Profitability of dairy cows submitted to the first service with the Presynch-Ovsynch or Double-Ovsynch protocol and different duration of the voluntary waiting period

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ABSTRACT

The objective of this study was to compare cash flow and parameters of economic performance for dairy cows submitted to the first service using a combination of insemination at detected estrus and timed AI (TAI) in cows synchronized with the Presynch-Ovsynch (PSOv) protocol versus all TAI after synchronization of ovulation with the Double-Ovsynch (DO) protocol with different durations of the voluntary waiting period. A secondary objective was to calculate the variation in cash flow under different input pricing scenarios through stochastic Monte Carlo simulation. Lactating Holstein cows from a commercial dairy farm were randomly assigned to 3 first-service management programs. Cows in the PSOv treatment ($n = 450$) received first service through a combination of insemination at detected estrus after a voluntary waiting period of 50 d in milk (DIM; i.e., after second PGF_{2α} treatment of the protocol) and TAI at 72 ± 3 DIM. Cows in the DO60 ($n = 458$) and DO88 ($n = 462$) treatments received first service by TAI at 60 ± 3 and 88 ± 3 DIM, respectively. Individual cow cash flow was calculated for the calving interval after enrollment and for an 18-mo period after calving. Cash flow was the aggregation of daily income over feed cost, replacement cost, calf value, recombinant bovine somatotropin treatment cost, reproductive cost, and other operating expenses. All analyses were conducted separately for primiparous and multiparous cows. Continuous, binomial, and time to event outcomes were analyzed using ANOVA, logistic regression, and Cox's proportional hazard regression in SAS (SAS Institute Inc., Cary, NC). Treatments affected the dynamics of pregnancy creation, which affected time to pregnancy during lactation. As a result, we observed differences in the proportion of nonpregnant cows at the end of lactation, herd exit dynamics, lactation length,

calving interval, and proportion of cows that calved again. Some of these effects varied by parity, affecting the direction and magnitude of treatment differences within parity group. For primiparous cows, maximum cash flow differences per slot for the 18-mo period were in the range of \$26 (PSOv > DO60) to \$29 (DO88 > DO60) but did not differ statistically. For multiparous cows, maximum cash flow differences per slot for the 18-mo period were in the range of \$122 (PSOv > DO88) to \$155 (DO60 > DO88) but did not differ statistically. Despite the substantial differences in cash flow (in particular for multiparous cows) caused by the effect of treatments on reproductive performance, herd exit dynamics, and calving interval, large variability in overall cash flow among individual cows and compensation between multiple outcomes resulted in lack of statistical differences in cash flow. Outcomes from the stochastic analysis indicated that similar trends for differences between treatments would be observed under varying scenarios for economic input values. In conclusion, we did not detect statistically significant cash flow differences between the PSOv, DO60, and DO88 treatments, but numerical trends and stochastic simulation indicated that the DO88 and PSOv treatments were more economically favorable than the DO60 treatment for primiparous cows. For multiparous cows, the DO60 and PSOv treatments were more economically favorable than the DO88 treatment.

Key words: Presynch-Ovsynch, Double-Ovsynch, voluntary waiting period, cash flow, dairy cow

INTRODUCTION

Effective strategies for submitting cows for first service are a critical component of successful reproductive management programs for lactating dairy cows. Submission of all cows to timed AI (TAI) after synchronization of ovulation or a combination of insemination at detected estrus (EDAI) and TAI are 2 common strategies used by dairy farms (Caraviello et al., 2006; Ferguson and Skidmore, 2013). All-TAI programs can be beneficial because they reduce the

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variation and number of days to the first service regardless of the ability of cows to display estrus and the farm's estrus detection efficiency. In addition, fertility programs such as Double-Ovsynch (**DO**; Souza et al., 2008), G-6-G (Bello et al., 2006), or Presynch-Ovsynch (**PSOv**; Moreira et al., 2001) increase pregnancy per AI (**P/AI**) compared with Ovsynch alone (Moreira et al., 2001; El-Zarkouny et al., 2004; Navanukraw et al., 2004) and may result in greater **P/AI** than EDAI services (Santos et al., 2017). Ultimately, a substantial proportion of cows eligible for pregnancy conceive at first service within a narrow range of DIM. Conversely, programs that combine EDAI and TAI through the use of synchronization of estrus and ovulation protocols (e.g., **PSOv**) result in a greater range of DIM to the first service and are more dependent on the ability of cows to display estrus and the farm's estrus detection efficiency. These programs are, however, appealing to many dairy farms that for various reasons prefer or need to submit cows for insemination through EDAI and reduce reliance on TAI. Indeed, combining EDAI and TAI through the use of the **PSOv** protocol is a widely adopted strategy in North American dairy herds (Caraviello et al., 2006; Ferguson and Skidmore, 2013).

In addition to designing a program to submit cows for the first service, dairy managers need to determine the duration of the voluntary waiting period (**VWP**). For lactating dairy cows, manipulating the duration of the **VWP** can have profound effects on their physiological status before first service as well as their reproductive and productive performance (Gobikrushanth et al., 2014; Stangaferro et al., 2018a, c). Through its influence on timing of pregnancy during lactation, the duration of the **VWP** also has direct consequences on the herd exit dynamics (Gobikrushanth et al., 2014; Stangaferro et al., 2018b). Ultimately, the combination of these effects leads to myriad interactions that affect the profitability of dairy herds (Arbel et al., 2001; Gobikrushanth et al., 2014; Stangaferro et al., 2018b).

In a recent experiment (Stangaferro et al., 2018a), we reported the reproductive performance and replacement dynamics of lactating dairy cows submitted to the first service using a combination of EDAI and TAI with the **PSOv** protocol and a **VWP** of 50 DIM versus all TAI after the **DO** protocol and **VWP** of 60 or 88 DIM. The effects of these reproductive management strategies on herd performance were characterized by complex interactions between the pattern of insemination and **P/AI** with the herd replacement dynamics and milk production performance. Moreover, primiparous and multiparous cows presented different responses for some of the outcomes evaluated. Although observations from this experiment may guide decisions about the type of first-service management strategy and **VWP**

duration that may benefit reproductive performance of lactating dairy cows, ultimately the choice of program should be based on expected herd profitability.

Thus, the main objective of this study was to compare cash flow and parameters of economic performance for cows enrolled in the experiment reported in Stangaferro et al. (2018a). Specifically, our objective was to analyze individual cow cash flow for the calving interval after enrollment and for a fixed period of time (18 mo) after calving in the experimental lactation. A secondary objective was to calculate the variation in cash flow under different input pricing scenarios through stochastic Monte Carlo simulation.

MATERIALS AND METHODS

Animals and Experimental Procedures

The Animal Care and Use Committee of Cornell University (Ithaca, NY) approved all procedures performed with cows. This experiment was conducted in a commercial farm in New York State following a complete randomized block design with parity (i.e., primiparous vs. multiparous) as the blocking factor. Detailed information about animals, management, and experimental procedures is reported in Stangaferro et al. (2018a). During the experiment conducted from March 2014 to August 2016, cows were commingled in freestall barns with 6 rows of stalls, concrete flooring, fans and sprinklers in the feedline, and self-locking headgates in the feedline. During the experiment, the average number of milking cows was 1,417, and 305-d milk yield was 11,065 kg. Cows were milked 3 times daily at approximately 8-h intervals and supplemented with recombinant bovine somatotropin (**rbST**; sometribove zinc, Posilac, Elanco Animal Health, Indianapolis, IN) following a 10- and 11-d schedule beginning at 110 DIM until dry-off.

