A retrospective analysis of bull:cow ratio effects on pregnancy rates of beef cows previously enrolled in fixed-time artificial insemination protocols

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ABSTRACT: This retrospective study aimed to determine if the number of cows exposed per bull affects pregnancy rates of cows returning to estrus after fixed-time artificial insemination (FTAI). Data were compiled over the course of 13 breeding seasons (six fall and seven spring seasons) between 2010 and 2017 from the Virginia Department of Corrections herd. Available records contained data from 17 farms and 324 groups of cows (average 47 cows/group). Multiparous cows and heifers (average age per group: 5.11 ± 0.14 yr; $n = 14{,}868$) were exposed to FTAI. After FTAI, animals were placed on pasture with bulls diagnosed as fertile by a breeding soundness exam for natural service of cows who did not become pregnant to FTAI ($n = 7{,}248$; average 22 cows/group). Animals were classified as pregnant to FTAI, to natural service on first return to estrus, or to natural service on second or subsequent estrus determined by fetal aging at pregnancy diagnosis. The bull:cow ratio for the total number of cows exposed ranged from 1:9 to 1:73 with an average of 1:31. The bull:cow ratio considering only open cows exposed after FTAI ranged from 1:2 to 1:44 with an average of 1:14. There was significant negative, small correlation between the bull:cow ratio for total number of cows exposed and return to estrus pregnancy rate in fall breeding seasons ($P = 0.01$, $r^2 = 0.04$) but not in spring ($P = 0.90$). There was a significant negative, small correlation between bull:cow ratio of open cows exposed and pregnancy rates to first return to estrus in fall herds with a single sire ($P < 0.001$, $r^2 = 0.11$). There was no correlation in fall herds using multiple sires or spring herds ($P \geq 0.12$). Bull:cow ratio accounted for only 1–11% of variation in the pregnancy rates, thus we conclude that a decreased bull:cow ratio (up to 1:73) did not affect natural service return to estrus pregnancy rate. Cattlemen may consider a reduced number of bulls needed for natural service breeding after FTAI, which can decrease bull related costs and increase the economic feasibility of adopting FTAI protocols.

Key words: bull, cow ratio, fixed-timed artificial insemination

INTRODUCTION

Estrous synchronization and fixed-time artificial insemination (FTAI) benefit cattlemen

genetically and economically through shortened calving seasons, increased calf uniformity, and production of more pounds of calf per cow exposed to FTAI due to earlier calving (Odde, 1990; Holm et al., 2008; Rodgers et al., 2012). Unfortunately, adoption of FTAI protocols in the United States beef industry is poor: only about 11% of cattle operations surveyed utilize artificial insemination in their operations, with the majority of these being medium to large operations with 50 or more head (USDA, 2020). While adoption of estrus synchronization and artificial insemination in the beef industry is growing, the prevalence of FTAI in the beef industry is still extremely low, especially when compared to the dairy industry which reports 89.3% of all operations using some method of estrous synchronization and artificial insemination (USDA, 2018).

What prevents the adoption of these reproductive technologies? For most producers, labor and cost considerations are largest hinderances to adoption of management changes (USDA, 2020). When cattlemen implement estrous synchronization protocols, they are challenged with balancing a trade-off between up-front costs and required labor: protocols utilizing few synchronization drugs require added labor with estrus detection, while more intensive protocols that do not require estrus detection have a greater cost input for synchronization drugs. Improving economic feasibility is likely the easiest method to improve adoption of reproductive technologies in beef cattle production. Utilization of FTAI generally results in a gain of $49 per cow exposed (Rodgers et al., 2012). Altering bull-related costs, primarily through altering the bull:cow ratio, can increase the economic returns in a FTAI program (Rodgers et al., 2012). However, it is not known to what extend this ratio can be altered when animals are estrous synchronized and artificially inseminated. While we cannot control the costs associated with working cattle and synchronization drugs, we may be able to alter the bull:cow ratios used after FTAI to reduce bull related costs and improve the economic feasibility of implementing FTAI protocols.

