Interrelationships between herd-level reproductive performance measures based on intervals from initiation of the breeding program in year-round and seasonal calving dairy herds

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ABSTRACT

In year-round calving herds, reproductive performance has traditionally been described in relation to each cow's calving date. This research described reproductive performance in year-round and seasonal calving dairy herds using herd-level measures based on interval from each cow's initiation of breeding program date, and assessed interrelationships between such measures. A large, prospective, single cohort study, implemented in 1997 and 1998, included 29,327 cows from 167 Australian dairy herds. Herd reproductive performance was described using 2 measures of primary importance to herd managers: the proportion of cows that became pregnant by 6 wk after their initiation of breeding program date (6-wk pregnancy rate) and the proportion of cows that were nonpregnant 21 wk after their initiation of breeding program date (21-wk nonpregnancy rate). Measures that contribute to these primary measures (secondary measures) were calculated for each herd for both the first and second 3-wk periods of each cow's breeding program; submission rates were calculated as proportions of cows that were inseminated at least once in the 3-wk period, and conception rates were calculated as the proportions of inseminations in the 3-wk period that resulted in pregnancy. The individual herd was the unit of analysis. The study results indicate that high submission rates are essential if herd reproductive performance is to be achieved. Six-week pregnancy rate was predicted to increase by 6 to 8 percentage points following a 10-percentage-point increase in submission rates in both 3-wk periods, and by 6 to 10 percentage points following a 10-percentage-point increase in conception rates. Submission rates were more variable than conception rates, indicating that managers may be able to achieve large increases in submission rates more easily than substantial increases in conception rates. However, the predicted benefits of increasing submis-

sion rates were greatest when conception rates were high and vice versa, highlighting the need to improve both submission and conception rates when both are low. The study results indicate that some herd managers can concurrently achieve high submission and conception rates.

Key words: reproductive performance, fertility, dairy cow, dairy herd

INTRODUCTION

In year-round calving herds, mean intervals from calving to conception or subsequent calving have been widely used to describe herd reproductive performance, but these indices have important limitations. The distribution of these intervals is usually positive or right-skewed, and mean intervals from calving to conception or subsequent calving can be markedly influenced by small numbers of extreme values, particularly in small herds. A second limitation is that mean intervals from calving to conception or subsequent calving do not account for cows that fail to conceive or fail to recalve, or for maximum allowed number of inseminations (Eddy, 1980). Thus, these measures can result in underestimation of differences in reproductive performance between populations. For example, in a large observational study, although mean intercalving intervals were increased by only 3 to 10 d among cows affected by dystocia, retained fetal membranes, or both, culling rates were substantially higher among affected cows (Joosten et al., 1988), possibly because of reproductive failure.

One approach to address these limitations of mean interval from calving to conception in year-round calving herds is to describe reproductive performance using proportions of cows pregnant by specified intervals after their calving date. Various intervals have been used, and 100-d pregnancy rate and 200-d nonpregnancy rate have been selected as national standard measures of herd reproductive performance for year-round calving herds in Australia (InCalf, 2007).

The methods discussed above describe reproductive performance relative to calving date. Reproductive performance can also be described relative to each cow's

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initiation of breeding program date (Esslemont and Ellis, 1974; Bailie, 1982; Esslemont, 1993; Ferguson and Galligan, 2000; Chang et al., 2007). In year-round calving herds, each cow's initiation of breeding program date is the day immediately following the end of her voluntary waiting period. The voluntary waiting (or withholding) period is the interval after calving for each cow during which no inseminations are performed (Fetrow et al., 1990) even though estrus may be detected.