At 7 ± 3 DIM, cows ($n = 1,370$) were blocked by parity and stratified based on milk production in the previous lactation (multiparous cows only) and then randomly allocated to receive first service with one of the following treatments: (1) TAI after the **DO** protocol (GnRH, 7 d later PGF_{2 α} , 3 d later GnRH, 7 d later GnRH, 7 d later PGF_{2 α} , 56 h later GnRH, and 16 to 18 h later TAI) at 60 ± 3 DIM (**DO60**; $n = 458$), (2) TAI after the **DO** protocol at 88 ± 3 DIM (**DO88**; $n = 462$), or (3) a combination of EDAI or TAI with the **PSOv** protocol ($n = 450$; PGF_{2 α} , 14 d later PGF_{2 α} , 12 d later GnRH, 7 d later PGF_{2 α} , 56 h later GnRH, and 16 to 18 h later TAI). For the **PSOv** treatment, cows underwent EDAI if detected in estrus after the second PGF_{2 α} treatment of the Presynch portion of the protocol given at 50 ± 3 DIM. Cows not detected in

estrus completed the Ovsynch portion of the protocol and received TAI at 72 ± 3 DIM. Estrus detection was conducted by farm personnel using a combination of visual observation and physical activity monitoring using neck-mounted physical activity monitoring tags (DeLaval Activity Meter System, DeLaval International AB, Tumba, Sweden).

Cows received second and subsequent AI services after detected estrus any time after a previous insemination. Cows not reinseminated at detected estrus 32 ± 3 d after AI received the d 32 Resynch protocol (GnRH, 7 d later PGF_{2α}, 56 h later GnRH, 16 to 18 h later TAI) for resynchronization of ovulation and TAI 42 ± 3 d after their previous insemination.

Exclusion criteria for this experiment included (1) cows that left the herd due to sale or death from 7 to 30 DIM and (2) first AI outside the DIM range specified for their respective treatment. Sixty-eight cows (DO60, $n = 22$; DO88, $n = 33$; PSov, $n = 13$) were removed from the study because they met the exclusion criteria. Therefore, the total number of cows with data available for each treatment was 436 for DO60, 429 for DO88, and 437 for PSov.

Individual cow data for milk production (i.e., monthly test-day milk), reproductive events (calving, insemination, pregnancy testing, abortion), and culling (i.e., sale or death) for 18 mo after calving in the experimental lactation (i.e., lactation in which cows received treatments) were collected from the dairy herd management software (DairyComp305, ValleyAg Software, Tulare, CA) using custom-built commands to retrieve the information of interest. For cows that completed the experimental lactation before the end of the 18-mo study period, data for the dry period and subsequent lactation were also collected to have data available for a total of 18 mo after calving in the experimental lactation.

Estimation of Individual Cow Inputs

Milk and FCM Production. The MilkBot model (Ehrlich, 2013) was used to calculate daily milk production for the experimental and subsequent lactations (if present in the 18-mo study period) for each cow enrolled in the experiment as described in Stangaferro et al. (2018b). Briefly, this nonlinear lactation prediction model used monthly milk test data retrieved from DHIA tests to estimate the lactation curve based on 4 MilkBot parameters: scale, ramp, offset, and decay. Details about Milkbot parameters and daily milk yield calculations have been previously described (Ehrlich, 2013).

Individual daily FCM yield, needed for DMI estimation, was calculated based on daily milk yield data (retrieved from the MilkBot model) and monthly milk fat percentage data (from DHIA tests) as follows:

$$\text{FCM (kg/d)} = 0.4 - \text{DMW} + 0.15 \times \text{fat \%} \times \text{DMW},$$

where DMW = daily milk weight (kg/d) estimated by the MilkBot model and fat % = fat percentage in milk reported by the DHIA in monthly tests. Because daily milk fat percentage data were not available and could not be estimated with MilkBot, data for a specific test were repeated each day for a 30-d period (e.g., first test from 1 to 30 DIM, second test from 61 to 90 DIM, and so on).

BW. Individual daily BW was calculated using the following equation (Van Arendonk, 1985):

$$\begin{aligned} \text{BW (kg)} = & A \times \{1 - [1 - (B/A)^{1/3}] \\ & \times \exp(-C \times \text{age})\}^3 - (P1/P2) \times \text{DIM} \\ & \times \exp(1 - \text{DIM}/P2) + P3^3 \times \text{DPC}^3, \end{aligned}$$

where age = cow age in days; A = mature live weight (kg); B = birth weight (kg); C = growth rate; P1 = maximum decrease in live weight during lactation; P2 = time during lactation with minimum live weight; P3 = pregnancy parameter; and DPC = number of days after conception minus 50 (being 0 for the first 50 d of gestation). Mature live weight and birth weight used were fixed at 723 and 40 kg, respectively (Stangaferro et al., 2018b). Parameters C, P1, P2, and P3 were 0.004, 30, 60, and 0.0187 for primiparous cows and 0.006, 50, 80, and 0.0187 for multiparous cows based on Kalantari et al. (2010).

DMI. Individual DMI was estimated daily for the 18-mo period (experimental and subsequent lactation) using NRC (2001) equations. During lactation, DMI was calculated based on FCM, BW, and week of lactation (DIM/7) using the following equation:

$$\begin{aligned} \text{DMI (kg/d)} = & 0.372 \times \text{FCM} + 0.0968 \times \text{BW}^{0.75} \\ & \times \{1 - \exp[-0.192 \times (\text{DIM}/7 + 3.67)]\}. \end{aligned}$$

On the other hand, daily DMI during the dry period was estimated as a percentage of BW, which was calculated as follows:

$$\text{DMI (\% of BW)} = 1.97 - 0.75 \times \exp^{0.16 \times t},$$

where t = days pregnant minus 280.

Input Prices

Price selection for different inputs of the economic analysis are described in detail in Stangaferro et al. (2018b) and represent the economic conditions of the New York State dairy industry from March 2014 to August 2016 (experimental period). Briefly, milk price was set at \$0.41/kg (\$18.53/hundredweight) based on the average monthly price reported by the Dairy Market Watch report (Cornell Cooperative Extension of Chautauqua County, 2017) from March 2014 to August 2016. Feed cost was \$0.29 and \$0.22/kg of DM for a lactating and a close-up cow diet, respectively, based on data from the New York Farm Dairy Farm Business Summary from 2014 to 2015 (Knoblauch et al., 2015, 2016). Calf price was \$170 for females (Progressive Dairyman, 2017), \$85 for males (i.e., half of the female value), \$0 for stillborn calves, and \$85 per calf in male–female twins assuming that females were freemartins. For replacement costs calculations, market price during the study period for a replacement heifer was \$1,925 (USDA Economic Research Service, 2017) and beef price for cows sold was \$1.32/kg based on the average price for “good” and “lean” culled cows during the study period (Empire Livestock Marketing, 2017).

Prices required to calculate reproductive program implementation cost included hormones, semen, labor, and pregnancy testing. For hormones, GnRH and PGF were set at \$1.60 and \$2.10/dose, respectively, based on the market value of 2 commercially available products in New York State. Semen price was set at \$10/dose. Labor cost was set at \$0.25/injection (assuming 60 injections/h) and \$1/insemination (assuming 15 inseminations/h) based on a labor cost of \$15/h. Estrus detection cost was set at \$0.028/cow per day based on 2 h of detection/day (\$15/h for labor) divided by the number of cows in the herd. Pregnancy testing was set at \$2.75/examination based on a veterinary cost of \$110/h and 40 cows tested/h. Cost of rbST supplementation was set at \$7/dose (Posilac, Elanco Animal Health) and the labor cost needed to apply the treatments (\$0.25/injection, assuming 60 injections/h and \$15/h of labor).

Other operating expenses were set at \$3/cow per day and included the following items: hired labor, professional nutritional services, machine repairs, rent and lease, fuel, oil and grease, veterinary and medicine, milk marketing, bedding, milking supplies, utilities, and other professional fees. This fixed cost was calculated based on data from accrual operating costs reported in the Dairy Farm Business Summary from 2014 to 2015 (Knoblauch et al., 2015, 2016).

