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Comparison of reproductive performance by artificial insemination versus natural service sires in California dairies

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Abstract

This study compared the calving to conception intervals for cows in AI pens with cows exposed to natural service sires, controlling for milk production, mastitis occurrence, parity and calving month effects. Records from 10 western United States dairy herds (mean herd size = 2058 cows) were evaluated retrospectively over an 18-month period. Eight bull breeding analysis cohorts were created (the first cohort 0–50 days in milk and the remaining cohorts at 25 days in milk intervals through 226 days). The cohorts contained non-pregnant cows that were first moved into bullpens during the described cohort period. Equal numbers of non-pregnant cows only exposed to AI during the cohort period were randomly selected from the pool of eligible non-pregnant cows. An AI cow was used only once in the data analysis, but was included in a bull breeding cohort at a later date if she remained non-pregnant and was transferred to a bullpen. Univariate and multivariate survival analysis was used to compare the calving to conception intervals. Cows in AI groups had higher hazard rates for pregnancy across all cohorts. Parity and milk production were significantly associated with risk for pregnancy. In herds that practice a mixture of AI and bull breeding, overall herd reproductive performance might be improved by allowing cows more opportunities at AI prior to moving them into clean-up bullpens.

Keywords: Natural service; Artificial insemination; Reproduction; Cohort analysis; Survival analysis

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1. Introduction

Artificial insemination (AI) has dramatically affected the worldwide dairy industry by reducing the risk of venereal disease transmission, increasing the rate of genetic change in dairy breeds, and in particular, increasing the milk yield of dairy cattle. In comparison to daughters of natural service (NS) sires, daughters of AI sires have produced 113–136 kg more milk per year that can be attributed solely to genetic improvement [1,2]. Records evaluated between 1984 through 1998 demonstrate that milk yield of AI-proven bull daughters was 366–444 kg greater than milk yield of daughters from NS sires [3].

Despite the well-documented advantages of AI, many dairy producers still use NS sires. Based on surveys of dairy producers, between 55 and 96% used NS sires for at least a portion of their lactating herd breeding program [4–6]. While many producers are using NS sires, few are using them exclusively. From herd records processed in the Dairy Records Management System (Raleigh, NC, USA) during 1999 through 2002, only 1% of herds relied on bulls as the mainstay of their reproductive program whereas, 26% relied exclusively on AI [6]. In California, 4% of herds relied exclusively on bulls for reproductive management of lactating cows, while 4% depended entirely on AI [4].

Common scenarios for using NS sires included dairies undergoing expansion where bulls may be used during and immediately following the expansion to allow the day-to-day management some flexibility to meet the reproductive demands of increased cow numbers. Other producers use NS sires as a low input approach to manage reproduction, foregoing genetic progress to avoid the cost of training personnel, purchasing equipment, or hiring additional employees to implement AI. A common utilization of NS sires, especially in the western United States, is to start all cows in AI pens, provide access to AI breeding for two or three services or for a set period of time, and then move both pregnant and non-pregnant cows into bullpens. This approach of using "clean-up" bulls concentrates the effort of the AI technician or herdsman, while providing a theoretical safety net for cows that fail to conceive or that may later abort. In addition, many producers feel that cows become pregnant faster with bulls, but desire at least one or two AI opportunities in an attempt to capture the genetic benefits of AI.

Ultimately, the goal of a dairy reproductive program is to impregnate cows in a timely manner and manage them through a normal parturition. The economics of reproductive programs support this approach. In early to mid lactation, feed costs relative to milk production are at their lowest and the return per feed dollar is approximately 3:1 [7]. Aside from culling, the way to increase the percent of herd lactation days spent in this most profitable area is to ensure that cows quickly conceive following the herd's stated voluntary waiting period and then maintain the pregnancy through a normal gestation.

