization.

▪ Quantifying the Opportunity Cost of Delayed Pregnancy

Dykhuizen et al (1985) estimated the cost of an extra day open at approximately $1.16 US at 165 DIM, but they only considered cows producing between 5000 and 10,000 L. Using Canadian data, validated in 3 representative Ontario herds, Plazier et al (1997) estimated a cost $4.70 per day open at 150 DIM, but this included an estimate of the cost of cows culled for non-pregnancy. More recently, Meadows et al (2005) estimated the cost of a day open at $0.44 US at 130 DIM, $1.37 at 160 DIM, and $1.71 at 190 DIM. So which number is correct? In reality, there is no one value that applies across herds, or even within a herd. The opportunity cost of an extra day open relative to the economically ideal calving interval, or the value of a pregnancy at a given interval after calving depends substantially on milk yield and persistency, the price of milk, the availability and cost of replacements, and herd pregnancy rate. Additionally, cow parity and age, current DIM for open cows or stage of gestation for pregnant cows, cull cow values, herd breeding policy, and discount rate also influence the economics of reproduction (Groendaal et al, 2004; DeVries, 2006; Overton, 2006a).

The cost of a day open varies considerably through lactation for a given cow, and between cows. Calculation of precise estimates is complex. The key elements and the direction of their influence are briefly reviewed below. However, it is not necessary to have a sophisticated estimate of the cost of a day open in order to make sound economic decisions about implementing management interventions to improve herd PR.

Production

A major determinant of the value of a pregnancy is future expected production, which is a function of current production, age, risk of culling, probability that an open cow will become pregnant in the next cycle (or at least while it is still profitable to do so; i.e. the herd PR), and breeding policy. Production includes two main elements: yield and persistency. Milk yield refers to the height of the lactation curve. As yield increases, the value of getting that cow pregnant increases. However, for a given cow, with other factors held constant, as yield increases the cost of per day open at a given stage of lactation generally goes down. Models of the economics of pregnancy generally do not consider health variables, but assume that health will be reflected in production. Persistency refers to the shape of the lactation curve. Higher persistency is desirable as this extends the window of greater profitability for a given yield. Therefore, as persistency increases, the value of pregnancy at a given time decreases. The effect of increased persistency after peak on reproductive economics may be large, depending on the mathematical method used to generate the lactation curves in the economic model. Persistency is highly correlated with parity.

In simple terms, high producing cows incur opportunity cost of non-pregnancy more slowly and later than low producing cows, but getting these cows pregnant is of larger economic significance. This does necessarily imply that the voluntary waiting period for high yielding and/or highly persistent cows can or should always be extended, just that it may be profitable to do so, because other variables are also important, particularly the probability that these cows will become pregnant soon after they become eligible for breeding (i.e. herd PR). In any case, the impact of yield on reproduction economics is relative to the alternative of the replacement heifer that would be expected to take the cow's place.

Timing

The stage of lactation (current DIM for open cows) is important because after peak production is passed the race against time is on for cows to become pregnant before production falls to a level at which profit is not optimized. Ultimately, cows reach the break-even point relative to a new heifer, at which point they should be replaced. In an open cow, with other variables constant, as DIM increases, the value of pregnancy decreases, because the future cash flow from this cow is being delayed and diminished. Persistency has a significant effect on this relationship. Conversely, the cost of an extra day open increases as DIM increases, because cows will be spending more time in the less profitable tail of the lactation curve. The effect of time is also influenced by breeding policy. Generally, the decision on whether to breed a cow and how long to continue to breed her should be based on individual calculations of net present value based on optimal replacement, which will change over lactation. However, if there is a fixed policy for a maximum breeding period as would be the case in seasonal production systems, then as the breeding period is shortened, the value of the pregnancy increases because profitability is constrained to drop massively if cows are not pregnant by the end of the breeding period (DeVries, 2006).