The current recommended bull:cow ratio is 20 to 30 cows in pasture for every one bull (Chenoweth, 2015; King, 2015). The Auburn formula, similarly, recommends the number of cows serviced be proportional to bull age for those less than 36 mo, or proportional to scrotal circumference of bulls greater than 36 cm in a single sire setting (Wenzel et al., 2012). However, cattlemen tend to air on the lower end of these recommendations, with the average number of beef cows exposed to yearling bulls at 15.2 and for mature bulls 22.0, regardless of the use of synchronization and FTAI (USDA, 2020). The recommended 1:25 bull:cow ratio may not even be reaching the bulls full breeding potential, according to Rupp et al. (1977). They reported no changes in pregnancy or estrus rates when cows were on pasture with bulls in ratios of 1:25, 1:44, or 1:60 bulls per cow. However, this work was done in a purely natural service setting, and recommendations need to be adjusted when females are exposed to estrous synchronization and FTAI prior to natural service. Cows that remain non-pregnant will be returning to estrus in a synchronized manner, with the majority returning 20 to 23 d post-FTAI (Larson et al., 2009), and put added pressure on the bull to breed as many females in a much shorter amount of time. Current recommendations for bull:cow ratios after synchronization are set around 1:25 bulls per cow (Healy et al., 1993; Chenoweth, 2015). However, the data provided by Healy is based only on estrous synchronization of heifers immediately exposed to natural service.

To our knowledge, there is no literature examining how the bull:cow ratios influence pregnancy rates after cows have been synchronized and artificially inseminated using an FTAI protocol. We hypothesize that the bull:cow ratio has no influence on pregnancy rates for cows bred by natural service on their first return to estrus after FTAI. If this proves true, the bull:cow ratio can ideally be reduced to increase the number of cows serviced by a single bull, particularly if a large portion of the cows become pregnant to FTAI. This retrospective analysis aimed at assessing if the number of cows exposed per single bull influences pregnancy rates after cows have been enrolled in an estrus synchronization and FTAI protocols and its implications for cattlemen.

MATERIALS AND METHODS

Animals

Herds of commercial beef cattle (primarily Angus × Simmental crosses) from the Virginia Department of Corrections (VDOC) located across 17 locations throughout the state of Virginia were enrolled in this study. Multiparous cows and heifers (average age per group = 5.11 ± 0.14 yr; $n = 14,868$) were exposed to an estrous synchronization and FTAI protocol, typically the 7-d CO-Synch + CIDR. Different synchronization protocols were utilized in some breeding seasons due to enrollment of cows on FTAI experiments; however, the 7-d

CO-Synch + CIDR was always utilized as the control FTAI protocol and when no FTAI experiment occurred. Only data from breeding seasons that utilized frozen conventional semen and synchronization protocols with progestin releasing intravaginal devices (variations of the 7-d CO-Synch + CIDR) were included in the analysis. Fall breeding to FTAI occurs in mid to late December, while FTAI in the spring season occurs in early May. After FTAI, groups of cows and heifers (47 ± 1 head/group) were maintained on pasture with bulls to breed any females not pregnant from FTAI. Mature, commercial bulls were diagnosed as fertile from breeding soundness exams prior to initiation of the breeding season. Bulls are introduced into herds 10 d after FTAI and maintained in pastures with cows for an approximate 70-d breeding season. Pregnancy diagnosis was performed by transrectal ultrasonography. Females were checked for pregnancy twice during each breeding season. The initial pregnancy check was performed between 55 and 65 d after FTAI, and final pregnancy diagnoses were performed at least 45 d after bulls were removed. For each cow at first positive pregnancy diagnosis, fetal age was determined using fetal measurements by ultrasonography.

Data

The VDOC is a client and partner of the VA-MD College of Veterinary Medicine Teaching Hospital and Production Medicine and Management (PMM) Services. This partnership allows for the use of VDOC beef herd for research and teaching. All data from the VDOC beef herd is collected, managed and stored by clinicians, technicians and veterinary students working at PMM. Data is collected on farm and transcribed into paper sheets prepared previously to each herd visit. Upon return to the teaching hospital, all data is entered into a Microsoft Excel Worksheet (Microsoft, Version 2003). Data from each breeding season including all locations is uploaded into a master Excel worksheet and stored in a computer.

