Economic Comparison of Timed Artificial Insemination and Exogenous Progesterone as Treatments for Ovarian Cysts¹

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ABSTRACT

The objective of this study was to compare the economic benefits of timed artificial insemination (AI) and a progesterone insert as therapeutic treatments for cows diagnosed with cystic ovarian disease (COD). A secondary objective was to illustrate the use of a stochastic dynamic simulation model to fully account for all changes in revenues and costs affected by differences in treatments. First, 4 herds of 1,000 cows each were simulated until steady state. These cows were free from COD and inseminated based on estrus only. Herds differed by probability of estrus detection (46 or 70%) and days in milk (DIM) when nonpregnant cows were culled (330 or 400 d). Second, 3 herds were created with 1,000 nonpregnant cows at 90, 170, or 250 DIM. These cows were considered diagnosed with COD at the start of the simulation (d 0); no new cases of COD developed after d 0. Cows spontaneously recovered or were treated. Treatments were either timed AI or intravaginal device containing progesterone followed by PGF_{2α} and then AI if estrus was detected. Effects of treatments were evaluated in 48 scenarios based on compliance of timed AI (82 or 100%), probability of estrus detection (46 or 70%), and DIM when nonpregnant cows were culled (330 or 400 d). As cows became pregnant or were replaced, the herd evolved into the associated steady-state herd. Seven scenarios resulted in less than 50% of cows conceiving before they were culled. The percentage of cows diagnosed with COD that calved again ranged from 14.0 to 74.4% and was significantly reduced when COD was diagnosed later in lactation. Treatments in all cases were more valuable than waiting for spontaneous recovery. The average values of timed AI (82 or 100% compliance) and the progesterone insert were \$83.29, \$86.83, and \$71.89, respectively,

compared with waiting for spontaneous recovery. Treatments were least beneficial at 90 DIM. The benefits of timed AI (82 or 100% compliance) compared with the progesterone insert, adjusted for DIM and days to culling, were \$14.98 and \$21.53 when the probability of estrus detection was 46%. At 70% probability of estrus detection, the benefits were \$7.81 and \$8.34, respectively. Overall benefit of treatment by timed AI was \$11.39 greater than by progesterone insert.

Key words: ovarian cyst, progesterone, Ovsynch, economics

INTRODUCTION

Bovine ovarian cysts are follicles that fail to ovulate at the time of estrus (Garverick, 1999). Cows with ovarian cysts are infertile as long as the condition persists (Kesler and Garverick, 1982); consequently, profitability is reduced (Bartlett et al., 1986). Economic evaluation of therapeutic strategies is therefore important.

Cystic ovaries can recover spontaneously with reported rates ranging from 20% (Youngquist, 1986; Peter, 1997) to nearly 70% (Whitmore et al., 1974). White and Erb (1980) surveyed the literature and found that about 50% of the cows with cystic ovarian disease (COD) recovered spontaneously within 60 d postpartum. Carroll et al. (1990) reported an average duration of 31.0 ± 4.3 d postdiagnosis. However, the distribution of time between occurrence or diagnosis to spontaneous recovery is not clear.

Treatment of COD may reduce days nonpregnant, but it is associated with handling and drug costs. Information on economic benefits of treatments is limited. Bartlett et al. (1986) reported an average economic loss of \$137 per lactation because of COD. Their study did not report differences in economic losses between treatments or compared with cows not treated for COD.

White and Erb (1980) used a decision tree to calculate the economic benefits of treatment with GnRH over waiting for spontaneous recovery during early lactation and reported a response rate of approximately 80% to treatment with GnRH. The benefit of treatment varied from \$5.39 to a loss of \$0.02 for cows diagnosed with COD within the first 8 DIM. Benefits depended primar-

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ily on the assumed cost per day nonpregnant. Analyses of the benefits of treatment later in lactation were not presented.

The preferred treatments for cows with COD have changed since the study of White and Erb (1980). Bartolome et al. (2000, 2005) showed that the Ovsynch protocol (GnRH on d 0, PGF_{2α} on d 7, GnRH on d 9, and timed AI on d 10 after diagnosis) was effective in treating COD. Ambrose et al. (2004) found that GnRH and PGF_{2α} with and without exogenous progesterone resulted in healthy new ovarian follicles. Use of the exogenous progesterone was recommended as an additional strategy to increase the chances of resolving a cystic ovarian follicle.

