

The value of pregnancy diagnosis – a revisit to an old art

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Abstract

Rectal palpation (RP) for pregnancy diagnosis between 35 to 50 days post-insemination has been a fixture of veterinary practice since the 1950's. In the last decade ultrasound (US) has replaced palpation for pregnancy diagnosis as it facilitates early days to diagnosis, typically 26 to 28 days post-insemination. More recently, blood tests for bovine pregnancy proteins (BP) have become available. These tests typically can be used by 30 days post-insemination in cows more than 90 days post-calving. In general all three tests have similar sensitivity and specificity for pregnancy diagnosis. Attributes differ slightly in cost, but differ significantly in veterinary involvement in performing the test. Blood pregnancy testing may be performed by cattle managers with no veterinary intervention, which has significant implications for veterinary practice.

No matter the test, the value of pregnancy diagnosis is in identifying non-pregnant cows earlier post-insemination and returning them to a re-insemination program. Heat detection rate (HDR) and conception rate (CR) influence the optimal days post-insemination for pregnancy diagnosis. As HDR and CR increase, the value of pregnancy diagnosis must be performed earlier post-insemination. However, earlier pregnancy diagnosis post-insemination detects more pregnancies which will be lost due to early embryonic mortality, dictating re-testing of pregnant animals in a more timely fashion. Herd programs structured on weekly and biweekly testing are more valuable than those scheduled monthly. The optimal pregnancy test post-insemination is influenced by EED, HDR and CR, number of cows tested within each period and cost of herd visit and test. Programs should be structured on a herd-to-herd basis based on utility to the producer.

Keywords: Pregnancy diagnosis, dairy cattle, rectal palpation, ultrasound, BioPryn

Introduction

The value of a pregnant cows decreases with increasing days in milk at pregnancy (days open, Figure 1). The value of a pregnant cow is influenced by days open, the value of milk, the value of a calf, the cost of replacement for reproductive failure, and the age and producing value of the cow.¹ As seen in Figure 1, with a milk value of \$0.10/lb the value of a day open is -\$2.18/day; if milk is valued at \$0.17/lb then the value of a day open is -\$3.48 (calves are valued at \$100/head, replacement heifers at \$1200/head and cull reproductive cows at \$500/head for the analysis).

The essence of a reproductive program is “to get cows pregnant fast” after calving. Driving this system are insemination efficiency (HDR) and CR (defined as cows determined pregnant after insemination by a diagnostic test). The combination of these events is the pregnancy rate, the proportion of cows pregnant every 21 days from the voluntary waiting period (VWP). Heat detection is nuanced, as management of first insemination is different than management of repeat insemination due to the phenomenon of early embryonic death (EED) and the need to ensure cows are not pregnant prior to applying technologies to control estrus. Hence the value of routine pregnancy examination; non-pregnant cows (open cows) may be identified sooner post-insemination than management may observe and re-assigned to an insemination protocol, reducing days between inseminations and days open.

Rectal palpation for pregnancy examination became a staple of veterinary practice due to the convergence of several changes in the dairy industry: artificial insemination (AI), increasing herd size, and the recognition of the economic value of reduced days open. However, AI necessitated accurate estrus detection, which became more difficult with larger cattle groups and more confinement on concrete floors. With these developments in the 1950's and 1960's, the veterinary profession was able to promote the economic benefit of routine reproductive examinations as an aid in the control of reproductive performance. Reproductive programs were marketed under the concept of “herd health” as they benefited the economic performance of the farm by improving the performance of aggregate groups of cows. It was

a win-win situation for the dairy producer and the veterinarian. In many regions, veterinary services became structured around the herd check, a regularly scheduled visit of the veterinarian to the farm to examine cows for reproductive status.

Diagnosis of open and pregnant cows has been based on manual examination of the reproductive tract per rectum between 35 to 50 days post-insemination.²⁻⁴ Positive diagnosis of pregnancy was defined by the palpable presence of an embryonic vesicle, fetal membrane slip, or a fetus. Absence of these structures indicated an “open cow”, identified for return to estrus. Rectal palpation was viewed as safe for the fetus and reliable as a diagnostic tool, although pregnancy losses associated with RP were variable between palpators.^{3,5,6} Abbitt et al observed that palpation for fluctuation of fluid alone was accurate and safe for pregnancy diagnosis, as membrane slip increased fetal loss. With advancement of skill, practitioners found they could reduce the days post-insemination for examination, and many veteran practitioners could successfully palpate cows from 30 days post-breeding.

A diagnosis of “open” in a cow, to be of value, must reduce the days to next insemination compared with days if the diagnosis had not been made.^{7,8} Thus, reproductive examinations should be linked with management interventions that make use of the information to reduce the days to next insemination.⁸⁻¹⁰ Prostaglandin F₂α (PGF) treatment in open cows with a mature corpus luteum makes it possible to shorten the time to next estrus and focus attention on estrus detection in treated cows. It is critical to accurately identify an open cow so PGF will not abort a pregnant cow. In addition the diagnostic test should not cause injury of the embryo which can result in abortion. Incorporation of gonadotropin releasing hormone (GnRH) injections in sequence with PGF treatment has made it possible to schedule AI at specific times after a diagnosis of not pregnant, enhancing the likelihood that a cow is re-inseminated in a timely fashion.^{11,12} Gonadotropin releasing hormone in combination with PGF can be used for timed AI from about 26 days post-insemination in open cows.¹¹ The association between a veterinary “open” diagnosis with application of a managed breeding program has greatly increased reproductive efficiency in dairy herds.

Currently, US and BP have begun to replace the time honored art of RP for pregnancy diagnosis¹³⁻¹⁵ Ultrasound may reduce the days post-insemination for a diagnosis of pregnancy to 26 to 28 days post-insemination for a skilled operator.¹⁵⁻¹⁷ The BP test is diagnostic from 30 days post-insemination as long as the cow is at least 90 days post-calving.^{14,17} Both these tests offer producers options for employing methods to manage repeat insemination in open dairy cows.

Veterinary reproductive diagnostic programs interface with management in controlling days between sequential inseminations. The value in reduction in days to pregnancy is a function of the value of a day open.⁹ The relative value of the diagnostic test is determined by the reduction in days relative to not having performed the test multiplied by the proportion of cows influenced by the test. Therefore the value of pregnancy diagnosis will be influenced by the time post-insemination the test may be performed, the proportion of cows available to be tested, and the errors associated with the test. Costs associated with testing include the test itself, factors associated with employing the test (for the veterinarian: the trip fee to the farm; for the producer: the time spent to perform the herd check or bleeding cows, for the blood test, the cost of mailing and time waiting for information), and possible losses associated with misdiagnosis or time delays due to a questionable diagnosis which requires re-testing at a later period.

The distribution of days between inseminations is presented in Table 1 for several scenarios. The days are divided into categories as follows: <10 days (heat detection errors); 10 to 17 days (heat detection errors and short intervals); 18 to 24 days (normal estrous interval); 25 to 35 days (heat detection errors, extended interval due to EED); 36 to 48 days (a long interval due to a missed earlier estrus or a long interval due to EED); ≥ 49 days (long intervals). The proportion of cows that have a period over 48 days between inseminations ranges from 5.6% to 51.9% (Table 1). The proportion over 48 days is related to the HDR and the reproductive management program employed by the farm management. Since most pregnancy tests are only viable at the earliest 26 to 28 days post-insemination and at best only 60% of cows can only be induced into estrus for re-insemination by 3 to 5 days after a diagnosis of not pregnant with a PGF injection, routine pregnancy testing can only significantly reduce the proportion of cows that have more than 48 days between inseminations.