Data from individual cows in VDOC herds were available from fall and spring breeding seasons from 2010 to 2017, for a total of 13 breeding seasons. Data included cow ID, location, group or herd the cow was maintained within location, age, body condition score (BCS) at start of synchronization, semen sire, inseminator, natural service sire(s), days pregnant at pregnancy diagnosis, and previous calving data. Animals with incomplete data on natural service sire, fetal age at pregnancy diagnosis, or having been removed from a group during the breeding season were excluded from analysis. The unit of analysis was group of animals ($n = 392$), as classified by VDOC records or by natural service sire mating. Groups were composed of heifers or mature cows based on provided age and records on previous calving information. Mature cows were defined as being 2 yr of age and older and/or had calving data from earlier in the year. Each group was also categorized by sire setting: either single sire for groups exposed to one bull, or multiple sires for groups exposed to two or more bulls at once.

Within each group of animals, we determined the number of animals bred to FTAI, bred by natural service following first return to estrus, or bred late in season (on second return to estrus or later) based off fetal age at the initial pregnancy diagnosis. The total number of cows exposed per bull was calculated by dividing the total number of cows in a group by the number of bulls to whom cows were exposed. The number of open cows per bull was calculated by dividing the number of cows who were not classified as bred to FTAI by the number of bulls to whom cows were exposed on pasture. The total number of cows exposed per bull and the number of open cows exposed per bull were further divided into quartiles for further analyze sources of variation within the data.

Statistical Analysis

Statistics were analyzed in R version 3.3.1. Linear regression was performed to analyze the relationship between pregnancy rates on first return to estrus and the fixed effects of bull to total cows ratio or bull to open cows ratio (R Core Team, 2016). Models also included interactions between bull:cow ratio and season, BCS, or age (heifer or mature cow). Student's t-test (or Welch's t-test when appropriate for unequal variances) was performed to assess differences in pregnancy rates between seasons and BCS between seasons. One-way ANOVA followed by Tukey's post-hoc test with the agricolae package (Felipe de Mendiburu and Yaseen, 2020) was also used to compare pregnancy rates to FTAI, pregnancy rates on first return to estrus between quartiles of the total number of cows exposed and the number of open cows exposed. All percentage data were given an arcsine transformation for analysis and results are presented as the back-transformed values, with SEMs based off Jøgensen and Pedersen (1998) and 95% confidence intervals calculated on the transformed scale before being back-transformed. Significance was set at $P < 0.05$, and tendencies at $0.05 < P < 0.1$.

RESULTS

Table 1 lists the bull:cow ratios overall, divided by season, and divided by single and multiple sire groups. Overall, groups averaged a 31 total cows per bull, but ranged from 9 to 73 cows per bull. The average bull to open cow ratio was 1:14, but ranged from 2 to 44 open cows per bull.

There were no significant interactions of total ratio with BCS, use of multiple or single sire, and dam age ($P > 0.34$). We did observe a significant interaction between total number of cows exposed per bull and season ($P = 0.03$). There was also tendency for an interaction between the number of open cows exposed per bull and season ($P = 0.08$). Thus, we decided to analyze the data from spring and fall breeding seasons separately. In spring breeding seasons, there were no effects of BCS, age, or sire setting nor interactions with the total number of cows or the number of open cows exposed on first return to estrus pregnancy rates ($P \geq 0.27$). In fall seasons, there was no effect of BCS, age, or sire setting and the interactions with total number of cows on pregnancy rates for first return to estrus ($P \geq 0.15$). We observed a tendency for effect of sire setting ($P = 0.057$) and the interaction between sire setting and number of open cows exposed per bull ($P = 0.086$) in fall data. We further separated fall data by single and multiple sire groups, where there