Economic Analyses

Two economic analyses were performed for this study: (1) cash flow per cow for the experimental lactation (i.e., the lactation in which the experimental treatments were applied) and subsequent dry period if the cow completed the lactation, and (2) cash flow per slot (i.e., unit of space at the dairy) for each cow enrolled in the experiment for 18 mo after calving in the experimental lactation. The first analysis represented the calving interval if cows calved again or the period until they left the herd. The second analysis (i.e., per slot) was designed to represent the dynamics of a commercial dairy herd during an 18-mo period, whereby every cow that left the herd was immediately replaced by a first-lactation animal to keep herd size constant (i.e., every slot—stall or unit of space—was filled during the entire study period). First-lactation replacement cows were randomly selected from the data set for the same treatment group in the experiment so that the slot remained occupied with a representative cow (i.e., managed under similar conditions and under similar environmental conditions as during the experiment). The aim of this analysis was to compare the effect of treatments for a fixed period of time, and the choice of 18 mo was to provide sufficient time for cows to complete their experimental lactation and dry period and generate cash flow data for up to approximately 150 DIM for the subsequent lactation.

Milk Income Over Feed Cost. Daily milk income over feed cost (**IOFC**) was estimated by subtracting feed cost (i.e., DMI kg $\times$ DM cost/kg) from milk revenue (i.e., milk volume kg $\times$ milk price/kg) during lactation and the dry period (milk revenue = \$0).

Calf Value. All cows that became pregnant and started a new lactation generated a one-time revenue when the calf was born. Calf value was based on market value of calves by sex (\$0 for calves born dead).

Replacement Cost. Cows that left the herd due to death or sale generated an expense based on the assumption that a replacement heifer replaced the cow immediately. Therefore, the replacement cost was equal to the market value of a replacement heifer minus the salvage value of the cow sold for beef (\$0 if the cow left the herd due to death) and the value of the calf born from the replacement. The salvage value for cows sold was calculated based on their estimated BW on the date of sale times the average beef price. The value of the calf born from a replacement heifer was set at \$123/calf to represent the average calf value for first-lactation cows enrolled in this experiment (accounting for male, female, stillborn, and twins).

Reproductive Cost. The cost of each AI (cost of hormonal treatments, semen, and labor), pregnancy testing (cost added every time a cow was tested for up to 2 times), and estrus detection was calculated for each cow enrolled in the experiment based on records retrieved from the dairy herd management software. Reproductive cost was calculated for the experimental calving interval and for the 18-mo period after calving in the experimental lactation (i.e., included cost during the experimental lactation and subsequent lactation).

rbST Supplementation. The number of rbST treatments that each cow received during the experiment was calculated for the experimental lactation and for the 18-mo period after calving in the experimental lactation based on the DIM at start of rbST treatment, lactation length, and interval between treatments (10- and 11-d schedule beginning at 110 DIM until dry-off). Accordingly, the cost of rbST supplementation was estimated for each cow by multiplying the total number of rbST treatments by the cost per treatment (including hormone and labor cost).

Other Operating Expenses. Other operating expenses were calculated for each cow based on the individual cow daily expense (\$3/d) multiplied by the number of days in lactation and dry period for the experimental lactation and by 540 d for the calculations per slot per 18 mo.

Cash Flow. Total cash flow and cash flow per day of calving interval or per day of the 18-mo period after calving were the main outcomes of the economic analysis. They were estimated for each cow and for each slot using the following equation:

$$\text{Cash flow} = \text{daily IOFC} + \text{calf value} - \text{replac} \\ - \text{repro} - \text{rbST} - \text{OE},$$

where replac = cost of replacing cows that left the herd due to sale or death; repro = cost of applying the reproductive management program; rbST = cost of rbST supplementation; and OE = operating expenses.

Stochastic Analysis Under Varying Market Conditions

Differences between treatments in cash flow for the 18-mo period (DO88 vs. DO60, DO88 vs. PSOv, and DO60 vs. PSOv) under varying market conditions for the most relevant input costs were evaluated through stochastic Monte Carlo simulation models using @Risk version 7.5 (Palisade Corp., Ithaca, NY). To build the models (one for primiparous and one for multiparous cows), production, reproduction, and herd exit dynamics data were used as fixed inputs (Supplemental Table

S1, <https://doi.org/10.3168/jds.2018-15567>). Thereafter, variation for every iteration of the simulation (stochasticity) was introduced for milk price, feed costs, reproductive costs (cost for a first TAI service and cost of second and greater services at detected estrus or TAI), price of a replacement heifer, calf value, beef price, and rbST cost (Supplemental Table S2, <https://doi.org/10.3168/jds.2018-15567>). Prices were calculated based on data from 2010 to 2017 for milk price (USDA Agricultural Marketing Service, 2017), feed cost (Gould, 2017b), beef price (Gould, 2017a), and the price for replacement heifers (USDA Economic Research Service, 2017). Stochasticity for the rest of the inputs (calf value, reproductive cost, and rbST price) was generated using a pert distribution with the average price calculated for this study as the most likely value and a 15% reduction or increment as minimum and maximum values, respectively. For example, the price for rbST was \$7/dose (most likely), with minimum and maximum values of \$6.0 and \$8.1, respectively. Distributions used for variables with historical data available were fitted using the BestFit function of @Risk. This function selects the best distribution based on the lowest value for the Akaike information criteria. Milk price was fitted with a beta distribution, feed costs (lactating and dry) with uniform distributions, and beef price and the price of a replacement heifer with triangular distributions. Conversely, calf value, reproductive cost, and rbST price were fitted with a pert distribution to emphasize the most likely value over minimum and maximum values (McArt and Oetzel, 2015). Values for the parameters used for each distribution are presented in Supplemental Table S2 (<https://doi.org/10.3168/jds.2018-15567>).

Statistical Analyses

Parity groups (primiparous and multiparous cows) were analyzed separately because of the well-described and expected differences in performance and profitability between primiparous and multiparous cows. Binary outcomes were analyzed with logistic regression using PROC GLIMMIX of SAS (version 9.4, SAS Institute Inc., Cary, NC). Generalized linear regression models using PROC MIXED of SAS were used for continuous outcomes. Time to event data (time to pregnancy and time to herd exit) was analyzed with Cox's proportional hazards models using PROC PHREG of SAS. The period at risk for pregnancy and herd exit for the calving interval of the experimental lactation was 350 DIM. For the analysis of time to pregnancy, cows had to maintain pregnancy up to 150 d of gestation to be considered pregnant.

Treatment (first-service management strategy: DO60, DO88, and PSOv) was forced in all models as a

fixed effect variable. For P/AI at first service, models were offered the effect of season at first service (cold: September 21 to June 20; warm: June 21 to September 20) and the treatment $\times$ season interaction (results presented in Stangaferro et al., 2018a). For reproductive performance and herd exit dynamics outcomes, the effect of milk yield accumulated up to 30 DIM (low, medium, and high based on tertiles from observed data) and the interaction of treatment $\times$ milk yield accumulated up to 30 DIM were offered to models (data in Stangaferro et al., 2018a). For the analysis of data that affected economic outcomes (milk production, DMI, all incomes and expenses, and cash flow), the effect of treatment and season of calving (cold: September 21 to June 20; warm: June 21 to September 20) was offered to the models.

Goodness of fit for statistical models was evaluated to test for overdispersion in all logistic regression models. The assumptions of normality and homoscedasticity of variance for linear regression models were evaluated with normal probability plots (normal quantile-quantile plot) and plots of residuals versus predicted values. To test the proportional hazard assumption for time to event data, graphical depiction of the $\log[-\log(\text{survival probability})]$ function obtained from PROC LIFETEST of SAS was evaluated. The final model for each outcome of interest was selected by backward elimination of explanatory variables with $P > 0.10$ and determination of the lowest value for the Akaike information criteria. When appropriate, the least significant different (LSD) post hoc mean separation test was used to determine differences between least squares means.

All proportions reported were generated using the FREQ procedure of SAS, whereas quantitative outcomes were reported as least squares means $\pm$ standard error of the mean. All explanatory variables and their interactions were considered significant if $P \leq 0.05$, and P -values >0.05 and ≤ 0.10 were considered a tendency.