Recently, Crane et al. (2006) assigned cows diagnosed with COD in a 1,500-cow dairy herd in north central Florida to 1 of 2 treatments. One treatment consisted of synchronization of ovulation with Ovsynch. The other treatment consisted of the insertion of an intravaginal device containing progesterone for 7 d starting on the day of diagnosis, immediately followed by PGF_{2α}, followed by AI if estrus was detected within 7 d. They showed no significant effects of treatment on conception rates, but insemination costs during the treatment period were significantly higher for Ovsynch. An economic advantage of one treatment over the other per diagnosis was not clear. Furthermore, economic benefits of treatments may depend on compliance of the Ovsynch protocol, level of estrus detection, culling policy, and DIM when COD was first diagnosed. Stochastic dynamic simulation is one approach to compare the economic benefits of various therapeutic treatments (Oltenacu et al., 1981; Sørensen and Enevoldsen, 1992).

The main objective was to compare the economic benefits of 2 therapeutic treatments of COD in lactating dairy cows by means of stochastic dynamic simulation. The treatments were synchronization of ovulation with timed AI following the Ovsynch protocol, and exogenous progesterone administration with AI based on detected estrus. The economic benefits of treatments compared with waiting for spontaneous recovery were evaluated. A secondary objective was to describe the use of stochastic dynamic simulation to measure the cumulative effects of interventions in a herd of dairy cattle.

MATERIALS AND METHODS

Simulation Model

A stochastic dynamic dairy herd simulation model was adapted to measure the technical and economic performance of cows treated for COD and their replacements. The model simulated a herd of dairy cows from day to day through time and recorded reproductive events, culling, milk production, feed intake, and all

revenues and costs when they occurred. Stochastic elements were incorporated in the milk-producing ability of animals, daily milk yield, occurrence and detection of estrus, risk of anestrus, occurrence and success of AI, occurrence of involuntary culling, occurrence of fetal loss, and death. The components of the simulation model have been described in more detail by De Vries (2001) and De Vries and Conlin (2005). Several functions were adapted for the current study. Prices were taken from several sources to mimic conditions for a typical dairy farm located in Florida. Effects of seasonality were not included because Crane et al. (2006) reported a lack of seasonal effect on response to treatment.

Reproduction of Cows Without COD. The reproductive cycle of cows was modeled as a sequence of discrete events, each with their own risk, timing, and outcomes. Reproductive events were calving, ovulation, estrus detection, insemination, conception, and fetal loss. The reproductive functions are first described for cows without COD.

Five percent of cows were assumed to be not cycling throughout their lactation. For the remainder of the cows, the time from calving to first ovulation was scheduled by a lognormal distribution with mean of 19 d and standard deviation of 11 d, truncated at 2 d, after data from Britt (1995). Second and later ovulations were scheduled by a normal distribution with mean of 21.5 d and standard deviation of 2.5 d, truncated at 14 and 29 d, after the previous ovulation if the cow was not inseminated. If the cow was inseminated, but did not conceive, then the second ovulation was scheduled by a normal distribution with mean of 23 d and a standard deviation of 2.5 d, truncated at 15.5 and 30.5 d. Both these distributions were fitted on data from Britt (1995). Pregnancy diagnosis was scheduled at 42 d after AI if the cow was not observed in estrus earlier. Accuracy of the diagnosis (pregnant or nonpregnant) was set at 100%. Cows diagnosed not pregnant were treated with PGF_{2α}. If the previous ovulation occurred between 4 and 16 d before pregnancy diagnosis, then the next ovulation was scheduled at d 2 (5% probability), d 3 (35%), d 4 (30%), d 5 (15%), d 6 (5%), or d 7 (5%) after the pregnancy diagnosis (J. A. Bartolome, personal communication). Otherwise, the timing of the previously scheduled next ovulation was not altered. Drugs to change the reproductive cycle were not used on cows without COD. Insemination was based on observed estrus. The probability of estrus detection was set at 46%. Every observed estrus after the voluntary waiting period of 60 d after calving resulted in an insemination. Otherwise, cows were not inseminated. The probability of conception at pregnancy diagnosis was 35% (Crane, 2005). Length of the gestation was modeled with a nor-