Table 1. Bull to cow ratios for combined data, fall and spring data, and single and multiple sire setting data for combined and seasonal data

	Mean	Min	Max
Fall breeding seasons			
Total cows exposed	**1:33**	**1:10**	**1:73**
Single sire	1:35	1:10	1:61
Multiple sire	1:31	1:14	1:73
Open cows exposed	**1:16**	**1:2**	**1:40**
Single sire	1:16	1:2	1:40
Multiple sire	1:15	1:6	1:39
Spring breeding seasons			
Total cows exposed	**1:30**	**1:10**	**1:62**
Single sire	1:36	1:14	1:61
Multiple sire	1:25	1:10	1:62
Open cows exposed	**1:14**	**1:4**	**1:44**
Single sire	1:16	1:5	1:44
Multiple sire	1:12	1:4	1:36
Combined seasons			
Total cows exposed	**1:31**	**1:9**	**1:73**
Single sire	1:34	1:9	1:61
Multiple sire	1:28	1:9	1:73
Open cows exposed	**1:14**	**1:2**	**1:44**
Single sire	1:15	1:2	1:44
Multiple sire	1:13	1:3	1:39

were no effects of BCS or dam age in neither single nor multiple sire groups ($P \geq 0.51$).

We observed a significant negative, but weak, correlation ($P < 0.01$, $r^2 = 0.04$; Figure 1) between the total number of cows exposed per bull and pregnancy rates on first return to estrus in fall breeding seasons. There was no correlation in the spring breeding season ($P = 0.90$, $r^2 = -0.01$). There was no correlation between the number of open cows exposed per bull and pregnancy rates on first return to estrus in spring breeding seasons ($P = 0.10$; $r^2 = 0.01$). There was no correlation in fall breeding seasons groups with multiple sires ($P = 0.12$; $r^2 = 0.02$). We did observe a significant, weak negative correlation ($P < 0.001$, $r^2 = 0.11$; Figure 2) between the number of open cows exposed per bull and pregnancy rates to first return to estrus in fall herds using a single sire.

Pregnancy rates to FTAI averaged 54.9 ± 0.7% overall, but ranged from 14.3% to 83.3% by group. There was a significant effect of season on pregnancy rates by the end of the breeding season, with fall breeding seasons having increased pregnancy rates (92.4 ± 0.5% vs. 89.8 ± 0.6%; $P < 0.001$). Pregnancy rates to FTAI and pregnancy rates following first return to estrus did not differ by season ($P \geq 0.61$). We did observe greater pregnancy rates for late bred cows (second return to estrus or later) in the fall breeding seasons compared to spring (64.9 ± 1.6% vs. 57.8 ± 1.4%; $P < 0.01$).

When the total number of animals exposed per bull was divided into quartiles, we observed no differences in pregnancy rate to FTAI, pregnancy rate on first return to estrus, nor pregnancy rate to subsequent estruses ($P \geq 0.24$; Table 2). There was a significant difference in pregnancy rates to FTAI between quartiles of the number of open animals exposed per bull ($P < 0.001$; Table 3). This is expected, as changes in pregnancy rates to FTAI will alter the number of open cows exposed for breeding to natural service. There were no differences in pregnancy rates on first return to estrus nor pregnancy rates on subsequent estrus between quartiles of open cows per bull ($P \geq 0.10$).

