Symposium review: Why revisit dairy cattle productive lifespan?*

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ABSTRACT

Dairy cattle productive lifespan averages approximately 3 yr after first calving. Changes in the last decade in reproductive performance, genetic merit, and societal concerns regarding animal welfare and the environmental footprint of dairy products warrant a critical review of decision making regarding dairy cattle productive lifespan. The objective of this study is to provide such a review. Economic decision making drives the majority of culling decisions and, by extension, dairy cattle productive lifespan. Historically, models focused on optimizing replacement decisions for individual cows found economically optimal productive lifespans of 40 mo or more. However, cow performance and prices have changed and the average findings of these models may no longer hold. Management and housing may affect productive lifespan through improvements in health care and cow comfort. Improvements in reproductive efficiency and the availability of sexed semen are leading to an abundance of dairy heifers on many dairy farms, which often results in shorter productive lifespans in herds of fixed sizes. There is also a growing interest in the use of beef semen in dairy cattle, which does not add to the supply of dairy heifers. Acceleration of genetic gain due to genomic testing should likely result in shorter productive lifespans. Younger herds capitalize on genetic progress but have fewer efficient mature cows and have greater replacement costs. Extending dairy cattle productive lifespan might decrease the environmental footprint of milk production because fewer heifers need to be raised. Short productive lifespans, especially as a result of much forced culling early in lactation, are often signs of reduced welfare. Possible extensions of productive lifespan through improved welfare may alleviate public concerns about dairy production, although longer productive lifespans for healthy cows are not necessarily

more profitable. A simple model of the economically optimal productive lifespan illustrates the tradeoffs between herd replacement cost, maturity and aging costs, genetic opportunity cost, and calf value opportunity cost. Combined, these factors suggest that an average productive lifespan of approximately 5 yr is warranted. In conclusion, increases in genetic gain, reproductive efficiency, cow comfort, and health care will increase the opportunity of herd managers to change productive lifespan to increase profitability, improve societal acceptance of dairy production, or both.

Key words: longevity, culling, productive life

INTRODUCTION

Productive lifespan of dairy cattle may be defined as the time from first calving to exit from the herd when the cow is no longer sufficiently productive. Exit occurs through either death or removal from the herd by the herd manager. The productive lifespan of average cows varies from less than 3 yr (Pinedo et al., 2014; SEGES, 2018) to at least 4.5 yr (Kerslake et al., 2018) in countries with modern dairy industries. Cows calve for the first time at 2 yr of age, which brings their total lifespan from birth to exit from the herd to between 4.5 and 6 yr. The natural lifespan of dairy cattle is approximately 20 yr (Nowak, 1999). Cows exit the herd on average much earlier than at the end of their natural lifespan, which is common for animals in agriculture and driven by economic considerations. Therefore, management decisions largely determine the average productive lifespan of dairy cattle (Fetrow et al., 2006).

Developments in the last decade provide motivation to revisit decision making regarding dairy cattle productive lifespan. Some developments require an evaluation of productive lifespan from an economic perspective, such as improved cow comfort, increased reproductive efficiency, and accelerated rate of genetic gain. Other developments may become more important for the social license to produce milk, such as increased emphasis on animal welfare and the environmental footprint of dairy production.

From a purely economic perspective, the optimum productive lifespan of individual cows maximizes profit

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per unit of most limiting factor (Barnard and Nix, 1973). For example, when milking capacity is the limiting factor, the goal is to maximize profit per milking stall per year. The unit of time is important; a long lifespan in itself does not necessarily increase profitability per unit of time. On the other hand, a short lifespan caused by health problems is likely not profitable and raises questions about the welfare and ethical use of dairy cattle.

The objective of this paper is to review how these developments may affect dairy cow productive lifespan. The literature on culling risks and animal replacement economics is vast, and the references in this article include only a fraction of the available literature. The emphasis of this paper is on productive lifespan of dairy cows in United States.

TRENDS IN PRODUCTIVE LIFESPAN AND REASONS FOR CULLING

The average percentage of cows that left the herd in a year, a proxy of annual cow cull rate, was 38% among 9,158 primarily Holstein herds with greater than 50 cows each (DRMS, 2018). This includes 4% of cows sold for “dairy” purposes that did not end their productive lifespan. The 34% of cows that were sold annually for reasons other than “dairy” had average productive lifespans of 35.3 mo (12 mo/34%). This is equivalent to fewer than 3 lactations. For a similar population of cows culled over 2 decades ago, the overall annual cow cull rate when all removal reasons were included was 35.1% (34.2 mo) and 31.6% (38.0 mo) when cows sold for “dairy” purposes were not included (Hadley et al., 2006). Earlier, Nieuwhof et al. (1989) reported an average productive lifespan of 38.4 mo for Holsteins that first calved after 1965 in the United States. Norman (2019) also reported that productive lifespans have decreased since 1960.