mal distribution with mean 280 d and standard deviation of 6 d, truncated at 268 and 292 d. The probability of fetal loss after pregnancy diagnosis was set at 0.035% per day, which resulted in an 8% risk of fetal loss during the pregnancy (data adapted from Santos et al., 2004). Cows that lost their pregnancy after pregnancy diagnosis ovulated 4 d later (J. A. Bartolome, personal communication).

The price of AI was set at \$10 per insemination. Each calving resulted in calf sales of \$300. The cost of a pregnancy diagnosis, excluding drug costs, was set at \$2.50 (Crane, 2005).

Reproduction of Cows with COD. Cows diagnosed with COD were immediately treated with either a progesterone insert or with GnRH as part of the Ovsynch protocol. The following parameters were taken from Crane et al. (2006). If the treatment started with a progesterone insert, then the insert was removed 7 d later and all cows were treated with PGF_{2α}. For 81% of these cows, the next ovulation was scheduled between d 2 and 7 after PGF_{2α} as before. The probability of estrus detection in cows that ovulated was the same as in cows without COD (46%), but the probability of conception during these days was 21%. The remaining 19% of the cows did not ovulate until d 21 after removal of the insert, after which 74% of these cows ovulated within 21 d using a uniform probability distribution. As a result, 5% of cows treated with the progesterone insert did not ovulate during the remainder of the lactation.

Cows treated with GnRH received PGF_{2α} on d 7 and a second GnRH on d 9 (Ovsynch protocol). Eighty-two percent of these cows were randomly time-inseminated the following day, but the remaining cows were not inseminated to mimic errors in compliance. The probability of conception at the timed AI was 21%. Eighty-one percent of cows were cycling the day after the second GnRH treatment. The remaining 19% of cows remained anovular until d 21 after PGF_{2α} treatment, after which 71% ovulated within 21 d using a uniform probability distribution. Five percent of cows that were treated with Ovsynch remained anovular during the remainder of the lactation. Diseases other than anestrus, COD, and fetal loss were not included.

A third scenario was modeled where all cows diagnosed with COD remained infertile for 60 d after the diagnoses after which 95% ovulated within 21 d using a uniform probability distribution. Five percent remained anovular during the remainder of the lactation.

The price of the progesterone insert was set at \$9.09. The costs of GnRH and PGF_{2α} were \$3.19 and \$2.32 per dose, respectively. Diagnosis of COD occurred as part of the routine herd visit and was therefore set at \$0 (Crane, 2005).

Milk and Fat Production. Daily milk yield by DIM was calculated using Wood's (1967) incomplete gamma function with adjustments for pregnancy, milk-producing ability, and random daily variation. Mathematically,

$$\text{MILK} = a \times \text{DIM}^b \times \exp(-c \times \text{DIM})$$

$$\times [1 + (\text{DPREG}/d)^2]^{-1} \times \text{PA} + 0.9896 \times e_{\text{DIM}-1} + e_{\text{DIM}}$$

where MILK = milk yield (kg/d) and a, b, and c are parameters in the incomplete gamma function. The adjustment for pregnancy, $1 + (\text{DPREG}/d)^2$, was modeled after van Arendonk (1985), where DPREG is the number of days pregnant, and d is a parameter. Cows were assigned a milk-producing ability (PA) during their lifetime from a normal distribution with mean 1 and standard deviation of 0.09. Random daily variations in milk yield of the current and previous day were correlated. Daily variation, e_{DIM} , was taken from a normal distribution with mean 0 and standard deviation of 0.59 kg (Allore et al., 1998). Separate parameters were estimated from typical lactation curves observed in Florida (De Vries, 2004). Parameters a through d for the first parity were 16.847, 0.156, 0.00189, and 509.28; and for the second and greater parities, 27.102, 0.127, 0.00305, and 355.74, respectively. Cows were dried off at 220 d of gestation. Bartlett et al. (1986) found that cows with COD produced more 305-d mature-equivalent milk than cows without COD, but cause and effect were not clear. No association was therefore assumed between COD and milk production in this study.