Herd Pregnancy Rate

This is the underlying probability that an open cow will become pregnant per unit of time in the future, and is a result of management. As herd PR increases, the value of pregnancy decreases because cows have a greater likelihood of becoming pregnant soon (DeVries, 2006; Overton, 2006a). In simple terms, if PR is high, the consequences of failing to achieve pregnancy this cycle are not as great, because there is good chance that the cow will be made pregnant in the next cycle, and therefore incur relatively low lost profit. Economic models consistently (Ferguson and Galligan, 1999; Overton, 2006a) indicate that the economically optimum PR is 30 to 35%. As pregnancy rate surpasses 20%, the law of diminishing returns becomes apparent. However, most herds are not nearly at the point of diminishing return for improving herd reproductive performance. On the contrary, with the average herd in Canada having a 21-day PR of 12 to 13% (LeBlanc, 2005), there is a huge opportunity for many herds.

Culling Risk

Typically, pregnant cows are very unlikely to be culled, whereas open cows are at increasing risk of replacement (Grohn et al, 1998). As the risk of culling of pregnant cows increases, the value of pregnancy decreases because the value of the average pregnancy must be discounted for those pregnancies whose profit in the subsequent lactation is never realized. While decisions to replace less profitable cows should generally be made before breeding, the risk of culling because of disease, lameness, or injury is probably equal for pregnant and non-pregnant animals. In herds with high culling and death rates in transition cows for example, the value of pregnancy would have to be discounted for cows that subsequently are culled in early lactation or whose expected production is not realized because of disease. However, such a problem should motivate better transition management, not argue against improved reproductive management. The value of cull cows influences pregnancy values, but this must be considered together with the price of a replacement.

When interpreting or applying the results of economic analyses of reproduction, although the details may be complex, it is important to consider how culling is modeled. For example, Meadows et al (2005) assume fixed, age-based culling irrespective of pregnancy or production (i.e. when a cow reaches the average number of lactations based on pre-determined cull rate, she is removed). Clearly this is not realistic. Conversely, more sophisticated models such as those by Groenendaal et al (2004) and DeVries (2006) calculate and apply optimal culling on a daily or monthly basis and assume that the moment it is economically optimal to replace an animal, this occurs. This also does not capture the variability of real-world situations in which some cows are culled too soon (e.g. deaths soon after calving) and others are retained longer than optimal. These issues do not negate the utility of these models, but simply demand understanding and thoughtful application of the specific results of the model scenarios.

Replacements

Because reproduction economics are largely about what cows will fill the slots on a dairy, the availability, cost, and expected milk yield of replacement heifers has a large impact on the value of pregnancy. If replacements are not available, the cost of a day open actually decreases because there is less pressure on the existing cows due to the lack of an alternative to fill the slot (Groenendaal et al, 2004). As the cost of replacements increases, the value of making open cows pregnant increases, other variables being the same (DeVries, 2006).

Milk Price

The price of milk links with yield and persistency to determine milk revenue. As milk price increases, the value of pregnancy increases because the potential profit from selling milk is greater. Milk prices in Canada are generally less variable than in the USA, but it is important to use an accurate milk price for comparison. In either market, marginal milk is almost always profitable, but the feed cost of making marginal milk must be accounted for in the net revenue from extra milk. Additionally, under the quota system, purchase and interest costs for extra quota to produce additional milk must be considered. If $1 CDN = $0.85 US, then $65 CDN/hL = $25 US/cwt. But if debt for quota purchase is $0.10/L, $0.20, or $0.30/L, this is the equivalent of $21.25, $17.40, and $13.50 US/cwt, respectively.

Stage of Pregnancy

The pregnancy value of a pregnant cow can be considered the loss in value if abortion occurs. The pregnancy value of a pregnant cow is generally considerably higher than that of an open cow, because the likelihood of profitably achieving a new pregnancy if the current one is lost is usually low. The value of pregnancy in a pregnant cow depends on the stage of pregnancy (i.e. the proximity of the next peak of lactation and new economic return), the risk of abortion, the risk of culling before calving, and the risk of death or culling as a newly fresh cow.