The proportion of pregnancies lost from the days post-insemination of a first pregnancy diagnosis to a second confirming diagnosis of pregnancy at 65 to 70 days post-insemination are presented in Figure 2 (early embryonic [and fetal] death). First diagnosis of pregnancy was made by various methods depending on the day of examination and the figure is a compilation across multiple studies (references available on request) in dairy cows. The proportion of pregnancy loss is high at 21 to 24 days post-insemination. From 5 to 25% of pregnancies were lost by 65 days post-insemination in studies where first examination was made at 26 to 32 days post-insemination (Figure 2). Losses were 5 to 19% when first examination was between 37 to 45 days post-insemination and only 2% when first examination was at 50 days post-insemination (Figure 2). Embryonic and fetal loss is variable between studies and therefore it would be expected to be variable across herds. It may be expected that EED would influence the value of early pregnancy diagnosis by increasing the apparent “false pregnancy” diagnosis via higher pregnancy loss post-diagnosis. This could extend days between insemination in a proportion of cows by withholding them from re-breeding for a period of time. Slightly later pregnancy testing will be associated with less EED, reducing “false pregnancy” diagnosis, but increasing days between insemination for cows not pregnant at diagnosis. Early pregnancy diagnosis (28 to 32 days) has value in identifying open cows sooner, but has a negative value in determining pregnancy in a proportion of cows that will be open in the next seven to 14 days, which may delay repeat insemination in this group of animals if not seen in estrus and re-examination does not occur until 65 days post-insemination. Thus, early open diagnosis must be weighed against increased EED in pregnant cows when examined early post-insemination.

Materials and methods

Several models were constructed based on a decision tree for flow of pregnant and open cows presented in Figure 3. Pregnancy was modeled based on the structure of pregnancy losses in Figure 2 as follows:

CR (defined as pregnant cows by days post-insemination) = $0.37 + 107.1 * \exp(-0.2845 * d)$; where d = days post-insemination. The intercept, 0.37, was then varied to examine CR from 0.22 to 0.54 with a similar form of EED.

Embryonic and fetal losses by 65 days post-insemination as a function of days post-insemination was modeled from figure 2 as follows:

$EED = -0.02 - 50 * \exp(-0.23 * d)$; where d = days post-insemination.

All models were constructed to control number of days to next insemination in open cows and cows with EED following a prior first service. Days to next insemination were either determined by HDR or were based on assigning cows to a re-synchronization program at time of pregnancy diagnosis. Mean days to next insemination for an underlying HDR was estimated as $21 * 1 / HDR$. Days to next insemination were valued based on the cost of a day open, which ranged from \$2.00 to \$5.00. Diagnostic tests for pregnancy were valued as the reduction in days to next insemination possible through routine herd visits compared to a management program with no pregnancy testing and days to next insemination was managed based on HDR.

The first model examined the influence of HDR and CR on the value of time of pregnancy testing from 21 to 60 days post-insemination. Heat detection rate and CR could vary; EED was set to zero. This model was used to examine the general value of time of examination post-insemination with varying HDR and CR when sensitivity and specificity were 100%. Cost of examination was \$3.00 and value of a day open was \$2.25.

Secondly, a model was constructed to compare three time periods post-insemination for pregnancy diagnosis: 28 days, 32 days and 39 days. This model was used to examination the interactions of sensitivity and specificity of a test on the value of the test. Sensitivity and specificity were varied from 70% to 100% and EED was varied by time post-insemination by weighting the coefficients in the model

described above. Pregnancy losses varied at 28 days post-insemination from 5.6 to 19.5%, at 32 days from 2.3 to 12.4%, and at 39 days post-insemination from 0.3 to 3.3%. Cows which lost a pregnancy could first be seen in estrus by one week after pregnancy loss and then 21 days later if not inseminated. If not seen in estrus, they were examined at 65 days, along with all previously pregnant cows, and if open, assigned to a re-synchronization program. The value of a day open was \$2.25 and the cost of a test was \$3.00.

A third model was constructed to evaluate three pregnancy test programs: US begun at 26 days post-insemination; RP begun at 35 days post-insemination; and BP begun at 32 days post-insemination. These programs were then modeled for a herd visit weekly, biweekly, triweekly (data not shown), or monthly. Cost of tests varied between \$1.00 to \$9.00 for US, \$0.50 to \$5.00 for RP, and \$2.00 to \$6.00 for BP. Trip fee for US and RP examinations varied from \$9.00 to \$100, and cows examined per test period ranged from 1 to 100 animals.

The basis of each test was the identification of true pregnancies (sensitivity of the test) and true open cows (specificity). Sensitivity and specificity for each test were varied from 0.8 to 1.0. A decision tree was constructed based on possible diagnostic findings at pregnancy examination: a cow may be found open (not pregnant), pregnant, or be classified for re-examination if diagnosis was not clear (questionable diagnosis). Data for BP suggest that 10% to 15% of samples may have questionable diagnosis. These cows were retested at the next scheduled herd test for model three, which was weekly, biweekly, triweekly, or monthly. Pregnant cows could lose the pregnancy as a function of a model fit to the loss data in Figure 2 and as described above. Pregnancy losses varied at 28 days post-insemination from 5.6 to 19.5%, at 32 days from 2.3 to 12.4%, and at 39 days post-insemination from 0.3 to 3.3%. All pregnant cows at the first examination were re-examined at 65 days post-insemination. All EED cows could be observed in estrus beginning one week following the EED and then were assumed to have normal estrous cycles and were re-inseminated based on HDR.

For all programs and diagnostic tests, cows classified as open at examination were assigned to a re-synchronization protocol.^{11,12} Re-synchronization resulted in re-insemination of open cows ten days after the days at pregnancy test. False positive cows, cows diagnosed as pregnant that were open, lost days to next insemination due to the false information and could be re-inseminated based on the HDR. False open cows, cows truly pregnant diagnosed as open, were aborted as they were placed into a re-synchronization program. This resulted in a days to next insemination of ten days from the time of examination. The cost of abortion of pregnant cows was assigned as marginal loss of -\$46. The additional loss assigned to an aborted cow was not the full value of the pregnancy, as these cows were re-inseminated within ten days from the time of examination. Superimposed on the value of test information for reproductive status is the frequency of herd visit, typically weekly, bi-weekly, or monthly.

Statistical models for models two and three combined categorical and continuous variables in regression models using PROC GLM in SAS statistical software. Statistical models examined value (value of reduced days open – cost of test and trip fee) as a function of HDR, CR, Exam, EED, sensitivity, and specificity. Models were as follows:

Model two: value = $u + \text{Exam}_k + \text{HDR}_i + \text{CR}_j + \text{EED} + \text{Sens} + \text{Spec} + e_{ijkl}$

Where u = overall mean,

Exam_k = the kth examination time post-insemination, 28, 32, 29,

HDR_i = ith HDR, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8,

CR_j = jth CR, 0.30, 0.40,

EED = as continuous variable from 1 to 6% of pregnancy,

Sens = sensitivity as a continuous variable from 0.7 to 1.0,

Spec = specificity as a continuous variable from 0.7 to 1.0,

e_{ijkl} = residual error

Model three regressed value of program (US examination beginning at 26 days post-insemination, RP beginning at 35 days post-insemination, and BP beginning at 32 days post-insemination) for herd visits

performed weekly, bi-weekly or monthly on the inverse of HDR, the inverse of CR, the percent EED based on time of examination, the number of cows tested at each frequency of test, the cost of herd visit, the cost of the test, the value of an open day, and the sensitivity and specificity of each test. In addition, the BP test had questionable test results. Up to three levels of interaction between variables of inverse HDR, CR, sensitivity and specificity were included in the model. Backward elimination was performed when three way interactions were not significant. Proc GLM in SAS statistical software was used with the solution option for the regression analysis.

Results and discussion

A total of 882 and 2005 simulations were done for model two and model three, respectively. Model one was used to examine the influence of HDR and CR on losses based on days to next insemination in a deterministic fashion. In general, pregnancy testing prior to 42 days (36 to 48 days) post-insemination is more valuable than after 42 days, as this corresponds to open cows passing through a second opportunity for estrus detection and re-insemination, reducing the proportion of open cows the test may benefit (Figure 4). As HDR increased the value of pregnancy testing decreased. As HDR increases to 70%, pregnancy testing becomes less valuable, and may be negative in value even prior to 36 (42) days because more cows are observed in estrus and re-inseminated. An increase in CR has a similar influence on decreasing value of examination, but the influence has less magnitude than for HDR (Figure 5).

