Assessing the Association of the Level of Milk Production with Reproductive Performance in Dairy Cattle

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Abstract. There is much debate about possible antagonism between high milk production and reproductive performance. This paper reviews methods of measuring reproductive performance and the association of the level of milk production with pregnancy rate at the herd and individual levels. The main question is whether fertility (the capacity for reproductive function and successful pregnancy) of dairy cows has in fact declined, as opposed to the success of management systems and people at meeting the metabolic, nutritional, housing, and social needs of increasingly productive animals but with no less inherent capacity to achieve and maintain pregnancy; and if fertility really has diminished, the extent to which this decline is caused by increased milk production. There is no doubt that production per cow has increased, but it is unclear how much of this increase can explain the apparent decrease in fertility. It is important to separate the biology of reproductive function from the effects of economically based management decisions about culling and continuation of breeding. Most traditionally-used measures of reproductive performance (calving interval, conception rate, non-return rate) are incomplete or severely biased outcome measures. Both herd and cow-level data should include as much information as possible on confounders of the relationship of production with reproduction. Population or herd-level data should not be used to make inferences about individual-level associations. Considering the quality of data and analytic methods in the published literature, it is not clear if there is any association between higher milk yield and the probability and timing of pregnancy, either among cows at various levels of production in a population at one time, or with increasing production over time.

Key words: Epidemiology, Management, Milk yield, Pregnancy rate, Selection

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Milk production and reproductive performance are two major determinants of dairy cow profitability. There is much debate among dairy producers and researchers about possible antagonism between high milk production and reproductive performance. Some worry about genetic selection for fertility or ask whether management can meet the needs of cows for both high production and timely and efficient pregnancy. This paper reviews methods of measuring reproductive performance and the association of the level of milk production with pregnancy rate at the herd and individual levels.

Many papers refer to a decline in fertility in dairy cattle over the last 20 to 30 years but valid primary data to support this assertion are scarce. While there are reports from 50 to 80 years ago expressing concern about reproductive performance and the effect of increasing production on it, it seems that measures of reproduction in large datasets only began to decline in the mid-1970's to mid-1980's [1–3]. In fact, very recent data suggest that the trend in the USA in some of the same measures has begun to improve [4] (despite ongoing increases in production per cow). There are a few frequently referred-to datasets [e.g., 2, 5, 6] that show an apparent decrease in conception risk over the last 50 years, during which time milk production per cow has increased substantially. These data warrant scrutiny. Temporal associations do not imply causation. Also, many aspects of dairy production have changed in the last two generations, so caution is needed in inferring a cause-and-effect relationship between high production and decreased repro-

ductive performance when the potential for confounding of the relationship is high.

Morton [7] reviewed studies examining the association of milk production and reproduction and underlined the key weaknesses that a) many studies ignored other variables that have changed over time along with production and reproduction, leaving them susceptible to confounding and therefore overestimation of the strength of the effect of production, b) biases in the apparent association due to one or both of reduction in milk yield associated with pregnancy itself, and potential decisions on the part of managers on the timing of first insemination as a function of milk production may not have been accounted for, and c) ecologic fallacy may be at play i.e., the erroneous drawing of inferences at the cow level from data that are at the herd or population level; in other words, even if reproduction is negatively correlated with production over time, it is not necessarily the cows with higher production within their cohort that have worse reproduction.

Royal *et al.* [6] measured milk progesterone thrice weekly through the postpartum period in 714 Holstein-Friesian cows in 7 herds and described the commencement and patterns of luteal activity. They compared their data to milk progesterone profiles from data from 2305 lactations in 1682 cows in 20 herds between 1975 and 1982. They also compared the timing and probability of pregnancy at first artificial insemination (AI). Despite a small difference in time of first AI (mean $\pm$ SD, 78 ± 27 vs. 74 ± 21 days postpartum), the probability of pregnancy at first AI was significantly lower (40 vs. 56%) for the 1995–1998 vs. 1975–1982 data,

respectively. Comparisons were univariable for the effect of dataset only and did not consider other variables such as management practices, herd size, feeding, labour, or housing. Data on calving interval (apparently based on subsequent parturition) were available for 540 cows in the 1995–1998 data (390 ± 60 days) and a small subset of 259 cows published in 1977 from the 1975–1982 data (370 ± 35 days). No statistical analysis was performed. Nevertheless, the authors claim to present “a clear decline in pregnancy rates”.