In seasonal calving herds (herds in which all calvings occur within a restricted time period each year), inseminations are allowed for a restricted period of time each year, commencing on the herd's initiation of breeding program date. For all cows in the herd in any given year, the initiation of breeding program date is the calendar date 282 d (i.e., 1 median gestation period) before the herd manager wants the subsequent calving period to commence. In these herds, reproductive performance is usually assessed as proportions of cows that became pregnant by specified intervals (e.g., 6 wk) after the herd's initiation of breeding program date or by the end of the breeding program (Brightling et al., 1990). Reproductive measures that describe performance relative to each cow's calving date are unsuitable measures of herd reproductive performance in seasonal calving herds. High mean intercalving intervals do not necessarily reflect poor reproductive performance in these herds because mean intervals from calving to conception or subsequent calving are longer among cows that calve early in the calving period (MacGregor and Casey, 1999; Cavestany and Galina, 2001), yet these cows conceive quickly after initiation of breeding program date (Brightling et al., 1990; McDougall, 2001) as desired by herd managers.

Measures that describe the distributions of conceptions in herds over time can be considered primary measures. These are determined by submission (i.e., insemination) rates and conception rates (the proportions of inseminations that resulted in pregnancy; Williamson, 1981). To allow advisors and herd managers to assess the relative benefits of various strategies to improve herd reproductive performance, it is important to understand the relative effects of improving submission and conception rates. Herd-level associations between these secondary measures of reproductive performance and mean calving to conception (Gaines et al., 1993) or recalving (Ferguson, 1996) interval have been reported, but relationships with measures based on initiation of breeding program date have not been reported.

A large research project (the InCalf Project) was conducted in Australia from 1996 to 2000 (Morton, 2004). The project consisted of a large, prospective, single cohort study using both year-round and seasonal calving herds, preceded by a smaller pilot study. Single

cohort studies involve enrolling subjects before ascertaining the exposure status of each for risk factors of interest, then assessing outcomes of interest during a specified follow-up period. The major objectives of the component of the project reported in this paper were 1) to describe primary and secondary reproductive performance measures in year-round and seasonal calving herds, 2) to describe the associations between cumulative pregnancy rate and week of breeding program, 3) to estimate the relative effects of improving submission and conception rates on herd 6-wk pregnancy rate, and 4) to assess correlations between submission and conception rates.

MATERIALS AND METHODS

Overview of Study

A multicentered, prospective, single cohort study was conducted in commercial Australian dairy herds. Eleven sites in 9 of Australia's 15 major dairy regions were purposively selected to ensure that 1) the majority of Australia's major dairy regions were represented, 2) both year-round and seasonal calving herds were enrolled, and 3) a suitable site coordinator with access to sufficient numbers of herds was available at each site. Study sites were in Queensland (Atherton Tablelands and southeast Queensland), New South Wales (Camden and Bega), Victoria [Goulburn Valley, southwest Victoria (2 sites), south and east Gippsland] and northwest Tasmania (2 sites).

At each site, a private dairy veterinary practitioner whose practice serviced herds in that area acted as site coordinator. In total, they purposively selected 170 herds from those that were both serviced by the selected site coordinator's veterinary practice and participating in milk production recording, where the herd manager was considered likely to maintain accurate data records and complete study tasks as requested, where the herd manager was not planning to synchronize returns to estrus following insemination, and, for year-round calving herds, where the herd manager was not planning to run bulls continuously with the lactating herd. Herds with extremely unusual herd characteristics, including atypical age structures (e.g., most cows in the herd being first-lactation heifers) or purchasing and culling patterns not typical for commercial dairy herds (e.g., herds managed by cattle dealers), were ineligible and the expected herd size (defined as number of cows expected to calve in the herd in the first 12 mo of the study) had to be at least 80 cows in year-round calving herds and 120 cows in seasonal calving herds. In addition, few herds with an expected herd size of greater than 300 cows were selected.

Within study herds, the earliest lactation that commenced with a calving in a specified period for each cow was selected. In year-round calving herds (herds where cows calved in at least 10 calendar months each year), this was either a 14- or 15-mo period from either September or October 1996 to November 1997. In seasonal calving herds (herds in which approximately 90% of calvings each year occurred within a period of 150 consecutive days or less), a 12-mo period was used. For autumn and winter calving herds (herds in which most calvings occurred between March and August), this was from January to December 1997. For spring calving herds (most calvings between August and October), this was from March 1997 to February 1998. Lactations in seasonal calving herds that commenced more than 130 d before or more than 59 d after herd initiation of breeding program date were ineligible for analyses.