RESULTS

Reproductive Outcomes and Culling Dynamics in the Experimental Lactation

The effect of first-service management strategy on reproductive performance and herd exit dynamics during the experimental lactation is presented in Table 1. Pregnancy per AI at first or second and subsequent AI services did not differ ($P > 0.10$). For primiparous cows, the hazard of pregnancy after calving was affected by treatment ($P < 0.01$), whereby cows in the DO60 and PSOv treatments had greater hazard of pregnancy than cows in the DO88 treatment. No difference was observed between the DO60 and the PSOv treatments (hazard

ratio: 1.10, 95% CI: 0.88–1.38). Additionally, the proportion of nonpregnant primiparous cows at 350 DIM did not differ ($P = 0.16$). For multiparous cows, time to pregnancy was also affected by treatment ($P < 0.01$), whereby cows in the DO60 and PSOv treatments had greater hazard of pregnancy after calving than cows in DO88. Conversely, the hazard of pregnancy was similar for cows in the DO60 and PSOv treatments (hazard ratio: 1.13, 95% CI: 0.93–1.37). At 350 DIM, a greater ($P = 0.04$) proportion of cows were nonpregnant in the DO88 than the DO60 treatment. The proportion of nonpregnant cows in the PSOv treatment did not differ from that in the DO60 and DO88 treatments.

The hazard of exiting the herd was similar ($P = 0.22$) between treatments for primiparous cows. On the other hand, there was an effect of treatment ($P = 0.02$) for multiparous cows, whereby cows in DO60 had reduced hazard of exiting the herd compared with cows in the DO88 and PSOv treatments (DO60 vs. DO88 in Table 1; PSOv vs. DO60, hazard ratio: 1.39, 95% CI: 1.03–1.85). No difference was observed between the PSOv and DO88 treatments (Table 1). The total proportion of cows that left the herd during the experiment (sold and died) was similar for the primiparous cow group ($P = 0.36$), but it was greater for the DO88 than the DO60 treatment within the multiparous cow group. The total proportion of cows that exited the herd was intermediate for the PSOv treatment. These differences in the total proportion of cows that left the herd for multiparous cows were mostly due to differences in the proportion of cows sold. A similar ($P = 0.65$) proportion across treatments was sold for the primiparous group, but for the multiparous group it was greater ($P = 0.04$) for DO88 than DO60. No differences were observed for PSOv and the other 2 treatments. The proportion of cows that died did not differ for primiparous ($P = 0.31$) or multiparous ($P = 0.20$) cows.

Lactation length for all cows (i.e., cows that completed the experimental lactation and cows that left the herd) was greater ($P = 0.01$) for primiparous cows in the DO88 treatment than for those in the DO60 and PSOv treatments, but it was similar between treatments for multiparous cows ($P = 0.43$). When including only cows that completed the experimental lactation, lactation length was longer ($P < 0.01$) for DO88 than for the other 2 treatments in both the primiparous and multiparous group. No differences were observed for dry period duration for primiparous ($P = 0.33$) and multiparous ($P = 0.40$) cows.

For both parity groups, calving interval was affected by treatment ($P < 0.01$), whereby cows in the DO88 treatment had longer calving interval than cows in the DO60 and PSOv treatments. In contrast, treatment affected ($P = 0.02$) the proportion of cows that calved af-

Table 1. Effect of first-service management strategy on reproductive performance and herd exit dynamics during the experimental lactation

Item	Primiparous				Multiparous			
	DO60 ¹ (n = 168)	DO88 ² (n = 166)	PSOv ³ (n = 168)	P-value	DO60 (n = 268)	DO88 (n = 263)	PSOv (n = 269)	P-value
P/AI ⁴ first service, % (no./no.)	48.8 (79/162)	54.5 (85/156)	46.6 (76/163)	0.38	37.4 (95/254)	37.3 (90/241)	31.0 (78/252)	0.14
P/AI second and greater AI, % (no./no.)	42.5 (76/179)	35.1 (65/185)	37.7 (75/199)	0.27	29.4 (131/445)	25.7 (105/409)	30.0 (134/447)	0.32
Time to pregnancy after calving								
Hazard ratio (95% CI)	1.50 (1.19–1.89)	Referent	1.37 (1.09–1.72)	<0.01	1.55 (1.27–1.89)	Referent	1.37 (1.14–1.69)	<0.01
Mean, d	105	130	108		133	163	136	
Median, d	81	91	80		102	130	112	
Not pregnant at 350 DIM, % (no./no.)	4.8 (8/168)	3.0 (5/166)	7.7 (13/168)	0.16	10.4 ^a (28/268)	18.6 ^b (49/263)	14.1 ^{ab} (38/269)	0.04
Herd exit dynamics ⁵								
Hazard ratio	1.12 (0.64–1.96)	Referent	1.56 (0.92–2.63)	0.22	0.67 (0.50–0.90)	Referent	0.93 (0.71–1.22)	0.02
Mean, d	318	328	323		299	294	290	
Median, d	—	—	—		—	—	—	
Exited the herd, % (no./no.)	16.1 (27/168)	13.8 (23/166)	19.6 (33/168)	0.36	29.1 ^a (78/268)	40.3 ^b (106/263)	36.8 ^{ab} (99/269)	0.02
Sold, % (no./no.)	14.3 (24/168)	12.1 (20/166)	15.5 (26/168)	0.65	26.9 ^a (72/268)	37.3 ^b (98/263)	31.6 ^{ab} (85/269)	0.04
Died, % (no./no.)	1.8 (3/168)	1.8 (3/166)	4.2 (7/168)	0.31	2.2 (6/268)	2.7 (7/263)	4.8 (13/269)	0.20
Lactation length								
All cows, d	298.9 ± 6.8 ^a	325.5 ± 6.9 ^b	304.4 ± 6.8 ^a	0.01	289.4 ± 5.4	291.1 ± 5.5	281.5 ± 5.4	0.43
Not culled, d	311.3 ± 3.9 ^a	335.2 ± 4.0 ^b	315.2 ± 4.0 ^a	<0.01	311.8 ± 3.4 ^a	332.9 ± 3.8 ^b	315.4 ± 3.6 ^a	<0.01
Days dry, d	58.8 ± 1.2	58.1 ± 1.2	56.3 ± 1.2	0.33	61.6 ± 1.4	63.8 ± 1.6	61.0 ± 1.5	0.40
Calving interval, d	370.1 ± 4.1 ^a	392.9 ± 4.2 ^b	371.3 ± 4.2 ^a	<0.01	372.9 ± 3.6 ^a	395.4 ± 4.0 ^b	376.3 ± 3.8 ^a	<0.01
Cows calved again, % (no./no.)	79.8 (134/168)	77.7 (129/166)	76.2 (128/168)	0.52	63.1 ^a (169/268)	51.3 ^b (135/263)	55.8 ^{ab} (150/269)	0.02

^{a,b}Different letters indicate a significant difference between LSM based on the least significant difference (LSD) post-hoc mean separation test.

¹DO60 = first service by timed AI at 60 ± 3 DIM after the Double-Ovsynch protocol.

²DO88 = first service by timed AI at 88 ± 3 DIM after the Double-Ovsynch protocol.

³PSOv = first service at detected estrus after the second PCF_{2a} treatment of Presynch-Ovsynch given at 50 ± 3 DIM or by timed AI at 72 ± 3 DIM after completion of the Presynch-Ovsynch protocol.

⁴P/AI = pregnancies per AI.

⁵Time to herd exit = time (d) from calving until herd exit because of sale or death.

⁶Not culled = cows that did not leave the herd from calving until dry-off in the experimental lactation.

ter the experimental lactation in the multiparous group only, whereby more cows calved again in the DO60 treatment than in the DO88 treatment, and the PSOv treatment was intermediate (i.e., similar to DO60 and DO88).