It has been assumed that greater milk production is a cause of the apparent decline in reproductive performance because it seems plausible and the two occurred concurrently; other variables that are obvious candidate influencers of the probability and timing of pregnancy (e.g. adequacy of diet and feeding management, housing, skilled labour, etc.) are ignored, or acknowledged but not assessed because the data are difficult to obtain. The main question is whether fundamental fertility (i.e. the capacity for reproductive function and successful pregnancy) of dairy cows has in fact declined, as opposed to the success of management systems and people at meeting the metabolic, nutritional, housing, and social needs of increasingly productive animals but with no less inherent capacity to achieve and maintain pregnancy; and if fertility really has diminished, the extent to which this decline is caused by increased milk production. There is no doubt that production per cow has increased, but it is unclear how much of this increase can explain the apparent decrease in fertility. It is important to separate the biology of reproductive function from the effects of economically based management decisions about culling and continuation of breeding. Higher producers are more likely to be inseminated and less likely to be culled [8]. It is not clear whether pregnancy rate (i.e. the probability of cows becoming pregnant per unit of time; literally, the speed at which cows become pregnant) is falling in all or any dairy production systems around the world.

The estimated heritability of fertility is low ($< 5\%$, compared to 25 to 50% for production traits) [9–11]. Genetic and phenotypic correlations between production and reproduction have been reported to be of low to moderate strength but generally in an unfavorable direction (summarized by Pryce *et al.* [12]), but it is difficult to assess how to apply such information when it is largely based on incomplete or biased data.

Measuring the Association of Milk Production and Reproductive Performance

Measures of production

Milk yield is measured numerous ways, each with benefits and weaknesses. Milk yield in early lactation such as first test day milk yield or 60 day milk yield has the benefit of including more animals in the analysis but it may not provide accurate predictions for a complete lactation. Sixty day milk yields may be used to measure production before breeding starts to avoid confounding of reproduction outcomes by culling for failure to conceive. Raw milk yield per day is affected by stage of lactation so standardized 305 day projections are better. However parity has a large effect on both production and culling, so to compare across parities the best measure of production is 305 day milk yield mature equivalent, or

parity should be accounted for in another way. Quist *et al.* [13] showed that projections from test days later in lactation are more accurate than projections in early lactation. Completed 305 day milk yields are a more accurate measure of production but limiting analysis of reproduction to cows with complete lactation records introduces a bias due to exclusion of information from cows removed up to 304 days in milk (DIM) because of low production or lack of reproductive success.

Milk production per cow has increased over time in most of the world. Holstein cows in Canada produced 9677 kg/yr on average in 2005, up from 7717 kg/yr in 1991 based on publishable records [14], or approximately 1.8% per year on average. In New York, between 1951 and 1996 there was an increase of approximately 2% per year in milk production from Holstein dairy cows [5]. Lucy [2] also reported an increase of 2% per year over 10 years in the United States. In England and Wales there was an increase of 1.8% per year, from 4817 kg/yr to 6638 kg/yr between 1975 and 1996 [6]. In 2003–2004, average production from milk recording in Canada was 8257 kg of milk per cow per year, in the United States 8504 kg, in England 7638 kg, and in Israel 10,575 kg [15]. This small example underlines that the same milk yield that would be considered high in one production system would be low under another, even among countries with developed dairy industries. A cow producing 8000 l of milk in 305 days in a pasture-based system may be considered either exceptionally productive or at risk of excessive metabolic demands, whereas a cow with the same level of production in an intensive production system may be average in one herd and a candidate for culling because of low production in another herd in the same region.

Measures of reproduction

Measures of phenotype for fertility should reflect the ability of a cow to become pregnant efficiently at an economically optimal time postpartum. It is difficult, but important, to differentiate physiologic function and capacity to become pregnant from management constraints such as confinement housing, slippery floors, large numbers of cows per worker, or lack of observation, that may result in fertile animals not expressing primary signs of estrus, estrus not being detected, or a low probability of pregnancy at insemination. To evaluate reproductive performance and quantify factors that may affect it requires accurate data and valid analytical techniques. Traditional methods to measure reproduction in lactating cows rely on indirect or biased measures such as time to first insemination, non-return rates, and calving interval.

Time to first insemination may be highly confounded by herd management, primarily by the low intensity of estrus detection in many herds (average heat detection rate in Canadian dairy herds is approximately 35% per 21-day period [16]), but also by decisions about when inseminate some or all cows in a herd. If a cow is not detected in estrus until 100 DIM is it because she did not undergo estrus until then, or despite several estrus cycles and ovulations, that was the first time a person observed the cow in heat?