Estimation of Conception Date

First conception date for each study lactation was estimated based on results of pregnancy diagnoses following manual rectal palpation of the reproductive tract by veterinary practitioners experienced in this technique, assisted by the last recorded estrus date. At the time of their first positive pregnancy diagnosis, most cows were estimated to have conceived between 5 and 15 wk previously. In seasonal calving herds, cows not diagnosed as pregnant at any stage since calving were examined at least 35 d after the end of the herd breeding program. Cows were classified as not having conceived during the breeding program only if they were not diagnosed as pregnant at any stage since calving and they were diagnosed as not pregnant at this examination. In year-round calving herds, cows that were not diagnosed as pregnant at any stage since calving and diagnosed as not pregnant when examined at least 35 d after their nominal end of breeding program date (150 d after their initiation of breeding program date) were classified as not pregnant. Cows not so examined were also classified as not pregnant if they had at least 1 estrus recorded within 45 d both before and after their nominal end of breeding program date.

Voluntary Waiting Period and Initiation of Breeding Program Date Determination

Voluntary waiting period was estimated for each year-round calving herd based on joint consideration of the distributions of intervals from calving to estrus without insemination and intervals from calving to insemination. The time from calving to when insemination was first allowed was assumed to be the shortest time when intervals from calving to insemination consistently

predominated over intervals to estrus without insemination; actual voluntary waiting period was calculated as 1 d less than this. Each cow's initiation of breeding program date was then calculated as calving date plus the actual voluntary waiting period determined for that herd plus 1 d. For seasonal calving herds, initiation of breeding program dates were determined from distributions of inseminations by calendar date.

Calculation of Reproductive Measures

Pregnancy rates (cumulative percentages of cows that became pregnant by specified times during the breeding program) were calculated up to the end of each week of the breeding program in each study herd. Six-week pregnancy rate and nonpregnancy rate by 21 wk after initiation of breeding program date (percentages of cows in each herd that became pregnant by the end of wk 6 after initiation of breeding program date and that did not become pregnant by 21 wk after initiation of breeding program date, respectively) were used as primary measures. In seasonal calving herds with total breeding programs of less than 21 wk, nonpregnancy rate was calculated as the percentage of cows that had not become pregnant by the end of the breeding program.

Herd submission patterns were described using first 3-wk submission rate (the percentage of cows that were inseminated at least once in the first 3 wk of the breeding program) and the second 3-wk submission rate (the percentage of those cows not diagnosed as becoming pregnant in the first 3 wk that were inseminated at least once in wk 4 to 6 of the breeding program). Conception rates (the percentages of inseminations that resulted in pregnancy) were described separately for inseminations in the first and second 3-wk periods of the breeding program. Because not all bull services may have been recorded in seasonal calving herds, second 3-wk submission rates and conception rates for inseminations in the second 3-wk period of the breeding program were calculated only for those seasonal calving herds whose AI period was 42 d or more.

Statistical Methods

All statistical analyses were performed using Stata (versions 8 and 10 for Windows; Stata Corporation, College Station, TX) using the individual herd as the unit of analysis. Regression equations for associations between pregnancy rate by the end of each week of the breeding program and week number were estimated separately for year-round and seasonal calving herds using generalized estimating equations to account for clustering within herds. Normally distributed errors