Production Performance and Economic Analysis for the Experimental Lactation

The effect of first-service management strategy on milk production and income, DMI, and feed cost during the experimental lactation is presented in Table 2. For the primiparous group, cows in DO88 had greater ($P = 0.02$) total milk yield and income than cows in the DO60 treatment, but no differences were observed between the PSOv and DO60 treatments and the PSOv and DO88 treatments. Total DMI and total feed cost during the milking period were greater ($P = 0.01$) for cows in the DO88 treatment than in the DO60 and PSOv treatments but were similar for DO60 and PSOv. Additionally, a tendency for a treatment effect was observed for daily milk yield and income ($P = 0.09$), daily DMI and feed cost during the milking period ($P = 0.10$), and total DMI and feed cost during the dry period ($P = 0.10$) for primiparous cows. For multiparous cows, there was no effect of treatment ($P > 0.10$) on milk production and income, DMI, and feed cost during the lactation and dry periods except for daily DMI and feed cost during the dry period ($P < 0.04$). There was an effect of calving season on milk production for multiparous cows. Cows that calved during the warm season had lower ($P = 0.03$) daily milk yield (warm: 38.8 ± 0.4 kg/d; cold: 39.8 ± 0.3 kg/d) and daily milk income (warm: $\$15.9 \pm 0.2$ /d; cold: $\$16.3 \pm 0.1$ /d) than cows that calved during the cold season.

The effect of first-service management strategy on revenues and expenses during the experimental lactation is presented in Table 3. For the primiparous group, cows in DO88 had greater ($P = 0.04$) IOFC than cows in the DO60 treatment, but similar IOFC was observed between PSOv and the other treatments. Moreover, rbST cost ($P < 0.01$) and operating expenses ($P = 0.02$) were greater for the DO88 treatment than for the DO60 and the PSOv treatments. Accordingly, cows in the DO88 treatment received more ($P < 0.01$) rbST injections (20.8 ± 0.6) than cows in the DO60 (18.1 ± 0.6) and PSOv (18.5 ± 0.6) treatments. No treatment effect was observed for calf value ($P = 0.96$), replacement costs ($P = 0.56$), reproductive costs ($P = 0.18$), cash flow ($P = 0.38$), and cash flow per day of calving interval ($P = 0.42$).

For the multiparous group, cows in DO88 and PSOv had greater ($P = 0.02$) replacement costs than cows in

the DO60 treatment. There was also a tendency ($P = 0.06$) for a treatment effect on reproductive costs. No difference was observed for IOFC ($P = 0.76$), calf value ($P = 0.14$), rbST cost ($P = 0.40$), operating expenses ($P = 0.39$), cash flow ($P = 0.61$), and cash flow per day of calving interval ($P = 0.48$). Furthermore, season of calving affected some economic outcomes during the experimental lactation. Multiparous cows that calved during the cold season had lower calf value ($P = 0.02$; cold: $\$66.2 \pm 6.1$ /cow; warm: $\$78.5 \pm 6.7$ /cow), greater replacement cost ($P = 0.02$; cold: $\$442.2 \pm 40.8$ /cow; warm: $\$354.3 \pm 45.1$ /cow), and lower operating expenses ($P = 0.05$; cold: $\$888.4 \pm 13.4$ /cow; warm: $\$932 \pm 17.8$ /cow) than cows that calved in the warm season.

Production Performance and Economic Analysis for 18 mo After Calving in the Experimental Lactation

The effect of treatments on milk yield and income, DMI, and feed cost for 18 mo after calving in the experimental lactation is presented in Table 4. For primiparous cows, a tendency ($P = 0.09$) for a treatment effect was observed for DMI and feed cost during the dry period. None of the other parameters evaluated differed ($P > 0.10$) between treatments or calving season. For the multiparous group, no differences ($P > 0.10$) were observed between treatments, but there was an effect of season of calving, whereby cows that calved during the cold season had greater ($P = 0.05$) milk yield (cold: $19,809 \pm 121$ kg/slot; warm: $19,411 \pm 162$ kg/slot) and income (cold: $\$8,122 \pm 50$ /slot; warm: $\$7,958 \pm 66$ /slot) than cows that calved during the warm season.

The effect of first-service management strategy on revenues and expenses during the 18-mo period after calving is presented in Table 5. For the primiparous group, cows in the DO88 and PSOv treatments had greater ($P = 0.01$) rbST cost than cows in the DO60 treatment because they received more ($P = 0.01$) injections (DO60 = 25.0 ± 0.3 ; DO88 = 26.5 ± 0.3 ; PSOv = 26.0 ± 0.3). No differences were observed for the rest of the parameters evaluated ($P > 0.10$) for primiparous cows. For the multiparous group, replacement cost tended ($P = 0.08$) to be different between treatments. Reproductive cost was greater ($P = 0.01$) for cows in the DO60 treatment than in the DO88 and PSOv treatments. Additionally, rbST cost was greater ($P = 0.04$) for cows in the DO88 treatment than in the DO60 treatment, with no differences between PSOv and the other 2 treatments. The number of rbST injections was 25.7 ± 0.3 , 26.6 ± 0.3 , and 25.9 ± 0.3 for cows in the DO60, DO88, and PSOv treatments, respectively ($P = 0.04$). Season of calving only affected calf value, with a tendency ($P = 0.10$) to be greater for multiparous

Table 2. Effect of first-service management strategy on milk production, milk income, DMI, and feed cost during the experimental lactation and dry period

Item	Primiparous			P-value ⁴	Multiparous			P-value
	DO60 ¹ (n = 168)	DO88 ² (n = 166)	PSOv ³ (n = 168)		DO60 (n = 268)	DO88 (n = 263)	PSOv (n = 269)	
Milk, kg/cow								
Total	10,089 ± 283 ^b	11,192 ± 286 ^a	10,563 ± 283 ^{ab}	0.02	11,526 ± 260	11,648 ± 263	11,300 ± 260	0.63
Daily	32.72 ± 0.47	33.64 ± 0.48	34.19 ± 0.47	0.09	39.40 ± 0.42	39.08 ± 0.42	39.40 ± 0.42	0.82
Milk income, \$/cow								
Total	4,136 ± 116 ^b	4,589 ± 117 ^a	4,331 ± 116 ^{ab}	0.02	4,726 ± 107	4,776 ± 108	4,633 ± 106	0.63
Daily	13.42 ± 0.19	13.79 ± 0.20	14.02 ± 0.19	0.09	16.16 ± 0.17	16.02 ± 0.17	16.15 ± 0.17	0.82
DMI, kg/cow								
Milking								
Total	7,174 ± 183 ^b	7,932 ± 184 ^a	7,416 ± 183 ^b	0.01	7,774 ± 165	7,855 ± 166	7,565 ± 165	0.44
Daily	23.48 ± 0.20	23.96 ± 0.20	24.05 ± 0.20	0.10	26.59 ± 0.16	26.47 ± 0.16	26.47 ± 0.16	0.84
Dry								
Total	772.0 ± 15.2	767.2 ± 15.5	729.2 ± 15.4	0.10	826.9 ± 17.9	865.4 ± 19.9	829.2 ± 19.0	0.29
Daily	13.15 ± 0.03	13.22 ± 0.03	13.18 ± 0.03	0.23	13.58 ± 0.03 ^b	13.68 ± 0.03 ^a	13.63 ± 0.03 ^{ab}	0.04
Feed cost, \$/cow								
Milking								
Total	2,061 ± 52 ^b	2,279 ± 53 ^a	2,131 ± 52 ^b	0.01	2,234 ± 47	2,257 ± 48	2,174 ± 47	0.44
Daily	6.75 ± 0.06	6.88 ± 0.06	6.91 ± 0.06	0.10	7.64 ± 0.05	7.61 ± 0.05	7.61 ± 0.05	0.84
Dry								
Total	170.2 ± 3.4	169.1 ± 3.4	160.8 ± 3.4	0.10	182.3 ± 3.9	190.8 ± 4.4	182.8 ± 4.2	0.29
Daily	2.90 ± 0.01	2.92 ± 0.01	2.91 ± 0.01	0.23	2.99 ± 0.01 ^b	3.02 ± 0.01 ^a	3.00 ± 0.01 ^{ab}	0.04

^{a,b}Different letters indicate a significant difference between LSM based on the least significant difference (LSD) post-hoc mean separation test.

