Challenging the norm: What is the perfect time to start inseminating dairy heifers?

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Abstract
Raising replacement heifers is a major cost for dairy farms, with the timing of insemination influencing reproductive biology, growth and economics. While earlier insemination may lower raising costs, it risks compromising future productivity. Conversely, delaying insemination might cause missed opportunities for cost savings. This narrative review challenges the traditional reliance on age at first calving (AFC) as a benchmark, exploring its limitations and assessing literature on optimal AFC and timing of first insemination. It highlights the hidden potential of focusing on growth monitoring from post-weaning to puberty and from puberty to calving. Shifting the focus from age to body weight and size allows for more tailored, herd- and heifer-specific reproductive management. This approach can optimize breeding eligibility, enabling earlier insemination, in some cases, to reduce costs without compromising long-term performance, or delaying breeding, when needed, to allow slower-developing heifers to reach their full potential. By incorporating both age and body size metrics, dairy operations can refine their heifer reproductive strategies to improve efficiency, productivity and economics.

Key words: body weight, first breeding, age at first calving

Introduction
In the United States and Canada, the cost of raising a replacement heifer is estimated at USD $2,500[1,2] and CAD $4,822[3]per heifer, respectively, from birth to freshening. Inseminating heifers earlier can shorten the raising period and reduce associated costs, enabling them to start their productive life and reach breakeven sooner; but breeding too early may compromise their future productivity. On the other hand, delaying insemination increases age at first calving (AFC), delaying return on investment, and increasing heifer raising costs, potentially without additional benefits. The goal for dairy producers, veterinarians and consultants is to develop a comprehensive heifer raising strategy that minimizes costs while maximizing lifetime performance. The objective of this narrative review is to highlight opportunities in heifer management, aimed at improving efficiency and maximizing profitability in raising dairy replacement heifers in programs tailored to each herd. The following sections reflect on current benchmarks used in heifer reproduction management (namely, AFC) and identify opportunities to improve heifer eligibility criteria for first breeding by challenging established norms.

Age at first calving
The average AFC in North America has been steadily decreasing over time. In 1997, only 2.7% of U.S. farms had an average AFC of ≤ 24 mo.[4] However, from 2006 to 2015, the average AFC in the United States decreased by 2.4 mo.[5] In Canada, ~50% of dairy farms have an average AFC of ≤24 mo.[6,7] Several factors influence the timing of a heifer's first calving, including previous health events, growth (ADG), reproductive management strategy (e.g., eligibility for first insemination, and reproductive efficiency [e.g., pregnancy rates]). While AFC is a straightforward metric, its use requires awareness of nuances it might not capture.

Benefits and limitations of using AFC as a benchmark
One key limitation of AFC is survival bias as it may present an incomplete picture of the overall heifer raising program. Average AFC only reflects data from heifers that successfully carried their first pregnancy to term, excluding animals that left the herd before that (e.g., culled due to disease, failure to conceive and abortions[8]). For example, in a survey including 19 British farms, it was reported that ~11% of the calves were born dead or died within the first month of age and ~ 9% of the heifers left the herd between weaning to first calving.[8] In the U.S., Masello et al. (2021) reported a post-puberty culling (sold and dead) of ~5.5 % in a randomized controlled trial of 1,000 nulliparous heifers from two commercial farms.[9] Focusing solely on calved heifers may overlook opportunities to improve pre- and post-pubertal health, growth and reproductive performance.

Age at first calving, as an average, does not fully represent the distribution of data within a herd. For example, when Holstein heifers were managed under similar conditions and all eligible to be bred for the first time between 12 and 13 mo. of age, their AFC ranged widely (from 22 to 36 mo.; median: 26[10]). This distribution is particularly pronounced due to variability in age at puberty onset, pre- and post- weaning health disorders (e.g., bovine respiratory disease [BRD] or diarrhea), growth rates, or suboptimal pregnancies per AI. Therefore, relying solely on AFC as a benchmark can lead to the oversight of significant variations both within and between herds.

Despite these limitations, AFC is a practical tool for assessing the financial implications of heifer management performance. By adjusting the AFC, producers can directly estimate changes in total raising costs by adding or subtracting days on feed before calving. For example, Hutchison et al. (2017) using an estimated cost of USD $2.50 per heifer per day, concluded that reducing the AFC by one month could save producers ~USD $75 per heifer.[5] This value could rise to ~USD $130 if using the greater value previously reported[1] (USD $2.04 to $4.32 per heifer per day). In Canada, a median cost of CAD $6.55 per heifer per day was estimated (~CAD $200 per heifer when reducing AFC by one month).[3] These figures highlight the economic importance of optimizing AFC. Yet, it is crucial to note that age alone does indicate body size, composition, or development–important factors for reproductive success, transition issues (e.g., stillbirths, dystocia), and future performance.