There are two central issues to be addressed in deciding how to design an on-farm reproduction program: (1) the relative cost of using NS sires compared to AI, and (2) the relative efficiency of each system at getting dairy cattle pregnant. Within the context of a mixed system, early AI use followed by clean-up bulls, the critical issue is to define the efficiency of AI relative to NS sires. The objective of this paper is to compare the calving to conception intervals for cows in AI pens with cows exposed to NS sires, controlling for milk production, parity, herd, mastitis, and seasonal effects.

2. Material and methods

2.1. Experimental design

This study was a retrospective cohort study involving 10 commercial Holstein dairy herds from central California. Seven of the dairies were typical western, four-row freestall dairies with dirt exercise lots adjoining the freestall pens. The remaining three dairies were dry lot dairies with fixed shade structures. All dairies fed total mixed rations balanced by professional nutritionists.

From each herd, lactation records for all milking cows (including animals removed from the herd) for an 18 months period were collected. Across all herds, these records covered the period from April 2001 until May 2004. To be eligible for inclusion, cows must have calved during the first 12 months of the herd review. Reproductive records were collected to include calving until conception, culling, or the end of the follow-up period. Cow records were excluded from the study if they accumulated fewer than 26 days in lactation (DIM) during the follow-up period, mature equivalent 305 days (ME 305) milk production was not recorded, first test milk production was not recorded, or if they initiated a new lactation by abortion rather than a parturition of normal gestational length.

2.2. Data analysis

The primary outcome of the study was days to conception, with the primary comparison being cows bred using AI versus NS breeding. To evaluate this comparison, eight NS breeding analysis cohorts were created based on DIM that a non-pregnant cow was first exposed to NS breeding. With the exception of the first cohort, that spanned 0–50 DIM, the remaining cohorts were created using 25 days intervals: 51–75, 76–100, 101–125, 126–150, 151–175, 176–200, and 201–225 DIM. For each cohort, comparison groups of equal numbers of non-pregnant cows exposed only to AI during the cohort period were randomly selected from a pool of eligible cows. An AI cow record was used only once in the study as part of a comparison group for NS breeding, but was later included as a NS breeding if she was exposed to a NS sire later in her lactation.

Within a cohort, cows were followed to determine days to conception. Cow reproduction status was followed for up to 350 DIM. Cows not pregnant by 350 DIM were censored. Non-pregnant AI cows (used as comparisons within an analysis cohort) that were exposed to NS breeding before they conceived and less than 350 DIM were censored on the day they were placed in a bullpen. Non-pregnant cows that died or were removed from the herd before 350 DIM were also censored.

Comparisons of days to conception between AI and NS breeding for each DIM cohort were made using survival analytic methods. Unadjusted survival curves were calculated using a Kaplan-Meier product limit method and 95% pointwise equal precision confidence bands determined for each curve. Cox proportional hazard models were developed to control for the potential confounding effects of calving month, herd, number of cases of mastitis (as reported by the herd), and milk production on the main effect of breeding method.

Table 1
Descriptive statistics of lactation records from 10 western United States commercial dairy herds used to evaluate artificial insemination (AI) vs. natural service (NS) sire breeding on days to confirmed conception, including number of cow records per farm, 305 days mature equivalent projected milk production (ME 305), first test period milk production, and days in lactation (DIM) for cows in the study

Herd	Number of lactation records	Mean (min–max) ME 305 milk production (kg)	Mean (min–max) first test milk production (kg)	Mean (min–max) DIM
1	1104	12925 (4968–17736)	40 (1–77)	228 (56–452)
2	1656	13045 (5059–20877)	40 (4–71)	290 (53–547)
3	2941	10203 (2600–16168)	29 (2–55)	262 (26–510)
4	3263	9798 (141–17632)	32 (1–75)	210 (26–456)
5	2578	9847 (2828–21468)	31 (1–63)	215 (26–453)
6	2179	11780 (4145–18877)	35 (1–71)	221 (46–866)
7	1488	10826 (7963–19145)	31 (2–64)	212 (55–437)
8	1551	12146 (4172–18963)	39 (20–74)	296 (50–544)
9	2917	13465 (5036–20118)	43 (7–74)	269 (45–534)
10	903	10470 (3854–14609)	35 (2–64)	294 (26–527)

