Does Higher Production Imply Worse Reproduction?[1]

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Take Home Messages

- 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.
- 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

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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 (e.g., Lucy, 2001). In fact, very recent data suggest that the trend in the USA in some of the same measures has begun to improve (Norman et al, 2009) (despite ongoing increases in production per cow). There are a few frequently referred-to datasets [e.g., Butler, 1998; Royal et al 2000) 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 (2000) 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 (2000) 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 ± 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 considered only the effect of dataset and not 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 d) and a small subset of 259 cows published in 1977 from the 1975-1982 data (370 ± 35 d). 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. 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). 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, 2000), 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 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. 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 (Canwest DHI 2007), 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 (Butler, 1998). Lucy (2001) 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 (Royal et al, 2000). 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 (LeBlanc, 2005)), but also by decisions about when to 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.

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. It is only surprising that inferences have been made for so long on the basis of data that are blatantly inaccurate. 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. 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. Yet, higher producing cows are more likely to be inseminated more times and for longer than lower producers (Eicker et al, 1996) 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. A value of 15% would be interpreted as “on average, 15% of open eligible cows became pregnant within the 21 day period”. A major advantage to use of a 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.

▪ 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 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 (Butler and Smith 1989). 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. Rather, high producing cows are likely those with the greatest feed intake postpartum and therefore not the greatest energy deficit.

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 (Wiltbank et al, 2005). 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 (Lopez et al, 2004).

Fetrow and Eicker (2003) 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. Stressors such as heat, lack of access to feed, inadequate nutrient supply, unavailability of comfortable resting space, and poor ventilation reduce milk production. If cows' needs are met as fully as possible, they will produce to their genetic 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 the management to provide for it are prerequisites for both good production and good reproduction.

▪ Herd-Level

Lucy (2001) 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. Butler (2003) 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 (Foote, 1978), 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 was defined as a live calf, abortion, confirmed pregnancy check or no heat in the 100 days following breeding (Spalding et al, 1975), whereas the measurement and data source for conception rate in 1996 and 2001 were not reported, although it is likely that these CR were based on diagnosed pregnancy.

Stevenson (1999) 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%. Nebel and McGillard (1994) 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). These reports suggested that better reproduction in the higher producing herds may be a reflection of better nutrition, healthier cows, and superior reproductive management.

■ Cow Level

A herd level study might conclude that higher producing herds had lower reproductive performance, but it may not be true that the higher producing individuals within the group had poorer reproduction. Lopez-Gatuis et al. (2005) 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. 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 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 (Eicker et al, 1996). Non-pregnant cows had a higher risk of being culled. 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.

■ New Research on the Question

We (Campbell et al, 2009) 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. 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-d pregnancy rate (PR), insemination rate (IR) and CR were 12.5 (4.7), 33.9 (10.5) and 37.2 (9.9), respectively. The average PR of 12.5% is comparable to other regions in North America. These measures have been calculated for

Canwest herds since 1999 and the average annual PR have varied between approximately 12 and 14%. It is not clear if there is a trend over time, or just year-to-year variation.

Herd PR was modeled with mixed linear regression with a random herd effect. We found that herds that have higher average milk production have higher pregnancy rates. 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 ($P < .0001$). For example, the association is illustrated in Figure 1 for herds with 100 cows in a freestall barn, and other factors held constant.

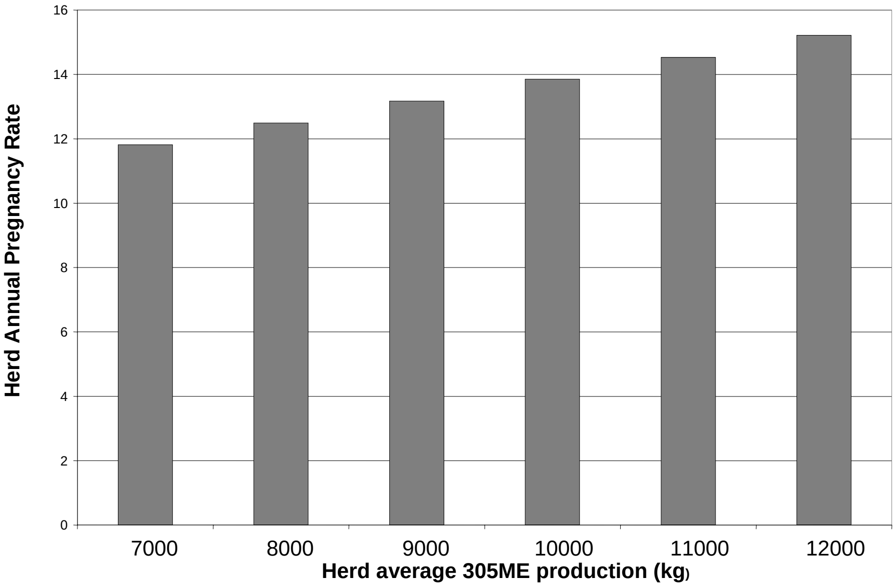

Figure 1. An example of the association of herd average milk production with herd annual pregnancy rate for 100 cow Holstein herds in freestall barns from Canwest DHI data from 2005.

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. We found that on average high producing cows were bred for the first time (i.e. days to first AI) at the same time as lower producing cows. Similarly there were very small associations of the level of milk production in early lactation (first test) or for 305 production based on 3 tests or more with the time until pregnancy, accounting for cows that never became pregnant. In the final analysis considering the absolute level of milk production in kg, accounting for parity, season of calving, and DIM at test day, higher producing cows became pregnant a few days sooner than lower producing cows. 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.

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