¹DO60 = first service by timed AI at 60 ± 3 DIM after the Double-Ovsynch protocol.

²DO88 = first service by timed AI at 88 ± 3 DIM after the Double-Ovsynch protocol.

³PSOv = first service at detected estrus after the second PGF_{2α} treatment of Presynch-Ovsynch given at 50 ± 3 DIM or by timed AI at 72 ± 3 DIM after completion of the Presynch-Ovsynch protocol.

⁴The effect of season of calving is described in the text.

Table 3. Effect of first-service management strategy on revenues and expenses during the experimental lactation¹

Item, \$/cow	Primiparous			P-value ⁵	Multiparous			P-value
	DO60 ² (n = 168)	DO88 ³ (n = 166)	PSOv ⁴ (n = 168)		DO60 (n = 268)	DO88 (n = 263)	PSOv (n = 269)	
Income over feed cost	1,939 ± 66 ^b	2,177 ± 66 ^a	2,075 ± 66 ^{ab}	0.04	2,377 ± 60	2,419 ± 61	2,357 ± 60	0.76
Calf value	94.61 ± 5.37	96.85 ± 5.42	96.13 ± 5.37	0.96	78.50 ± 6.84	65.98 ± 6.87	72.55 ± 6.84	0.14
Replacement cost	202.3 ± 34.4	224.7 ± 34.7	254.8 ± 34.4	0.56	329.4 ± 46.0 ^b	440.2 ± 46.2 ^a	425.0 ± 46.0 ^a	0.02
Reproductive cost	55.06 ± 1.99	54.99 ± 2.00	50.50 ± 1.99	0.18	61.95 ± 1.84	59.77 ± 1.85	55.87 ± 1.83	0.06
Recombinant bovine somatotropin cost	130.8 ± 4.4 ^b	151.0 ± 4.5 ^a	134.1 ± 4.3 ^b	<0.01	124.7 ± 3.8	126.4 ± 3.8	119.4 ± 3.8	0.40
Other operating expenses	968.1 ± 20.1 ^b	1,039.7 ± 20.3 ^a	973.5 ± 20.1 ^b	0.02	925.3 ± 18.8	915.1 ± 18.9	890.3 ± 18.7	0.39
Cash flow	677.9 ± 64.3	803.8 ± 64.9	757.9 ± 64.3	0.38	1,006.3 ± 59.8	936.3 ± 60.4	931.2 ± 59.7	0.61
Cash flow per day of calving interval	1.02 ± 0.34	1.21 ± 0.35	1.65 ± 0.34	0.42	2.15 ± 0.30	1.68 ± 0.30	1.73 ± 0.30	0.48

^{a,b}Different letters indicate a significant difference between LSM based on the least significant difference (LSD) post-hoc mean separation test.

¹Includes milking and dry period.

²DO60 = first service by timed AI at 60 ± 3 DIM after the Double-Ovsynch protocol.

³DO88 = first service by timed AI at 88 ± 3 DIM after the Double-Ovsynch protocol.

⁴PSOv = first service at detected estrus after the second PGF_{2α} treatment of Presynch-Ovsynch given at 50 ± 3 DIM or by timed AI at 72 ± 3 DIM after completion of the Presynch-Ovsynch protocol.

⁵The effect of season of calving is described in the text.

Table 4. Effect of first-service management strategy on milk production, milk income, DMI, and feed cost during 18 mo after calving in the experimental lactation

Item	Primiparous			Multiparous				P-value
	DO60 ¹ (n = 168)	DO88 ² (n = 166)	PSOv ³ (n = 168)	P-value ⁴	DO60 (n = 268)	DO88 (n = 263)	PSOv (n = 269)	
Milk, kg/slot ⁵	17,736 ± 192	17,839 ± 193	18,025 ± 192	0.56	19,570 ± 170	19,503 ± 171	19,757 ± 170	0.54
Milk income, \$/slot	7,272 ± 79	7,314 ± 79	7,390 ± 79	0.56	8,023 ± 70	7,996 ± 70	8,100 ± 70	0.54
DMI, kg/slot	12,071 ± 81	12,230 ± 81	12,282 ± 81	0.16	13,043 ± 70	13,072 ± 71	13,114 ± 70	0.77
Dry	764.5 ± 15.8	759.5 ± 16.2	718.9 ± 16.0	0.09	789.4 ± 18.1	807.3 ± 19.5	775.4 ± 18.4	0.49
Feed cost, \$/slot								
Milking	3,468 ± 34	3,515 ± 23	3,529 ± 23	0.16	3,748 ± 20	3,756 ± 20	3,768 ± 20	0.77
Dry	168.6 ± 3.5	167.4 ± 3.6	158.5 ± 3.5	0.09	174.0 ± 4.0	178.0 ± 4.3	170.9 ± 4.1	0.49

¹DO60 = first service by timed AI at 60 ± 3 DIM after the Double-Ovsynch protocol.

²DO88 = first service by timed AI at 88 ± 3 DIM after the Double-Ovsynch protocol.

³PSOv = first service at detected estrus after the second PGF_{2α} treatment of Presynch-Ovsynch given at 50 ± 3 DIM or by timed AI at 72 ± 3 DIM after completion of the Presynch-Ovsynch protocol.

⁴The effect of season of calving is described in the text.

⁵Slot is the unit of space occupied by each cow enrolled in the experiment for an 18-mo period after calving in the experimental lactation.

Table 5. Effect of first-service management strategy on revenues and expenses during 18 mo after calving in the experimental lactation

Item, \$/slot ¹	Primiparous			P-value ⁵	Multiparous			P-value
	DO60 ² (n = 168)	DO88 ³ (n = 166)	PSOv ⁴ (n = 168)		DO60 (n = 268)	DO88 (n = 263)	PSOv (n = 269)	
Income over feed cost	3,656 ± 61	3,660 ± 61	3,726 ± 61	0.66	4,147 ± 80	4,124 ± 80	4,211 ± 80	0.48
Calf value	101.7 ± 5.3	97.3 ± 5.3	99.2 ± 5.3	0.84	85.29 ± 6.82	74.22 ± 6.83	85.93 ± 6.81	0.12
Replacement cost	365.3 ± 45.7	327.0 ± 46.0	401.3 ± 45.7	0.52	573.3 ± 41.0	694.5 ± 41.4	676.0 ± 40.9	0.08
Reproductive cost	95.5 ± 2.3	92.7 ± 2.3	94.5 ± 2.3	0.69	106.4 ± 2.1 ^a	97.9 ± 2.1 ^b	99.4 ± 2.1 ^b	0.01
Recombinant bovine somatotropin cost	180.8 ± 2.4 ^b	192.1 ± 2.5 ^a	187.8 ± 2.4 ^a	0.01	185.6 ± 2.0 ^b	192.6 ± 2.0 ^a	187.3 ± 2.0 ^{ab}	0.04
Other operating expenses	1,512	1,512	1,512	—	1,512	1,512	1,512	—
Cash flow	1,604 ± 85	1,633 ± 85	1,630 ± 85	0.97	1,874 ± 76	1,719 ± 76	1,841 ± 76	0.32
Cash flow per day	2.97 ± 0.16	3.02 ± 0.16	3.02 ± 0.16	0.97	3.47 ± 0.14	3.18 ± 0.14	3.41 ± 0.14	0.32

^{a,b}Different letters indicate a significant difference between least square means based on the least significant difference (LSD) post-hoc mean separation test.

¹Slot is the unit of space occupied by each cow enrolled in the experiment for an 18-mo period after calving in the experimental lactation.

²DO60 = first service by timed AI at 60 ± 3 DIM after the Double-Ovsynch protocol.

³DO88 = first service by timed AI at 88 ± 3 DIM after the Double-Ovsynch protocol.

⁴PSOv = first service at detected estrus after the second PGF_{2α} treatment of Presynch-Ovsynch given at 50 ± 3 DIM or by timed AI at 72 ± 3 DIM after completion of the Presynch-Ovsynch protocol.