▪ The Cost of a Day Open

Simple spreadsheet models do not account for all the factors that influence the value of a pregnancy. Dynamic programming models do, but are complex, not readily available and their details are impenetrable to most users (DeLorenzo et al, 1992; Hady et al, 1994; Pecsok et al, 1994; Groenendaal et al, 2004). Partial budgets for reproductive management interventions typically require a fixed value for the cost of an extra day open. As discussed, the opportunity cost of an extra day of non-pregnancy relative to the economic optimum varies between cows and through lactation even in one cow. Therefore, $1, $2, or $3 per day open may be useful inputs into a partial budget, but they cannot be taken as precise or broadly applicable values for all cows under all circumstances. Nevertheless, estimation of the cost of extra time open beyond the optimal is useful to quantify the order of magnitude of this opportunity cost, and to provide a reasonable range of inputs for decision-making around management interventions to increase pregnancy rate.

Using the Groenendaal's model (Groenendaal et al, 2004; available at www.dgalligan.com/culling) with inputs intended to reflect a Canadian herd (22,000 lbs (10,000 kg) production; $20/cwt; replacements available at $1200; cull cows worth $500; $20 per AI; VWP = 50 days; insemination rate = 35%; conception risk = 38%; discount rate = 8%) the cost per day open for cow at herd average production was approximately $1.50 at 90 DIM, $2.10 at 150 DIM, and $2.50 at 210 DIM. The estimates varied considerably by DIM, parity, and relative production level, from 0 (low producing cows that should be culled, not bred, if not pregnant by < 150 DIM) to nearly $3 per day at 210 DIM. Estimates adapted from Overton (2006a) assuming $40/hl milk, 11,500 kg 305ME production, and $2100 replacements were similar: approximately $0.60 per day open at 100 DIM, $2.10 at 150 DIM, $3.25 at 210 DIM, and $3.60 at 250 DIM.

Estimation of the economic value of pregnancy is a more difficult exercise, but also more useful for herd-level analysis than attempting to estimate and sum the cost of days open (Overton, 2006a). Using Overton's model (Overton, 2006a), inputs intended to reflect a Canadian situation were used to estimate the value of improving herd PR. Assuming 23,400 lb 305ME, \$23/cwt, VWP = 50 DIM, replacement cost = \$1260, cull value = \$360, cull rate = 36%, and interest = 8%, the incremental value of improving herd PR from a baseline of 10% to 12% was approximately \$66 per point of PR per cow-slot; from 18 to 20% PR, approximately \$21 per point of PR per cow-slot; and from 24 to 26% PR, approximately \$8 per point of PR (M. Overton, personal communication). These values cannot be applied to every herd, but illustrate the substantial profit potential of improving PR from below average or average to levels (16 to 20%) are that achievable with successful implementation of systematic reproduction management programs in herds with good transition management. These estimates also illustrate that as herds achieve PR ≥ 20%, investments to further improve PR must be evaluated critically.

Devries (2006) developed a sophisticated model to estimate the economic value of pregnancy, considering many variables as discussed above. Based on economically optimized culling, a baseline PR = 16%, 11,400 kg 305ME production, \$14/cwt, replacement cost = \$1600, feed cost = \$0.20/kg DM, discount rate = 8% and breeding period from 61 to 456 DIM, the average value of a new pregnancy was \$278 US. However, considering just parity, DIM, and relative milk yield, pregnancy values varied from < 0 to > \$550.

Cow-specific estimates of the value of making an open cow pregnant (pregnancy value) can be calculated in Dairy Comp 305 (Valley Agricultural Software), to which all customers of CanWest DHI have access. Simplistically, producers could think of a cow they might consider buying at sale – how much more would the same cow be worth if she were pregnant today?

Using this tool with the default inputs of \$40/hl milk (net of quota purchase), \$10/hl marginal feed cost, \$2/day maintenance cost, 10% discount rate, VWP = 60 DIM, replacement cost = \$1600 and cull value = \$750, a convenience sample of 50 herds with complete data from Ontario, Alberta, and BC, was used to describe pregnancy values in Canadian herds. The program uses current herd-specific values for production, culling risk by parity, and the expected performance of replacement heifers. The results are illustrated in Figure 1. The mean herd average value of making an open cow pregnant was \$459 ± 130, with a median of \$437.