Daily percentage fat in the milk was described as $\text{FAT\%} = 12.86 \times \text{DIM}^{-1.081} \times 0.0926^{\text{DIM}} \times \log(\text{DIM}^{1.107})$ for all parities (De Vries, 2001). Using this function, average FAT% in 305-d was 3.61%. Daily FCM was estimated as $0.4 \times \text{MILK} + 0.15 \times \text{FAT\%} \times \text{MILK}$. Prices for milk (skim) and fat were set at \$0.27/kg and \$3.70/kg, respectively, in accordance with milk pricing in Florida.

BW. Body weight was modeled following the function described by van Arendonk (1985). Mathematically,

$$\text{BW} = A \times \{1 - [1 - (B/A)^{1/3}] \exp(-C \times \text{AGE})\}^3 - P1 \\ \times \text{DIM}/P2 \times \exp(1 - \text{DIM}/P2) + P3^3 \times \text{DPC}^3$$

where BW is expressed in kg, AGE is the cow's age in days, DPC is the maximum of 0 and (the number of days after conception minus 50). The parameters A, B, C, P1, P2, and P3 were fit on BW data in NRC (2001). For the first parity, parameters were respectively 600, 42, 0.0039, 20, 65, and 0.0187. For second and greater parities, parameters were respectively 600, 42, 0.0060,

40, 70, and 0.0187. Body weight was used to calculate cull price and DMI of lactating cows.

Feed Intake. Dry matter feed intake for lactating cows was taken from NRC (2001). Mathematically,

$$\text{DMI} = 0.372 \times \text{FCM} + 0.0968 \times \text{BW}^{0.75} \\ \times \{1 - \exp [-0.192 \times (\text{DIM}/7 + 3.67)]\}$$

where DMI is expressed in kg/d. Other parameters were as described above. Dry cows were assumed to consume 12 kg of DM/d. The price of the lactating ration was \$0.24/kg of DM and the dry cow ration was \$0.14/kg of DM.

Culling and Replacement. Cows were culled if they were not pregnant after 400 DIM and their last known milk yield was less than 15 kg/d. Furthermore, cows were subject to the risk of death (0.0219%/d) and involuntary culling. Daily risk of involuntary culling was modeled after the average monthly risk described by De Vries (2004) with linear interpolation between months. Cows that were culled were replaced the following day by a calving heifer. Therefore, herd size remained at 1,000 cows at any time. The price of a heifer was set at \$1,850 and the price of a culled cow was set at \$0.72/kg of BW.

Other Costs. Other costs were set at \$3.50/cow per day. These costs included, among others, labor costs and costs for routine herd visits by a veterinarian who performed the COD diagnosis. Interest rate was set at 6% per year.

Herd Statistics. Numerous technical and economic herd statistics were collected per 7-d period during a run with the simulation model. Estrus detection rate was calculated as the number of detected estruses divided by the number of expected estruses in a period. One estrus was expected per 21 d for cows that were not pregnant, but eligible for insemination. Cows with an unknown pregnancy status, shortly after insemination, were assumed to have one expected estrus per 42 d to account for cows that were not eligible because of pregnancy. Pregnancy rate was calculated as the number of pregnant cows at pregnancy diagnosis divided by the number of expected estruses.

Experimental Design

The parameters described above are referred to as the default assumptions. In addition, the economic benefits of both treatments were evaluated for 3 management factors that were thought to affect the difference in economic benefits of both therapeutic strategies the most: the probability of estrus detection (46 or 70%), compliance of timed AI (82 or 100%), and DIM when

nonpregnant cows were culled (330 or 400). A 2-step approach was used as follows.

For each of the 4 combinations of estrus detection and culling policy, a herd consisting of 1,000 cows without COD was created and simulated until the herd reached steady state. After steady state was reached, each of the 4 herds was simulated during 100 runs of 2,100 d (5.75 yr) in each run. Herd statistics were collected and compared with typical technical and economic data for dairy herds located in Florida to validate the parameters and prices in the simulation model.