After a pregnancy test, the probability of re-insemination has to be increased by 50% or more for the pregnancy test to be of value.⁷ Not shown is the influence of the boost in HDR needed for the examination to be profitable. Model one assumed a 100% efficiency in boost in re-insemination; if the boost in re-insemination efficiency declined below 60%, the value of a pregnancy test prior to 42 days was lost. This is slightly higher than that observed by Oltenacu et al,⁷ but the relative value will be influenced by the value of a day open and cost of the test.

Oltenacu et al found that risk of aborting a cow had to be less than 5% for RP to be profitable.⁷ In model two, the risk of aborting a pregnant cow was related to sensitivity of the test, as cows diagnosed as open were assigned to a re-synchronization program. In Figures 6 and 7 and Table 2 the influence of sensitivity and specificity of a pregnancy test on value of the test is presented. The influence of sensitivity is almost four-fold the effect of specificity (Table 2) and the relative value of pregnancy testing becomes negative with decreasing sensitivity below 90% with varying HDR and CR (Figure 6). Specificity can decrease to 70% and still have a positive value with varying CR and HDR (Figure 7). Reducing sensitivity decreased the value of pregnancy diagnosis due to losses associated with aborting a cow through missed diagnosis as open. These cows were assigned to a re-synchronization program, forcing re-insemination in ten days. This reduced the losses of aborting a pregnant cow compared with losses due to damage to the embryo, which may delay diagnosis to time of re-examination and prolong time to re-insemination, increasing possibility of culling due to long days open. It is likely that RP would have the greatest probability of causing abortion compared to US, and the BP test would have little chance of inducing abortion.

Decreasing specificity in model two was associated with decreasing test value, as cows falsely diagnosed as pregnant were not assigned to re-synchronization, and these cows may not be found open until re-examination at 65 days. Increasing HDR decreased these losses, as open cows would have a higher probability of being seen in estrus at an earlier time than 65 days at re-examination. If specificity of a test is low, it may be more profitable to re-examine pregnant cows sooner than 65 days, particularly if scheduled visits are done frequently, but the test would need to have a high sensitivity.

In general RP, US, and BP tests increase in sensitivity with time post-insemination and false diagnosis should decline with time post-insemination.^{13,15-17,19} Pregnancy losses after re-examination increase the risk of culling, as these cows will not be re-examined, and therefore become more costly. This was not modeled in this paper.

In model two, questionable diagnosis was assessed based on 0 to 15% of examinations. Cows with questionable diagnosis were re-examined at the next scheduled herd visit, weekly, bi-weekly, or monthly. Later examination improved sensitivity and specificity of all tests. Questionable diagnosis was

not as negative as decreasing sensitivity or specificity, particularly on a one week program, as cows were more likely to have a correct diagnosis and, if open, be re-assigned to a re-insemination program sooner. Cost of examination increased slightly, but if a herd visit was scheduled, or if blood samples scheduled for collection, then the cost was small compared to the error of a false diagnosis. The BP test is more likely to have a questionable diagnosis than RP or US. Questionable diagnosis with re-examination was preferable to false diagnosis. A problem with RP and US is that operators tend to view their diagnosis as 100% accurate, when they are not. Thus, questionable diagnosis may be overlooked as an option in fewer examinations than should be.

Factors identified as significant in model one and two which influence the value of a pregnancy test include underlying HDR and CR, time post-insemination the test is done, the sensitivity and specificity of the test, and abortion caused by the test. This is consistent with Galligan et al who found HDR and sensitivity of a test the two major factors influencing value.⁹ In general, the test should be as early as possible post-insemination, it should be combined with a re-synchronization program, and it should have a high sensitivity.

Model three compared three programs: US examination at 26 days, BP test at 32 days, and RP at 35 days post-insemination, scheduled at varying frequencies (Tables 3, 4 and 5). For weekly herd visits, the US model examined cows from 26 to 32 days post-insemination; for the BP test cows were tested from 32 to 38 days post-insemination; for RP cows were tested from 35 to 41 days post-insemination. The days post-insemination were increased for the bi-weekly and monthly herd visits based on the time interval of visits. For model three, sensitivity and specificity varied from 80 to 100%, the baseline level of 80% determined from model two. These ranges included reported or calculated sensitivity and specificity of US, RP, and the blood pregnancy test.^{13,14,16,20,21} Overall, all three tests had similar sensitivity and specificity, but optimal time of examination differ.

Two thousand five simulations were run to examine the value of the three methods and programs. Cows available for examination for each test period ranged from 1 to 100 cows, with a mean of 15.9 (sd 12.0) cows, which would correspond to a herd size of approximately 500 cows having a weekly herd check. The mean trip fee was \$50.00 (sd \$25.10) and ranged from \$9 to \$100 per visit. Mean value of days open was \$2.80 (sd \$ 0.70) and ranged from \$2.00 to \$5.00. Mean value for HDR was 0.477 (sd 0.21, range 0.1 to 0.9) and mean value for CR was 0.38 (sd 0.06; range 0.222 to 0.517). Embryonic mortality was modeled based on Figure 2 and was higher for earlier examinations. Questionable diagnoses were re-examined at the next scheduled herd test.

Mean values for benefit of the three programs by HDR were similar (Table 3) when sensitivity and specificity and costs of the tests were similar and the average trip fee was \$50.00 and 15 cows were examined at each period. Weekly and bi-weekly programs were not greatly different in value, although biweekly programs tended to have slightly lower value relative to weekly visits (Table 3; Figure 8 presents the difference in biweekly and monthly programs relative to a weekly herd program). Weekly and bi-weekly programs were similar as most cows were examined prior to 42 days post-insemination. Monthly (and tri-weekly, data not shown) programs had a lower value as more cows were examined after 42 days post-insemination, giving a second opportunity for estrus detection, reducing open cows that could be managed by the test. It was anticipated that EED would influence the time of the test, but the effect was not significant even with rates varying from 4 to 20%, particularly for US at 26 days.

In general, values for all three weekly programs were very similar as a function of HDR (Figure 9). Each program became negative in value when HDR exceeded 60%. Low HDR herds obtain the greatest benefit from a consistent program. Possibly depending on labor costs for HDR on a dairy, herd managers should consider using routine herd programs to control post-insemination and eliminate HDR. This would depend on relative costs of herd testing versus labor for heat detection.

Table 4 presents regression models for the weekly herd visits for the three pregnancy tests. Heat detection rate and CR had significant interaction influencing value of testing in all programs, which is not surprising given the data in model one. Interestingly, HDR interacted with sensitivity and specificity as did sensitivity and specificity with each other. This interaction represents changing predictive value positive and negative with changes in underlying prevalence of open and pregnant cows at examination.

Heat detection rate (and to a lesser extent CR) strongly influence open cows at time of examination, altering prevalence, changing predictive values for the tests. These interactions capture this effect. Surprisingly, cost of an US test, varying between \$1 to \$9, did not significantly influence value of examination. Cost of RP and to a lesser extent, cost of the BP test influenced value. Possibly this was related to the earlier time of examination in the US program versus the BP and RP programs.

Trip fee (for RP and US) and number of cows tested at examination did influence value of a test and the program. As cost of herd visit increased, value of US and RP declined. This did not influence BP, as no herd visit is associated with the test. In general, if fewer than ten cows were tested then BP test was more valuable than US or RP (Figure 10, Table 5). However, this benefit may change with differences in sensitivity and specificity and cost of test (Table 5). If the sensitivity or specificity of the BP test decreased then US became more valuable a test at similar costs. Rectal palpation in general was less valuable, as it was performed later days post-insemination. However, if RP at 39 days were combined with routine GnRH at 32 days in all cows in a re-synchronization program, then RP may be a more valuable option. This was not modeled in this paper and would depend on relative costs of GnRH and RP.

