Conception Rates. 1. Derivation and Estimates for Effects of Estrus Detection on Cow Profitability

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ABSTRACT

Objectives were to derive equations and obtain estimates per cow of days to conception, milk production, semen purchases, calvings, and reproductive failures based on the probability of estrus detection and AI conception. The net benefits of changing rates of estrus detection, including changes in milk production, semen purchases, and replacement inventories (culled cows and calves) were converted to annual values and multiplied by fixed prices to obtain estimates of the annual financial benefit of a change in rates of estrus detection. Improvement in milk production because of a 1-d decrease in DIM at conception was dependent on DIM, peak milk production, and monthly rate of decline in daily milk production. Variation was considerable in expected benefits of improved estrus detection. Under the assumption that replacement was not planned prior to breeding (in which case improved estrus detection would have no value), estimated financial benefits for increasing the probability of estrus detection from 60 to 70% with a 70% AI conception rate were $6/yr; increasing from 20 to 30% the rate of estrus detection with a 50% AI conception rate increased estimated annual benefits to $83. This wide range of values occurred with fixed costs and prices so that fluctuating prices would introduce further variation in financial benefits. Derived equations allow point estimates of expected benefits with input values estimated. (Key words: estrus detection, conception, profitability)

INTRODUCTION

Definition and improvement of optimal reproductive efficiency has long been researched and evaluated. A 13-mo calving interval has generally been regarded as an optimal goal (6, 13, 15); however, a number of producers find that the calving interval of their cows exceeds this number (12). Barr (2) and Rounsaville et al. (14) found that the leading cause of extended calving intervals was inefficient detection of estrus. The efficiency of estrus detection reported by Stevenson and Brit (16) was approximately 50%. To achieve an optimal calving interval, additional benefits that are due to decreasing the calving interval must be less than additional costs incurred. Gwazdauskas et al. (5) reported that estrus detection improved 1.3 to 6.2% when two methods of estrus detection were used instead of one, and Williams (18) found 20% improvement in efficiency using two methods instead of one. Several researchers have calculated costs for additional days open that were attributable to production losses and increases in breeding, veterinary, and replacement costs, implying marginal benefits for decreased days open. With current milk prices, those costs range annually from about $1.50 per cow for a change of 1 d open to $2.50 (4, 8, 11); calculations of Louca and Legates (9) were slightly less, and others (6, 7, 15) were substantially less.

Changes in annual income and expense items because of improved estrus detection that are examined in this paper include increases in milk income minus feed cost attributable to increased milk production, semen purchases, calvings, and decreases in reproduc-
EFFECTS OF ESTRUS DETECTION

was exchanged for a different cow, and a new parturition started 280 d after the last possible breeding date. Delayed conception could result in less average milk per day because a lower proportion of time was spent in peak milk production. Failure to conceive could result in less average milk per day for the same reason, but also the loss of a calf and the difference in value between a milking cow and her value as a reproductive cull.

Herd Parameter Equations

The first step in deriving herd parameter equations was to define PC as the product of EDP and AICP

\[
PC = EDP \times AICP \quad [1]
\]

where PC, EDP, and AICP have a minimum value of 0 and a maximum of 1 (1).

Days Open. The EDO can be computed by adding the voluntary waiting period plus one-half of the length of the estrous cycle, a second term to represent the sum of the weighted PC, and a third term to account for the weighted probability of a cow not being pregnant after a maximum number of breeding periods, as shown in Equation [2].

\[
EDO = V + \sum_{h=1}^{H} [PC \times (h - 1)] \times (1 - PC)^{h-1} + \left[(F - V) \times (1 - PC)^H\right] \quad [2]
\]

where

- \(V\) = voluntary waiting period plus one-half of the length of the estrous cycle,
- \(L\) = length of estrous cycle (21 d),
- \(h\) = estrous period (1 \ldots H),
- \(H\) = maximum estrous cycles after the voluntary waiting period, and
- \(F\) = maximum DIM for breeding and EDO calculation.