Second, from the steady-state herds, 3 herds were created with 1,000 cows each that were nonpregnant. The cows in each herd were at the same stage of lactation: 90, 170, or 250 DIM. Cows within a herd differed only in milk production and parity. Each cow was assumed to be diagnosed with COD that day (d 0). Each herd was simulated in 100 runs of 2,100 d per treatment (Ovsynch with 82% compliance, Ovsynch with 100% compliance, progesterone insert, or no treatment). The economic benefits of each of these 4 treatments were evaluated for the 12 combinations of estrus detection, culling policy, and DIM at diagnosis. This resulted in 48 scenarios. No new cases of COD were developed after d 0. Thus, if a cow in the starting herd calved again, then her next lactation was considered normal (without COD). All cows that entered the herd after d 0 to replace culled or dead cows were free of COD. Because cows with COD calved or were replaced over time, the starting herd gradually transformed into a herd without COD that had reached steady-state conditions before the end of each run. Therefore, all effects of treatments on future cash flows were accounted for on or before d 2,100. The present values of revenues and costs collected during the 2,100 d were obtained by discounting weekly after d 0. The difference in the cumulative profits (net present values) of each scenario was used as the measure of relative economic benefits of each treatment. The cumulative profits of the treatments were compared through ANOVA using the GLM procedure of SAS, version 9.0 (SAS Institute, Inc., Cary, NC) with all explanatory variables as fixed effects. Of primary interest were means and standard errors of the means of the results; *P*-values were added to help interpret the confidence intervals.

RESULTS AND DISCUSSION

Steady State

Herds of cows without COD with 70% probability of estrus detection had better technical and economic results than those with a 46% probability (Table 1). Culling policy had little effect on profitability. Annual cull rate varied between 32 and 39%. Estrus detection

Table 1. Steady-state economical (\$/cow per year) and technical results from the simulation model for cows without cystic ovarian disease

Measure	Probability of estrus detection (%)			
	46		70	
	Days to culling ¹			
	400	330	400	330
Milk sales	3,333.62	3,368.87	3,335.09	3,352.28
Cow sales	127.63	142.94	110.23	116.55
Calf sales	291.98	302.42	304.30	309.15
Feed costs	1,492.78	1,494.23	1,484.73	1,484.98
Heifer purchase costs	643.91	706.51	575.21	600.66
Breeding costs	27.43	27.24	29.38	29.35
Other costs	1,278.22	1,278.29	1,278.14	1,278.17
Profit	310.89	307.96	382.16	384.82
21-d estrus detection rate (%)	44.07	44.51	65.44	66.85
21-d pregnancy rate (%)	15.39	15.58	22.87	23.37
Days to conception	159.39	150.99	135.03	132.46
Annual cull rate (%)	35.80	39.26	31.98	33.38
Milk yield (kg/cow per yr)	10,078	9,968	10,016	10,078

¹Days after calving when a nonpregnant cow is culled.

rates varied from 44 to 67%, whereas pregnancy rates ranged from 15 to 23%. Average time to first conception ranged from 132 to 159 d. Milk yield in all 4 herds was approximately 10,000 kg/cow per year.

Breeding costs in Table 1 included the cost of PGF_{2α}, pregnancy diagnosis, and inseminations and were lower for herds with a 46% probability of estrus detection. Profits ranged from \$308 to \$385/cow per year. Among sales and costs, the greatest difference was in cow sales (\$110 to \$143/cow per year) and heifer purchase cost (\$575 to \$707/cow per year), which were associated with annual cull rates. These technical and economic results were similar to averages for dairy herds located in Florida (De Vries et al., 2005) and lend credibility to the choice of the input parameters.

Treatment Benefits

To illustrate the treatment results, Figure 1 shows the number of nonpregnant cows after being diagnosed with COD at 90 DIM by days after diagnosis when the probability of estrus detection is 46% and days to culling of nonpregnant cows is 400 d. In this example, average median days to conception after diagnosis of COD were 94.4 ± 0.3 for Ovsynch, 103.9 ± 0.6 for the progesterone insert, and 156.9 ± 0.6 when the cow was not treated.

