Is a high level of milk production compatible with good reproductive performance?*

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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.
Introduction

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. There are a few frequently referred-to datasets [e.g., 2, 3, 4] 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 reproductive performance when the potential for confounding of the relationship is high.

Morton [5] 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.

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 [6]. 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 – 9]. 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 [10]), 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. Completed 305 day, parity-adjusted 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 approximately 2% per year across many countries with divergent production systems. 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. 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 [11]), 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. The stage of diagnosis of pregnancy is important for comparison between studies because of the high rate of pregnancy loss between 28 and 50 days post insemination [12]. 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 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. 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.

**Calving Interval and Days Open**

Both calving interval and “days open” (count of days from calving to conception) are severely biased by including only cows that become pregnant. 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. Pregnant cows are very unlikely to be culled across all levels of production [15]. Yet, higher producing cows are more likely to be inseminated more times and for longer than lower producers [16]. 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 [11]. Given that, on average, cows should be in estrus every 21 days, pregnancy rate is commonly calculated on a 21 day basis. 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 [14]. Pregnancy is a dichotomous event, days open are generally not normally distributed, and number of inseminations never follows a normal distribution.

The correct method for analysis of pregnancy data at the individual level is multivariable survival analysis [5, 13, 14, 17]. 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.

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 [16].

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 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 [18]. 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. 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) [19].

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 [20, 21]. 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 [22].

Fetrow and Eicker [23] 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, the only way to achieve and sustain high milk yields is to meet the nutritional and behavioural needs of the cows. Stressors such as disease, 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 near their breaking point. 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 health 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. 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 [24] 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 [25], 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 [24] was defined as a live calf, abortion, confirmed pregnancy check or no heat in the 100 days following breeding [26], whereas the measurement and data source for conception rate in 1996 and 2001 are not reported in [3] or [24], although it is likely that these CR were based on diagnosed pregnancy.

Stevenson [27] 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.

Cow level

Lopez-Gatuis et al. [28] examined 2756 pregnancies in 2 high producing (> 11,700kg/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. These data support the 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 [16]. 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.

Recently, Madouasse et al (2010) [29] developed a model of milk components and yield in early lactation to predict the probability of pregnancy in intervals between 20 and 145 DIM. They found mixed associations of milk volume and components with pregnancy. For example, milk yield at the first test in lactation was not associated with pregnancy, but higher milk volume at test 2 was associated with reduced probability of pregnancy by 145 DIM; protein percentage at test day 2 (and to a small extent at test day 1) was associated with increased probability of pregnancy.

New and sophisticated approaches to modelling the association between production and reproduction (summarized in Stevenson and Bello, 2011 [30]) underline that this association may be different at the herd (generally positive for full lactation measures) and cow (negative for the corresponding analysis) levels. However, there is further heterogeneity in these relationships between herds, herd management practices (e.g. milking 2 or 3 times per day; use of rBST), and regions (even within 1 state in the USA).

Our 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 [31] are summarized here.

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-d 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. 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 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.

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