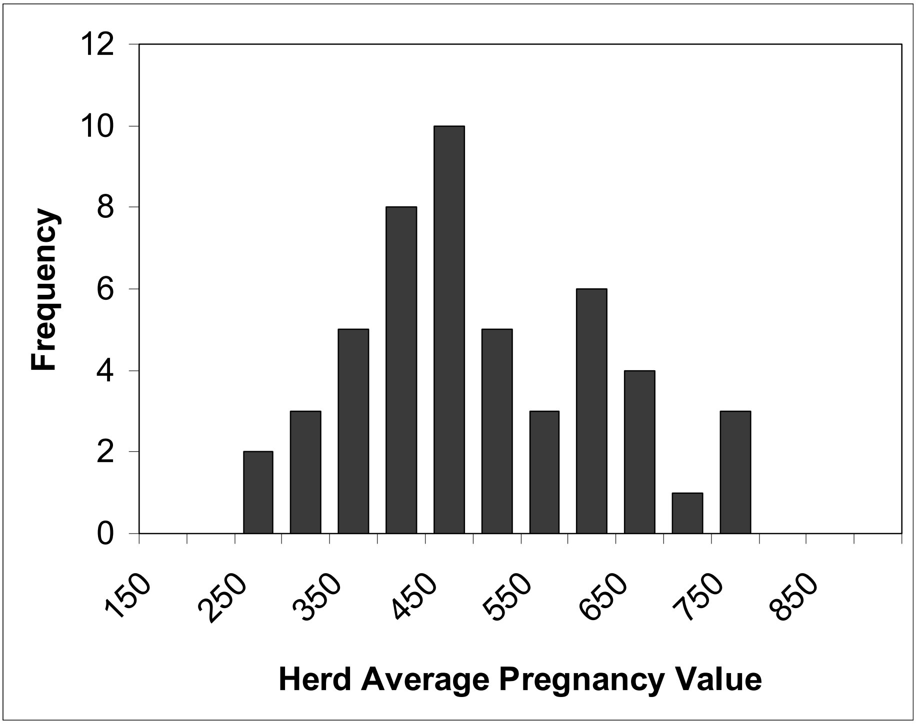

Figure 1. Herd average value (in dollars) of making an open cow pregnant. Data are from a convenience sample of 50 herds in Ontario and western Canada, estimated using the CowValue module in Dairy Comp 305, with herd-specific data for production, reproduction and culling, and the Canwest DHI default prices.

The economic benefit of an intervention to increase pregnancy rate can be estimated by: [(change in PR) × (average PregVal of OPEN cows) × (average number of pregnancy eligible cows per 21 days)] minus the cost of the intervention. In a typical 100-cow herd, about 20 open cows are past the VWP and not bred, or open. If PR is presently 10% but a change in breeding program that costs $11 per cow is expected to increase PR to 16%, and open cow pregnancy value is estimated at $450, then 16%-10% = 6% expected increase in PR. (6% × 20 cows = 1.2 extra pregnancies per 21 days × $450) = $480 – ($11 × 20 cows = $220) = net benefit of $260 per cycle or $4519 per year.

Alternatively, if making a cow pregnant today is worth $300 and the conception risk is 35% (35% chance of earning $300 now is worth $105), then even targeting a 2:1 return on the decision to breed the cow means that one could profitably spend $52 to inseminate the cow (semen + cost of hormones and/or labour).

■ The Profitability of Investing In a Systematic Reproduction Management Program.

There are now many published studies evaluating numerous variants of synchronization programs for TAI. Recent summaries of synchronized breeding programs and their performance (Lucy et al, 2004; Sterry et al, 2006; Thatcher et al, 2006) as well as the attitudes of Canadian producers and veterinarians toward these programs (Wichtel et al, 2004) are available.