Cannon and Hansen (1939) reported that it was necessary to replace approximately 21 to 28% of the milking herd annually in the 1930s. Current annual cull rates for beef cows are typically between 10 and 20%, leading to productive lives of 5 to 10 yr after first calving. However, within groups of farms, average productive lifespans vary greatly. The annual cow cull rates reported by DRMS (2018) varied from less than 10% to more than 60%. Risks of culling vary by stage of lactation and parity, among other factors (Pinedo et al., 2014). Animal housing, environment, type traits, and availability of replacement animals also affect cull risks and hence productive lifespan (De Vries and Marcondes, 2020). On the other hand, few of the investigated herd characteristics and management routines

were associated with average cow productive lifespan in Sweden (Alvåsen et al., 2018).

Health problems, including failure to conceive, are major culling reasons mentioned by herd managers. In a sample of 27 herds in New England, the primary reasons for culling were failure to conceive, mastitis, and low production (Bascom and Young, 1998). Hadley et al. (2006) found that up to 80% of all culling in the 1990s was due to health issues as reported by dairy farmers. In a data set of cows calving between 2001 and 2006 in 2,054 herds in the eastern United States, the primary disposal code was died (20.6% of all culling), followed by reproduction (17.7%), injury/other (14.3%), and low production and mastitis (both 12.1%; Pinedo et al., 2010). For 2015, the most reported reason was injury/other, followed by reproduction failure, then mastitis and died in herds participating in DHIA (CDCB, 2019b). The distribution of recorded culling reasons may be a poor indicator of actual culling reasons (Pinedo et al., 2010). For example, because only one reason can be reported, the allowable reasons in the herd management program may not match with reality, or no reason is reported.

Although culling for health reasons is common, most culling is the result of decision making by the herd manager (Fetrow et al., 2006). Cows could have been culled earlier or kept longer and treated. Because culled cows are generally replaced with calving heifers, determination of the length of productive lifespan is a form of asset replacement decision making (e.g., Perrin, 1972). Older research using asset replacement theory and decision-support models (e.g., VanArendonk, 1985; Rogers et al., 1988) has estimated optimal annual cow replacement rates to range from 19 to 30%. Optimal annual cow replacement rates are sensitive to many assumptions regarding current and future cow performance and prices. For example, variations in heifer entry cost and fertility led to optimal annual cow cull rates ranging from 28 to 64% in one study (De Vries, 2017). In addition, studies on optimal cow replacement rates may or may not assume a risk of forced culling due to diseases that is not subject to decision making. A complicating factor is that prices likely change unpredictably during the year and across years. Consequently, optimal replacement decisions and optimal annual cow replacement rates are dynamic and change over time. Herd managers may make replacement decisions based on more simplistic calculations and, for example, keep a cow as long as the value of her milk is greater than her feed cost.

Discrepancies between actual annual cull rates and optimal cow replacement rates provoke questions about herd managers' abilities to make economically optimal

culling decisions but also about how well decision-support models mimic the real world in which replacement decisions are made. Herd managers often include other factors in decision making on culling that are seldom included in models, such changes in body condition, udder functionality, mastitis and SCC status, risk attitude, and dynamic price forecasts. In addition, changes in the last decade regarding availability of heifers, rate of genetic gain, and societal appreciation of dairy production warrant revisiting replacement decision making and might alter the productive lifespan.

REPRODUCTION AND PRODUCTION OF CALVES

Historically, and before the advent of sexed semen, most farms raised all dairy heifers to replace their culled cows. Given typical reproductive performance resulting in approximately 1 calving per cow per year and the use of conventional semen only, raising all heifer calves, and a fixed herd size, the average productive lifespan is approximately 3 yr.

Changes in management and genetic selection for improved fertility have led to increases in reproductive efficiency in the last 2 decades, after decades of decreases (e.g., CDCB, 2019a). Average 21-d pregnancy rate in the 9,158 herds in DRMS (2018) was 19.3%. However, 21-d pregnancy rates greater than 25% and even 30% are increasingly common. In addition, female sexed semen has been widely used since 2009 (Hutchinson and Bickhart, 2016). Collectively, many dairy farms now have an abundance of replacement heifers. Herd managers often cull cows to make room for heifers that have calved (R. Jackson, STgenetics, Navasota, TX; personal communication). This closed system results in higher annual cow cull rates and therefore shorter productive lifespans.