Median days to conception for all 48 scenarios are shown in Figure 2. In 7 scenarios, less than 50% of cows conceived before they were culled. In 6 of these, COD was diagnosed at 250 DIM. Of the data shown in Figure 2, median days to conception for Ovsynch, 100% compliance and 82% compliance, were 76 and 81 d, respectively. Median days for the progesterone insert were 88 d and when no treatment was applied were 138 d. Me-

dian days to conception for scenarios with the same probability of estrus detection, days to culling, and compliance differed only because of differences in the risk of involuntary culling by DIM and random sampling.

The percentage of cows diagnosed with COD that calved again ranged from 14.0 to 74.4% (Figure 3) and was significantly reduced when COD was diagnosed later in lactation. Nontreated cows had a lower ($P < 0.001$) chance of calving again than treated cows. The differences between the treated cows were less than 4 percentage units.

Differences over time in the cumulative profits of both treatments compared with waiting for spontaneous recovery after diagnosis using the default inputs (COD diagnosed on 90 DIM, 46% probability of estrus detection, 400 d to culling of nonpregnant cows, 82% compliance of timed AI in the Ovsynch protocol) are shown as an example in Figure 4. The economic benefits of both treatments became positive on d 310 after diagnosis when nonpregnant cows were replaced because they had reached 400 DIM. Steady-state conditions were reached approximately 1,500 d after diagnosis and all effects of the treatments were included. These steady-state conditions were not formally tested. Figure 4 showed further that compared with no treatment, profit after treatment with a progesterone insert was $\$55.85 \pm \6.76 , whereas profit after treatment with Ovsynch was $\$73.46 \pm \6.71 .

The cumulative discounted revenues and costs for cows treated under the default assumptions with either a progesterone insert or Ovsynch, compared with no treatment, are illustrated in Table 2. The economic value of both treatments was primarily caused by increases ($P < 0.001$) in milk sales and calf sales, and

Figure 1. Number of nonpregnant cows after being diagnosed with cystic ovarian disease at 90 DIM (46% probability of estrus detection and 400 d to culling of nonpregnant cows): no treatment ($\diamond$), progesterone insert (—), and timed insemination ($\circ$).

reductions ($P < 0.001$) in feed costs and heifer replacement costs. Nontreated cows had greater ($P < 0.001$) cow sales and lower ($P < 0.001$) breeding costs.

The economic benefits of treatment compared with no treatment of all 36 differences between scenarios (Figure 5) showed that treatment was, in all cases, more ($P < 0.001$) valuable than no treatment. The advantages of treatments ranged from $\$53.09 \pm \6.42 to $\$120.65 \pm$

$\$7.39$. Treatments were least beneficial at 90 DIM and most beneficial at 170 DIM, when interval to culling was 400 d, or at 250 DIM, when interval to culling was 330 d. The average benefits for Ovsynch (82% compliance or 100% compliance) and the progesterone insert, compared with no treatment, were respectively $\$83.29 \pm \12.28 , $\$86.83 \pm \12.24 , and $\$71.89 \pm \12.33 per treatment.

Figure 2. Median days to conception for cows treated for cystic ovarian disease by days to culling of nonpregnant (Cull), probability of estrus detection (Estrus), and DIM at diagnosis (Days). Treatments: nontreated cows ($\diamond$), cows treated with progesterone insert ($\bullet$), cows treated with Ovsynch (+, 100% compliance) or ($\times$, 82% compliance). Missing observations indicate that less than 50% of the cows conceived before culling.

Figure 3. Percentage of cows diagnosed with cystic ovarian disease that calved again, by days to culling of nonpregnant cows (Cull), probability of estrus detection (Estrus), and DIM at diagnosis (Days). Treatments: nontreated cows (◇), cows treated with progesterone insert (●), cows treated with Ovsynch (+, 100% compliance) or (×, 82% compliance).