Based on published literature, sensitivity of US and RP have a value of 0.97 and a specificity of 0.87.^{13,15,16} The BP test has a sensitivity of 0.90 to 0.95 and a specificity of 0.85 to 0.90.^{13,14,20} If costs of the tests are \$2.75 to \$3.00 and a trip fee is \$50 and at least ten cows are examined each week, then relative values of the programs would be: US, \$37.00; RP, \$35.10; BP, \$37.80 to \$34.96, with lower or higher specificity. These values are similar and suggest there is no strong economic difference among the tests. Herd managers should select a program which integrates with their management system and affords them the greatest flexibility in managing their time for pregnancy testing. The effects of management were not included in this model.

Conclusion

At the sensitivity and specificity (80 to 100%), questionable diagnosis (10 to 15%, for the BP test) and cost (\$2.00 to \$5.00 per test) examined in this study, US, RP, and BP provide similar options for producers for pregnancy testing, if incorporated with a herd re-insemination program. The value of all three tests was influenced by underlying heat detection and CR. Heat detection had the greatest influence on the value of the tests, value decreasing with increasing HDR. Weekly or biweekly test intervals are more valuable than monthly or tri-weekly intervals (not shown), even when only one to two cows are tested, particularly for the BP test when there are fewer than ten cows to examine. Producers and veterinarians need to design herd programs which integrate pregnancy testing with re-insemination programs which have the greatest utility for the producer.

Questionable diagnosis was not as negative, as cows were re-examined one week later, increasing cost of examinations to a small extent, but not aborting cows by assigning them to re-synchronization programs and more quickly assigning open cows to re-insemination.

After first insemination, identifying pregnant and non-pregnant (open) cows as early as feasible has economic value to the producer if open cows can be re-inseminated more quickly.^{7,8} Re-synchronization protocols^{11,12} have been effective when GnRH injections have been initiated between 25 to 33 days post-insemination. This requires an accurate pregnancy diagnosis prior to an injection of PGF one week following the GnRH injection. Pregnancy diagnosis may be made using the blood BP test, US, or by RP.¹² What has become apparent with earlier pregnancy diagnosis is the high rate of EED which occurs between 28 to 42 days post-insemination and continues up to 90 days post-insemination. Embryonic loss rates from 28 to 42 days have typically been in the range of 10 to 20% and have averaged about 14%.^{22,23} Fetal loss from 42 days to 90 days has been lower, but still has been in the range of 5%.^{22,23} In fact, using serum progesterone concentrations at 20 to 23 days post-insemination, 60% to 70% of cows have elevated progesterone,²⁴ suggesting they are not returning to estrus, but only approximately half of these cows are pregnant by 30 to 40 days post-insemination. Reproductive efficiency is greatly reduced by the high loss of embryos from 21 to 42 days post-insemination. Twin pregnancies, low body

condition, uterine infection, and heat stress have been implicated as causes²³ but many losses occur with no apparent cause.

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Table 1. Distribution of days between inseminations (%) of inseminations and mean interval between first and second service.

Herd	Num.	<10	10-17	18-24	25-35	36-48	>=49	Mean, days
HDR40	563	0.9	4.4	15.1	12.4	15.3	51.9	60.1
HDR70	1596	6.9	3.3	47.9	18.6	11.9	11.4	32.8
ReSynch-32d	1636	0.6	1.1	6.1	3.6	78.0	10.7	44.2
USSynch-26d	843	4.4	4.5	21.9	46.5	17.1	5.6	31.2
HDRReSynch-39d	509	5.3	4.9	44.0	13.9	10.4	21.41	31.1
BioPryn	625	1.1	2.7	15.2	5.9	62.2	12.8	69.8

HDR40: Herd using heat detection to manage reproduction with a 40% efficiency of detection

HDR70: Herd using heat detection to manage reproduction with a 70% efficiency of detection

ReSynch-32d: Herd using a Pre-Synch first insemination program and a Re-Synch program in open cows beginning at 32 days post-insemination with rectal palpation at 39 days and non-pregnant cows injected IM with PGF and given GnRH two days later and re-inseminated 16 hours later.

USSynch-26d: Herd using ultrasound examination to diagnose open and pregnant cows at 26-32 days post-insemination and assigning cows to a re-synchronization program based on ultrasound scan of ovarian structures on a weekly schedule

HDRReSynch-39: A herd using heat detection for post-insemination management and palpation of cows not re-inseminated by 39 days post-insemination and assigning non-pregnant cows to a re-synchronization program

BioPryn: Herd using re-synchronization program based on blood pregnancy examination at 32 days post-insemination with low intensity estrus detection.

Table 2. Regression output for model two examining value of pregnancy testing for varying heat detection rate (HDR) conception rate (CR), early embryonic death (EED), examination day (EXAM), sensitivity and specificity of the test. Number of observations: 882.

Item	beta	sem	f-test	P<
EXAM 28	20.319	1.404	14.47	<.0001
EXAM 32	20.555	1.401	14.67	<.0001
EXAM 39	18.326	1.402	13.07	<.0001
CR 0.3	3.947	0.178	22.17	<.0001
CR 0.4	0	.	.	.
HDR 0.3	26.036	0.318	81.98	<.0001
HDR 0.4	18.508	0.308	60.01	<.0001
HDR 0.5	11.997	0.318	37.77	<.0001
HDR 0.6	7.068	0.319	22.14	<.0001
HDR 0.7	3.133	0.304	10.31	<.0001
HDR 0.8	0	.	.	.
EED	-81.857	1.100	74.39	<.0001
Sensitivity	46.733	0.919	50.87	<.0001
Specificity	13.408	0.960	13.97	<.0001

R2 = 0.958

Value is calculated as the difference in reduction in mean days to re-insemination for HDR detection alone ($21 \cdot 1/\text{HDR}$) compared with identification of nonpregnant cows at three days post-insemination (28, 32, or 39 days) and assigning open cows to a post-synchronization program on day of examination. The difference in days is multiplied by the value of a day open, \$2.25, to assign a monetary value. Cost of test, \$3, and trip fee per cow examined, \$2, are subtracted from the value difference.

Early embryonic death (EED) is indexed from 0.8 to 1.0 to effect pregnancy loss rates of 1% to 6% at 32 days post-insemination.

Range in sensitivity and specificity: 0.7 to 1.0.

Table 3. Least square means for three pregnancy tests as a function of heat detection rate and schedule of herd visits.

HDR	US_26	sem	RP_35	sem	BP_32	sem

Weekly visit						
0.1	-197.46	1.52	-196.62	1.55	-201.48	1.46
0.2	-98.69	1.08	-96.23	1.09	-98.63	1.03
0.3	-43.11	0.91	-39.62	0.92	-42.53	0.87
0.4	-20.03	0.97	-17.14	0.99	-19.68	0.93
0.5	-7.19	0.94	-4.45	0.96	-7.59	0.90
0.6	0.48	0.96	2.91	0.98	-0.09	0.92
0.7	4.79	0.93	6.54	0.95	3.22	0.90
0.8	6.61	1.20	8.50	1.22	4.77	1.15
0.9	1.77	2.70	3.49	2.74	0.82	2.59
Biweekly visits						
0.1	-200.05	1.51	-188.98	1.46	-189.53	1.36
0.2	-98.24	1.06	-88.45	1.03	-88.08	0.96
0.3	-40.08	0.89	-32.74	0.86	-34.32	0.81
0.4	-17.14	0.96	-11.70	0.93	-13.50	0.87
0.5	-4.33	0.93	-0.53	0.90	-3.65	0.84
0.6	2.87	0.95	5.25	0.92	2.18	0.86
0.7	6.83	0.92	8.31	0.89	4.61	0.83
0.8	8.12	1.19	9.22	1.15	5.28	1.07
0.9	-0.09	2.67	1.95	2.58	0.11	2.41
Monthly visits						
0.1	-182.19	1.43	-175.31	1.38	-170.70	1.25
0.2	-82.04	1.00	-76.74	0.97	-72.45	0.88
0.3	-27.28	0.85	-23.90	0.82	-22.89	0.74
0.4	-7.80	0.91	-5.37	0.88	-5.51	0.80
0.5	2.03	0.88	3.69	0.85	1.56	0.77
0.6	6.66	0.90	7.68	0.87	5.06	0.79
0.7	8.82	0.87	9.50	0.84	5.93	0.77
0.8	9.07	1.12	9.68	1.09	5.70	0.99
0.9	1.47	2.52	2.91	2.45	1.30	2.22

US_26 = Ultrasound examination for pregnancy performed at a minimum of 26 days post-insemination

RP_35 = rectal palpation for pregnancy examination performed at a minimum of 35 days post-insemination

BP_32 = blood pregnancy protein test performed at a minimum of 32 days post-insemination

Sensitivity and specificity of tests ranged from 80% to 100%; all open cows re-assigned to a post-synchronization program and re-inseminated within 10 days of the test; mean CR was 0.36 and mean trip fee was \$50 and cost of mean cost of tests \$3.00.