Optimizing AFC

Traditionally, an age of between 23 and 24.5 mo. for AFC has been recommended, aimed at maximizing profitability by balancing feed costs with first lactation milk yield.[10–12] These recommendations were based on dated economic models that may not accurately reflect current heifer growth rates, genetics, nor feed cost and milk prices. For example, Mourits and colleagues[11] used a prepubertal growth of 1.5 lb (0.7 kg)/d, a predefined standard production of 6,800 kg of milk in first lactation, and an average mature BW (MBW) of 1,415 lb (642 kg). This contrasts with more recent data where ADG from 5 to 10 mo. was 2.0 ± 0.2 lb/d (0.91 ± 0.11 kg/d)[13] and a > 10,000 L production in first lactation seen as an average for top Canadian producers.[14,15]

Research on AFC has evaluated the data through many approaches (continuous or categorical) and considering different performance outcomes (e.g., first lactation milk yield vs. lifetime production). In a Holstein heifer study, including three farms in California (n = 1,905), the authors categorized AFC into three groups (< 23, 23-25, and > 25 mo.) and observed that heifers with an AFC < 23 mo. produced less milk (2.2 lb/d; 1 kg/d) during their first lactation than older calving heifers.[10] Furthermore, the incidence of stillbirth was reduced in AFC > 25 mo. than earlier calving groups (AFC < 23 mo.: 16%; 23-35 mo.: 20%, and > 25 mo.: 14%).

More recently, different authors have assessed the associations between AFC and lifetime milk production.[5,8,13] Wathes and colleagues found that although AFC of 24 to 25 mo. optimized first lactation performance, an AFC of 22 to 23 mo. was associated with greater for lifetime milk produced and longevity.[8] Similarly, Krpálková and colleagues[13]described that although heifers with AFC < 23 mo. produced less milk in the first 100 DIM in first lactation (-0.9 to – 2.9 lb/d; -0.4 to 1.3 kg/d), their lifetime production was comparable to those calving later (AFC < 23 mo.: 21,735 lb (9,859 kg) vs. AFC 23-25 mo.: 21,739 lb (9,861 kg) per lactation). Using records from more than 14 million U.S. cows, it was concluded that an AFC of 21 to 22 mo. maximizes lifetime production (+1124 to 1393 lb; +510 and 632 kg of milk, respectively, than AFC at 24 mo.) without an impact on stillbirth incidence.[5] It is speculated that lower AFC (< 23 mo.) is related to better reproductive performance: heifers able to breed earlier are likely to breed earlier as cows and more likely stay in the herd longer.[5,8] Interestingly, in Jersey heifers, an even lower AFC (< 21 mo.) was not detrimental for lifetime performance,[5] due to a more rapid maturity of smaller breeds compared to Holstein.[16] Overall, reducing AFC from 25 to 21 mo. could result in up to 18% savings in rearing costs, provided heifers achieve adequate body size at calving.[17] In the studies mentioned, body weight (BW) at calving was not reported, making it challenging to separate the effects of age and BW at calving.

Age, body weight and other confounders

Most published studies on the ideal timing for first breeding and first calving are observational in nature,[8,10,13] and the lack of randomization inherently introduces bias, as heifers with different AFC may have inherent pre calving characteristics that could confound the assessed outcomes.[18] For example, early-life disease, like BRD, is associated with lower BW after calving (Q1 [BW: 1,129 ± 1.8 lb {512 ± 0.8 kg}]: 35% BRD before first calving vs. < 26% BRD in remaining quartiles).[19] Further, the long duration of these observational studies (e.g., spanning from birth or first insemination to the end of the first lactation or life performance) poses additional challenges. Factors including changes in management, culling (and reasons for culling) as well as other losses to follow-up can introduce further biases and confounding variables.

A common confounder in studies on the timing of calving is the variation in BW and age. Clark and Touchberry stated that although both factors are associated with milk production, changes in BW have a greater magnitude of effect than age.[20] Specifically, when age was constant, each 100 lb (45 kg) increase in BW at calving was associated with 134 lb (61kg) increase of milk and 7.8 lb (3.5 kg) of fat during the first lactation. Conversely, maintaining BW constant while increasing AFC by one month only added 46 lb (21 kg) of milk and 1.2 lb (0.5 kg) of fat.[20] Hoffman and colleagues also examined this question and reported that heifers that calved at an earlier age, with a similar BW, had reduced lactational performance.[21] More recent data suggest that AFC has minimal impact on first lactation milk yield, provided heifers are at least 22 mo. old at calving.[22] In contrast, BW played a significant role. For every 154 lb (70 kg) increase in BW at calving, first lactation milk yield could increase by 1,000 kg.[22] Nonetheless, greater BW can pose long-term challenges, as heavier calving heifers are more likely to leave the herd prematurely.[23]