3. Results

3.1. Herd and animal characteristics

Data from 10 herds were included in the study for a total of 20,580 eligible cow records. The number of cow records per herd ranged from 903 to 3263. Milk production, cow numbers, and DIM for each study herd are shown (Table 1). As described previously, cows were allocated to an analysis cohort group to produce an equal number of NS and AI bred cows within the cohort. The cohorts are described (Table 2). The size of the cohorts varied with the number of cows that were first exposed to the NS sire during that DIM period. For the final analyses, a total of 9812 lactation records were used. The number of cows in the

Table 2
Description of analysis cohorts from a study of ten western United States commercial dairy herds used to evaluate AI vs. NS sire breeding on days to confirmed conception

Cohort (DIM[a])	AI			NS Sire		
	N	Mean ME 305 milk production (kg)	Mean first test milk production (kg)	*N*	Mean ME 305 milk production (kg)	Mean first test milk production (kg)
1–50	1028	11455	36	1028	9829	33
51–75	341	11383	35	341	10162	33
76–100	394	11473	35	394	10429	35
101–125	512	11692	36	512	11193	37
126–150	790	11874	36	790	11914	37
151–175	799	11884	36	799	11444	35
176–200	518	11874	36	518	11682	37
201–225	524	11872	36	524	11854	35

Cohorts are based on days in milk (DIM) when non-pregnant cows were first exposed to NS sires compared non-pregnant cows only exposed to AI during the cohort interval.
[a] Days in milk when non-pregnant cow was first exposed to NS sire and days in milk category for non-pregnant AI as the control group.

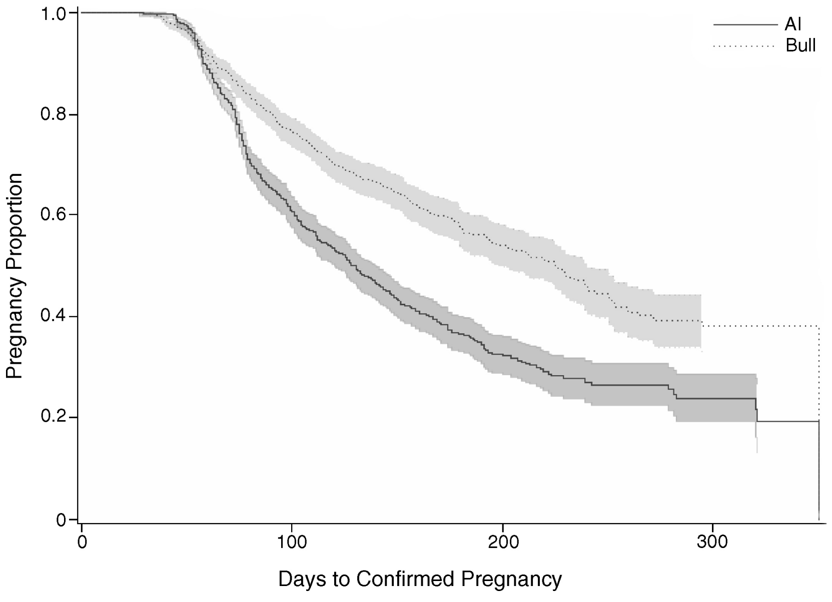

Fig. 1. Kaplan-Meier survival curves with 95% confidence bands comparing days to confirmed pregnancy between cows exposed to AI (n = 1028) and natural service (bull; n = 1028) breeding programs between 1 and 50 days in milk. Data are from ten western United States commercial dairy herds.