Negative values indicate more value relative to the underlying heat detection rate in the herd.

Positive values indicate the test had less value than the herd program

Table 4. Value of three weekly reproductive test programs, ultrasound examination at 26 to 32 days, rectal palpation at 35 to 41 days, and blood pregnancy test 32 to 38 days post-insemination as a function of heat detection rate, conception rate, cost of trip to farm, number of cows tested weekly, value of a day open, early embryonic death (EED) for each test at 28, 35 and 42 days post-insemination, cost of test, and sensitivity and specificity of each test.

	R2			0.949			Rectal palpation weekly			0.946			Blood test weekly			R2		
	beta	sem	t_test	P<	beta	sem	t_test	P<	beta	sem	t_test	P<	beta	sem	t_test	P<		
Intercept	-586.300	107.363	-5.46	<0001	-506.146	107.319	-4.72	<0001	-623.576	105.130	-5.93	<0001						
Inverse HDR	202.685	29.899	6.78	<0001	170.259	29.225	5.83	<0001	191.778	28.922	6.63	<0001						
Inverse CR	-4.816	1.184	-4.07	<0001	2.378	1.229	1.94	0.0531	1.503	1.170	1.29	0.1989						
InverseHDR*InverseCR	1.941	0.346	5.6	<0001	-4.232	0.359	-11.8	<0001	-3.956	0.342	-11.58	<0001						
Trip Fee	-0.113	0.012	-9.49	<0001	-0.107	0.012	-8.65	<0001										
Number Cows Tested	-0.211	0.025	-8.48	<0001	-0.201	0.026	-7.77	<0001	0.058	0.023	2.52	0.0118						
Value of DaysOpen	11.541	0.421	27.43	<0001	11.257	0.437	25.77	<0001	-21.026	16.844	-1.25	0.2121						
EED, 28, 42, 35	4.733	4.775	0.99	0.3217	-177.675	64.647	-2.75	0.006	10.409	0.411	25.3	<0001						
Cost of Test	-0.292	0.423	-0.69	0.4901	-1.291	0.485	-2.66	0.0079	-0.827	0.480	-1.72	0.0849						
Sensitivity of Test	724.968	118.995	6.09	<0001	604.407	118.872	5.08	<0001	733.165	116.562	6.29	<0001						
InverseHDR*Sensitivity of test	-233.160	33.242	-7.01	<0001	-178.874	32.244	-5.55	<0001	-201.816	32.106	-6.29	<0001						
Specificity of test	781.747	118.515	6.6	<0001	645.653	118.846	5.43	<0001	795.035	116.202	6.84	<0001						
InverseHDR*Specificity of test	-262.274	33.015	-7.94	<0001	-200.269	32.557	-6.15	<0001	-232.744	31.961	-7.28	<0001						
Sensitivity*Specificity of test	-839.628	131.098	-6.4	<0001	-684.152	131.390	-5.21	<0001	-844.725	128.509	-6.57	<0001						
InverseHDR*Sensitivity*Specif icity of test	259.647	36.685	7.08	<0001	190.568	35.953	5.3	<0001	224.772	35.461	6.34	<0001						

Inverse HDR = 1/ HDR, range HDR 0.3 to 0.9, mean HDR 0.477 sd 0.210
 Inverse CR = 1/CR, range CR 0.22 to 0.51, mean CR 0.385 sd 0.059
 Trip fee, cost of weekly herd visit, range \$9.00 to \$100, mean \$50.7 sd 25.0
 Number of cows tested each week: range 1 to 100, mean 15.9 sd 12.0
 Value of days open, range \$2 to \$5, mean \$2.81 sd 0.70
 EED28: range 4.2% to 30.9%, mean 11.5% sd 5.85
 EED35: range 2.3% to 10%, mean 4.1%, sd 1.6%
 EED 42 range 2% to 4.2% mean 2.5% sd 0.4%
 Sensitivity of tests: range 0.8 to 1.00, mean 89.8 sd 4.9
 Specificity of tests: range 0.8 to 1.0, mean 90.1 sd 4.8
 Cost of tests: Ultrasound range: \$1.00 to \$9.1, mean \$3.08 sd 0.66;
 Rectal Palpation range: \$0.50 to 5.000, mean \$2.97 sd 0.60
 Blood Test range: \$-2.00 to \$6.00, mean \$3.05 sd 0.57

Table 5. Relative value for ultrasound examination at 26 days for pregnancy (US_26), rectal palpation at 35 days for pregnancy (RP), and blood pregnancy test at 32 days (BP_32) for varying costs, number of cows examined and sensitivity of tests.

Input Items		Sensitivity/Specificity			Test value, \$-----		
Trip, \$	Num	US	RP	Blood	US_26	RP	BP_32
Cost per cow, \$					3.00	3.00	2.75
50	20	95/95	95/95	95/95	21.90	19.61	20.06
50	20	85/95	85/95	85/95	19.04	16.91	17.47
50	20	85/85	85/85	85/85	15.42	13.52	14.23
50	10	95/95	95/95	95/95	19.40	17.11	20.06
50	12	95/95	95/95	95/95	20.23	17.94	20.06
Cost per cow, \$					2.13	0.00	2.75
50	10	95	95	95	20.06	19.36	20.06
Cost per cow, \$					3.00	3.00	5.00
50	10	95	95	95	19.40	17.11	18.28
50	10	85	85	85	16.54	14.41	15.89
Cost per cow, \$					3.00	0.00	2.75
50	12	95	95	95	20.23	20.20	20.06
Cost per cow, \$					3.00	3.00	2.75
100	30	95	95	95	21.07	18.78	20.06
100	30	85	85	85	18.21	16.08	17.66
100	20	95	95	95	19.40	17.11	20.06