Han and colleagues assessed absolute BW on two commercial farms (quintiles; Farm A: Q1: 477 ± 24 kg; Q5:624 ± 35 kg; Farm B: Q1: 473 ± 21 kg; Q5: 604 ± 28 kg) after calving and proportion of MBW (mature body weight) at first calving in 2,300 Holstein heifers and observed that heavier heifers (either absolute BW or proportion of MBW) tended to yield more milk (e.g., 10,034 vs. 9,683 kg) in their first lactation than lighter heifers.[23] However, BW after calving was not associated with milk yield in the first 24 mo. of production after calving. In fact, heavier heifers lost greater BW in early lactation (2.7 to 3.6% loss in Q2-Q5; while Q1 gained weight, +1.7%) and experienced greater culling risk (primiparous heifers in Q 2, 3, 4 and 5 were 14, 22, 18 and 49% more likely to leave the herd at any given time than Q1, respectively). The authors concluded that a targeted 73 to 77% MBW at calving is optimal for maximized performance (a lower proportion that the recommended before; 82-85% MBW after calving[24,25]).

Similarly, Lauber and Fricke demonstrated that heifers calving lighter (lowest quartile; 1128± 1,7 lb; 512 ± 0.8 kg BW) produced 11 lb/d (5 kg/d) less milk in early lactation compared to heaviest primiparous cows (heaviest quartile; 1388 ± 1.8 lb; 630 ± 0.8 kg)[19].Additionally, this study assessed reproductive parameters and demonstrated that the lighter quartile corresponded to the earlier calving heifers (lowest AFC).[19] A greater pregnancy rate as nulliparous of lighter calving heifer explains the earlier AFC.[19] This study did not report lifetime performance.

Because growth and BW are variable, they are more flexible indicators to use when tailoring management practices, creating cohorts of animals and avoiding the one size fits all age approach.

Optimal timing for first breeding and onset of puberty

Determining the ideal time to inseminate a heifer for the first time requires balancing reproductive biology, growth, performance and economic considerations. General recommendations of optimal timing are based on BW; more specifically that heifers reach at least 55-60% of their MBW by the time of first breeding and 82-85% post-calving for optimal milk production in first lactation.[24,25] One of the largest challenges to use these metrics is to define MBW in each herd, or even more challenging, the predicted MBW of each individual heifer,[26] making age a common marker to set the eligibility for first breeding.

Duplessis and colleagues based on the recommended 55% MBW at breeding,[25] reported a median age of 13.3 months for optimal first breeding age in HO heifers but with abroad range (10.3 to 18.3 mo).[27] The lack of efficient tools for monitoring individual growth and determining herd MBW means that producers often rely on average age, rather than BW, to decide when heifers are eligible for first breeding.

Using age to set eligibility for first insemination can lead to underestimating BW and delaying insemination, thereby increasing AFC and missing opportunities to breed heifers that are ready.[27] For example, Cue and colleagues explained due to the inability of producers to accurately estimate BW, they prefer to wait two to three months longer for first breeding to guarantee heifers will have an appropriate body size at calving.[28] However, the opposite can also occur. Previous reports have shown that more than 50% of the heifers calving for the first time were below 85% MBW.[19,23,29] The need to assess and monitor ADG and target BW at calving is evident and crucial to improve overall performance of future lactating cows.

Recent data from Canada (a report on 41 Quebec herds) accentuate the variability in MBW within and between herds.[30] The authors detected differences exceeding 375 lb (170 kg) between the lightest and heaviest herds.[30] Heifers in the lightest herds would reach the 55% MBW at around 820 lb (372 kg), while those in the heaviest herds would reach it at approximately 1,052 lb (477 kg).[30] Considering the variability in MBW and growth rates across herds, it is essential to monitor heifer development closely and adjust the ideal timing for first breeding and calving based on the specific growth patterns of the population.

Ultimately, when to start inseminating heifers depends on the onset of puberty. Body weight has been described by many as the main trigger[31] and Mourits and colleagues stated that heifers are expected to achieve puberty at 43% of MBW.[11] Although not including MBW data, Bruinje and colleagues described the average onset of puberty at 8.3 mo. (ranging between 5.9 to 12.2 mo.,) for Holstein heifers and for every 22 lb (10 kg) increase in BW at 6 mo. of age, puberty onset decreased by 13 days.[32] However, in a randomized controlled trial (RCT) of feeding whole milk vs. milk replacer to Israeli Holstein heifers where BW was consistent between animals at puberty, nutritional management (and not BW), was consider the trigger for puberty (8.8 to 9.5 months of age).[33] Regardless of the exact trigger, it is recommended to wait at least one month after the onset of puberty before inseminating heifers for the first time.[34] However, waiting only one month would lead to an AFC of < 21 mo. Considering Hutchinson and Duplessis's work regarding optimal AFC (21-22 mo.) and breeding age (13 mo.), waiting until at least the third cycle would be preferred. It is important to highlight that these numbers do not consider the variation existent between herds and a one size fits all approach leaves out the opportunity to maximize performance and economics of each herd and within herd.