were assumed and identity links, first order autoregressive correlation structures, and robust standard errors used. Linear, quadratic, cubic, and quartic functions of week number were sequentially fitted and retained in the model if they or higher order variables were associated with pregnancy rate ($P < 0.05$). All 124 seasonal calving herds contributed an observation for the end of each of wk 0, 1, 2 to 21 regardless of length of breeding season. In herds where the breeding season ended before wk 21, the cumulative pregnancy rate was unchanged for subsequent weeks to wk 21. Strengths of associations between 6-wk pregnancy rates and both submission and conception rates were estimated separately for year-round and seasonal calving herds using multivariable linear regression models. When assessing these interrelationships in seasonal calving herds, only herds in which the AI period was 42 d or more were included. Multivariable models included a term for interaction between submission and conception rate in the first 3 wk of the breeding program and a separate corresponding term for the second 3 wk of the breeding program. Interaction terms between variables for the first and second 3-wk periods of the breeding program were not included because, during preliminary analyses, interaction terms between 3-wk pregnancy rate and each of submission and conception rates in the second 3-wk periods were not significant in year-round ($P = 0.223$ and 0.060 , respectively) and seasonal calving ($P = 0.156$ and 0.231 , respectively) herds, there was no a priori basis for such interactions, and the point estimate for the interaction term where $P = 0.060$ was implausibly large based on simulation modeling that predicted only small variation in effects of changes in submission and conception rates in the second 3-wk period, with different percentages pregnant in the first 3-wk period over the range of percentages pregnant by wk 3 observed in this study. Stata's `lincom` command was used to estimate effects of increases in each submission rate at various specified values of conception rate in the same 3-wk period adjusted for submission and conception rates in the other 3-wk period. These estimates reflect effects of strategies that increase submission rates only in the specified 3-wk period. Because some strategies would be expected to increase submission rates in both 3-wk periods, combined effects of increases in both submission rates at various specified values of conception rates were also estimated using the `lincom` command. Effects of increases in each conception rate both separately and combined at various specified values of submission rates were assessed using the same approach. Correlations between secondary reproductive measures were assessed using Spearman's rank correlation coefficients. Associated 95% confidence intervals were calculated using Fisher's transformation.

RESULTS

Numbers of Herds and Lactations

Of the 170 herds selected for the main study, 2 were lost to follow-up because the herd manager subsequently withdrew the herd from the project and data from 1 year-round calving herd were excluded because the manager commenced inseminating within only 4 distinct breeding periods each year. In the remaining 167 herds, 11.5% of selected lactations (3,803/33,130) were excluded or lost to follow-up; major reasons were death, culling, or cow declared by herd manager as to be culled between calving and initiation of breeding program date (1,213 lactations) and after that until end of breeding program date (1,587 lactations), and because reproductive status at end of breeding program date was not known (823 lactations). In the 167 study herds (43 year-round calving herds and 124 seasonal calving herds), data from 29,327 lactations were analyzed. The mean and median numbers of lactations analyzed per herd were 175.6 and 166, respectively (range = 73–526; 25th and 75th percentiles = 121 and 215, respectively).

Description of Herds and Reproductive Management

Most study herds were predominantly Holstein-Friesian (131 herds), Holstein-Friesian cross (1 herd), Holstein-Friesian and Holstein-Friesian cross (15 herds), or Holstein-Friesian and other breeds (10 herds). Other herds were predominantly Jersey (7 herds) or other breeds (2 herds). The predominant breed was not determined in 1 herd.

Cows calved in every month of the study in all year-round calving herds. In the seasonal calving herds, calving patterns varied substantially. Between 88 and 100% of all calvings within the specified 12-mo period were within 150 consecutive days or less (25th percentile = 99%; median = 100%), and the middle 98% of calvings occurred over periods varying from 48 to 259 d (median = 106 d; 25th and 75th percentiles = 81 and 146 d, respectively). Most of the remaining calvings were within the 2 mo immediately before or after these periods. Calving period durations for primiparous animals varied similarly. In the majority of seasonal calving study herds, the calving period for primiparous animals commenced within 21 d of that for multiparous cows. Calving was induced (Morton and Butler 1995) in at least 1 cow in 100 (80.6%) of the 124 seasonal calving herds. In these 100 herds, the median percentage of calvings that were induced was 13.2% (range = 0.4–36.7%; 25th and 75th percentiles = 8.8 and 19.3%, respectively). Cow age was determined for 2,906 of these