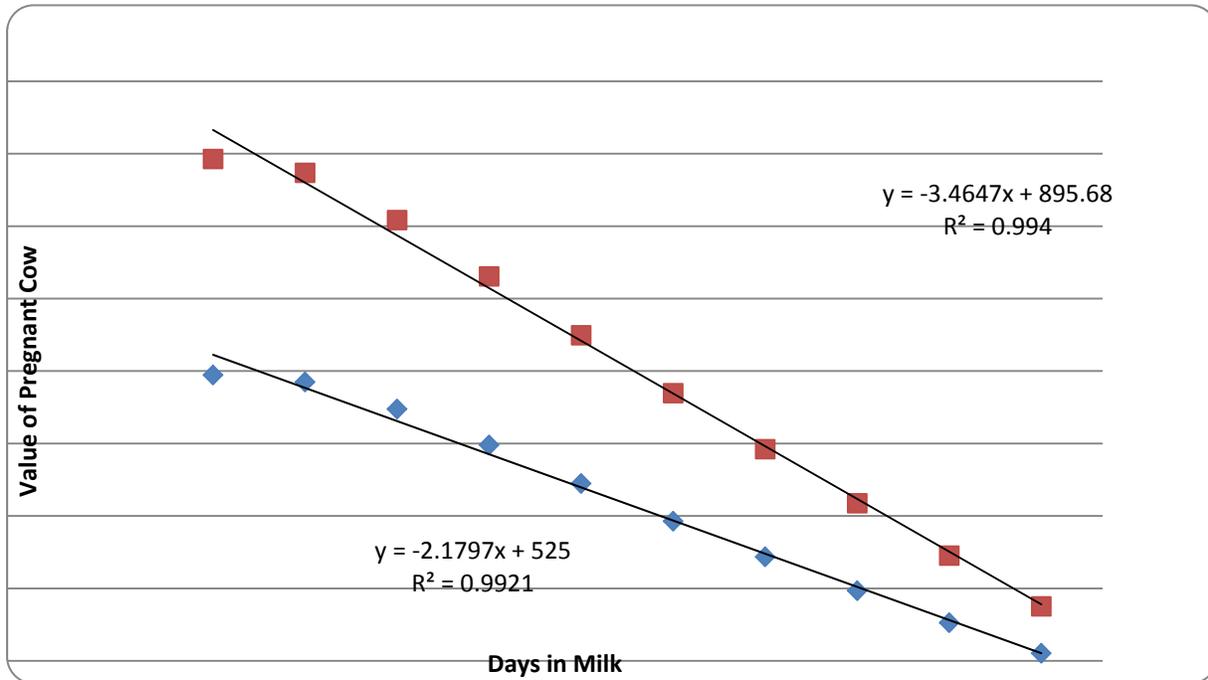


Figure 1. Value of a pregnant cow at two different values of milk, \$0.10/lb and \$0.17/lb. 1b. Data presented as a value of a day open, with milk at \$0.10/lb value is \$2.18/day, with milk at \$0.17/lb value is \$3.46/day. Value declines as days in milk increases.

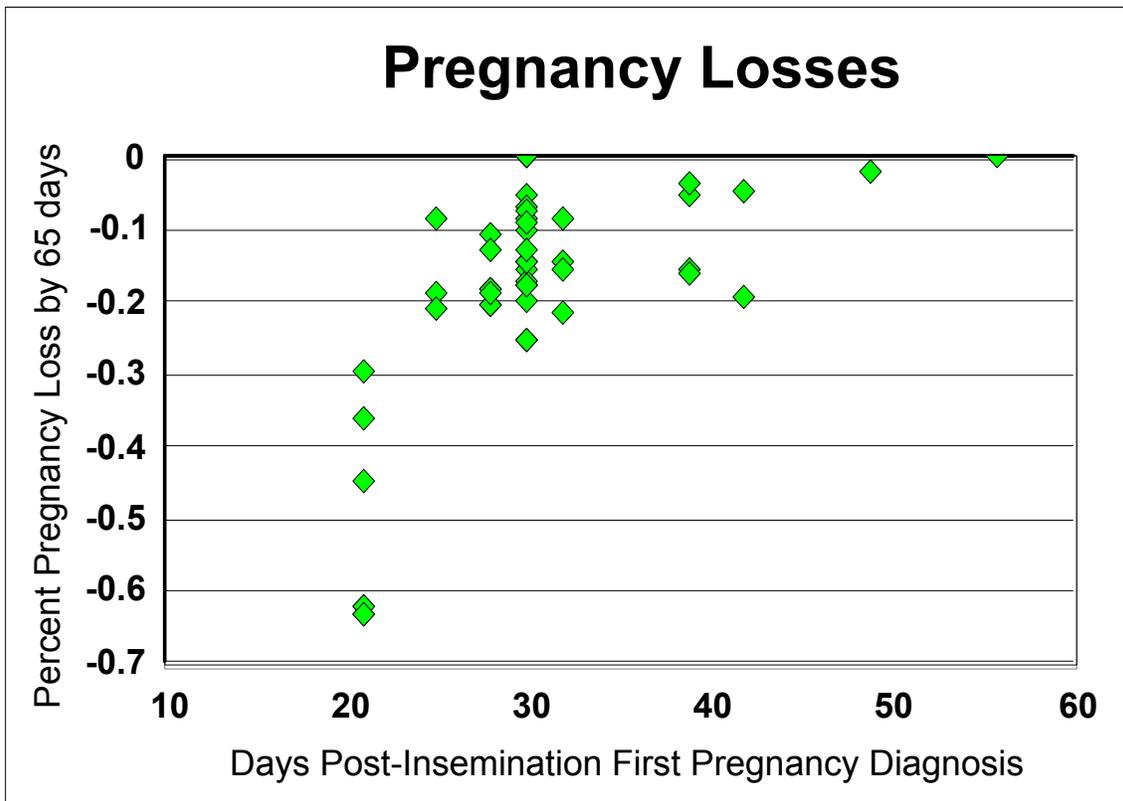


Figure 2. Proportion of pregnancies lost by 65 days post-insemination from time of first insemination. Data collected from multiple diagnostic tests used for first diagnosis of pregnancy based on either progesterone concentration (first examination 21 days), ultrasound, rectal palpation, and ruminant blood pregnancy protein – B. Re-examination for pregnancy at 65 – 70 days was by rectal palpation.

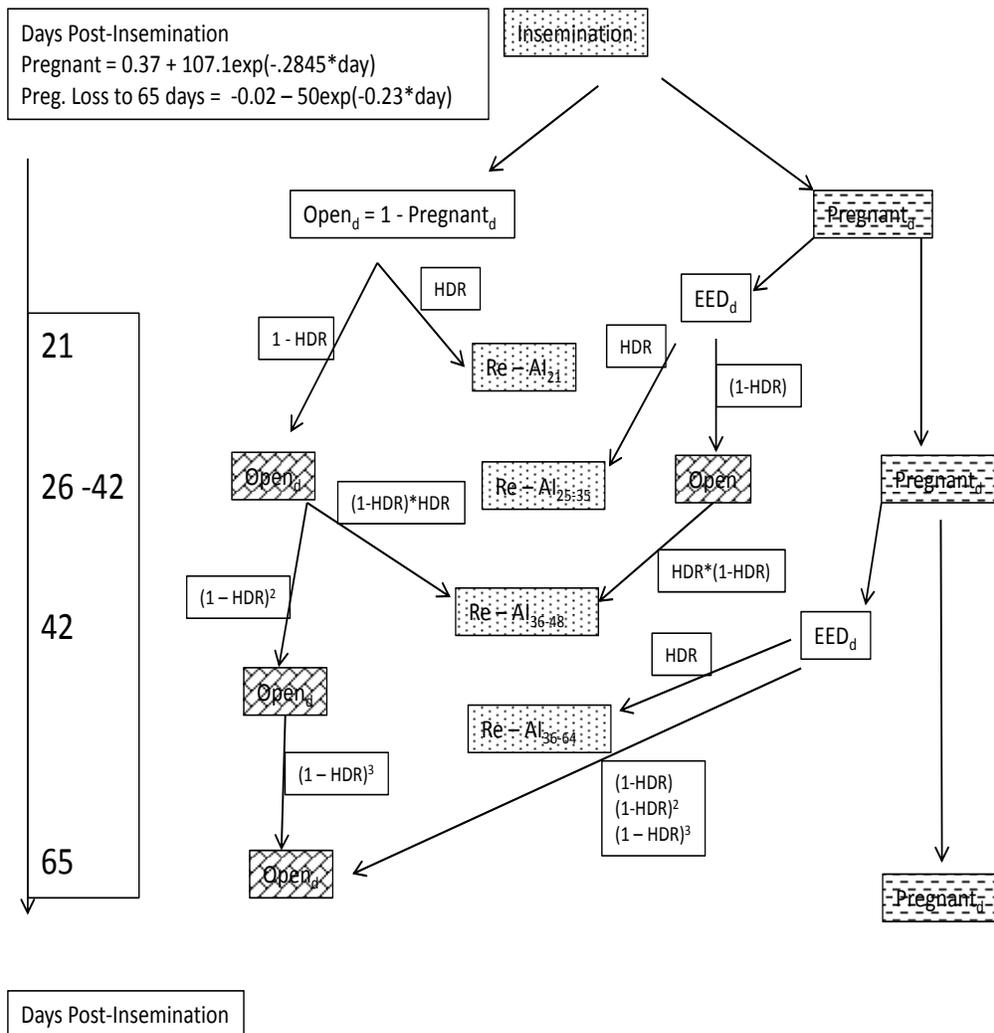


Figure 3. Schematic of pregnant and open cows by time post-insemination. HDR = heat detection rate. EED = early embryonic or fetal loss. Pregnancy is a function of days post-insemination: $CR = 0.37 + 107.1 \cdot \exp(-0.2845 \cdot \text{day post-insemination})$; EED loss to 65 days postbreeding by day post-insemination = $-0.02 - 50 \cdot \exp(-0.23 \cdot \text{day post-insemination})$. Cows either open or pregnant at day of examination were functions of three rates: HDR, CR, and EED. HDR was varied from 0.10 to 0.90; CR varied from 0.22 to 0.52 by varying the intercept of the model; EED varied by day post-insemination at ranged from a proportion of 0.309 to 0.042 of pregnancies between 26 days to 32 days post-insemination; EED after this time ranged as a proportion of pregnancies from 0.10 to 0.02.