Conception risk and non-return rate: Conception risk (CR) is the probability that an inseminated cow is diagnosed pregnant to that breeding, typically by examination by a veterinarian between 28 and 50 days post insemination. The stage of diagnosis of preg-

nancy is important for comparison between studies because of the high rate of pregnancy loss within this interval [17].

Some reports have focused on conception risk as a measure of fertility, but at best this only reflects part of the process of making open cows pregnant, in that it does not account for cows that were not inseminated, or for when insemination occurred. Conception risk reflects the efficiency of use of semen, and may reflect the accuracy of estrus detection, insemination technique, or compliance with a synchronization protocol but it cannot necessarily be taken as a measure of the fundamental fertility of cows.

Non-return rate, which is traditionally used by AI units to measure reproductive performance, overestimates conception risk. It is calculated as the proportion of inseminated animals for which re-insemination is not requested, typically within 56 days, which are then assumed to be pregnant. The major disadvantage of non-return rate is that it grossly overestimates the actual proportion of cows becoming pregnant, but it is widely available, easy to measure, and is not as biased as calving interval because it does not require a subsequent calving. Additionally, use of assumed pregnancy status can result in substantial inaccuracy in calculation of time to pregnancy [18]. A recent comparison of approaches to modeling reproductive performance for genetic selection concluded that veterinarian-diagnosed pregnancy should replace non-return rate as the trait to measure [19]. It is only surprising that inferences have been made for so long on the basis of data that are blatantly inaccurate. Analysis of CR based on subsequent calving removes the bias of assuming that pregnancy occurred, but a different bias is present if only cows that eventually calve are included. For example Huang *et al.* [20] concluded that increasing production (as well as heat stress) was associated with lower CR but they only considered primiparous animals that eventually became pregnant. To the extent that producers (rightly) abandon breeding on low producing animals but continue to inseminate high producing animals, it is not surprising that in this selected sample there is an apparent association between higher milk yield and a higher number of AI per pregnancy.

Calving interval and days open: Both calving interval (time between successive calvings) and “days open” (count of days from calving to conception) are severely biased by including only cows that become pregnant. Days open is undefined for animals that have been inseminated but are not confirmed pregnant [21]. Use of projected time of pregnancy (e.g., assuming that non-pregnant cows will become pregnant at the next service) to avoid exclusion bias on cows that are not pregnant but still in the herd, retains substantial inaccuracy in the measurement of performance. It is difficult to overstate the weakness of using calving interval as a measure of reproductive performance when all cows that fail to become pregnant are excluded from the measure. Calving interval is further biased by considering only multiparous animals. Additional potential bias comes from pregnant cows, which are very unlikely to be culled across all levels of production [22]. Yet, higher producing cows are more likely to be inseminated more times and for longer than lower producers [23]. Culling lower producers that do not become pregnant quickly sooner than higher producers leaves a data set which appears to have an increased number of high production cows with more inseminations and

longer times to pregnancy.

Pregnancy rate: The best available single measure of overall reproductive performance at the herd level is pregnancy rate (PR) which measures the probability that open cows become pregnant per unit of time [16]. Given that, on average, cows should be in estrus every 21 days, pregnancy rate is commonly calculated on a 21 day basis. The number of successful breedings that occur in the 3 week period is divided by the number of non-pregnant animals past the voluntary waiting period that were present in the herd at least 11 days of that 21 day period. A value of 15% would be interpreted as “on average, 15% of open eligible cows became pregnant within the 21 day period”. Furthermore, PR allows comparisons between artificially inseminated herds and natural service herds (assuming the date of movement to exclusive bull breeding is recorded). A major advantage to use of 21-day pregnancy rate is that non-pregnant cows are included and contribute time eligible for pregnancy to the denominator for as long as they are in the herd.

Methods for analysis of the association

Reproductive performance parameters that have economic value include the occurrence of pregnancy (or culling for non-pregnancy), the time from calving to subsequent pregnancy, and to a lesser extent, the number of inseminations required to produce the pregnancy [21]. Most commonly reported measures of reproductive performance are incomplete or biased [21, 24]. Traditionally, reproductive performance has been measured by mean days to first insemination, mean days open or calving interval, and mean conception rate or the number of inseminations per pregnancy. These measures are severely biased because they ignore animals that fail to become pregnant [24]. Furthermore, pregnancy is a dichotomous event, days open are generally not normally distributed, and number of inseminations never follows a normal distribution. Despite this, simple correlations and linear regression analysis of variance have often been used to evaluate these parameters. Widely available software and computing capacity mean that there are no longer computational limits that excuse the use of inappropriate analytic methodology. Furthermore, there is no inherent economic value in the interval to first service, which reflects heat detection intensity and management policy, or management response to perceptions resulting in a decision to delay breeding.