A spreadsheet by John Fetrow is available to calculate PR under different scenarios of reproduction management, including systematic TAI (www.cvm.umn.edu/dairy/software/listing/home.html). Using this software, for example, a systematic complete TAI program with no heat detection (i.e. Ovsynch to all open cows in odd-numbered cycles, assuming pregnancy diagnosis and re-synchronization to allow re-breeding of open cows by 42 days after the previous service, with no heat detection in the intervening cycles) and CR = 33%, over 12 cycles, the herd PR would be 20%. This scenario was compared with the average Canadian herd with an insemination rate of 35% and conception risk of 38%, resulting in a PR of 13%.

A partial budget spreadsheet (Fetrow and Eicker, 2005, personal communication) was used to estimate the economics of implementation of a timed AI program in a herd (Tables 1 and 2).

Table 1. Assumptions and initial inputs into a partial budget (Fetrow and Eicker, 2005) to evaluate implementation of a systematic Ovsynch program for all breedings in a dairy herd.

Variable	Initial value
Herd size	100 milking cows
Breeding period	12 21-day cycles
Average cost of a day open between 70 and 300 DIM	$2
Cost of a replacement	$1200
Revenue from a cull cow	$400
Expected lifespan for milking cows	2.5 lactations
Discount rate	8%
Labour	$12/hour
Cost of an insemination	$12
Cost of prostaglandin	$5/dose
Cost of GnRH	$3
Cost of pregnancy diagnosis	$3

Table 2. Description and results of a partial budget (Fetrow and Eicker, 2005) to evaluate implementation of a systematic Ovsynch program for all breedings in a dairy herd.

Variable	Management program			
	Status quo	**Total TAI**	Difference	
Description	Heat detection by observation; individual-cow use of prostaglandin and/or GnRH, but assumed no cost for hormones	All breedings by timed AI with Ovsynch, with pregnancy diagnosis and re-breeding within 42 days		
VWP	50 DIM	70 DIM		
Insemination rate	35%	100% in odd-numbered cycles; 0 in even-numbered cycles		
Conception risk	38%	33%		
Pregnancy rate	13%	20%		
Results			Benefit of improved PR with TAI	
			Annual discounted difference	Per cow
Cost of time non-pregnant (days open)	$8286	$6042	$2078	$21
Cost of culls of cows not pregnant at the end of 12 cycles	$9064	$4545	$4184	$42
Program costs	$7358	$10,597	($3221)	($32)
Net	$24,707	$21,166	$3041	$30

With these initial inputs, even though the program costs (hormones and labour) were greater for the total Ovsynch program, Table 2 indicates that this option was more profitable (net benefit of $30/cow/year over the status quo). This does not imply that total synchronized breeding to the exclusion of heat detection is the recommended program for all herds. However, this example is designed to illustrate the performance and profitability that are achievable with investment in a systematic reproduction management program. Other options, including choosing to do nothing should be compared against these results.

Sensitivity Analysis

Each of the main variables was changed, one at a time, through a range of values that might be observed in the field, including the cost of a day open ($0.50 to $3.00), the cost of a replacement ($1000 to $2000), the value of a cow culled open ($200 to $1000), the cost of AI ($10 to $35), and the pregnancy rate (9% to 17%) in the comparison group (the heat detection scenario). Given the inputs described above, the bottom line was insensitive to variation in all these inputs except the baseline PR achieved before the new TAI program. For all other variables, the TAI was more profitable than the status quo across the specified ranges. When the herd's starting PR was ≥ 16%, it was no longer profitable to implement a total TAI program, given the other initial inputs described. This is in agreement with a separate analysis by Overton (2006a).

▪ Conclusion

There is substantial profit available by improving herd reproductive performance. The precise cost of additional time not pregnant depends on DIM, age, production, availability & cost of replacements, culling, and milk price. Herds with average or low PR stand to gain the most from improving reproductive performance. Systematic timed insemination programs (Ovsynch-based) offer one practical means, with little or no capital investment, to predictably deliver a herd PR of 17 to 20%. It is not necessary to adopt Ovsynch-based programs as the sole method of insemination, but alternatives should be measured against the pregnancy rate that is practically achievable with a systematic TAI program. Although many producers balk at the initial cash costs of implementing a systematic TAI program, for producers with average herd reproductive performance, such a program is more profitable than the status quo, across a broad range of input costs.