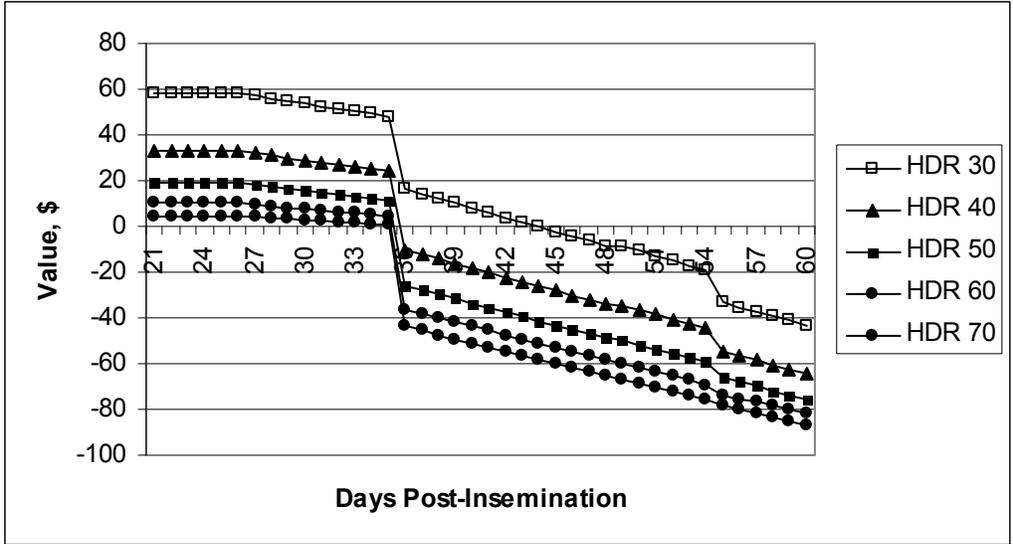


Figure 4. Influence of heat detection rate (HDR, %) on value of a diagnostic test to determine pregnancy and open status from 21 to 60 days post-insemination when non-pregnant cows are assigned for rebreeding. Sensitivity and specificity were set to 100% for the test. Embryonic mortality set to zero. Value of a day open was set to \$2.25 and cost of palpation to \$3.00 per cow. Steps are created by cows having an opportunity for a second and third estrus with time post-insemination, reducing the proportion of open cows at examination and reducing the possible reduction in days open from the baseline associated with HDR rates. Conception rate was 30%.

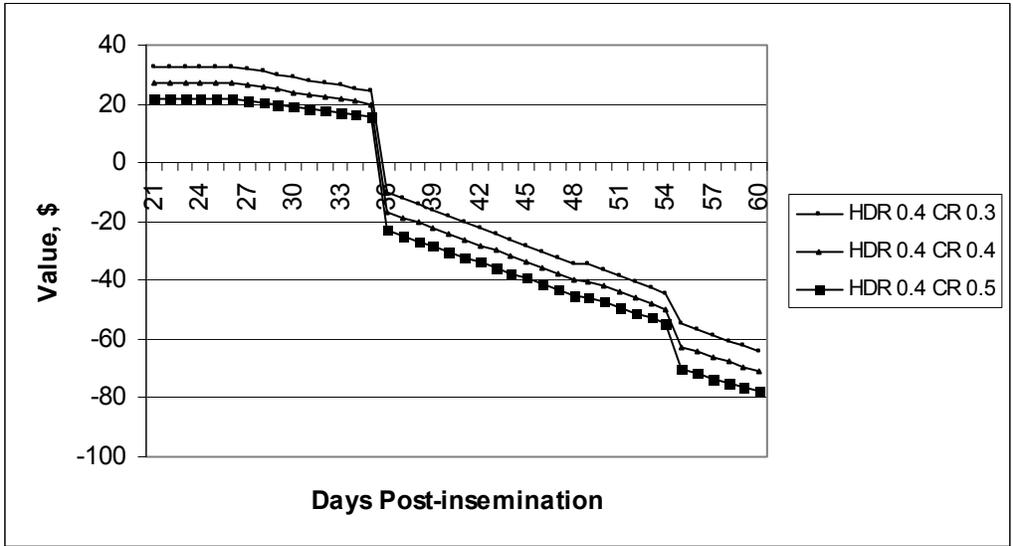


Figure 5. Influence of conception rate (CR) and heat detection rate (HDR) on value of pregnancy/non-pregnant diagnosis by days post-insemination. Sensitivity and specificity were set to 100% for the test. Embryonic mortality set to zero. Value of a day open was set to \$2.25 and cost of pregnancy test was \$3.00. As CR increases the value of the test decreases at a given HDR, represented here as 0.40.

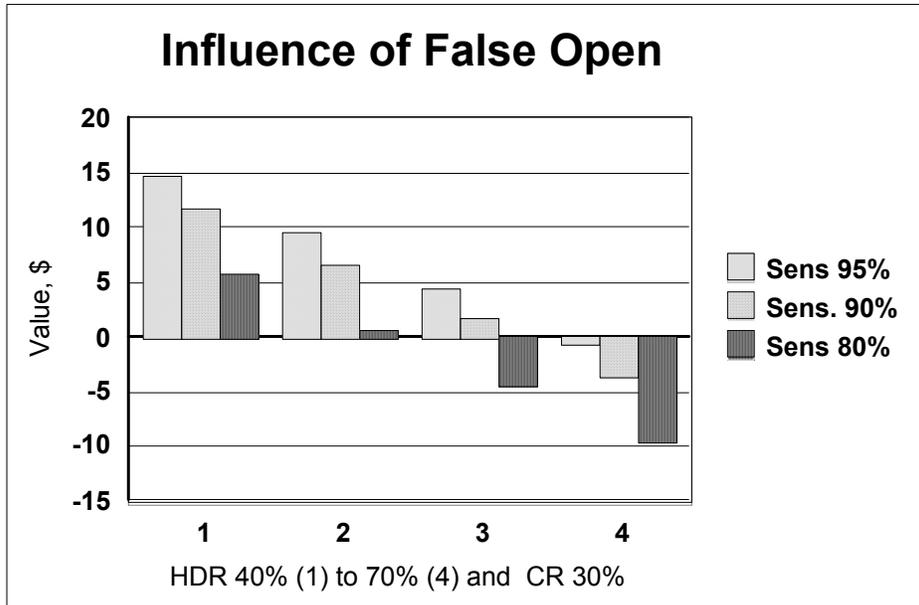


Figure 6. Influence of decreasing sensitivity and increasing false open diagnosis on value of examination at 32 days post-insemination with CR = 30% and HDR of 40% (1), 50% (2), 60% (3) and 70% (4) for controlling days to next insemination.