The correct method for analysis of pregnancy data at the individual level is multivariable survival analysis [19]. Survival analysis is a statistical methodology that measures time to an event, accounting for those subjects that do not experience the event of interest or are lost to follow-up during the study period, termed censored observations. Survival analysis can correct for some of the confounding effects of decisions to delay or stop insemination, and culling. Information from all cows, regardless of pregnancy or insemination status at the end of the study can be used, unlike the standard regression methods. Specifically, cows that are culled or remain non-pregnant contribute data on time at risk of pregnancy until they leave the herd or the study period ends. This tool is ideally suited to assessment of reproductive performance in dairy cows [21, 25]. Survival analysis based on diagnosed pregnancy provides more accurate estimation of the genetic merit of bulls for conception risk than traditional models used in genetic evaluation

[26], which have the twin weaknesses of inaccurate data (based on assumed pregnancies from the last insemination) and incorrect analytical methodology (linear regression of time-to-event data, which excludes censored data and may underestimate variance).

Assessment of the impact of one factor on reproductive performance may be highly confounded by individual and herd level factors with effects on reproduction, including cow age, season, diseases, nutrition, body condition, environment, herd management decisions, the intensity and accuracy of heat detection, and the use of reproductive management programs. In many studies, most of these factors were not measured. Most research on the association of production and reproduction is done using a cross sectional study design or with retrospective longitudinal data. Retrospective observational studies have the weakness of using historical data, which may be confounded by differentially higher culling of lower producers, and lower culling of pregnant cows irrespective of production [23]. Cows that become pregnant early (e.g., after one or two inseminations) are likely to be retained, whereas cows that are still not pregnant late in the breeding season or entering late lactation (e.g., above 200 DIM) that are considered high producing relative to herdmates will likely continue to be bred while low producing cows at the same time will not and will eventually be culled. In other words, the effect of non-pregnancy depends on both time (relative to the previous calving) and level of production [27]. Survival analysis does not entirely overcome such differential censoring, but it does reduce the bias of simply discarding all the information from cows that were culled or not pregnant at the end of data collection [7].

Physiology of the Cow and Management by People

A central question is whether increasing or “high” levels of milk production necessarily or irretrievably cause reduced fertility or whether higher production capability increases the demands on metabolism and management, which may not always be met. Negative energy balance (NEB) happens after calving when cows do not consume enough feed to completely support their capacity and homeorhetic drive to produce milk. Essentially all cows experience some degree of NEB in early lactation. The duration and severity of postpartum NEB, specifically the timing of the nadir, is associated with the timing of first ovulation [28]. A common perception is that high producers have the greatest energy deficit, but higher producing cows are not necessarily those with more severe or prolonged NEB or with the greatest loss or the lowest nadir of body condition [2]. Rather, high producing cows are likely those with the greatest feed intake postpartum and therefore not the greatest energy deficit. A recent study [29] had a low number ($n=240$) of cows for assessment of reproductive performance but illustrates some of the variables and interactions that must be considered. Australian Holstein-Friesian cows of average genetic merit for milk were managed for lower yield (6750 kg/lactation) by being fed pasture with restricted grain supplementation or for higher yield (8470 kg/lactation) by being fed more supplemental grain and silage. Relative to intensive production systems, both groups would be considered low producing. Despite making more milk, the higher production group had less negative energy balance and there was

no difference in time to luteal activity or to pregnancy between groups, albeit in a subset of only 78 cows. However, this underlines that it should not be assumed that cows that make more milk are in greater NEB or necessarily into a state of antagonism between production and reproductive function. Cows in lines genetically selected for higher or lower milk production had small differences in the interval to postpartum commencement of luteal activity (approximately 30 vs. 23 days, respectively) [30]. Although the prevalence of delayed luteolysis and atypical patterns of progesterone profiles increased over time, Royal *et al.* [6] reported no change in the prevalence of anovulation.