⁵The effect of season of calving is described in the text.

cows that calved in the warm season ($\$86.20 \pm 6.7/\text{slot}$) compared with cows that calved in the cold season ($\$77.50 \pm 6.0/\text{slot}$).

Stochastic Analysis for the 18-mo Period Under Varying Market Conditions

For primiparous cows, differences in cash flow under diverse pricing scenarios is presented in Figure 1. Differences in cash flow between the DO88 and DO60 treatments (DO88 – DO60) after 10,000 iterations ranged from a minimum of $-\$38.00/\text{slot}$ to a maximum of $\$75.40/\text{slot}$ per 18 mo, with a positive average (in favor of the DO88 treatment) of $\$16.70/\text{slot}$ per 18 mo (95% CI: $-\$14.40$ to $\$49.60/\text{slot}$ per 18 mo). Furthermore, the average difference between the DO88 and PSOv treatments (DO88 – PSOv) was $\$1.20/\text{slot}$ per 18 mo (95% CI: $-\$30.10$ to $\$36.40/\text{slot}$ per 18 mo), with a minimum and maximum of $-\$51.30$ and $\$61.00/\text{slot}$ per 18 mo, respectively. Last, the average difference in cash flow between the DO60 and PSOv treatments (DO60 – PSOv) was $-\$15.50/\text{slot}$ per 18 mo (95% CI: $-\$51.80$ to $\$18.20/\text{slot}$ per 18 mo), with a minimum of $-\$72.20$ and a maximum of $\$39.20/\text{slot}$ per 18 mo.

For multiparous cows, differences in cash flow (Figure 2) between the DO88 and the DO60 treatments (DO88 – DO60) were $>99\%$ of the time negative values (i.e., favored the DO60 treatment). The mean difference after 10,000 iterations was $-\$87.20/\text{slot}$ per 18 mo (95% CI: $-\$160.10$ to $-\$22.50/\text{slot}$ per 18 mo), and it ranged from $-\$208.10$ to $\$8.70/\text{slot}$ per 18 mo. Similarly, differences in cash flow between the DO88 and PSOv treatments were always negative (i.e., favored the PSOv treatment), with an average of $-\$83.50/\text{slot}$ per 18 mo (95% CI: $-\$120.70$ to $-\$47.30/\text{slot}$ per 18 mo). Finally, results for the differences in cash flow between the DO60 and PSOv treatments were almost equally distributed around zero, with a mean of $\$3.60/\text{slot}$ per 18 mo (95% CI: $-\$36.90$ to $\$49.00/\text{slot}$ per 18 mo) and a minimum and maximum of $-\$61.90$ and $\$76.00/\text{slot}$ per 18 mo, respectively.

DISCUSSION

In this study, we evaluated reproductive and economic outcomes for Holstein cows with different reproductive performance and herd exit dynamics in response to first-service reproductive management programs that used a combination of EDAI and TAI in cows synchronized with the PSOv protocol and a VWP of 50 DIM or all TAI after the DO protocol with a VWP of 60 or 88 DIM. Collectively, the results of the deterministic and primarily the stochastic analyses indicated that the first-service management treatments that are more

Figure 1. Relative frequency distribution of the difference in cash flow (\$/slot per 18 mo; slot is the unit of space occupied by each cow enrolled in the experiment for an 18-mo period after calving in the experimental lactation) between the (A) DO88 and DO60, (B) DO88 and PSOV, and (C) DO60 and PSOV treatment groups for primiparous cows after 10,000 iterations of simulation with stochasticity for economic input values. Differences in cash flow were calculated as follows: (A) cash flow for DO88 minus cash flow for DO60, (B) cash flow for DO88 minus cash flow for PSOV, and (C) cash flow for DO60 minus cash flow PSOV. DO60 = first service by timed AI at 60 ± 3 DIM after the Double-Ovsynch protocol. DO88 = first service by timed AI at 88 ± 3 DIM after the Double-Ovsynch protocol. PSOV = first service at detected estrus after the second $\text{PGF}_{2\alpha}$ treatment of Presynch-Ovsynch given at 50 ± 3 DIM or by timed AI at 72 ± 3 DIM after completion of the Presynch-Ovsynch protocol.

Figure 2. Relative frequency distribution of the difference in cash flow (\$/slot per 18 mo; slot is the unit of space occupied by each cow enrolled in the experiment for an 18-mo period after calving in the experimental lactation) between the (A) DO88 and DO60, (B) DO88 and PSOV, and (C) DO60 and PSOV treatment groups for multiparous cows after 10,000 iterations of simulation with stochasticity for economic input values. Differences in cash flow were calculated as follows: (A) cash flow for DO88 minus cash flow for DO60, (B) cash flow for DO88 minus cash flow for PSOV, and (C) cash flow for DO60 minus cash flow PSOV. DO60 = first service by timed AI at 60 $\pm$ 3 DIM after the Double-Ovsynch protocol. DO88 = first service by timed AI at 88 $\pm$ 3 DIM after the Double-Ovsynch protocol. PSOV = first service at detected estrus after the second PGF_{2 α} treatment of Presynch-Ovsynch given at 50 $\pm$ 3 DIM or by timed AI at 72 $\pm$ 3 DIM after completion of the Presynch-Ovsynch protocol.

likely to increase herd profitability are DO88 and PSOV for primiparous cows and DO60 and PSOV for multiparous cows.

Primiparous Cows

For primiparous cows, TAI at 88 DIM after the DO protocol delayed pregnancy, extended lactations, and extended calving intervals. Consequently, the differences for individual economic outcomes during the experimental calving interval were primarily a reflection of differences in revenues and expenses affected by lactation length. Longer lactations with similar dry period length for cows in the DO88 treatment resulted in more days of positive IOFC during the calving interval. Nevertheless, a substantial proportion of this gain was offset by the additional cost of extended lactations, primarily other operating expenses and rbST treatment cost. Similar to our previous study comparing the DO60 and DO88 treatments using a larger data set from an experiment conducted in 3 commercial farms (Stangaferro et al., 2018c), compensation among the multiple revenues and expenses (regardless of statistical significance) and large variation among cows precluded detection of statistically significant differences in cash flow. This is despite substantial numerical differences in average cash flow (up to \$126/cow per lactation) for the different treatments.

Consistent with most trends for reproductive performance, revenues and expenses for the PSOV treatment were intermediate. These results for the calving interval of the experimental lactation were likely a reflection of the pregnancy dynamics generated by the method of submission to the first service. Unlike the DO60 and DO88 programs, in which all cows received first service within a week range of DIM, pregnancy creation after first service for the PSOV treatment followed a bimodal distribution (reported in Stangaferro et al., 2018a). A substantial proportion of pregnancies were created immediately after Presynch and before 60 DIM through EDAI, whereas the rest of the pregnancies to the first service were created at 72 ± 3 DIM through TAI. Moreover, inseminations at detected estrus for second AI service generated pregnancies even before all cows received first service by TAI in the same group (i.e., PSOV) and DO88. Ultimately, economic outcomes for cows with earlier pregnancy were balanced by outcomes for cows with later pregnancy, resulting in intermediate economic performance for PSOV. Therefore, it is apparent from these data that combining EDAI and TAI with the PSOV protocol so that average DIM to the first service is approximately 60 DIM may result in relatively similar herd cash flow during a lactation compared with programs with all TAI in the range of

60 or 88 DIM after synchronization of ovulation with the DO protocol.