Because cows cycle every 18 to 24 d (an average of 21 d) and because estrus would have an equal probability of occurring on any of the 21 d past the voluntary waiting period,
minimum EDO (PC = 1) was determined by the voluntary waiting period plus one-half of the length of the estrous cycle. Maximum EDO, which would occur when PC = 0, was defined as DIM at last possible breeding. If the cow was not pregnant after a maximum number of estrous cycles, she remained in the herd until 280 d past DIM at final breeding, but EDO was fixed at days open at final breeding (260 d). This method established a constant relationship between EDO and termination of lactation as EDO plus 220 d.

As a geometric progression, the summation representing the second term in Equation [2] can be simplified, and

$$
EDO = V + L \times \left( \frac{(1 - PC) - (1 - PC)^H}{PC} - (H - 1) \times (1 - PC)^H + (F - V) \times (1 - PC)^H \right) \tag{3}
$$

with all variables as before. If PC = 1, all terms drop, except that representing the voluntary waiting period, establishing minimum EDO. If PC = 0, the second set of terms is reduced to 0, leaving the first and third terms to establish maximum EDO. As H approaches infinity, the equation reduces to

$$
EDO = V + L \times \frac{(1 - PC)}{PC} \tag{4}
$$

with all variables as before, and

$$
EDP = \frac{L}{AICP \times (EDO + L - V)} \tag{5}
$$

which is commonly used for DHI records.

**Milk Production.** After an expression to compute EDO based on PC was derived, milk production was estimated with EDO as an independent variable. The first step in this procedure was to measure milk production for a hypothetical cow by approximating parameters in Wood's equation (3, 19) as

$$
Y_n = a \times t^b \times e^{-ct} \tag{6}
$$

where

- $Y_n$ = milk production in quarter-month $n$,
- $t$ = month in lactation,
- $e$ = base of natural logarithm,
- $a$, $b$, and $c$ are parameters,
- $Y_m$ = maximum daily milk production,
- $t_m$ = month of maximum production,
- $t_f$ = final month of lactation,
- $RD$ = average monthly percentage rate of decline in daily milk production from $t_m$ to $t_f$.

To expedite calculations, months were divided into four quarters so that 4 wk/mo and 12 mo/yr constituted a 48-wk yr. Quarter-month milk production was summed to calculate total milk production for a lactation. Total milk production in a lactation was multiplied by quarter-months in a year and divided by quarter-months in milk plus a 2-mo dry period (8 quarter-months) to calculate average yearly milk production as

$$
AM = \frac{Y_{t_m}}{(t_f + 2) \times 4} \times \sum_{t=1}^{t_m} Y_t \times \frac{t \times 4}{12} \tag{7}
$$

where $AM$ = average yearly milk production per cow, and $Y_t$ = milk production in quarter-month $t$.

To predict milk production for a wide range of scenarios, Equation [6] was used to compute quarter-month milk production for a lactation with 5 RD percentages (1, 4, 7, 10, and 13%), 45 different quarter-months in milk at successful breeding (0 to 44 quarter-months), and peak daily milk production fixed at 50 kg in mo 2. After weeks in milk were replaced with EDO (assuming 30 d/mo), 225 observations were substituted in Equation [7], and ordinary least squares were used to derive regression estimates to predict average yearly milk production. All variables were significant at $P < .01$ ($R^2 = .99$); parameter estimates are shown in Table 1. The prediction equation can be modified to account for cows not peaking at 50 kg/d of milk by multiplying by actual kilograms of peak daily milk production and dividing by 50.

**Semen Purchased.** Semen purchased in any given estrous cycle is EDP times the probability of a cow being open in that period; semen per lactation (SU) is the sum of purchases in all cycles.
TABLE 1. Parameter estimates for prediction of annual milk production (kilograms) per cow based on monthly percentage rate of decline in daily milk production (RD), expected days open at conception (EDO), and assumption of 50 kg/d of peak milk production.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter estimate</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>13,508.6</td>
<td>109.61</td>
</tr>
<tr>
<td>RD</td>
<td>-292.81</td>
<td>7.591</td>
</tr>
<tr>
<td>EDO</td>
<td>7.74</td>
<td>3.19</td>
</tr>
<tr>
<td>RD × EDO</td>
<td>-1.13</td>
<td>.018</td>
</tr>
<tr>
<td>RD²</td>
<td>10.21</td>
<td>.485</td>
</tr>
<tr>
<td>EDO²</td>
<td>-0.013</td>
<td>.001</td>
</tr>
</tbody>
</table>

\[
SU = EDP \times \sum_{h=1}^{H} (1 - PC)^{H-1}. \tag{8}
\]