Raising all born heifer calves to replace cows appears in many cases not to be most profitable. One viable option that has emerged since genomic testing became feasible around 2010 is selecting only the necessary number of heifers and selling those with the lowest genetic merit (Weigel et al., 2012; Calus et al., 2015). Determination of the necessary number of heifers is an economic question with many facets that is not easy to answer. In addition, the use of sexed semen on genetically superior heifers and cows likely reduces the genetic lag of the herd with the best service sires available for AI (e.g., Ettema et al., 2017).

Another option is to use beef semen and sell crossbred calves. Crossbred calves may capture higher sale prices than surplus purebred dairy calves. In the United States, beef semen sales climbed from 1.2 million units in 2010 to more than 4 million units in 2018 (NAAB,

2019). This increase of almost 3 million units is due to the greater use of beef semen in dairy cattle. High premiums for crossbred calves suggest a greater marginal value of extending dairy cattle productive lifespan.

The number of dairy heifer calves can also be reduced by extending lactations through a longer voluntary waiting period for first insemination. Extended lactations will reduce the number of calves born per cow per year and reduce the frequency of transition risk periods (Lehmann et al., 2019). However, longer days from calving to conception might increase the risk of death and live culling around calving (Pinedo and De Vries, 2010). If managed well, extended lactations may have no adverse effects regarding milk production, involuntary culling, udder health, or BCS gain (Niozas et al., 2019). Niozas et al. (2019) also describe studies in which extended lactations were not advantageous or were found to be disadvantageous.

Economic evaluation of insemination and replacement options may alter productive lifespan of individual cows and herds. Accurate evaluations are not easy to accomplish, and advisors and herd managers may need the help of decision-support software (e.g., Van Arendonk, 1988). Decision aids must have accurate predictions of future cash flows for alternative decision options. For example, cash flow predictions could be improved by incorporating genomic data and data from precision technologies that help predict future disease risks, fertility, and milk production.

GENETICS

Productive lifespan of an incumbent asset should be shortened when the economic efficiency of the challenger asset is better. This principle also applies to culling of dairy cows when replacement heifers are genetically improved (e.g., Groenendaal et al., 2004). Changes in genetic traits because of selective breeding are well documented (CDCB, 2019a). The average value of the economic selection index lifetime net merit (NM\$; VanRaden et al., 2018) has consistently increased since 1975 (CDCB, 2019a). The rate of genetic gain has accelerated from approximately \$30 PTA of NM\$ per year before 2010 to approximately \$70 PTA of NM\$ per year currently (CDCB, 2019a) as a result of the use of genomic testing for sire selection (García-Ruiz et al., 2016). Consequently, the average difference in genetic merit (e.g., NM\$) between heifers and older cows is increasing.

Historically, many herd managers have interpreted genetic gain in replacement heifers as an incentive to raise all available heifers and therefore cull more cows, thereby limiting length of productive lifespan.

The accelerated genetic gain due to genomic selection has a minor effect on the optimal productive lifespan. Compared with the rate of genetic gain before genomic selection, the optimal productive lifespan may be a few months shorter (De Vries, 2017). The shorter productive lifespan, and hence greater replacement rate, does not warrant raising all heifer calves born on the dairy farm in a situation in which an abundance of dairy heifer calves are made. A cow replacement rate based on genetic progress alone is not optimal because it ignores phenotypic differences between parities and herd replacement cost, among other factors, as is illustrated below.

Current selection indices such as NM\$ aim to breed dairy cattle that are productive but also fit for use by providing good health, fertility, and functional type. The genetic trait productive life was added to the NM\$ index in 1994, and fertility traits have been added since 2004 (VanRaden et al., 2018). Breeding values for productive life have continuously increased since 1962 (De Vries, 2017; CDCB, 2019a). Phenotypic trend for productive life decreased between 1962 and 2011 but has slightly increased again (CDCB, 2019a). The reductions in fertility and health that were observed when selection was primarily directed to selection for milk yield have since reversed. The reversal in these functional traits shows that improved fitness allows cows to stay longer in their herds if management so decides. In the 2018 NM\$ index, which has 14 traits, 44% of the relative value was on the traits milk, fat, and protein and 56% was on other traits that improve fertility, health, and type. Collectively, the NM\$ selection index aims to improve overall lifetime profitability during the standardized lifespan of 2.8 lactations.

