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A novel system for on-farm fertility monitoring based on milk progesterone

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ABSTRACT

Timely identification of a cow's reproduction status is essential to minimize fertility-related losses on dairy farms. This includes optimal estrus detection, pregnancy diagnosis, and the timely recognition of early embryonic death and ovarian problems. On-farm milk progesterone (P4) analysis can indicate all of these fertility events simultaneously. However, milk P4 measurements are subject to a large variability both in terms of measurement errors and absolute values between cycles. The objective of this paper is to present a newly developed methodology for detecting luteolysis preceding estrus and give an indication of its on-farm use. The innovative monitoring system presented is based on milk P4 using the principles of synergistic control. Instead of using filtering techniques and fixed thresholds, the present system employs an individually on-line updated model to describe the P4 profile, combined with a statistical process control chart to identify the cow's fertility status. The inputs for the latter are the residuals of the on-line updated model, corrected for the concentration-dependent variability that is typical for milk P4 measurements. To show its possible use, the system was validated on the P4 profiles of 38 dairy cows. The positive predictive value for luteolysis followed by estrus was 100%, meaning that the monitoring system picked up all estrous periods identified by the experts. Pregnancy or embryonic mortality was characterized by the absence or detection of luteolysis following an insemination, respectively. For 13 cows, no luteolysis was detected by the system within the 25 to 32 d after insemination, indicating pregnancy, which was confirmed later by rectal palpation. It was also shown that the system is able to cope with deviating P4 profiles having prolonged follicular or luteal phases, which may suggest the occurrence of cysts. Future research is recommended for optimizing sampling frequency, predicting the optimal insemination window, and establishing rules to detect problems based on deviating P4 patterns.
Key words: milk progesterone, monitoring fertility, on-line algorithm, statistical process control

INTRODUCTION

Correct identification of a cow's fertility status is important to further optimize reproductive performance in dairy cattle and consequently enhance farm profitability (Inchaisri et al., 2010). To minimize fertility-related losses, it is essential to obtain a complete image of a cow's reproduction status as soon and accurately as possible. This should include information on the onset of cyclicity and estrus, successful inseminations, pregnancy, embryonic loss, and the occurrence of ovarian abnormalities causing fertility problems (Friggens and Chagunda, 2005; Walsh et al., 2011). Today, systems based on external estrous symptoms fail to detect silent estruses, nor are they suitable to identify other fertility events such as pregnancy or acyclicity. This presses the need for a system which combines (silent) heat detection with the detection of pregnancy, embryonic loss, and the presence of ovarian abnormalities (Friggens and Chagunda, 2005).

Milk progesterone (**P4**) measured over time is widely accepted as a useful parameter to obtain a complete and direct image of a cow's reproduction status (Friggens and Chagunda, 2005; Martin et al., 2013), and an automated system for on-farm measuring milk P4 is already commercially available (Mazeris, 2010). One of the most important challenges is the interpretation of the raw sensor data (Rutten et al., 2013). Milk P4 measurements are subject to a large variability, partly caused by the measurement technique and calibration

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method (Adriaens et al., 2017), the sampling technique, or the fat content in the milk sample (Pennington et al., 1981; Friggens et al., 2008). Additionally, P4 profiles also vary both within and between cows, for example in absolute values, slopes, and lengths, and often show irregular patterns (Meier et al., 2009; Blavy et al., 2016; Bruinjé et al., 2017a). However, a recently developed mathematical model enables characterization of P4 dynamics, thereby allowing for data-based interpretation of a cow's fertility status (Adriaens et al., 2017).

For milk P4 to be useful as an indicator for fertility events, the raw P4 measurements should be converted into specific information, or even better, actions to be taken by the herdsmen on farm. In this context, it is shown that both the variability of the measurements and the variability between estrous cycles should be taken into account (Friggens and Chagunda, 2005; Friggens et al., 2008; von Leesen et al., 2013). In general, this means that the monitoring algorithm should meet following requirements: (1) it should be robust against outliers and different levels of measurement errors, which might be dependent on the measurement and calibration technique (Adriaens et al., 2017); (2) it should be able to discriminate between luteal and follicular concentrations to indicate actions such as insemination, embryonic loss, and possible cyst in an individualized way; and (3) it should be automated and implementable on farm.

The closest attempt to this so far was published in 2005 by Friggens and Chagunda (2005), who developed a biological model to predict the reproductive status of dairy cows based on milk P4. Besides different cow-specific factors, they used the smoothed level of the milk P4 obtained with a multiprocess Kalman filter to account for the variability in the measurements. Next, this level is monitored and when it underruns a fixed threshold, the cow is indicated in estrus and can be inseminated. Although this model has proven to be useful (Friggens et al., 2008) and easy to interpret, it has 2 major disadvantages, also identified in Friggens et al. (2008) and Bruinjé et al. (2017b): (1) the use of a smoothed P4 level causes a lag in the detection moment (dependent on, e.g., sampling frequency and rate of luteolysis); (2) using a fixed threshold on the (smoothed) P4 level provides no flexibility to cope with the variability in individual P4 levels between cycles. For example, when a measurement fails at the crucial point of luteolysis, the smoothed level is not updated, and the next measurement of low P4 will be marked by this filter as very unlikely. Accordingly, the smoothed P4 level will adapt just moderately. Only when the following measurement is also low, it will move toward follicular P4 concentrations and ultimately undercut the fixed threshold (Bruinjé et al., 2017b). Moreover, this depends on milking and sampling frequency, and may occur for example more than 3 milkings after the actual occurrence of luteolysis, resulting in a large delay on the predicted ideal insemination moment. Additionally, if the follicular P4 concentrations are close to the fixed threshold, the detection lag will be even larger and successful timing of insemination even more unlikely. The mathematical model described in Adriaens et al. (2017) has the potential to overcome these drawbacks, while maintaining the flexibility to deal with various P4 dynamics, though being robust for measurement-related noise. However, in its current described form, it is not suitable for on-farm monitoring purposes.

The objective of this study was to develop a new approach to monitor fertility based on milk P4 measurements and the concepts of synergistic control (Mertens et al., 2009; Huybrechts et al., 2014; Maselyne, 2016). It was hypothesized that a system which combines a mathematical model to describe the P4 dynamics (Adriaens et al., 2017) with an on-line updated statistical control chart on the residuals of this model will allow on-line identification of the fertility status of a dairy cow and indicate important fertility events such as estrus, pregnancy, and ovarian problems. Moreover, the proposed approach would be independent of fixed thresholds and does not cause a lag in the description of events such as luteolysis, which would make the system more consistent and less dependent on the sampling rate and measurement errors.

MATERIALS AND METHODS

Experimental Data

For this study, both milk P4 data and additional information on reproduction status were collected from the eligible cows on an experimental dairy farm in Geel, Flanders. Two trials in which additional data were collected from the cows were set up in the spring of 2016 and 2017. In both periods, cows were milked automatically with an automated milking system of DeLaval (VMS, Delaval, Tumba, Sweden) and were fed a mixed ration of grass and corn silage, supplemented with concentrates provided in the milking robot and through concentrate feeders. Because the procedure of data collection differed between the 2 periods due to the availability of an on-line milk P4 analyzer (Herd Navigator, Lattec, Hillerϕd, Sweden) in the second period, each trial is described separately, and the information on cows and P4 data per period is summarized in Table 1. Nevertheless, for both trials, the P4 analyses were performed on mixed milk samples automatically collected from each milking following the procedure of the DHI protocol (ICAR, 2014).