The benefits of treatment were greater than those reported by White and Erb (1980). Days in milk at diagnosis in that study varied greatly compared with the current study. In addition, timing and frequency of spontaneous recovery, response to treatment, and

method of analysis were different in both studies. White and Erb (1980) reported that about 50% of cows recovered spontaneously within 60 d postdiagnosis. They modeled 21 d for return to cyclicity following diagnosis for those cows that recovered. Exact data on the fre-

Figure 4. Cumulative discounted profit per cow after diagnosis of cystic ovarian disease at 90 DIM and treatment with a progesterone insert (○) or Ovsynch (—), compared with no treatment of the default assumptions (46% probability of estrus detection, 400 d to culling of nonpregnant cows, 82% compliance of timed AI in the Ovsynch protocol). The profit of Ovsynch is \$73.46 per cow and the profit of the progesterone insert is \$55.85 per cow.

Table 2. Cumulative discounted revenues and costs per cow (mean $\pm$ SE) for cows treated for cystic ovarian disease at 90 DIM with either Ovsynch or a progesterone insert, compared with no treatment of the default assumptions¹

Statistic	Ovsynch, \$/cow	Progesterone insert, \$/cow
Milk sales	24.99 $\pm$ 4.80	24.62 $\pm$ 5.07
Cow sales	-11.09 $\pm$ 1.60	-10.37 $\pm$ 1.83
Calf sales	22.84 $\pm$ 0.90	17.23 $\pm$ 0.98
Feed costs	-8.84 $\pm$ 1.00	-5.83 $\pm$ 1.06
Breeding costs	18.46 $\pm$ 0.18	17.27 $\pm$ 0.18
Heifer replacement costs	-46.39 $\pm$ 7.86	-35.84 $\pm$ 8.33
Other costs	0.04 $\pm$ 0.01	0.03 $\pm$ 0.01
Profit	73.46 $\pm$ 6.81	55.85 $\pm$ 6.89

¹Default assumptions: 46% probability of estrus detection, 400 d to culling of nonpregnant cows, 82% compliance of timed AI in the Ovsynch protocol.

quency and time to spontaneous recovery of cows diagnosed with COD under conditions similar to those in the study by Crane et al. (2006) were not available. The maximum rate of spontaneous recovery found in the literature (70%; Whitmore et al., 1974) suggests that the value of treatment in this study is likely underestimated.

Although we did not attempt to report the economic losses caused by COD, the total cost could easily be estimated by the stochastic dynamic simulation model as advocated by Seegers et al. (2003). Incidence and distribution of COD, as well as the distribution of spontaneous recovery would be required.

The differences in economic benefits between Ovsynch and the progesterone insert are listed in Table 3. For all 24 differences, the Ovsynch protocol was numerically advantageous between \$1.29 and \$28.92 per treatment. The difference was significantly greater when the probability of estrus detection was low (46%), which was expected because the efficacy of the progesterone insert treatment depended on detection of estrus for AI to be performed. A major determinant of increased profitability after treatment is to inseminate as many cows as possible after the diagnosis. Standard errors of the differences were between \$6.20 and \$7.39, despite 100 runs of 1,000 cows each. Differences for the same days of culling, probability of estrus detection, and DIM were the results of differences in insemination costs, scheduling of the subsequent ovulation, and random error.

If the profits were adjusted for DIM, probability of estrus detection, compliance, and the treatment by DIM interaction, then Ovsynch was \$11.39 $\pm$ \$2.33 ($P < 0.001$) more beneficial than the progesterone insert as treatment of COD. The treatment $\times$ DIM interaction was not significant.

The benefits of Ovsynch (82% compliance or 100% compliance) compared with the progesterone insert, adjusted for DIM and days to culling, were \$14.98 $\pm$ \$2.73 and \$21.53 $\pm$ 2.75 ($P < 0.001$) when the probability of estrus detection was 46%. When the probability of estrus detection was 70%, these benefits were reduced to

Figure 5. Profit for cows treated for cystic ovarian disease compared with no treatment by days to culling of nonpregnant cows (Cull), probability of estrus detection (Estrus), and DIM at diagnosis (Days). Treatments: cows treated with progesterone insert (●), cows treated with Ovsynch (+, 100% compliance) or (x, 82% compliance).