It is likely that total merit of dairy cattle, as a sum of all desirable traits, will continue to increase for at least the next 40 yr, resulting in a doubling of milk production per cow (Britt et al., 2018). Such cows will have even more improved health and greater capacity for longer productive life. These changes do not necessarily mean that the optimal productive lifetime will be increased, although more robust cows will lead to reduced forced culling due to health problems, especially in early lactation. Increases in the genetic trait productive life have not led to marked increases in phenotypic productive lifespan (CDCB, 2019a). However, reductions in health problems before culling will be a sign of improved welfare, even when length of productive life may not be increased (Britt et al., 2018).

Genetic selection has the ability to change cash flows during a dairy cow's life, which in turn may affect optimal productive lifetime. For example, faster improvement in health might favor longer productive

lifespans. More persistent lactations may have health benefits and reduce the need to quickly get cows pregnant after calving (Cole and VanRaden, 2006). Later-maturing cows should have longer productive lifespans as well. Selection of sires should be based on financial investment analysis techniques, including accounting for opportunity cost, when the goal is to maximize profitability per unit of time. This might require some changes in the construction of current selection indices to better account for changes in production with changes in productive life (Schmitt et al., 2019).

ENVIRONMENTAL FOOTPRINT

An increasing desire to reduce the environmental footprint of dairy production is being driven by concerns of the general public (Hristov et al., 2013; Thoma et al., 2013; Knapp et al., 2014). Increasing productive lifespan has been shown to reduce the environmental impact of dairy production. For example, Knapp et al. (2014) showed that replacement heifers contribute between 20 and 33% of whole-herd enteric methane emissions, with a decreasing contribution for younger age at first calving and a longer productive lifespan. A herd with a high proportion of young animals emits more methane and excretes more phosphorus in the environment per unit of milk compared with a herd with a greater proportion of multiparous cows (Hristov et al., 2013). However, extending the productive lifespan of dairy cows is less effective at reducing greenhouse gas emissions per unit of milk when the amount of beef produced is accounted for (Knapp et al., 2014; Vellinga and de Vries, 2018). Still, beef from dairy animals produces significantly less greenhouse gas per unit of meat when greenhouse gas allocated to milk is accounted for than does meat produced by animals that produce no or low amounts of milk (Zehetmeier et al., 2012; Britt et al., 2018). In at least one study, extending productive lifespan both reduced greenhouse gas production and improved profitability of dairy cattle (Grandl et al., 2019).

ANIMAL WELFARE

Good animal welfare is an important aspect of socially acceptable and preferable dairy production systems (e.g., Cardoso et al., 2016). Important welfare concerns by the general public include the high prevalence of lameness on many dairy farms (von Keyserlingk et al., 2013). Failure to conceive can also be considered reduced animal welfare (Oltenacu and Broom, 2010). Further, short productive life is thought of by some as a symptom of reduced animal welfare (Oltenacu and

Broom, 2010). Many cows are culled for health reasons that suggest temporarily poor welfare before culling and slaughter. Maintaining high animal welfare up to death is increasingly more important. The public has also indicated a willingness to pay for improved dairy cattle welfare (Wolf and Tonsor, 2017). However, reductions in forced culling early in life do not necessarily lead to equivalently longer economically optimal productive lifespans because herd managers would instead cull cows for low milk production and failure to conceive (Van Arendonk, 1995). It is conceivable, however, that the public will demand longer productive lifespans in the future. The dairy community might focus on reducing the likelihood that animals lose value through poor welfare instead of accepting that culling itself is likened to a welfare concern.

A SIMPLE MODEL OF OPTIMAL PRODUCTIVE LIFESPAN

The following simple model illustrates the key factors that determine optimal productive lifespan from an economic perspective. For a variation in the number of lactations from 2 to 10, the optimal productive lifespan is the one in which the total cost of the herd structure is lowest (Figure 1). The total cost of herd structure in this model is the sum of replacement cost, lack of maturity cost, aged cow cost, genetic opportunity cost, and calf value opportunity cost. In this model, the risk of culling is the same every lactation, depending only on the number of lactations modeled. For simplicity, 1

lactation is set to 1 yr. I make no claim that the model represents a real set of farms.

Replacement cost is calculated as the heifer replacement cost minus the price received when the cow exits the herd (either dead or alive), divided by the productive lifespan. For example, assuming \$1,700 for a replacement heifer and \$900 for exit price, the replacement cost is \$267/yr when herd average productive lifespan is 3 yr and \$133/yr when herd average productive lifespan is 6 yr. Interest cost is not included. Total replacement cost per year decreases with a longer productive lifespan.