Comparing cash flow per slot for a fixed period of time (i.e., 18 mo after calving in the experimental lactation) as previously reported by our group (Stangaferro et al., 2018b) and in simulations studies (De Vries, 2004, 2006) was meant to compare individual slots for the same amount of time while accounting for the effect of timing of pregnancy during the experimental lactation and the herd replacement dynamics. As expected, additional economic compensation for the differences observed in the experimental lactation was observed for comparisons per slot per 18 mo. Earlier onset of the subsequent lactation (i.e., second lactation) for primiparous cows in the DO60 and PSOV treatments generated enough IOFC to offset the substantial differences observed in the previous calving interval. Other minor (i.e., calf value and reproductive cost) and moderate (i.e., replacement cost and rbST treatment cost) differences for revenues and expenses further compensated for the original difference, which resulted in no significant overall cash flow differences between groups. These results are in agreement with our previous report (Stangaferro et al., 2018b), whereby there were no significant differences between the DO60 and DO88 groups for primiparous cows despite economic differences of a magnitude that may be relevant to dairy farms. Substantial variation among cows due to major variability between those that exit the herd due to sale or death and those that do not and lack of major differences in IOFC are the main reasons for the lack of significant differences in overall cash flow (Stangaferro et al., 2018b). Others have also reported similar results (Gobikrushanth et al., 2014); however, reasons for lack of differences have not always been the same due to the type of economic analysis conducted. Consistent with the observations for the calving interval of the experimental lactation, cows in the PSOV treatment presented similar cash flow per slot per 18 mo as cows in the DO60 and DO88 treatments, indicating that combined approaches including the PSOV protocol or alike could result in similar profitability compared with all TAI after the DO protocol and with VWP duration similar to those evaluated in our study.

Adding stochasticity to input values for calculations of revenues and expenses allowed us to estimate the range of differences in cash flow under varying market conditions. The stochastic analysis for primiparous cows indicated that under fixed reproductive performance, herd exit dynamics, and milk production, changes in inputs continued to favor the DO88 over the DO60 treatment. Although the average difference after 10,000 iterations was less than that of the deterministic comparison, the vast majority of the scenarios

generated positive outcomes for the DO88 treatment. This suggests that under a wide range of values for inputs, the latter treatment would be economically favorable compared with TAI at 60 DIM after the DO protocol. Conversely, implementing the DO88 or PSov treatments would be neutral because values for their difference were almost equally distributed around zero (i.e., ~50% of the time the difference was positive or negative). Finally, the distribution of differences for the PSov and DO60 comparison indicated that under varying input pricing scenarios PSov had greater cash flow more than 75% of the time.

Multiparous Cows

More complex effects of treatments were observed for multiparous cows. Delaying first service by TAI with DO from 60 to 88 DIM in the latter group delayed pregnancy, extended lactation length (cows not culled only), and extended the calving interval. Moreover, for the DO88 treatment group there were fewer pregnant cows at 350 DIM, cows exited the herd earlier, more were sold, and fewer calved again. Lack of improvement in P/AI to the first service by TAI after extending the VWP in the DO88 treatment explained most of these observations because P/AI and the proportion of cows EDAI for second and greater AI services were similar for DO60 and DO88. For the most part, outcomes for multiparous cows in the PSov treatment were intermediate. Of note, multiparous cows in PSov became pregnant at a faster rate than those in DO88 but at a similar rate as cows in the DO60 treatment. Except for lactation length for cows not culled, which was shorter than for cows in the DO88 treatment, cows in the PSov treatment had similar outcomes compared with the other 2 groups.

The effect of treatments on economic outcomes was more profound and complex than for primiparous cows because reproductive performance affected not only lactation length and the calving interval but also the herd replacement dynamics and the number of AI services. During the calving interval of the experimental lactation, more cows sold translated into greater replacement costs for the DO88 treatment than for the DO60 treatment. This difference was, however, compensated for by gains for other revenues and expenses (in particular IOFC) to the extent of resulting in no significant differences in overall cash flow with the DO60 group. As for primiparous cows, the behavior of the PSov treatment was intermediate but resembled more closely that of the DO88 treatment than the DO60 treatment, in particular for replacement cost, which was within a \$15 range of the DO88 treatment but almost \$100

more than that of the DO60 treatment due to a slightly greater proportion of cows replaced due to sale and death. The observed tendency for differences in reproductive cost was in line with the lesser cost of submitting cows for AI with PSov and the greater number of inseminations for cows in the DO60 treatment than in the DO88 treatment. Nevertheless, the contribution of reproductive cost to overall cash flow differences was inconsequential (i.e., ~\$2 to 6/cow). This is agreement with studies that reported minor contributions of reproductive program implementation cost to cash flow differences between different reproductive management programs (Giordano et al., 2011, 2012; Gobikrushanth et al., 2014).

Although cash flow differences in the range of \$120 to \$155/slot per 18 mo would be valuable to dairy farms, we failed to detect significant differences between treatments. As previously stated, this was the result of the disparity in overall cash flow among cows. The greater proportion of cows that left the herd during the calving interval of the experimental lactation and the fewer cows that calved again for the DO88 treatment than the DO60 treatment generated major differences in replacement cost (\$121/slot per 18 mo) that, along with negative outcomes for the rest of the revenues and expenses, easily compensated for the slight reproductive cost reduction for the DO88 treatment. It is important to note that because the herd exit dynamics were not fully controlled by the researchers and a strict protocol with well-defined criteria for culling decisions was not followed, bias cannot be fully excluded and could have influenced part of the analyses. As for primiparous cows, the PSov treatment had outcomes that were intermediate between the DO60 and DO88 treatments but were more closely aligned with those of the DO60 group. Therefore, a first-service management program that combines EDAI and TAI through synchronization with the PSov protocol and includes a VWP of 50 DIM may lead to relatively similar cash flow as all TAI after the DO protocol at 60 DIM and be more likely to optimize profitability than an all TAI after the DO protocol with a VWP closer to 90 DIM. In this case, earlier pregnancies after EDAI for first and second service in PSov favored cash flow for this group.

The stochastic analysis for cash flow reinforced the observations from the deterministic analysis and showed similar trends as for the primiparous group. We observed smaller mean differences in cash flow between treatments but a wider range of differences. Under the input pricing scenarios generated, the simulations indicated with greater than 95% confidence that the DO60 treatment would be more profitable than the DO88 treatment. Likewise, results indicated with greater

than 99% confidence that the PSov treatment would be more profitable than the DO88 treatment. Based on the range and shape of the distribution for cash flow differences, it was also apparent that the PSov treatment would lead to greater and more consistent differences compared with the DO88 treatment than the DO60 treatment. Conversely, the almost even distribution of differences around zero for the comparison of the DO60 and PSov treatments indicated that approximately 50% of the time selecting either one of these treatments would lead to a gain or a loss in profitability.

CONCLUSIONS

We conclude that for primiparous cows, TAI at 88 DIM after synchronization of ovulation with the DO protocol or a combination of EDAI and TAI using the PSov protocol for synchronization of estrus and ovulation with a VWP of 50 DIM favored profitability by a small margin (<\$30/slot per 18 mo) compared with TAI at 60 DIM after the DO protocol. Conversely, for multiparous cows, profitability was more favorable by a substantial margin (\$155/slot per 18 mo) for cows that received TAI at 60 rather than 88 DIM after synchronization with the DO protocol. Multiparous cows in the PSov treatment had outcomes that were intermediate but slightly more similar to those of cows that received TAI at 60 DIM rather than 88 DIM after synchronization with DO. Therefore, the choice of all-TAI program after the DO protocol or a use of EDAI and TAI with the PSov protocol first-service management may be based on individual farm preferences and resources available rather than potential differences in profitability. Implementation of a combined program using the PSov protocol with a VWP of 50 DIM and pregnancy dynamics similar to those observed in our experiment would be expected to result in similar cash flow as all TAI after the DO protocol when TAI occurs around 88 DIM for primiparous cows and 60 DIM for multiparous cows. If an all-TAI strategy with DO is preferred, the duration of the VWP can be adjusted based on parity in an attempt to increase profitability. Extrapolation of the current study results to other herd and economic conditions should be conducted with caution for many reasons, in particular the use of rbST to increase milk production (Peel and Bauman, 1987; Chalupa and Galligan, 1989; Bauman and Vernon, 1993). It is plausible that without rbST supplementation, economic outcomes related to milk production efficiency would be different. This is because the rate of decline in milk production in later lactation is more noticeable in cows not treated with rbST, which can have profound effects on dairy cow profitability.

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