Table 1. Distributions of primary and secondary measures of herd reproductive performance for 43 year-round calving dairy herds and 124 seasonal calving dairy herds

Measure ¹	Minimum	25th percentile	Median	75th percentile	Maximum
Primary measures of herd reproductive performance					
6-wk pregnancy rate (%)					
Year-round	28	39	45	54	66
Seasonal	23	55	63	69	86
21-wk nonpregnancy rate ² (%)					
Year-round	4	8	13	17	42
Seasonal	1	6	9	12	37
Secondary measures of herd reproductive performance					
First 3-wk submission rate (%)					
Year-round	17	37	51	62	84
Seasonal	29	69	77	85	95
Second 3-wk submission rate (%)					
Year-round	39	47	57	65	79
Seasonal	28	60	69	76	87
First 3-wk conception rate (%)					
Year-round	27	38	47	54	66
Seasonal	25	44	51	55	70
Second 3-wk conception rate (%)					
Year-round	27	43	50	56	65
Seasonal	22	44	50	54	79

¹For seasonal calving herds, second 3-wk submission and conception rates were calculated only for herds whose AI period was 42 d or more ($n = 70$).

²In seasonal calving herds with total breeding programs less than 21 wk in duration, nonpregnancy rate was calculated as the percentage of cows that had not become pregnant by the end of the breeding program.

2,974 induced calvings and almost all (2,788/2,906 or 95.9%) were in multiparous animals.

The median voluntary waiting periods in year-round calving herds was 50 d (range = 24–88 d; 25th and 75th percentiles = 44 and 57 d, respectively). In all seasonal calving herds, initially from initiation of breeding program date, only AI was performed and bull services were not allowed. The median duration of the AI periods was 43 d (range = 21–152 d; 25th and 75th percentiles = 36 and 54 d, respectively). In 70 of the 124 seasonal calving herds (56%), the AI period was 42 d or longer. After the AI period, in most (120/124 or 97%) of the seasonal calving study herds, bulls were run with the herd for the remainder of the breeding program. The median total duration of the breeding programs was 137 d (range = 53–198 d; 25th and 75th percentiles = 111 and 152 d, respectively). In 120 seasonal calving herds, bulls were run with the herd immediately after the AI period for a median of 88 d (range = 7–148 d; 25th and 75th percentiles = 67 and 111 d, respectively).

Descriptive Statistics for Primary and Secondary Reproductive Performance Measures

There was large variation in all reproductive performance measures between herds within both calving systems (Table 1). Among the seasonal calving study herds, median 6-wk pregnancy rates were higher in those that used calving induction (64%; $n = 100$ herds) compared with those that did not use this technique (58%; $n =$

24 herds), but variability within both groups of herds was large and high 6-wk pregnancy rates were observed in both groups. Minimum, 25th and 75th percentiles, and maximum 6-wk pregnancy rates in herds that used calving induction were 38, 57, 70, and 86%, respectively, compared with 23, 52, 63, and 80%, respectively, in herds that did not use this technique. Among secondary reproductive performance measures, variability between herds was larger for submission rates than for conception rates. Median submission rates were higher in seasonal calving study herds relative to year-round calving herds, but median conception rates were similar in both calving systems.

Associations Between Pregnancy Rate and Week of Breeding Program

Pregnancy rates by week of the breeding program are shown in Figure 1. In both year-round and seasonal calving study herds, pregnancy rate increased most rapidly early in the breeding program. Pregnancy rate (expressed as a percentage) by the end of each week of the breeding period was related to week number (W) by the following equations for year-round calving herds [equation 1] and seasonal calving herds [equation 2].

$$\begin{aligned} \text{Pregnancy rate by week } W = & 2.331 \text{ (SE 0.356)} \\ & + 7.514 (0.594) \times W + 0.008 (0.098) \times W^2 \\ & - 0.019 (0.006) \times W^3 + 0.001 (0.000) \times W^4 \quad [1] \end{aligned}$$

Figure 1. Median pregnancy rates (cumulative percentage of cows pregnant) in 43 year-round calving herds (■) and 124 seasonal calving herds (◇) by week of breeding program. Bars indicate 25th and 75th percentiles.