Setting first insemination eligibility: Minimum age or weight?

Most observational studies on heifer reproductive management assume the same first insemination eligibility for all animals in the herd. Studied cohorts are then defined based on age or weight observed at first calving. This can be justified by the given norm of inseminating all heifers at a minimum age, without considering individual BW (absolute or proportion of MBW) at first breeding. While AFC depends on the timing of conception, most published studies are not designed to address questions from an earlier moment in heifer's life – the timing of first breeding. Literature has shown that animals of the same age can vary significantly in size and maturity stages. This raises the question: Should the norm be challenged by initiating breeding based on a set weight criterion rather than minimum age?

A randomized field study conducted on 418 Jersey heifers from a single herd in California sought to challenge the traditional first insemination eligibility criteria, comparing a minimum age requirement (control: 12 months of age) to a minimum absolute BW (480 lb [217 kg]).[35] The minimum BW was set based on previous exploratory analysis using retrospective farm data that demonstrated heifers bred at < 480 lb (217 kg; lowest quartile) produced 4 lb/d (1.8 kg/d) less milk during the first four tests after calving.[35] The set minimum BW corresponded to ~ 50% of MBW assessed as a group average of 3rd+ lactation cows in the herd. The authors hypothesized that allowing each heifer to reach the minimum BW before breeding, regardless of age, would avoid the negative effects of breeding underweight heifers on milk yield.[35] At allocation, heifers were blocked by a preexistent variable collected at the end of the weaning period for farm management purposes. This is consistent of two categories ("light" and "heavy"; based on thoracic ultrasound, weight, and height; dsort management tool; Feedlot Health and Management Services). The majority were classified as "heavy" (64% of the heifers), and presumably healthier. The interaction between these categories and treatment groups was significant in most models, so results were stratified accordingly. While first lactation data are not yet available, the authors observed differences in reproductive efficiency between treatment groups in the non-lactating phase. Among the heifers bred based on minimum BW (n = 217), 32% were inseminated before reaching 12 months, the minimum age criterion for the control group. The odds of being bred (heat detection), pregnancy at first AI, and overall pregnancy rates were comparable between groups, indicating that the proportion of heifers that conceived was similar regardless of the strategy used. However, in "heavier" group, heifers bred based on BW had a median age to pregnancy reduced by 23 d compared to the control group (HR = 1.5 [1.1-1.9]; median time to pregnancy: CON = 393 days, 13.1 mo, TRT = 370 days, 12.3 mo).[35] This strategy of breeding based on minimum BW is particularly interesting given it may offer dual benefits. Not only can some heifers be bred earlier than the current set minimum age, but those that require more time to reach the minimum BW can do so, allowing them to develop a larger body size before their first insemination. One of the obstacles encountered during the implementation of this trial was the intensity of labor necessary to weigh every individual animal every four weeks. When translating this to an on-farm practice, its implementation may encounter some barriers.

Nonetheless, manipulating time to first breeding, heifer raising resources could be applied more efficiently. Assuming a conservatively estimated daily cost of USD $2.00 per heifer at this facility, and that all heifers will carry gestation to term, this reduction could translate into a cost savings of USD $46 per "Heavy" Jersey heifer due to the overall reduced days on feed before the start of lactation for the group. This simplified analysis did not account for possible abortion and culling before calving as well as potential differences in first lactation performance.

Tying it all together and challenging the norm

Average AFC alone may not reflect the full picture. Factors like health events, loss of follow-up and confounders must be considered to understand their impact on lifetime heifer performance. While recommendations based on a proportion of MBW are not new, they are often overlooked due to a lack of tracking of growth and MBW. This can lead to suboptimal breeding timing, AFC, and BW at calving. Implementing farm-specific programs to monitor growth is essential for optimizing heifer reproductive management and efficiency. The critical question is: how much can we reduce AFC and associated costs without negatively impacting lifetime health and performance? Using health and growth curves for breeding eligibility, rather than age alone, may unlock the answer.

By targeting reproductive and management strategies based on early life health and growth patterns, it is possible to improve efficiency and profitability while addressing individual herd needs. Because genetics and management practices are crucial, the ideal breeding timing should be be specific to each farm and potentially to cohorts of heifers within a farm. Revising traditional age-based strategies and adopting a more personalized approach could significantly enhance heifer management and overall herd performance.

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