References

Delorenzo, M.A., H. Spreen, R. Bryan, D. K. Beede, J.A.M. Van Arendonk (1992) Optimizing Model: Insemination, Replacement, Seasonal Production, and Cash Flow. J Dairy Sci 75:885-896.

De Vries A. (2006) Economic Value of Pregnancy in Dairy Cattle J. Dairy Sci. 89:3876–3885

Grohn Y. T., S. W. Eicker, V. Ducrocq, J. A. Hertl (1998) Effect of Diseases on the Culling of Holstein Dairy Cows in New York State. J Dairy Sci 81:966–978.

Ferguson, J.D., D.T. Galligan (1999) Veterinary Reproductive Programs. Proc. Annual Conference of the AABP, Nashville, TN, September 1999. The Bovine Proceedings No. 32 p. 131 - 137

Fricke, P.M, S. Stewart, S. Eicker, P. Rapnicki, M. Overton (2005) Pregnant vs. Open: Getting cows pregnant and the money it makes. Proc. Western Dairy Management Conference (http://www.wdmc.org/2005/6Fricke.pdf)

Groenendaal, H., D. T. Galligan, and H. A. Mulder. (2004) An Economic Spreadsheet Model to Determine Optimal Breeding and Replacement Decisions for Dairy Cattle J. Dairy Sci. 87:2146–2157

Hady, P.J., J.W. Lloyd, J.B. Kaneene, A.L. Skidmore. (1994) Partial Budget Model for Reproductive Programs of Dairy Farm Businesses. J. Dairy Sci. 77:482-491

Laven, R.A., J. Stewart, C. Dyer (2006) Factors affecting the monetary return from programmes for synchronising oestrus in dairy cows with gonadotrophin-releasing hormone and prostaglandin F2α. Veterinary Record 158, 367-372

LeBlanc, S. (2005) Overall Reproductive Performance of Canadian Dairy Cows: Challenges We Are Facing. Advances in Dairy Technology 17:137-157.

Lucy M.C. S. McDougall, D.P. Nation (2004) The use of hormonal treatments to improve the reproductive performance of lactating dairy cows in feedlot or pasture-based management systems. Animal Reproduction Science 82–83: 495–512.

Meadows C., P. J. Rajala-Schultz, and G. S. Frazer. (2005) A Spreadsheet-Based Model Demonstrating the Nonuniform Economic Effects of Varying Reproductive Performance in Ohio Dairy Herds J. Dairy Sci. 88:1244–1254.

Overton, M.W. (2006) Cash flows of instituting reproductive programs: cost vs. reward. Proc. 39 Annu. Conf. Amer. Assoc. Bovine Practitioners 39:181-188.

Overton, M.W. (2006) Improving decision making by consideration of type I and type II error costs. Proc. 39 Annu. Conf. Amer. Assoc. Bovine Practitioners 39:190-195.

Pecsok S. R., M. L. McGllliard, and R. L. Nebel (1994) Conception Rates. 1. Derivation and Estimates for Effects of Estrus Detection on Cow Profitability. J Dairy Sci 77:3008-3015

Plaizier, J.C.B., G. J. King, J.C.M. Dekkers, and K. Lissemore (1997) Estimation of Economic Values of Indices for Reproductive Performance in Dairy Herds Using Computer Simulation. J Dairy Sci 80:2775–2783.

Sterry R. A., M. L. Welle, P. M. Fricke (2006) Effect of Interval from Timed Artificial Insemination to Initiation of Resynchronization of Ovulation on Fertility of Lactating Dairy Cows J. Dairy Sci. 89:2099–2109.

Thatcher W.W., T.R. Bilby, J.A. Bartolome, F. Silvestre, C.R. Staples, J.E.P. Santos (2006) Strategies for improving fertility in the modern dairy cow. Theriogenology 65:30–44.

Wichtel, J., S. LeBlanc, L. DesCoteaux (2004) Synchronized breeding programs in Canadian dairy herds: Attitudes and opportunities. Large Animal Veterinary Rounds, May 2004 4(5):1-6. (available at www.canadianveterinarians.net/larounds)