DISCUSSION

We observed that the number of open cows exposed per bull is roughly half of the number of total cows exposed per bull after cows have been enrolled in estrous synchronization and FTAI (Table 1). This makes sense as we observed an average pregnancy rate to FTAI of 50% meaning half of the total animals exposed per bull would
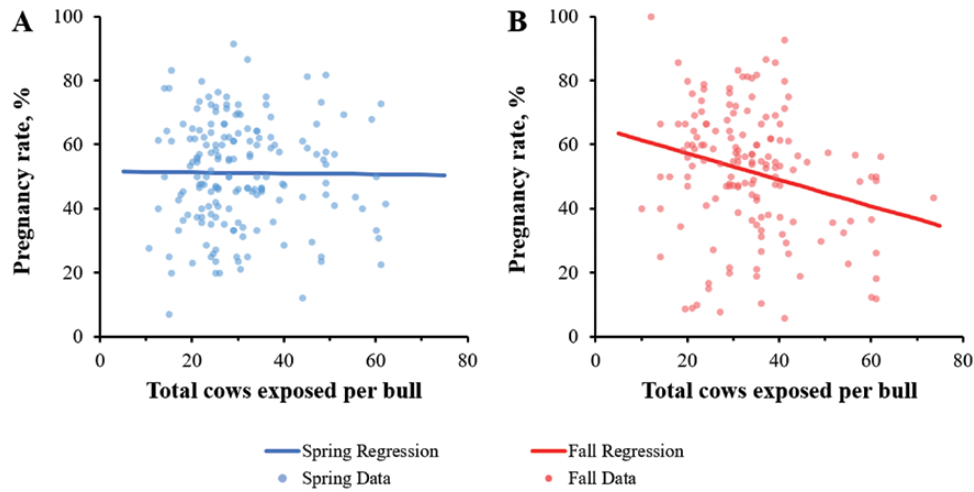
Figure 1. Pregnancy rate for first return to estrus following fixed-time artificial insemination compared to the total number of cows exposed per bull for spring (A) and fall (B) seasons. There was no effect of ratio in spring ($P = 0.90$; $r^2 = -0.01$; arcsine($\sqrt{(y)}$) = $-0.0001x + 0.80$), but there was a negative correlation in fall ($P < 0.01$; $r^2 = 0.04$; arcsine($\sqrt{(y)}$) = $-0.0042x + 0.94$).
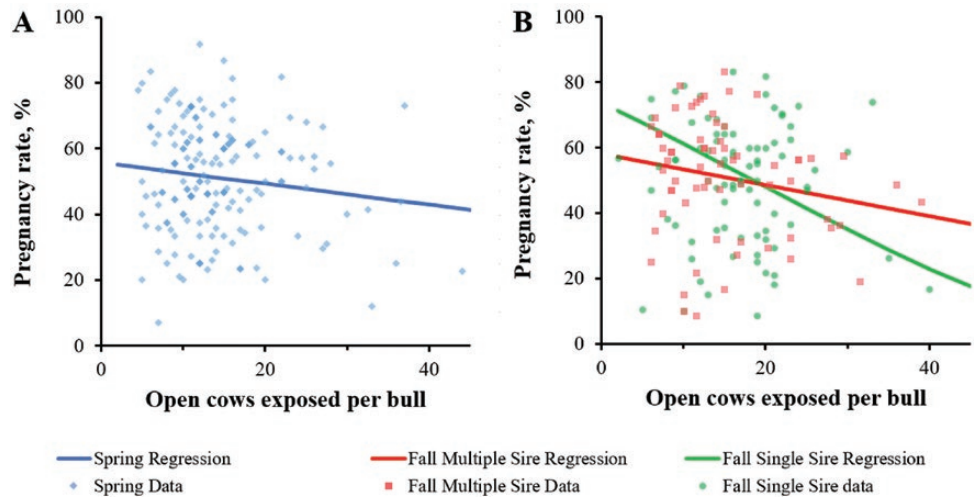

Figure 2. Pregnancy rate for first return to estrus following fixed-time artificial insemination compared to the number of open cows exposed per bull for spring (A) and fall (B) seasons. There was no effect of ratio in spring ($P = 0.10$; $r^2 = 0.01$; arcsine($\sqrt{(y)}$) = $-0.0001x + 0.80$). There was a tendency for effect of sire ($P = 0.058$) and interaction of sire and ratio in the fall ($P = 0.086$). When separated by sire setting, there was a negative correlation in herds with a single sire ($P < 0.001$; $r^2 = 0.12$; arcsine($\sqrt{(y)}$) = $-0.0133x + 1.03$) and no effect of ratio in herds with multiple sires ($P = 0.12$; $r^2 = 0.02$; arcsine($\sqrt{(y)}$) = $-0.0048x + 0.87$).