On the other hand, high producing cows may experience greater challenges to at least some aspects of reproductive function. Higher feed consumption, which is characteristic of higher production, leads to increased blood flow through the liver and increased steroid catabolism, increasing the rate of clearance of progesterone and estradiol, resulting in lower circulating concentrations [31, 32]. The lower circulating sex steroid concentrations have the potential to affect reproductive physiology at several levels. The same research group demonstrated that cows with higher production (46 vs. 34 kg/day at approximately 94 DIM) had a shorter duration of estrus, stood to be mounted fewer times, and despite having larger ovulatory follicles, had lower plasma estradiol concentrations [33].

Fonseca *et al.* [34] found that first ovulation occurred about 3 wks postpartum regardless of production. There was no association between timing of first ovulation or duration of the first 2 postpartum estrus cycles and higher milk yield. Age at calving and clinical abnormalities had greater influence than milk yield on reproductive measures. Tracking of the reproductive cycle was done with serial blood sampling instead of visual estrus detection, which avoided the problems of low intensity and possible inaccuracy of estrus detection that are typical in the field even if record keeping is good [34].

Fetrow and Eicker [35] point out that there is little data available to support the notion that high producing cows suffer negative effects from milk production. On the contrary, it may be argued that the only way to achieve and sustain high milk yields is to meet the nutritional and behavioural needs of the cows. If dairy producers reduce stresses, the cows will respond by consuming more feed and water and producing more milk. Stressors such as heat, lack of access to feed, inadequate nutrient supply, unavailability of comfortable resting space, and poor ventilation reduce milk production and when these are removed the cows approach their genetic potential. However some assume cows that produce a lot of milk to be operating at their maximum potential and near their breaking point. This is not necessarily or at all true unless producers were doing something like feeding cows to bolster milk production but at the risk of causing disease [35]. If cows are managed appropriately and their needs met as fully as possible, they will produce to their capacity because the demands of their production are met. The effects of milk production cannot be blamed wholly for a reduction in health that may affect reproductive performance. Rather, good health and management to provide for it are prerequisites for both good production and good reproduction [1].

Herd-Level

Lucy [2] summarized data from 1970 to 2000 using 143 herds from an American DHI record system that were continuously enrolled in the program. Rolling herd average milk production increased from around 6500 kg milk to almost 9000 kg of milk per lactation. At the same time services per conception increased from around 1.75 to 3, and calving interval increased from just below 13.5 months to 14.8 months. Although the same herds were followed over time, management, facilities, and technology surely changed and the herds may have been exposed to other unaccounted factors which confound the observations. Additionally, herd or population level studies may be susceptible to ecologic fallacy or bias: the (mis)attribution of inferences to individuals based on group level data. For example, a herd level study might conclude that higher producing herds had lower reproductive performance. However, both pregnancy and amount of production are fundamentally individual level variables. Therefore it is possible that such a group level inference might be accurate, but it may not be true that the higher producing individuals within the group had poorer reproduction. Butler [36] illustrated an apparent antagonistic relationship between CR and milk production per cow over 50 years. However, CR was not quantified in the same manner. The CR of 66% in 1951 was for first AI only [37], and while it was reported as being distinct from (and 2.6% lower than) non-return rate, the basis of the CR is not clear. The 1975 data point in [36] was defined as a live calf, abortion, confirmed pregnancy check or no heat in the 100 days following breeding [38], whereas the measurement and data source for conception rate in 1996 and 2001 are not reported in [5] or [36], although it is likely that these CR were based on diagnosed pregnancy.

Stevenson [39] reported summary cross-sectional data from 1.2 million Holstein cows in 9684 herds and 50,000 Jersey cows from 546 herds. On average, higher producing herds were larger. As rolling herd average milk production went from less than 6800 kg to greater than 11,300 kg, days open decreased from 195 to 156, interval to first service went from 102 to 94 days, number of services per conception increased from 1.8 to 2.2, and heat detection efficiency went from 19 to 41%. This report suggested that better reproduction in the higher producing herds may be a reflection of better nutrition, healthier cows, and superior reproductive management.

Laben *et al.* [40] compared herd average production (between 5000 and 10,000 kg) and days open in 200 herds in California and found that pregnant cows in the highest producing herds were pregnant approximately 3 weeks earlier than cows in lower producing herds. Nebel and McGillard [1] reported data from 4550 herds in 1992 stratified by herd average production. Despite a decrease in CR as production increased from 6300 to 10,000 kg, higher producing herds had higher insemination (estrus detection) rates, producing the net effect of a lower interval to pregnancy in pregnant cows (days open). This is likely explained by better management leading to both higher production and better net reproduction.