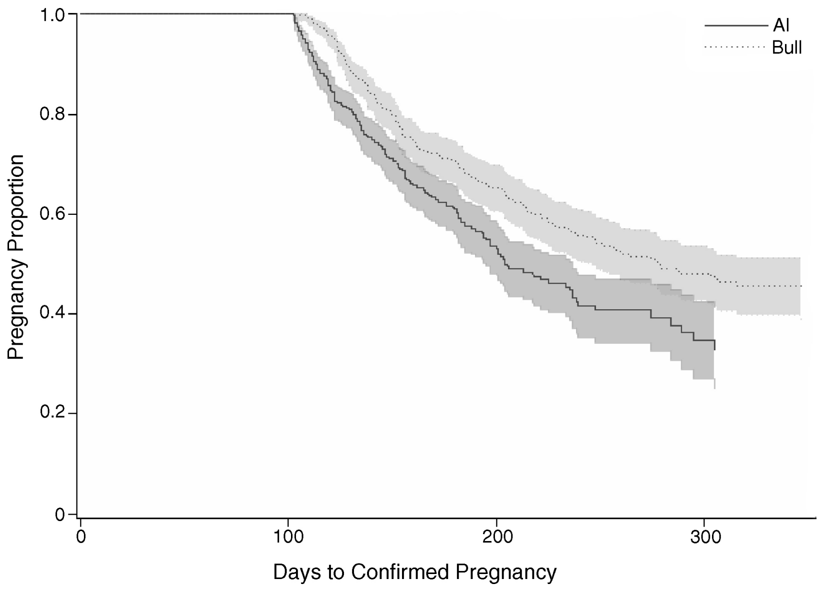

Fig. 2. Kaplan-Meier survival curves with 95% confidence bands comparing days to confirmed pregnancy between cows exposed to AI (n = 512) and natural service (bull; n = 512) breeding programs between 101 and 125 days in milk. Data are from 10 western United States commercial dairy herds.

various cohorts varied and reflects the choices for managing reproduction on these dairy herds. The high number of animals in the 1–50 DIM cohort reflects cows going directly to the bull as either the overall reproduction strategy or for animals that are considered poor producers or high risk for reproductive failure, and is an attempt by the producer to salvage the cow. The increase in numbers in the two cohorts 126–150 and 151–175 reflects a decision made on these dairy farms to move non-pregnant animals out of the AI pens and into bullpens. The most notable difference between the cohorts is the numeric difference in ME 305 milk. AI exposed animals generally had higher ME 305 milk production and this effect was most pronounced in the early cohorts.

3.2. *Effects on days to conception*

Kaplan-Meier-based days to conception curves stratified by AI and NS exposure were calculated for each analysis cohort. The curves for the cohorts 0–50, 101–25, and 151–175, and 95% confidence bands are shown (Figs. 1–3). For the 0–50 DIM cohort, the median days to conception for NS exposure was 225 days, compared to 129 days to conception for the AI cows. The curves are distinct throughout the follow-up period. For the 101–125 DIM cohort the median days to conception for NS exposure was 239 days, compared to 182 days for AI cows. While the curves are distinct in the early part of the follow-up, they have a similar rate later in the follow-up period but do not converge. For the 151–175 DIM cohort, the median days to conception for NS exposure was greater than 350 days, compared to 303 days for the AI cows. Again these curves were distinct early in the follow-up period but are converging at the end of the follow-up. The curves for all the analysis cohorts exhibited similar patterns.