Table 3. Economic benefit of Ovsynch compared with the progesterone insert for treatment of cystic ovarian disease (mean $\pm$ SE)

Days to culling ¹	Estrus detection, %	Timed AI compliance, %	Profit of Ovsynch vs. a progesterone insert (\$/cow)		
			90 DIM ²	170 DIM	250 DIM
400	46	82	17.61 $\pm$ 6.70**	12.14 $\pm$ 6.42	2.59 $\pm$ 6.51
400	46	100	17.54 $\pm$ 6.76**	22.26 $\pm$ 6.25***	15.45 $\pm$ 6.51*
400	70	82	6.01 $\pm$ 6.30	5.16 $\pm$ 6.34	15.22 $\pm$ 6.36
400	70	100	2.45 $\pm$ 6.36	9.81 $\pm$ 6.20	13.38 $\pm$ 6.41*
330	46	82	20.46 $\pm$ 6.70**	22.81 $\pm$ 6.64***	14.29 $\pm$ 7.33
330	46	100	28.92 $\pm$ 6.85***	17.17 $\pm$ 6.71*	27.87 $\pm$ 7.39***
330	70	82	1.29 $\pm$ 6.34	6.77 $\pm$ 6.33	12.42 $\pm$ 6.77
330	70	100	9.42 $\pm$ 6.42	8.70 $\pm$ 6.31	6.26 $\pm$ 6.83

¹Days after calving when nonpregnant cows are culled.²DIM when cystic ovarian disease was diagnosed.*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

\$7.81 $\pm$ \$2.91 ($P < 0.01$) and \$8.34 $\pm$ \$2.70 ($P < 0.01$), respectively.

The results of this study indicate that the culling policy for nonpregnant cows has a major effect on the economic benefits of treatments for COD. If cows are given more opportunity to get pregnant, the economic benefits of treatment are reduced. These trends are in agreement with López-Gatius et al. (2002), who recommended that treatment of primiparous cows with COD early in lactation should be delayed to allow for the opportunity of spontaneous recovery.

Approach

The stochastic dynamic simulation approach used is an alternative to the decision tree approach used by White and Erb (1980). Both approaches follow paths to the cumulative benefit of each treatment. One major difference is that decision trees weigh the probabilities of decision nodes with their economic implications; therefore, the benefits are weighted averages of their probabilities. The Monte-Carlo approach used in the current study “flips coins” to determine the outcome of an event with multiple possible outcomes. The results are, therefore, stochastic, and multiple runs of each scenario are needed to obtain accurate estimates of the average results. Although decision trees are easy to visualize, they necessarily depend on aggregate inputs such as cost per day nonpregnant or the loss caused by premature culling to remain manageable. Such inputs often are obtained under different circumstances than the situation for which the decision tree is built. An advantage of the stochastic dynamic simulation approach used is that all cost and revenues can be observed under conditions for the herd in question when they occur. Another benefit of the stochastic simulation approach is that cow performance can be described in a very detailed manner; for example, the distribution

of time to return to estrus. A disadvantage of the stochastic simulation approach is that numerous runs are needed to obtain small standard errors for the estimates. Computing time of the 48 scenarios in this study was a full day.

The stochastic simulation model assumed that no new COD cases after d 0 were developed. In practice, a fraction of the cows would develop new COD cases, but incidence and time after calving were not available. In addition, the effects of including new COD cases on the outcomes of this study would be minimal assuming development of new cases is independent of previous treatment. If efficacy of treatments differed, then having reoccurring cases of COD would likely have considerable effect on the outcomes evaluated.

CONCLUSIONS

Treatment of COD with either Ovsynch or the progesterone insert was economically beneficial over waiting for spontaneous recovery in all scenarios. The benefit of Ovsynch compared with the progesterone insert ranged from \$1.29 to \$28.92 for the 48 scenarios considered but the difference was not always significant. Adjusted for DIM at diagnosis and culling policy, Ovsynch was economically at least \$7.81 more beneficial than treatment with the progesterone insert. The average advantage of Ovsynch over the progesterone insert was \$11.39 per case.

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