Methodology of Evaluation for Female Fertility

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Introduction

Female fertility is a complex trait. It is affected by time to first heat, voluntary waiting period, heat detection rate, conception rate, embryo survival and fetus mortality. All of these component traits are functions of genetics management and seasonal effects. Some of these traits behave differently under estrus synchronization than under a natural heat. Additional issue is an interrupted breeding season due to implementation of pasture systems or hot weather.

There are many traits and methods used for the evaluation of fertility (Jamrozik *et al.,* 2005). They include non-return rate (NR) at 45 to 90 days, days open (DO) analyzed by several models, outcomes of services, etc. Some of the traits are binary or categorical, and some are censored.

It is desirable that an evaluation for fertility provide accurate predictions as early as possible with a good utilization of data. There are many factors that may make an evaluation inaccurate. Long voluntary waiting periods or voluntary non-breeding may be misinterpreted as poor fertility. Much larger variance of DO in farms with poor fertility may result in higher proportion of good bulls used in farms with poor fertility; voluntary non-breeding during hot weather results in bimodal days open (DO) (Oseni *et al.,* 2004). Poor heat detection or slow return to heat, e.g., "phantom cow syndrome" (Cavalieri *et al.,* 2003), and subsequently longer service intervals may result in misleading data.

Analysis of Field data on fertility is often limited in scope by the amount of missing information. In particular, information on heat detection or embryo mortality is usually unavailable. Therefore, data simulation is a useful tool for comparison of methods under different circumstances, e.g., as in Schneider *et al.* (2005, 2006). Drawbacks of simulations include unrealistic outcomes with unrealistic assumptions, and favoring of models under which the data was simulated.

The purpose of this study was to compare the ability of different models, via data simulation, to correctly analyze female fertility.

Materials and Methods

Data

A threshold-liability model was used to generate our simulated data. The liability to conception η in a single service was modeled as:

$$\eta_{ijklm} = \mu + month_i + milk_j + dim_k + s_l + e_{ijklm}$$

where μ is a mean, month is an effect of month of service, milk is the effect of class of milk level, dim is the effect of days-in-milk class, and s is the effect of sire Any breeding service with $\eta > 0$ would result in a pregnancy.

All first services occurred at 69 d DIM. If it was not successful, the next service was generated 21 d later, up to 250 d DIM.

The heritability was set to 2%. The simulation involved 55,000 cows and 1000 sires, and the average number of services per cow was 4.2. The average conception rate was set at 22%; it decreased with the level of production, decreased during the summer months, and increased with DIM. Proportion of cows becoming pregnant by 150, 200 and 250 d was 46%, 74% and 88%, respectively.

Methods for analysis of simulated data

The following methods were used:

RPT - Repeatability model of outcomes of services, similar to Boichard *et al.* (1997) or Averill *et al.* (2006), was used.

Each insemination was considered a separate event under the RPT model allowing for considering fixed effects specific to each service. Genetic and permanent environmental covariances for insemination success at different times were assumed to be constant. Both a threshold and linear model was analyzed

NR - Non-return rate; measures the success of a breeding by noting the occurrence or lack of occurrence of any additional breeding after X number of days. In our study, X number of days was 21, NR 21 was equivalent to the success of the first insemination.

COX - Cox proportional hazards model on days open.

The proportional hazards models assume a smooth flow of time, as in life. In such a case, it accounts for non-normal distribution and censoring. A loss of efficiency is likely if intervals between inseminations are not equally spaced. Also, this model as implemented by Ducrocq and Soelkner (1998) cannot easily be used with an animal or multiple trait model.

DOx - Days open with censored records at day x treated as missing

DOxPEN - Days open with censored records at day x treated as equal to x (penalized model).

DOx/CS – a bivariate model of DOx and calving success (CS); calving success was set to 1 if there was pregnancy by day x, and it was 0 otherwise (Arnason, 1999; Foulley, 2004).

Implementation and computations

The RPT model included all the effects used in the liability calculations. The remaining models used the effects of months at calving, milk and sire. Computations in the COX model involved the survival kit by Ducrocq and Soelkner (1998).

All models were evaluated by the correlation between simulated and predicted sire effects. Thresholds models were used whenever appropriate. Computations with the RPT model were also repeated using the linear model.

Results

The table below provides correlations between simulated and predicted sire effects (R), and estimated heritabilities (h^2).