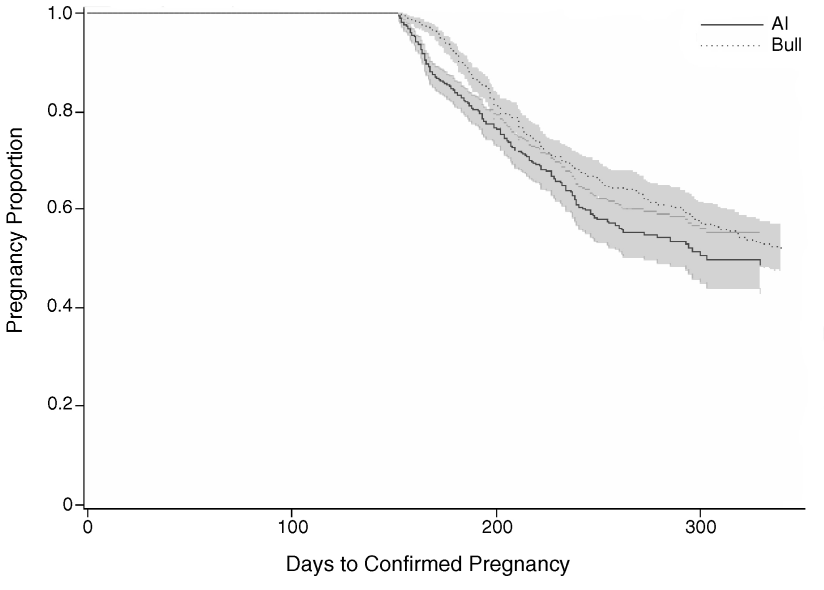

Fig. 3. Kaplan-Meier survival curves with 95% confidence bands comparing days to confirmed pregnancy between cows exposed to AI ($n = 799$) and natural service (bull; $n = 799$) breeding programs between 151 and 175 days in milk. Data are from ten western United States commercial dairy herds.

Table 3
Hazard ratios for days to confirmed pregnancy comparing dairy cows from ten western United States commercial dairy herds exposed to AI compared to NS sire for varying days in milk (DIM) categories when first exposed to bull breeding

Variable	Level	DIM when first exposed to bull breeding and AI controls							
		Hazard ratios							
		1–50	51–75	76–100	101–125	126–150	151–175	176–200	201–225
Breeding method	AI	1.5[b]	1.9[b]	1.6[b]	1.7[a]	1.6[b]	1.3[a]	1.8[b]	1.5[a]
	NS	Reference							
Lactation number	1st	1.9[b]	1.2	1.1	1.4[a]	1.4[a]	1.3[a]	1.4	1.8[b]
	2nd	1.2[a]	1.0	0.9	1.1	1.0	1.1	1.3	1.6[b]
	3rd	Reference							
Calving month	Jan	0.8	0.8	1.3	0.7	0.9	0.9	0.3[a]	0.3[b]
	Feb	0.8	0.5	1.3	0.8	0.8	1.0	0.8	0.4[b]
	Mar	0.9	0.7	1.6	0.3[a]	0.3[a]	0.4[a]	0.7	0.4[a]
	April	1.0	0.2[a]	1.4	0.6	0.6	0.7	0.9	0.9
	May	0.6	0.6	2.0	0.7	1.4	1.1	1.9[a]	0.9
	June	0.8	0.9	2.1[a]	0.9	1.7[a]	1.3	1.2	0.8
	July	1.0	0.4[a]	0.5	0.7	1.5	1.0	0.9	0.9
	Aug	1.0	0.7	1.7	1.0	0.9	1.2	0.8	0.3[b]
	Sept	1.1	0.4[a]	2.4[a]	1.4	0.8	0.8	0.5	0.4[b]
	Oct	1.0	1.0	1.8	1.3	0.7	0.6	0.4[a]	0.5
	Nov	0.8	0.5	1.5	0.7	0.9	0.4[a]	0.6	0.4
	Dec	Reference							
ME 305 ($\times$1000 kg)		1.1[b]	1.1[b]	1.1[b]	1.0	1.0	1.1[b]	1.1[a]	1.0
First test milk production ($\times$10 kg)		1.1[a]	0.9	0.9	1.2[a]	1.1	1.0	0.9	1.0

[a] $p < 0.05$.
[b] $p < 0.01$.