Eliminating the summation from Equation [8] and recalling the definition of EDP from Equation [1] yields

\[
SU = \frac{1 - (1 - PC)^H}{AICP}. \tag{9}
\]

where \( H = \) maximum number of estrous cycles. As maximum estrous cycles increases, the second term of the numerator approaches 0, and semen per lactation becomes the inverse of AICP. For example, with no limit on estrous cycles and AICP of .40, 2.5 units of semen per cow would be expected to be purchased each lactation.

Culled Cows and Calvings. When an assumption of full-term pregnancies for each lactation is used, a cow would be expected to have one calving minus the probability of not being bred at the end of the imposed maximum number of estrous cycles. All cows that did not calve are culled; therefore, the probability of a cow being culled is the probability of the cow not being bred at the end of the imposed maximum number of estrous cycles (H). The expected probability of being open (EO) at the end of the maximum number of estrous cycles is

\[
EO = (1 - PC)^H. \tag{10}
\]

With no limit on estrous cycles, EO approaches 0 as H approaches infinity. Expected calvings per cow (EC) is 1 minus the probability of being open:

\[
EC = 1 - (1 - PC)^H. \tag{11}
\]

Conversion of semen, calves, and reproductive cullings from a lactation basis to an annual basis is achieved by multiplying the respective variable (X) by lactations in a year

\[
AX = X \times \frac{365}{EDO + 280}. \tag{12}
\]

where AX is the annual value of the respective variable.

Improved Profitability

Increase in contribution to annual profitability that is due to improvement in estrus detection can be estimated if changes in quantities are multiplied by costs and prices. This procedure allows profitability estimates to maintain relevance as prices change. For discussion, values for income over feed cost, semen purchases, calvings, and reproductive cullings had to be obtained or assumed.

Change in annual milk revenue can be obtained by multiplying the change in annual milk production by the price of milk. To account for change in annual net revenue, or increased profitability, milk price can be adjusted for increase in DMI because of additional milk production. Given that all additional feed is in concentrate form with 90% DM, that increase in DMI is .3 kg for an increase of 1 kg in milk production (10), and that the milk:feed price ratio is 1.67 (17), the cost of additional feed is .2 times the milk price. Therefore, the price of milk multiplied by a factor of .8 reflects additional income minus the cost of feed.

A semen value equal to price was assigned; calving value was obtained by assuming equal probability of heifer or bull-calf and using the mean value. Because reproductive failure represents a loss in value of a cow that was to be retained in the herd, the cost of a reproductive culling was the difference in the value of the cow if she had been bred and her value as an open, reproductive cull at 18 mo in lactation. If the producer had planned to cull her regardless of reproductive status, this component of the model would have no cost.
TABLE 2. Expected days open at conception (EDO) based on probability of estrus detection (EDP) and AI conception (AICP) with 60-d volunteer waiting period to first breeding, 21-d estrous cycle, and maximum of nine estrous cycles (260 EDO).

<table>
<thead>
<tr>
<th>AICP</th>
<th>EDP</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<td>.3</td>
<td>234</td>
<td>211</td>
<td>192</td>
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<td>218</td>
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<td>162</td>
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<td></td>
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<tr>
<td>.7</td>
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<td>166</td>
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<td>92</td>
<td>86</td>
<td>82</td>
<td></td>
</tr>
</tbody>
</table>

The total increase in annual profitability per cow attributed to an improvement in EDP of .1 can be described as

\[
\text{CAP} = (P_m \times \text{CAM}) - (P_s \times \text{CSU}) + (P_c \times \text{CEC}) - (P_0 \times \text{CEO})
\]  

where CAP = change in annual profit, \( P_m \) = additional income over feed cost because of increase in milk production ($0.24/kg), CAM = change in annual milk production, \( P_s \) = cost of semen ($20/unit), CSU = change in annual semen unit purchases, \( P_c \) = calving value ($150), CEC = change in annual calvings, \( P_0 \) = difference in value between the cow as a member of the milking string and as a reproductive cull ($400), and CEO = change in annual reproductive cullings. Positive signs associated with milk production and calvings represent income; negative signs associated with semen and reproductive culls represent costs.