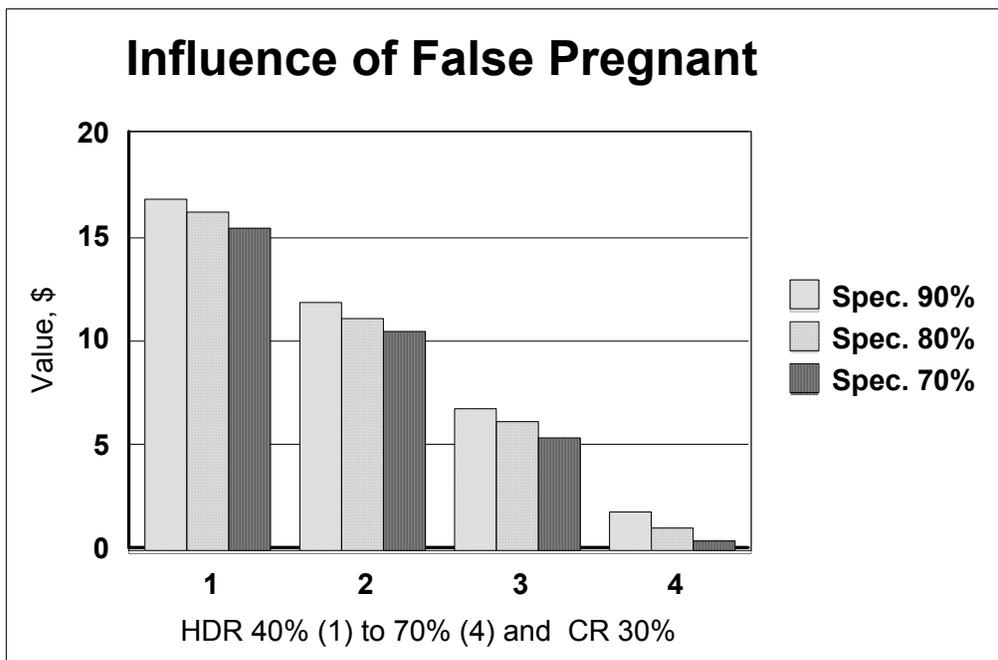


Figure 7. Influence of decreasing specificity (false pregnant) on value of examination at 32 days post-insemination with CR = 30% and HDR of 40% (1), 50% (2), 60% (3) and 70% (4) for controlling days to next insemination.

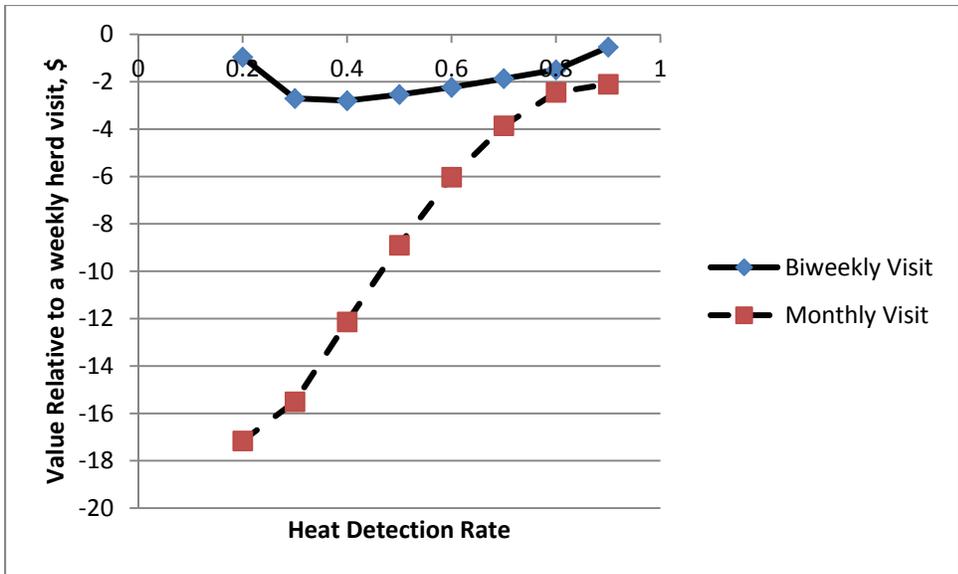


Figure 8. The relative value of biweekly and monthly herd visits compared to weekly visits in dollars at different heat detection rates.

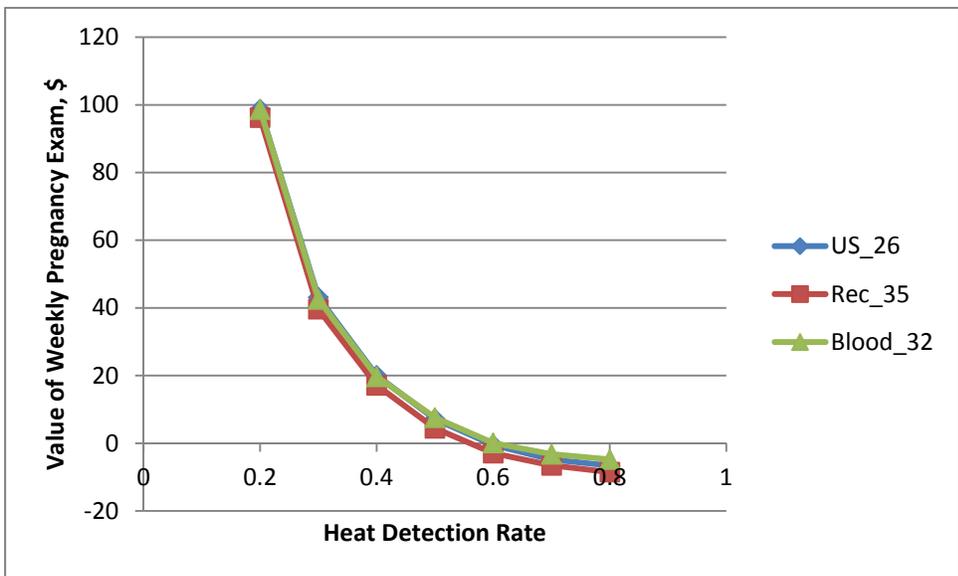


Figure 9. Relative values of ultrasound examination at 26 days (US_26), rectal examination at 35 days, and blood pregnancy test at 32 days (Blood_32) post-insemination as a function of heat detection rate.

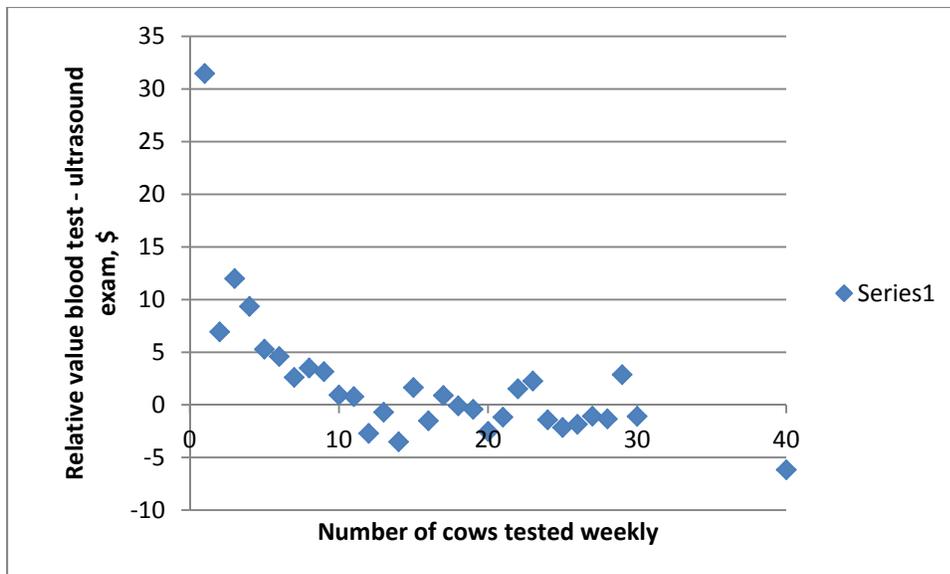


Figure 10. Relative value of ultrasound examination versus blood pregnancy test as a function of number of cows tested weekly. Cost of tests \$3.00, ultrasound test includes trip fee. Sensitivity and specificity of tests equal.