Multivariate proportional hazard models comparing AI and NS breeding, controlling for ME 305, milk production at first monthly test, parity, number of cases of mastitis, calving month, and herd were developed. Hazard ratios (HR) for days to conception are shown in Table 3. While herd was forced into all models, it was considered to be a nuisance variable and the associated HR are not listed in the table. The number of recorded cases of mastitis was not a significant covariate in any of the cohort models and was removed from the models. In all analysis cohorts, the AI exposed cows were 1.3–1.9 times more likely to have decreased days to conception or pregnancy compared to NS exposed cows. In most cohorts, first parity cows were more likely to have decreased days to pregnancy compared to 3+ parity cows. Also, in most cohorts, cows with higher ME 305 had decreased days to pregnancy.

4. Discussion

The purpose of this paper was to compare the reproductive efficiency of AI versus NS sires within commercial dairy herds. Across all cohorts, the AI cows had higher risks for becoming pregnant than cows in bullpens. This result from the early cohorts (1–50, 51–75, 76–100) is not surprising as many dairies with bullpens may move cows that experience calving related trauma and secondary adhesions or reproductive tract injuries directly into bullpens, or will move them when cows are believed to have fertility problems. However, the continued higher risk of pregnancy throughout the remaining cycles is somewhat surprising considering that anecdotal reports suggests that cows remaining non-pregnant after multiple AI breeding attempts are likely to be unsuccessful in further AI attempts.

Dairymen reported that cows are moved from AI into bullpens based on a combination of number of times inseminated, DIM, and a cow's current milk production [4]. This behavior suggests that the dairy producers believe that bull breeding improves the likelihood that these non-pregnant and potentially lower producing cows will become pregnant, and that NS breeding lowers their input costs to these less productive cows. In contrast, producers appear willing to give higher producing cows more opportunities at AI. This approach to management of bullpens is consistent with the current dataset, where approximately 4.5% of cows analyzed were moved to the bulls between 1 and 50 DIM, but only 1.5% were moved in the two succeeding cohorts. The number of cows moved increases after 100 DIM, peaking at 126–175 DIM with a total of 7% of the analyzed cows being moved at this time period. Although not evaluated, cows moved at 126–175 DIM have been in the AI pen long enough to have received two or three AI services, assuming a voluntary waiting period of 50 days and reasonable estrus detection efficiency.

Dairymen move cows from AI to bullpens for a variety of reasons including a common belief that these cows are less fertile and may have improved odds of becoming pregnant in bullpens, a decision to stop investing more capital in the form of semen, hormones, or labor into these lower fertility cows, or due to a lack of labor or housing capacity in AI pens. Conception rates in California herds have been shown to decrease as the number of services increases [8]. However, the results of the current study suggest that keeping cows in the AI pen longer may improve the probability of becoming pregnant, despite the potential drop in expected conception rate. The rate at which cows become pregnant is due to a combination of breeding submission rate and conception rate. While conception rates may be similar in bull and AI pens, cows in bullpens do not receive the benefit of prostaglandin $F2\alpha$ interventions to induce estrus or timed AI programs like Ovsynch [9,10]. Despite the drop in predicted conception rates over time, cows in AI pens were at higher risk of becoming pregnant throughout the entire study period.

Bullpens serve a useful function on many dairies as they often house predominantly pregnant cows. Estrus detection and insemination in these pens is an inefficient use of personnel, and bull service in these pens covers later lactation open cows (either AI failures or as a consequence of late term abortion). Bullpens also allow dairymen to delay culling decisions on non-pregnant cows by moving them into pens containing NS sires. The culling decision is then based on pregnancy status at the time when milk production declines to an unprofitable level, rather than on the value of semen and projected value of current and future milk production. However, the results of this study suggest that dairymen might obtain higher herd pregnancy proportions by maintaining cows in AI pens longer, if there is sufficient labor to support the additional efforts at estrus detection and insemination.