Method	R	h^2
RPT	0.559	2.01%
RPT[1]	0.556	0.88%
NR	0.331	0.42%
COX	0.538	1.86%
DO150		
DO200	-0.300	0.83%
DO250	-0.419	1.73%
DO150PEN	-0.444	1.32%
DO200PEN	-0.518	2.55%
DO250PEN	-0.550	3.21%
DO150/CS[3]	-0.464	0.08%
DO200/CS[3]	-0.543	1.02%
DO250/CS[3]	-0.552	1.93%

[1]linear model; [2] estimated heritability close to 0; [3]results for DO

The highest correlation as well as heritability close to that used in the simulation was obtained with the RPT threshold model. This was expected because this model was close to the one used to simulate the data. In particular, it was the only one that accounted for environmental differences during each service. Substituting the threshold by the linear model resulted in a slight decrease in correlation and less than half of the heritability estimates. In a study by Ramirez-Valverde *et al.* (2001), the threshold model showed the greatest improvement with an animal bivariate model but little improvement with the sire model. Either RPT model ignores the length of time between inseminations making them a desirable choice when a period of voluntary non-breeding occurs. A potential source of bias is that poor heat detection may provide inflated estimates of fertility for cows that have poor expression of estrus.

With the NR21 model, the correlations were low. This was due to low probability of conception for a single service. In such a case, NR21 has low data utilization. Selecting the most appropriate time interval may be dependent upon the average level of fertility. With low fertility data (involving poor heat detection) several breeding opportunities may be needed to determine that an earlier insemination was unsuccessful. Ravagnolo and Misztal (2002) found that in Florida, where the service intervals are long, the heritability of NR was only 0.6% at 45 d but increased to 5.3% at 90 d. NR at 90 d may be unsuitable for regions with good fertility

The COX model resulted in the correlation below those of several other models. While this model accounts well for censoring, it was not the model used in the simulation.

DO is an easily measurable trait, however it can be biased by different voluntary waiting periods, unequal variances due to different levels of fertility, and periods of voluntary nonbreeding. Some of these problems can be mitigated by a careful selection of contemporary groups and an adjustment for heterogeneous variances

All DO models showed increased heritability and correlations with increasing x, as expected. Methods that analyze DO take censoring into account by either assuming truncation or stochastic censoring. With truncation censoring (DOxPEN, COX), it is implicitly assumed that given enough time the cow will conceive. With stochastic censoring, calving success is correlated, but is not the same trait as DO. In particular, this model allows some cows to never conceive. In beef cattle under grazing system, DO/CS provided much more accurate prediction than DOxPEN (Urioste *et al.,* 2007).

The most accurate model was DO250/CS followed by DO250PEN, however differences were small. In this case, DO250/CS is similar to a regular censored model that implicitly predicts DO for incomplete records. The advantages of DO250/CS would be higher if censoring were not past day x but stochastic, e.g., partly based on health status.

Gonzalez-Recio *et al.* (2005) found that several models provided nearly identical PTAs despite of different source of information and a different type of accounting for censoring. This can be due to relatively uniform environment for the majority of cows in the study, or the averaging effects where sires are used in a variety of environments. Another possibility is that the component traits of fertility are strongly correlated.

General comments

Next steps in the simulation would involve adding liability to heat detection, age to first service, voluntary waiting periods, voluntary seasonal non-breeding, the animal model, etc. Countries with different levels of genetic ability for fertility, environmental circumstances and management practices will need to experiment with a variety of models before identifying the best choice for their situation.

It would be best to evaluate each component trait of the fertility complex separately. The overall goal of producing a healthy calf is dependent upon a succession of many different events being successful. Poor performance in any one step will lead to a poor outcome. However, data recording on estrus detection or embryo mortality is often lacking. Some indirect measures of several component traits may be obtained by comparing PTAs from different methods.

Conclusions

Most models are likely to provide robust evaluations if sires are well sampled across environments or the majority of data originates from farms with similar environmental conditions. If data are available and heat detection is not a problem, perhaps the best evaluation would be to analyze each service record (RPT). If heat detection is an issue, a separate evaluation (e.g., DO/CS that accounts for stochastic censoring) would provide extra information. Evaluation under highly variable environments would require careful selection of fixed effects and possibly adjustments for heterogeneous variances.

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