not become pregnant to FTAI. The average bull to total number of cows exposed ratios followed the typical producer recommendations of 20 to 30 cows per bull. However, we see that the ratio of bulls to cows needing to be serviced (open cows) is reduced to 1:15. Previous work done by Healy and colleagues identified the ideal bull:cow ratio for estrous synchronized heifers to be 1:25 (Healy et al., 1993), based off economic evaluation and pregnancy rates of varying bull:cow ratios. While the economic analysis is outdated, their recommendation for bull:cow ratios after synchronization

still exceeds our observed number of open animals exposed. Based on our results, it is possible to decrease bull:cow ratios to at least 1 bull per every 50 cows exposed to FTAI to achieve a ratio of 1 bull per 25 open cows.

All significant correlations we observed demonstrated a negative relationship between the bull:cow ratio and pregnancy success on first return to estrus. However, the r^2 of these correlations was quite small. Bull:cow ratio only represented between 1% and 11% of the variation in the data. Given the use of healthy bulls of proven fertility, this indicates

Table 2. Pregnancy rates to fixed time artificial insemination (FTAI), pregnancy rates for first return to estrus, body condition score (BCS), and dam age for quartiles of the total number of cows exposed per bull. Differing superscripts across columns represent significant differences ($P < 0.05$) and 95% confidence intervals are displayed in paratheses

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Range of bull:total cows exposed ratio	1:10–1:23.5	1:23.6–1:30	1:31–1:37.5	1:37.6–1:73.5
Mean ratio bull:cow ratio, mean ± SD	1:19.3 ± 3.45	1:27.0 ± 2.13	1:33.9 ± 2.07	1:48.5 ± 8.5
Pregnancy rate to FTAI, mean % ± SEM	55.6 ± 1.5 [a] (52.6–58.5)	55.0 ± 1.4 [a] (52.3–57.6)	55.0 ± 1.4 [a] (52.2–57.7)	54.5 ± 1.3 [a] (51.9–57.0)
Pregnancy rate on first return to estrus, mean % ± SEM	53.5 ± 2.4 [a] (48.8–58.1)	50.9 ± 2.1 [a] (46.7–55.0)	53.2 ± 2.0 [a] (49.3–57.1)	47.9 ± 2.3 [a] (43.5–52.3)
Pregnancy rate on subsequent estruses, mean % ± SEM	62.1 ± 3.6 [a] (54.9–68.9)	62.7 ± 2.5 [a] (57.7–67.5)	65.8 ± 2.3 [a] (61.3–70.1)	62.8 ± 3.2 [a] (56.4–68.9)
BCS, mean ± SD	5.33 ± 0.71	5.47 ± 0.80	5.63 ± 0.70	5.76 ± 0.70
Dam age, mean years ± SD	5.38 ± 2.44	5.72 ± 2.20	4.97 ± 2.27	4.31 ± 2.60

Table 3. Pregnancy rates to fixed time artificial insemination (FTAI), pregnancy rates for first return to estrus, body condition score (BCS), and dam age for quartiles of the number of open cows exposed per bull. Differing superscripts across columns represent significant differences ($P < 0.05$) and 95% confidence intervals are displayed in paratheses

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Range of bull:total cows exposed ratio	1:10–1:23.5	1:23.6–1:30	1:31–1:37.5	1:37.6–1:73.5
Mean ratio bull:cow ratio, mean ± SD	1:7.80 ± 1.69	1:12.24 ± 1.15	1:16.47 ± 1.47	1:25.46 ± 5.72
Pregnancy rate to FTAI, mean % ± SEM	63.4 ± 1.2 [a] (61.0–65.7)	57.1 ± 1.1 [b] (54.9–59.3)	51.9 ± 1.2 [c] (49.4–54.3)	46.1 ± 1.3 [d] (43.5–48.6)
Pregnancy rate on first return to estrus, mean % ± SEM	54.0 ± 2.4 [a] (49.3–58.6)	52.9 ± 2.0 [a] (49.0–56.7)	51.3 ± 2.2 [a] (47.1–55.5)	46.5 ± 2.2 [a] (42.2–50.9)
Pregnancy rate on subsequent estruses, mean % ± SEM	62.1 ± 3.8 [a] (54.6–69.4)	64.8 ± 2.6 [a] (59.7–69.7)	63.2 ± 2.5 [a] (58.2–68.0)	62.8 ± 2.7 [a] (57.4–68.0)
BCS, mean ± SD	5.39 ± 0.77	5.50 ± 0.72	5.65 ± 0.77	5.64 ± 0.65
Dam Age, mean ± SD	5.34 ± 2.49	5.78 ± 2.11	4.71 ± 2.49	4.44 ± 2.44