Milk production (ME 305 milk production and first test milk production) was included as a covariate in all multivariate assessments of days to conception. In five of the eight cohorts evaluated, increasing ME 305 milk production was associated with decreased days to conception. Increasing first test milk was also associated with decreased days to pregnancy in two of eight cohorts. These findings are in contrast to published data suggesting a negative association between milk production and reproductive efficiency [11,12]. In these reviews, it is speculated that a portion of the negative relationship between milk production and reproduction may be due to lower estrus detection. It has been shown that high milk production decreases the duration of estrus probably as a result of decreased circulating concentrations of estradiol [13]. However, Laben et al., in a review of California herds, suggested that the effects of high production on reproduction may be offset partially by improved management [14]. Looking only at days open or services per conception is potentially misleading, as high producing cows tend to get more opportunities for breeding by remaining in the herd longer. Within the current study, perhaps the reason for higher reproductive efficiency in higher producing cows was due to better overall health (less lameness or mastitis, potentially), or that the analytic approach used in this study clustered and compared cows in DIM cohorts which accounted for the likelihood that higher producing cows may have extended AI opportunities but were being compared to a cohort of NS sire exposed cows at the same stage of lactation (DIM).

Other risk factors for days to conception evaluated in this study included parity (lactation 1, 2, or 3+), cases of mastitis, and calving month. Primaparous cows had numerically higher hazard ratios for decreased days to conception in all cohorts evaluated and were statistically better in five of the eight analysis cohorts. Second lactation cows were not different in risk for pregnancy, as compared to 3+ lactation cows, except in the first and last cohorts. These results of higher hazard rates for pregnancy in primiparous cows are consistent with other reports [8,15,16]. While primiparous cows may have longer intervals to first insemination in herds without timed AI programs, conception rates and estrus detection rates are usually higher, possibly due to few periparturient problems and lower risks for lameness during their first lactation.

Month of calving was considered to be a potential confounder in the analyses and was used as a class variable. There was no consistent pattern of effect of calving month, but within each cohort, there was at least one instance where calving month was significantly associated with risk of pregnancy, and therefore it remained in the final model.

Mastitis, previous attempts at insemination, and nutrition all may affect reproductive performance. Mastitis has been shown to have significant effects on conception risk, interestrus interval length, and risk of embryonic death [17–19]. Mastitis, expressed as the number of cases per cow as reported by the dairy, was not a significant predictor of days to conception in our study. Risk for mastitis is assumed to have been equally distributed within farm and between pens, with the exception of cows moved to bulls very early in lactation. Cows moved to bullpens at 1–50 DIM may represent an abnormal group of cows and care should be taken in the interpretation of this cohort's results.

Nutrition can have direct and indirect effects on risk of pregnancy due to impacts on cyclicity and risk of conception [20–24]. Specifically, dietary components such as whole cottonseed and cottonseed byproducts may have negative effects on reproduction in both males and females, although the effects are more commonly seen in bulls [24–26]. Most of the herds in the dataset feed single group total mixed rations, but some of the dairies feed a high ration and a low ration. The primary differences in these two rations are the level of energy and the protein sources. It is possible that some of the differences in risk of pregnancy may be the result of ration influences, primarily the negative effect of gossypol on NS sires. We did not directly adjust for ration differences in these analyses but indirectly account for its confounding effect using herd as a covariate. Effects on days to conception associated with between herd nutrition differences are expected to be minor.

The number of previous services within the current lactation has been shown to be associated with the odds of pregnancy at the subsequent insemination [8]. No attempt was made to adjust for this potential confounder as the records did not include the number of services in the bullpen. Few dairymen actually record estruses or services in bullpens. However, the consistency of the results, with all cohorts showing higher hazard rates for AI, would suggest that the overall effect of number of services is likely small.

Choice of approach for reproductive management on dairies varies depending on prior experiences of the management team, type of facility, and availability of qualified labor. The purpose of this paper was to compare the risk for pregnancy between AI and bullpens, while adjusting for effects of milk production, parity, month of calving and herd effect. The results of this paper show that dairymen may be moving cows into bullpens too early, and that overall herd reproductive performance might be improved by allowing cows more opportunities at AI before movement into bullpens.

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