RESULTS AND DISCUSSION

Derived equations can be used to calculate expected values for any combinations of EDP and AICP at different values of RD and peak daily milk production. In the discussion, peak milk production was fixed at 50 kg/d because of the linear relationship between it and change in annual milk production; actual change in annual milk production can be modified in direct proportion to the ratio of actual peak daily milk production to 50 kg/d. In addition, although five percentages of RD were used to generate data, only the more moderate 4, 7, and 10% were used in discussion of results. Results present selected combinations of EDP and AICP to calculate EDO, milk production, semen purchases, calvings, and reproductive cullings with emphasis on the effect of EDP on these values.

Days Open

With a 60-d voluntary waiting period, .3, .5, and .7 AICP were combined with EDP values beginning at .1 in .1 increments to a maximum of 9, as shown in Table 2. Any product of EDP and AICP that results in identical PC also results in identical EDO; e.g., 140 EDO is predicted by .3 EDP and .7 AICP and by .3 AICP and .7 EDP. The EDO can be used to determine combinations of EDP and AICP that translate to a goal EDO. For example, EDO <100 can be achieved with .6 EDP and .7 AICP. Because .5 EDP and .5 AICP predict 128 EDO, calving interval under these conditions would approximate 13.5 mo with a 280-d gestation.

Decreases in EDO that are due to an increase of .1 in EDP are shown in Table 3. No conception can occur without estrus detection, so 0 EDP predicts maximum EDO of 260 d regardless of AICP, and the improvement in

TABLE 3. Decrease in expected days open (EDO) because of increase of .1 in estrus detection probability (EDP).

<table>
<thead>
<tr>
<th>AICP</th>
<th>.0 to</th>
<th>.1 to</th>
<th>.2 to</th>
<th>.3 to</th>
<th>.4 to</th>
<th>.5 to</th>
<th>.6 to</th>
<th>.7 to</th>
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<td>.3</td>
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<td>19</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>4</td>
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</table>

\(^1\)The AI conception probability.
TABLE 4. Annual change per cow in milk produced, semen purchased, number of calvings, and number of reproductive cullings because of increase of .1 in estrus detection probability (EDP) with 60-d volunteer waiting period to first breeding, 21-d estrous cycle, and maximum 9 estrous cycles.

<table>
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<tr>
<th>Variable</th>
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<th>.2 to .3</th>
<th>.3 to .4</th>
<th>.4 to .5</th>
<th>.5 to .6</th>
<th>.6 to .7</th>
<th>.7 to .8</th>
<th>.8 to .9</th>
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<td>.7</td>
<td>.8</td>
<td>.9</td>
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<td>-4</td>
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<tr>
<td>Milk, kg (7% RD)</td>
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<td>.029</td>
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<td>.001</td>
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</tbody>
</table>

1The AI conception probability.
2Average monthly rate of decline in daily milk production from peak milk production (RD).

EDO at .1 EDP is the difference between 260 and EDO with .1 EDP. The EDO decreases with an increase in EDP at any fixed AICP, but at a decreasing rate.

The rate of improvement is also dependent on AICP. As EDP changes from .1 to .2 with AICP fixed at .7, estrus detection is the main barrier to conception, and EDO decreases by 38 d, compared with 23 d with AICP fixed at .3. However, with AICP fixed at .7 and increase in EDP from .8 to 9, the improvement in PC is so slight that EDO decreases only 4 d, compared with 8 d with AICP fixed at .3.

Annual Milk Production

The EDO in Table 2 were used with the regression estimates in Table 1 to determine annual milk production (with a 2-mo dry period assumed and taken into account) for the previously described AICP and EDP with peak milk production of 50 kg/d. Differences in annual milk production between successive increments of .1 EDP with RD fixed at 4, 7, and 10% and 50 kg of peak daily milk production are shown in Table 4. The importance of RD is apparent from the results. With 4% RD, annual milk production decreases as lactation length is shortened for a number of combinations of high EDP and AICP. These decreases can be attributed to a relatively persistent lactation, in which higher milk production in early lactation does not sufficiently compensate for lost milk production in the dry period. With 7% RD, improvements in all combinations of EDP and AICP show increases in annual milk production. Increases occur at a nonlinear decreasing rate with the same pattern for EDO. At 10% RD, improvement in annual milk production is often twice that for 7% RD.