that the bull is not the limiting factor in the success of a FTAI and natural service program. This is further confirmed with our insignificant differences between pregnancy rates on first return to estrus when assessed by comparing between quartiles of total cows exposed and open cows exposed. Thus, increasing the number of females serviced by a single sire will likely not impact pregnancy rates on first return to estrus. As previously stated, decreasing the bull:cow ratio to 1:50 or 1:60 would achieve a bull to open cow ratio of 1:25 or 1:30, following recommendations (Healy et al., 1993; Chenoweth, 2015; King, 2015). Provided the bull is proven fertile, decreasing the bull:cow ratio will likely have more economic benefit by reducing the bull associated costs than would be detrimental from any potential decreases in pregnancy rates to first service.

Reduced bull:cow ratios, however, comes with added risk and cattlemen should take care in assessing what production practices will be most beneficial to them. In order to ensure productivity, increased emphasis should be placed on the reproductive capability of individual bulls, as well as practicality of implementing this research. Bull servicing capacity and general health are crucial to account for if reducing the number of natural service bulls used on operations. While utilizing bulls with greater libido does not necessarily correspond with increased pregnancy rates, there is an increase in the number of animals serviced, which may be beneficial if bull:cow ratios are decreased (Chenoweth, 1997). Bulls that are able to successfully service more females are also beneficial when cows have previously been exposed to estrous synchronization and FTAI because the majority of nonpregnant cows will return to estrus in a 3-d window (Larson et al., 2009). Continual selection of bulls with high reproductive capacity can ensure breeding success after decreasing bull:cow ratios. Scrotal circumference is one such trait to select for, as it is a moderately heritable trait and positively correlated with semen output and semen quality (Brito, 2015). Yearly breeding soundness exams for producers using only one bull are highly

recommended for maintaining good pregnancy rates, especially if choosing increase the number of females exposed. While all bulls used underwent a breeding soundness exam to be diagnosed as fertile, there may have been a larger variation in bull libido and fertility in the fall, explaining our observed significant negative correlation in fall single sire groups, but no influence of single or multiple sire settings in the spring. Unfortunately, we did not have much data on individual bulls to truly examine what bull related factors impact pregnancy rates.

Other factors apart from the bull can also influence variation in pregnancy success in beef cattle herds. As we observed, season had an influence with fall herds having increased pregnancy rates. Fall-calving systems produce more fertile cows as demonstrated by increased calving rates, decreased calving intervals, and increased pregnancy rates (King and Macleod, 1984; Caldwell et al., 2013; Campbell et al., 2013). Seasonal heat stress can affect female and male fertility, and it may be playing a role in the observed seasonal differences in pregnancy rates, especially since the decreased pregnancy rates are observed later in the breeding season (Collier et al., 2017; Wolfenson and Roth, 2019). Removal of bulls from pastures with cows for fall breeding typically occurs between March and April, while bulls are removed from cows during late July and August for spring breeding. Condition of animals entering the breeding season likely also contributes to our observed increase in fall pregnancy rates. Body condition score is an important factor influencing conception rates, and cows with a BCS greater than 5, assessed preceding synchronization, achieve higher pregnancy rates to FTAI than cows with a score less than or equal to 5 (Stevenson et al., 2015). In the current study, fall cows had a significantly greater BCS prior to synchronization compared to cows in the spring breeding groups (5.85 ± 0.04 vs. 5.19 ± 0.05; $P < 0.01$). Caldwell et al. also noted, in agreement with our results, increased body condition scores of fall calving animals (Caldwell et al., 2013). Body condition score at parturition also influences pregnancy rates in the succeeding season (Spitzer et al., 1995). Fall breeding cows in this study typical calve around October and likely have improved BCS at parturition compared to spring breeding cows which calve in February.