Pregnancy rate by week $W = 0.000$ (SE 0.000)
 $+ 16.289 (0.459) \times W - 1.262 (0.077) \times W^2$
 $+ 0.048 (0.005) \times W^3 - 0.001 (0.000) \times W^4$ [2]

Relative Effects of Improving Submission and Conception Rates on 6-wk Pregnancy Rate

The multivariable models explained high proportions of the variation in 6-wk pregnancy rate for both year-round and seasonal calving herds ($R^2 = 0.98$ and 0.97 , respectively). Within both year-round and seasonal calving herds, interaction terms between submission and conception rate in the first 3 wk of the breeding

program and the corresponding term for the second 3 wk of the breeding program were both significant ($P = 0.001\text{--}0.015$). Estimated effects of improving submission rates on 6-wk pregnancy rate for various conception rates are shown in Table 2. For a 10-percentage-point increase in submission rate in either 3-wk period, the predicted increases in 6-wk pregnancy rate were 3 to 4 percentage points. With increased submission rates in both 3-wk periods, 6-wk pregnancy rate was predicted to increase by 6 to 8 percentage points. Estimated effects of increased submission rates were similar whether in the first or second 3-wk period and were larger when conception rates were higher.

Estimated effects of improving conception rates on 6-wk pregnancy rate for various submission rates are shown in Table 3. For a 10-percentage-point increase in conception rate in either 3-wk period, the predicted increases in 6-wk pregnancy rate were 3 to 5 percentage points. Estimated effects of increased conception rates were similar whether in the first or second 3-wk period and were larger when submission rates were higher. With increased conception rates in both 3-wk periods, 6-wk pregnancy rate was predicted to increase by 6 to 9 percentage points in year-round calving herds and 8 to 10 percentage points in seasonal calving herds.

Correlations Between Submission and Conception Rates

Submission rates for both 3-wk periods were correlated in year-round ($r = 0.44$, 95% CI = $0.16\text{--}0.65$) and seasonal ($r = 0.69$, 95% CI = $0.55\text{--}0.80$) calving herds, as were conception rates for both 3-wk periods ($r = 0.71$, 95% CI = $0.52\text{--}0.83$; $r = 0.27$, 95% CI = $0.04\text{--}0.47$, respectively). However, within both the first and second 3-wk periods (Figure 2), submission rates were not closely associated with conception rates ($r = -0.12$ to 0.08).

Table 2. Predicted percentage point increases in 6-wk pregnancy rate (95% CI) following a 10-percentage-point increase in submission rates at selected conception rates, estimated from 43 year-round calving and 70 seasonal calving dairy herds

Conception rate ¹ (%)	Submission rate increased in:		
	First 3-wk period	Second 3-wk period	Both 3-wk periods
Year-round calving herds			
40	2.9 (2.5, 3.4)	3.1 (2.4, 3.7)	6.0 (5.3, 6.7)
55	3.9 (3.3, 4.5)	4.1 (3.3, 4.9)	8.0 (7.4, 8.7)
Seasonal calving herds			
44	3.3 (2.8, 3.8)	3.3 (2.7, 3.8)	6.6 (6.2, 7.0)
54	3.8 (3.3, 4.3)	3.7 (3.1, 4.3)	7.5 (7.1, 8.0)

¹Conception rate for inseminations in both first and second 3-wk periods of the breeding program. Means of 25th percentiles for both 3-wk periods were selected as lower values; means of 75th percentiles were selected as upper values.

Figure 2. Scattergraphs of submission versus conception rates for 43 year-round calving herds (■) and 124 seasonal calving herds (◇) for the first (upper graph) and second (lower graph) 3-wk periods of the breeding program.

DISCUSSION

This study has demonstrated that there is substantial variation in reproductive performance measures between herds, indicating that important increases in reproductive performance would be possible in many commercial Australian herds if causal factors were identified and modified. There was high variability between herds within regions (results not presented), supporting the hypothesis that many of these causal factors were influenced by herd management.