Cow Level

Although many studies suggest an antagonistic relationship between milk production and reproduction, Raheja *et al.* [41] observed low genetic and phenotypic correlations of production with fertility using days from calving to first insemination, number of inseminations per conception, and days open as the measures of reproduction. Lopez-Gatuis *et al.* [42] examined 2756 pregnancies in 2 high producing (> 11,700 kg/year) herds in Spain and found that cows that were pregnant by 90 days in milk produced a mean of 49.5 kg/day of milk at day 50, in contrast to 43.2 kg/day among cows that became pregnant later, accounting for the effects of parity and retained placenta. This study would have been strengthened by consideration of the probability and timing of pregnancy in all cows, rather than only dichotomization of the timing of pregnancy among pregnant cows. Nevertheless, the study underlines the need to consider time-ordering of the path to pregnancy. While many imply that high production may lead to poorer reproduction, these data support an alternative hypothesis that cows that are healthy produce more milk (arguably better fulfilling their genetic potential) and also become pregnant sooner than cows that may be less healthy. In other words, selection for lower yield would not lead to better reproduction; rather, management for greater health may lead to both higher yield and pregnancy rate.

Additionally, a study in New York reported no significant association of 60 day milk production with pregnancy rate, using survival analysis [23]. Non-pregnant cows had a higher risk of being culled. High milk yield, along with older age, and winter calving were risk factors for several reproductive disorders which in turn delayed insemination and conception. Cumulative 60 day milk yield had no effect on time to pregnancy, although cows in the highest quartile of 60 day yield (2541 kg) had a slightly lower, but not statistically significant, pregnancy rate than the lowest quartile. Reproductive disease (e.g. RP and metritis) had larger effects on time to pregnancy than the level of milk production in early lactation. Because managers might intentionally delay insemination of high yielding cows, the association between milk yield and time to first insemination was considered. As 60 day milk yield increased so did insemination rates; that is the highest yielders were inseminated sooner than the lowest yielders. They concluded that farmers were making rational decisions by breeding young, healthy, high yielding cows [23].

New Research on the Question

We set out to measure the relationship of the level of milk production with reproductive performance in Canadian dairy cows at both the herd and individual animal levels, using a large, representative sample of records with diagnosed pregnancies and employing valid analytic techniques. The results have been presented as an abstract [43] and are summarized here.

Data were extracted from all 6326 herds on milk recording in Ontario and western Canada. There were 3297 herds with complete AI and pregnancy data for the year 2005 to which herd size, demographics, production, milking frequency and housing type were added. Herd annual mean (SD) 21-day pregnancy rate (PR),

insemination rate (IR) and CR were 12.5 (4.7), 33.9 (10.5) and 37.2 (9.9), respectively. Herd PR was modeled with mixed linear regression with a random herd effect. Accounting for herd size, parity distribution, breed, and housing, each 1000 kg increase of herd mean mature equivalent milk was associated with an increase of 0.7 points of PR ($P < .0001$).

Individual data (at least the first 3 test days) were available for 103,060 Holstein cows in 2076 herds. Times to first AI and to pregnancy were modeled with survival analysis with a random herd effect. Production was described by kg of milk and 305 day projections at test days 1, 2, and 3, and late lactation 305 day records, each of which had a significant univariable association with shorter time to pregnancy. Milk yield at test day 1 was not associated with time to first AI. In the final model considering the absolute level of milk production in kg, accounting for parity, season of calving, and DIM at test day, there was a small association of increased milk yield at test day 1 with longer time to pregnancy (hazard ratio (HR)=0.997 per kg, $P=.02$) and in the same model increasing 305 day projection at the last-recorded test day was associated with shorter time to pregnancy (HR=1.07 per 1000 kg, $P<0.0001$). A separate analysis considered milk production relative to herd-mates by classifying each cow into intra-herd quartiles of production at the first test day. Cows in the highest intra-herd quartile of production in early lactation were inseminated slightly earlier, and became pregnant slightly sooner than cows in the lowest quartile for production. Overall, by either measure, higher producing cows became pregnant a few days sooner than lower producing cows. These associations should not be surprising if good nutrition, cow comfort, and attentive management provide the conditions for high production and good reproductive performance.

In summary, herd pregnancy rate was significantly higher in higher producing herds, and for individual cows there were significant but conflicting and practically small effects of level of production on time to pregnancy. These results suggest that managing to provide for high production can be compatible with good reproductive performance.