Decreasing the bull:cow ratio may not be feasible for every producer. With roughly 80% of beef operations managing less than 50 head (USDA, 2019), many cattlemen are likely using a single bull during the breeding season. In this scenario, some beef operations may benefit from using only FTAI and eliminating natural service entirely. Implementing FTAI and decreasing the bull:cow ratio reduces breeding costs per cow (Rodgers et al., 2012), and may provide an opportunity for cattlemen to either invest in FTAI or purchase a more expensive bull with greater genetic merit. Interestingly, we observed that average pregnancy rates to FTAI were greater than average pregnancy rates to natural service on first return to estrus (54.9 ± 0.6 % vs. 51.3 ± 0.9%). Our results indicate the sole use of a FTAI system with multiple inseminations may be more economically feasible than maintaining a bull for smaller beef cow-calf operations. In the United States, 54% of beef cattle operations own less than 20 head (USDA, 2019). Assuming FTAI costs at $33.19 (Rodgers et al., 2012), 50% pregnancy rates, and a herd of 20 head undergoing four rounds of FTAI, cost of breeding alone would reach $1,226.92; nearly half of a bull's purchase value (Rodgers et al., 2012).

Pessoa and colleagues examined reproductive efficiency of beef cattle having undergone resynchronization protocols followed by a second round of FTAI and noted increased pregnancy rates by d 60 of the breeding season compared to animals exposed to one round of FTAI and then natural service (Pessoa et al., 2018). Crepaldi and colleagues took this one step further and compared three consecutive rounds of FTAI, 2 rounds of FTAI plus natural service, and 1 round of FTAI plus natural service. They achieved overall pregnancy rates of 87% in a 64-d breeding season, and observed similar pregnancy rates between the three rounds of FTAI and two rounds plus natural service, both of which yielded greater pregnancy rates than one round of FTAI plus natural service (Crepaldi et al., 2017). These studies demonstrate that it may be possible to entirely eliminate natural service sires from beef cattle production systems. Furthermore, even with only two rounds of FTAI, there is a significant increase in the number pregnancies occurring earlier in the breeding season, allowing for the breeding season to be shortened dramatically and helping to contribute to the economic benefits of FTAI (Holm et al., 2008; Rodgers et al., 2012). More studies need to be conducted to evaluate the feasibility of these in U.S. production systems, especially since estradiol, used in both studies, is not approved for use in estrous synchronization of cattle. The downside of resynchronization followed by FTAI is that it requires early pregnancy diagnosis which will incur more costs, in addition to more synchronization drugs. A more in-depth economic analysis is needed to determine if the economic gains can outweigh

the costs; however, for small herds, eliminating the bull entirely may be profitable.

This retrospective study aimed to determine if the bull:cow ratio affects pregnancy success after estrous synchronization and FTAI in beef cattle. Decreasing the bull:cow ratio had a negative correlation with pregnancy rates, but only a small portion of the observed variation (1–4% for bull to total number of cow ratio, 1–11% of variation for bull to open cow ratio) can be attributed to the bull:cow ratio. As seen in our data, bull:cow ratios remained similar to the 1:30 recommendation, yet after FTAI, the number of open cows that need servicing is reduced by half. Therefore, we recommend that a bull:cow ratio of at least 1:50 be used when implementing estrous synchronization and FTAI in combination with natural service. Decreasing the bull:cow ratio may help alleviate bull related costs by reducing the number of bulls needed, thus helping to alleviate the economic burden with estrous synchronization and FTAI. This in turn will help encourage adoption of FTAI protocols in the U.S. beef industry.

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