These study results also highlight the importance of achieving high submission rates if herd reproductive performance is to be achieved. Estimated effects on 6-wk pregnancy rate were similar following increases of 10 percentage points in either submission or conception rates in year-round calving herds, and in both year-round and seasonal calving herds, submission rates were more variable than conception rates, indicating that managers may be able to achieve large increases in submission rates more easily than substantial increases in conception rates. The importance of submission rates is also emphasized in comparisons between year-round and seasonal calving herds; the generally lower primary reproductive measures in year-round calving herds were largely caused by lower submission rates. These comparisons between year-round and seasonal calving herds should be viewed cautiously because neither population of herds was selected using probability sampling methods. However, estrus detection efficiency or sensitivity is a key determinant of submission rates, and year-round calving herds appear to generally achieve lower estrus detection sensitivity than seasonal calving herds (Wilson et al., 1994).

Benefits of increasing submission rates are greatest when conception rates are high, and vice versa. This explains the larger effects of increases in conception rates on 6-wk pregnancy rate in seasonal calving herds relative to year-round calving herds. It also highlights the need to improve both submission and conception

Table 3. Predicted percentage point increases in 6-wk pregnancy rate (95% CI) following a 10-percentage-point increase in conception rates at selected submission rates, estimated from 43 year-round calving and 70 seasonal calving dairy herds

Submission rate ¹ (%)	Conception rate increased in:		
	First 3-wk period	Second 3-wk period	Both 3-wk periods
Year-round calving herds			
42	2.6 (1.9, 3.4)	3.1 (2.0, 4.2)	5.7 (4.7, 6.7)
64	4.0 (3.0, 5.1)	4.6 (3.8, 5.5)	8.7 (7.7, 9.6)
Seasonal calving herds			
64	3.9 (3.3, 4.5)	4.2 (3.7, 4.7)	8.1 (7.4, 8.8)
80	4.8 (4.1, 5.4)	4.9 (4.2, 5.6)	9.6 (8.8, 10.4)

¹Submission rate for both first and second 3-wk periods of the breeding program. Means of 25th percentiles for both 3-wk periods were selected as lower values; means of 75th percentiles were selected as upper values.

rates in herds in which both are low. The study results demonstrate that some herd managers can concurrently achieve high submission rates and high conception rates. Some strategies to increase submission rates may reduce conception rates. For example, treatment of anestrus cows with intravaginal devices increases submission rates but decreases conception rates (Rabiee et al., 2004), and false positive insemination frequency can increase when herd managers and staff attempt to increase estrus detection sensitivity (Fetrow, 1993) and inseminate cows showing signs less predictive of estrus. However, herd managers inseminate a high proportion of cows not seen standing to be mounted but showing other signs, and achieve moderate conception rates in these cows (Badinga et al., 1985). This indicates that a substantial proportion of these cows are, in fact, in estrus and failure to inseminate would have reduced estrus detection sensitivity. Other factors such as longer calving to initiation of breeding program date intervals (Morton, 2004), factors associated with milk protein concentration (Morton, 2004) and improved body condition in early lactation (Buckley et al., 2003), increase both submission and conception rates. It seems likely that managers of herds achieving both high submission and conception rates had optimized these factors and were using optimal criteria for selection of cows for insemination.

The high R^2 values for the models indicate that submission and conception rates and interactions between the 2 account for almost all variation in 6-wk pregnancy rates between herds. High R^2 values have also been reported using herd measures to explain mean calving to conception interval in year-round calving herds. Ferguson (1996) explained 92% of variation in calving interval using voluntary waiting period, average submission rate, and conception rate. Gaines et al. (1993) accounted for 97% of variation in calving to conception between herds using mean days to first service and estimated estrus detection efficiency. Jansen et al. (1987) accounted for 73% of variation in financial loss because of suboptimal calving interval using calving to service interval and an index of estrus detection sensitivity. Collectively, these studies indicate that advisers need to focus on increasing only a small number of secondary reproductive measures to increase primary reproductive performance measures in dairy herds.