Conclusion

It is not clear whether pregnancy rate in the dairy cattle population is falling, and data are needed to quantify and begin to benchmark performance over time. It is not appropriate to measure reproductive performance on the basis of conception risk alone, and data on the association of milk production with pregnancy rate are conflicting. Questions about whether metabolic demands for production and reproduction are reaching a biological or management limit and whether genetic selection criteria for fertility are optimized are important and warrant valid, large-scale studies.

References

1. Nebel RL, McGillard ML. Interactions of high milk yield and reproductive performance in dairy cows. *J Dairy Sci* 1993; 76: 3257–3268.
2. Lucy MC. Reproductive loss in high-producing dairy cattle: Where will it end? *J Dairy Sci* 2001; 84: 1277–1293.
3. Stevenson JS. Reproductive management of dairy cows in high milk-producing herds. *J Dairy Sci* 2001; 84 (E. Suppl.): vE128–E143.
4. Norman HD, Wright JR, Hubbard SM, Miller RH, Hutchison JL. Reproductive status of Holstein and Jersey cows in the United States. *J Dairy Sci* 2009; 92: 3517–3528.
5. Butler WR. Review: effect of protein nutrition on ovarian and uterine physiology in dairy cattle. *J Dairy Sci* 1998; 81: 2533–2539.
6. Royal MD, Darwash AO, Flint APF, Webb R, Woolliams JA, Lamming GE. Declining fertility in dairy cattle: changes in traditional and endocrine parameters of fertility. *Anim Sci* 2000; 70: 487–502.
7. Morton JM. Potential bias in observed associations between milk yield and reproductive performance in dairy cows. In: Proc 11th Intl Symp Vet Epidem Econ. 2006.
8. Grohn YT, Rajala-Schultz PJ. Epidemiology of reproductive performance in dairy cows. *Anim Reprod Sci* 2000; 60–61: 605–614.
9. Marti CF, Funk DA. Relationship between production and days open at different levels of herd production. *J Dairy Sci* 1994; 77: 1682–1690.
10. Kadarmideen HN, Thompson R, Coffey MP, Kossabati MA. Genetic parameters and evaluations from single- and multiple trait analysis of dairy cow fertility and milk production. *Livest Prod Sci* 2003; 81: 183–195.
11. Jamrozik J, Fatehi J, Kistemaker GJ, Schaeffer LR. Estimates of genetic parameters for Canadian Holstein female reproduction traits. *J Dairy Sci* 2005; 88: c2199–2208.
12. Pryce JE, Royal MD, Garnsworthy PC, Mao IL. Fertility in the high producing dairy cow. *Livest Prod Sci* 2004; 86: 125–135.
13. Quist MA, LeBlanc SJ, Hand KJ, Lazenby D, Miglior F, Kelton DF. Agreement of predicted 305-day milk yields relative to actual 305-day milk weight yields and parlour electronic identification accuracy. *J Dairy Sci* 2007; 90: 4684–4692.
14. Canwest Dairy Herd Improvement. Ontario Progress Report. 2007.
15. International Committee for Animal Recording. 2009. Subject: Yearly enquiry on cow milk recording (2003–2004). [http://www.icar.org/Documents/Yearly%20inquiry/2003_2004/Table 01.pdf](http://www.icar.org/Documents/Yearly%20inquiry/2003_2004/Table%2001.pdf). Accessed March 19, 2009.
16. LeBlanc S. Using DHI records on-farm to evaluate reproductive performance. *Adv Dairy Technol* 2005; 17: 319–330.
17. Santos JEP, Thatcher WW, Chebel RC, Cerri RLA, Galvao KN. The effect of embryonic death rates in cattle on the efficacy of estrus synchronization programs. *Anim Reprod Sci* 2004; 82–83(SI): 513–535.
18. Wiggins GR, Gooding RC. Accounting for pregnancy diagnosis in predicting days open. *J Dairy Sci* 2005; 88: 1873–1877.
19. Weigel K. Improving the reproductive efficiency of dairy cattle through genetic selection. *J Dairy Sci* 2004; 87(E Suppl): E86–E92.
20. Huang C, Tsuruta S, Bertrand JK, Misztal I, Lawlor TJ, Clay JS. Environmental effects on conception rates of Holsteins in New York and Georgia. *J Dairy Sci* 2008; 91: 818–825.
21. Ferguson JD, Galligan DT. Assessment of reproductive efficiency in dairy herds. *Compend Cont Educ Pract Vet* 2000; 22: S150–S158.
22. Grohn YT, Eicker SW, Ducrocq V, Hertl JA. Effect of diseases on the culling of Holstein dairy cows in New York State. *J Dairy Sci* 1998; 81: 966–978.
23. Eicker SW, Grohn YT, Hertl JA. The association between cumulative milk yield, days open, and days to first breeding in New York Holstein cows. *J Dairy Sci* 1996; 79: 235–241.
24. Stewart S, Eicker S, Fetrow J. Analysis of current performance on commercial dairies. *Compend Cont Educ Pract Vet* 1994; 16: 1099–1103.
25. Lee LA, Ferguson JD, Galligan DT. Effect of disease on days open assessed by survival analysis. *J Dairy Sci* 1989; 72: 1020–1026.
26. Schneider M del P, Strandberg E, Ducrocq V, Roth A. Survival analysis applied to genetic evaluation for female fertility in dairy cattle. *J Dairy Sci* 2005; 88: 2253–2259.
27. Allore HG, Warnick LD, Hertl J, Grohn YT. Censoring in survival analysis, a simulation study of the effect of milk yield on conception. *Prev Vet Med* 2001; 49: 223–234.
28. Butler WR, Smith RD. Interrelationships between energy balance and postpartum reproductive function in dairy cattle. *J Dairy Sci* 1989; 72: 767–783.
29. Pedernera M, Garcia SC, Horagadoga A, Barchia I, Fulkerson WJ. Energy balance and reproduction on dairy cows fed to achieve low or high milk production on a pasture-based system. *J Dairy Sci* 2008; 91: 3896–3907.
30. Garmo RT, Ropstad E, Havrevoll O, Thuen E, Steinshamn H, Waldmann A, Reksen O. Commencement of luteal activity in three different selection lines for milk yield and fertility in Norwegian Red cows. *J Dairy Sci* 2009; 92: 2159–2165.
31. Sangsritavong S, Combs DK, Sartori R, Wiltbank MC. High feed intake increases blood flow and metabolism of progesterone and estradiol-17 β in dairy cattle. *J Dairy Sci* 2002; 85: 2831–2842.
32. Wiltbank M, Lopez H, Sartori R, Sangsritavong S, Gumen A. Changes in reproductive physiology of lactating dairy cows due to elevated steroid metabolism. *Theriogenology* 2005; 65: 17–29.
33. Lopez H, Satter LD, Wiltbank MC. Relationship between level of milk production and estrous behavior of lactating dairy cows. *Anim Reprod Sci* 2004; 81: 209–223.
34. Fonseca FA, Britt JH, McDaniel BT, Wilk JC, Rakes AH. Reproductive traits of Holsteins and Jerseys. Effects of age, milk yield, and clinical abnormalities on involution of cervix and uterus, ovulation, estrous cycles, detection of estrus, conception rate and