Lack of maturity cost is the result of cows in the herd that are in their first through fourth lactation that are less efficient milk producers. I assumed that cows in their fifth and sixth lactation are mature (Mißfeldt et al., 2015) and have the highest milk sales minus feed cost. For example, milk production in first-lactation cows may be 80% or less of maturity. Feed intake will also be lower than in mature cows. I assumed that lack of maturity cost in first- through fourth-lactation animals was \$500, \$428, \$340, and \$182, respectively, compared with mature cows (\$0). These inputs are calculated based on average milk production per lactation in 5 herds, their estimated feed intakes, a milk price of \$0.35/kg, and a DM price of \$0.25/kg. The lack of maturity costs are assumed to be free from genetic gain over time. Herds with shorter average productive lifespans have relatively more cows in their first through fourth lactation compared with older cows and therefore a greater lack of maturity cost. For example,

Figure 1. The 5 drivers of total cost of maintaining herd structure: genetic opportunity cost, herd replacement cost, lack of maturity cost, aged cow cost, and calf value opportunity cost. The optimal productive lifespan (number of lactations; 1 lactation is set to be 1 yr) is the one in which the total cost is the lowest. The optimal productive lifespan is 5 yr in this example. The blue line goes with the right axis, and the bars go with the left axis.

lack of maturity cost is \$330/yr when herd average productive lifespan is 3 yr and \$200/yr when herd average productive lifespan is 6 yr. Total lack of maturity cost decreases with a longer productive lifespan.

Aged cow cost is the result of older cows in the herd that are in their seventh or later lactations. These cows are assumed to have lower milk sales minus feed cost compared with mature cows due to advanced age. I assumed that aged cow cost increased by \$50/yr after the sixth lactation. For example, cows in their ninth lactation had \$350 aged cow cost compared with mature cows (\$0). Aged cow cost is difficult to estimate in practice because few older cows remain past their sixth lactation and they have survived culling for low production in their earlier lactations. Aged cow cost is also assumed to be free from genetic gain over time. In Figure 1, aged cow cost was \$13/yr when herd average productive lifespan was 3 yr and \$81/yr when herd average productive lifespan was 6 yr. Total aged cow cost increases with a longer productive lifespan.

Genetic opportunity cost is the loss from keeping older, less genetically improved cows in the herd instead of younger, more genetically improved cows. Genetic improvement in heifers is also a main driver for dairy farmers to cull dairy cows. Here I assumed a genetic gain of \$40/yr in PTA for NM\$ (CDCB, 2019a). This value is less than that observed for sires during the last 5 yr but greater than that observed 20 yr ago. The change in genetic progress for females lags behind that for sires. The \$40 in PTA translates to \$80 EBV per year. Lifetime is approximately 3 yr; therefore, the genetic opportunity cost is \$27/yr. With the genetic opportunity cost of the sire of the cow set to \$0, the genetic opportunity cost of the cow was \$300/yr when herd average productive lifespan was 3 yr and \$438/yr when herd average productive lifespan was 6 yr. Genetic opportunity cost favors a younger herd.

Finally, calf value opportunity cost is the cost of not producing calves that can be sold because the calf is needed to replace the cow to be culled. In addition, surplus calves could have value added through insemination with beef semen. A longer productive lifespan allows for production of more and higher valued surplus calves. I assumed that the calf value opportunity cost was \$38/yr when average productive lifespan was 3 yr and \$10/yr when average productive lifespan was 6 yr. These costs are based on a premium of \$75 for crossbred dairy–beef calves over purebred dairy bull calves and a calculation of the number of surplus calves. Calf value opportunity cost decreases with increased productive lifespan.

Using these 5 drivers as the total cost of herd structure, Figure 1 shows an optimal productive lifespan of

5 yr. Total cost is \$20 greater when productive lifespan is 4 yr and \$3 greater when productive lifespan is 6 yr. The marginal value of increasing productive lifespan is greatest when productive lifespan is short. Extensions of productive lifespan past 4 yr have small marginal values. Figure 1 shows that genetic gain itself does not warrant the productive lifespan of approximately 3 yr that is currently observed in practice. These results should be interpreted with caution because the model is simple and individual farm conditions vary. One factor not included in the analysis is a possible willingness to pay by consumers for an extended productive life if this is seen as a measure of improved animal welfare (e.g., Wolf and Tonsor, 2017).

CONCLUSIONS

The main driver of productive lifespan is economic decision making by the herd manager. Developments in the last decade, especially the ability to produce an abundance of dairy heifer calves, increased genetic gain, and environmental and animal welfare considerations, warrant a critical evaluation of decision making on dairy cow culling and, consequently, productive lifespan. Results of this evaluation may improve profitability of dairy production or the social acceptability of dairy production or both.

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