Among seasonal calving herds, median submission rate was lower in the second 3 wk relative to the first 3 wk. This is caused, in part, by cows inseminated during the first 3 wk failing to be reinseminated in wk 4 to 6 yet not being pregnant to the first insemination when subsequently assessed by pregnancy diagnosis. Relative to estruses without insemination, insemination markedly increases the incidence of long returns to service,

particularly following inseminations soon after calving (Pino et al., 2006). Among year-round calving herds, the reverse pattern was observed, with median submission rate higher in the second 3-wk period relative to the first 3-wk period. Because it seems likely that long returns to service also occurred in these herds, it is possible that increases in sensitivity of ovulation detection in the second 3 wk more than counterbalanced the increased frequency of long returns in this period.

When interpreting primary reproductive performance measures based on interval from initiation of breeding program date in year-round calving herds, voluntary waiting periods must also be considered. These reproductive measures can be increased by prolonging voluntary waiting periods (a strategy available to managers of year-round calving herds) because both 3-wk submission rate (Morton, 2004) and conception rate (Mayne et al., 2002; Morton, 2004) increase with interval from calving. However, long voluntary waiting periods may result in excessive proportions of cows with intercalving intervals substantially longer than 18 mo. Long intervals between calvings are not economically optimal unless lactation persistence is high (Dekkers et al., 1998). Annual milk volumes may be reduced if lactation lengths are longer than 10 mo and important reductions in both milk solids and volume occur with lactations over 16 mo and, hence, in intercalving intervals over 18 mo (Auldist et al., 2007). In addition, cows that have not conceived by 150 to 240 d after calving are at greatly increased risk of culling (Rajala Schultz and Grohn, 1999). This latter study was conducted in herds that presumably used voluntary waiting periods similar to those used in the current study herds, and further research is required to assess culling patterns in commercial herds using long voluntary waiting periods.

The approach used to estimate voluntary waiting period in the current study based on distributions from calving to estrus and to insemination has some potential limitations. First, it is based on the assumption that the voluntary waiting period is consistent across all cows within any 1 herd throughout the study period. This appeared to be a valid assumption in most study herds because distributions from calving to estrus and to insemination had minimal overlap, but more complex methods would be required where voluntary waiting periods are varied between cows within herds. Second, estimates using this method may be biased in herds with low estrus detection sensitivity or high prevalence of prolonged postpartum anestrus, and further work is required to assess the effect of these potential biases. Finally, this approach is likely to be more reliable when based on large numbers of intervals from calving to estrus and to insemination.

Linear regression using untransformed 6-wk pregnancy rate as the dependent variable has an important advantage over other approaches for the purposes of this study. Coefficients from these models can be interpreted as the estimated changes in the dependent variable in units of 6-wk pregnancy rate. Thus, when applied to herd reproductive performance, these are more readily communicated than coefficients after transformation or other types of regression. In general, linear regression models are inappropriate when analyzing proportions and percentages because fitted values may be outside of 0 to 1 (or 0–100%) and residuals are heteroscedastic, with residuals less variable at small and large fitted values relative to fitted values closer to 0.5 (or 50%). However, in the models in the current study, most fitted values were between 0.4 and 0.8 (or 40–80%), a range over which distributions of residuals are reasonably constant, and, for each model, no fitted values were less than 0 or greater than 1 (or 100%).

CONCLUSIONS

High submission rates are essential if herd reproductive performance is to be achieved. Effects on 6-wk pregnancy rate were similar or only slightly less following increases of 10 percentage points in submission rates relative to the same increase in conception rates, and submission rates were more variable than conception rates, indicating that managers may be able to achieve large increases in submission rates more easily than substantial increases in conception rates. However, the benefits of increasing submission rates are greatest when conception rates are high, and vice versa, highlighting the need to improve both submission and conception rates when both are low. Some herd managers can concurrently achieve high submission and conception rates.

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