- days open. *J Dairy Sci* 1983; 66: 1128–1147.
35. **Fetrow J, Eicker S.** High production and health—A curious paradox. *Bov Practitioner* 2003; 37: 128–136.
 36. **Butler WR.** Energy balance relationships with follicular development, ovulation and fertility in postpartum dairy cows. *Livest Prod Sci* 2003; 83: 211–218.
 37. **Foote RH.** Reproductive performance and problems in New York dairy herds. *Cornell Univ Agr Exp Stn Search* 1978; 8.
 38. **Spalding RW, Everett RW, Foote RH.** Fertility in New York artificially inseminated Holstein herds in dairy herd improvement. *J Dairy Sci* 1975; 58: 718–723.
 39. **Stevenson JS.** Can you have good reproduction and high milk yield? *Hoard's Dairyman* 1999; 144: 536.
 40. **Laben RL, Shanks R, Berger PJ, Freeman AE.** Factors affecting milk yield and reproductive performance. *J Dairy Sci* 1982; 65: 1004–1015.
 41. **Raheja KL, Burnside EB, Schaeffer LR.** Relationships between fertility and production in Holstein dairy cattle in different lactations. *J Dairy Sci* 1989; 72: 2670–2678.
 42. **Lopez-Gatius F, Garcia-Ispuerto I, Santolaria P, Yaniz J, Nogareda C, Lopez-Bejar M.** Screening for high fertility in high-producing dairy cows. *Theriogenology* 2005; 65: 1678–1689.
 43. **Campbell MS, Hand K, Kelton DF, Miglior F, LeBlanc SJ.** The association of level of milk production with reproductive performance. *J Dairy Sci* 2009; 92, E-Suppl. 1 335 (abstr.)