Although results show the effect of improvement in estrus detection on annual milk production, the change in milk from a 1-d decrease in EDO can be obtained by dividing milk change (Table 4) by corresponding EDO change (Table 3). With 4% RD, results vary from negative to 2.2 kg/yr. At 7% RD, the range is 2.5 to 5.1 kg/yr, and at 10% RD, the range is 6 to 8.1 kg/yr. Within this range of RD, the results are consistent with previously reported production losses attributed to increased days open (6, 11, 12, 15).

Annual Semen Purchases

Changes in units of semen purchased annually also are presented in Table 4. Unlike milk production, for which PC is the true determin-
Figure 1. Expected increase in annual profitability per cow because of increase of .1 in probability of estrus detection and 7% average monthly rate of decline in milk production between month of peak lactation and final month of lactation, $.24/kg milk net income over feed cost for increased milk production, increased semen purchases with semen at $20/unit, increased calvings at $150/calving, and decreased number of reproductive cullings with $400 difference between cow as member of milking string and as a reproductive cull.

Annual Calvings and Reproductive Cullings

Table 4 also presents the change in annual calvings and reproductive cullings per cow because of an increase of .1 in EDP. As estrus detection increases, more calves per cow per year are produced, and the probability of culling for reproductive reasons decreases. Per lactation, the numbers of calvings and cullings are identical with opposite signs. A calving can occur between 12 and 18 mo after parturition, but reproductive culling is constrained to occur 18 mo after parturition. Therefore, the change in annual calvings, although following a similar pattern, is larger than the annual change in reproductive cullings. The effect of estrus detection is largest at low AICP and low EDP and decreases at nonlinear rates as EDP and AICP improve.

Revenues and Expenses

Figure 1 uses Equation [13] and the assumed costs and prices to combine effects of changes in estrus detection rates on the different categories into a common unit of profitability. Annual profitability changes per cow ranged from 6 to $83. Increased semen purchases represent a cost, and part of the increased milk net income over feed cost in Figure 1 is offset by increased semen purchases. The largest effects were at low EDP, at least partially because the relative increase in estrus detection from .2 to .3 is 50%, but the relative increase from .6 to .7 is only 17%. Increases are clearly more difficult to obtain when success has already been achieved. Benefits might be expected to be lower at higher AICP, but this is not always the case, because increasing EDP from .2 to .3 causes
the maximum benefit of $83 to be gained at AICP of .5, not .3. This response might be attributed to the very low overall PC when EDP and AICP are both .3.

A final element of Figure 1 suggests that a large portion of financial benefits, in many cases approximately one-half, results from reducing the number of reproductive cullings. Deviation from assumed values of $1000 per cow and $600 per cull ($400 difference) could create a strong bias in total results. For instance, a young, genetically superior cow may have a higher value than that assumed, and an older, genetically inferior cow may contribute little to reproductive culling loss. Estimates of financial benefits could be profoundly affected by these changes.

CONCLUSIONS

Within the range of analyzed EDP and AICP and with RD fixed at 7%, the maximum financial benefit attained for improving EDP by .1 was $83. If this number were extrapolated to 100 cows, the increase would be worth $8300/yr to a producer. This value would not be appropriate for generalizations because 1) it depends on RD, which could vary across herds and cows; 2) it assumes maximum daily milk production of 50 kg/d; 3) it represents an extreme, so, even with 7% RD and 50 kg/d of maximum daily milk production, a more average value for one cow might be $34 (increasing from .4 to .5 EDP with AICP of .5); 4) no benefits derive from estrus detection if a cow is not to be bred back, which is usually the case for at least some cows in the herd, so $3400 would need to be reduced by an appropriate percentage; and 5) if anticipated benefits are weighed against additional estrus detection costs, the maximum (break-even) expenditures need to be discounted (reduced) to account for uncertainty of results. However, with estimates of specific parameters, derived equations can be applied to estimate expected financial benefits of improved estrus detection.

REFERENCES
