Introduction

Healthy animals are the cornerstone of sustainability in animal agriculture. It is through improvements in health, genetics, and management leading to increased efficiency that the US dairy industry has made large strides in sustainability over the past 50 years. These aspects of dairy management will continuously improve as the dairy sector learns more through research and careful review of historical performance. One area of interest receiving increasing attention is dairy cow longevity. The longevity of an individual cow and how that life plays out have implications for the complicated relationship among welfare, productivity, sustainability, and dairy herd turnover rate. This is a topic of consideration regarding sustainability because many have casually observed that older cows make more milk and thus draw the conclusion that they are more profitable. The idea of having older cows in a herd would seem to indicate that a farm has better welfare, and some modeling might suggest that long-lived dairy cows have a lower environmental footprint. In the companion Currents in One Health by Nguyen et al., *JAVMA*, January 2023, we explored how dairy products contribute to a modern, nutritious food system. That piece was focused on how modern dairy production is good for cows, for people, and for the planet. This piece will explore concepts for furthering the contributions of certain modern dairy production practices to welfare, farm efficiency, and sustainability. Specifically, herd turnover, dairy medicine and management drivers for herd turnover, and the implications of it on profitability, welfare, and sustainability are examined.

Herd Turnover

Dairy producers and veterinarians are constantly striving for improved production, animal well-being, and profitability. As part of the normal processes of dairy farming, cows calve, enter lactation, and their female offspring have the opportunity to become the next generation of producers. Most dairies operate at full capacity with a relatively constant herd size. As replacement heifers approach calving, these
dairies must decide whether to bring a new animal into the herd and displace an existing animal or market the heifers as replacements for another herd. The process of replacing an existing cow with a new animal in the lactating herd is known as herd turnover. Herd turnover can be described as a rate and has been defined as the number of cows leaving the herd, by death or sale, divided by the cow time at risk for leaving. Commonly, dairy farms or consultants calculate an annual herd turnover using the number of cows that left the herd in a 12-month period as the numerator and the average number of adult cows (milking or dry) in the herd over that same time as the denominator. The measurement and tracking of herd turnover rate are very common dairy management practices, but the authors caution against benchmarking with this metric and managing a herd turnover rate for several reasons. Herd turnover is the consequence of numerous upstream events and decisions rather than a performance indicator that should be directly managed. There can be significant lag between when an event occurs (or fails to occur) and when an animal is replaced. Managing to a targeted herd turnover rate leads to incorrect decision-making and often compounds problems within the herd. Herd owners and managers should look forward and make the appropriate on-going decisions regardless of what happened in the past to improve the dairy’s profitability instead of delaying replacement decisions to meet some turnover goal.

The reasons cows lose sufficient value to justify replacement are numerous and seldom can a single “reason” be determined. Some dairy cows will die, or be euthanized, and some will be sold or slaughtered. Culling is the term used for the decision to remove a cow from the dairy herd. Each culling decision is based on many factors. Several of the most important factors will be explained. Generally speaking, cows that are removed should be immediately replaced to avoid empty slots and decreased herd-level production efficiency. Producing milk, generating revenue, and striving for profit and food system sustainability relies on an ongoing dairy production system that outlasts an individual growing season, lactation, reproductive cycle, or cow lifetime. Preventative health management is improving all the time and resources exist to help the dairy community continue to strive for excellent health, fertility, and welfare. Still, variations in performance, as well as all-out failures occur; therefore, culling and euthanasia will be indicated at times. Producers and veterinarians need to make timely and appropriate decisions regarding culling and euthanasia when indicated to improve welfare and performance. This often means deciding against furthering the longevity of an individual animal, but the welfare implications of timely culling decisions are positive for cows whenever the alternative is a drawn-out health management challenge that results in an undesirable outcome. The increases in herd turnover rates that have accompanied other progressive changes in modern dairy management have also coincided with lower condemnation rates at slaughter, a discontinuation of the practice of slaughtering recumbent cows for human consumption, and increasingly important contributions by the dairy sector to the beef, biomedical reagent, and pet food supply chains.

In the efficiency and economic management of the dairy herd, it is wise to think of the operation as a number of slots available to be occupied by cows. In some dairy operations, the number of slots will simply be the number of stalls, and in others, it will be governed by milking facility capacity, housing space, or other constraints. Good veterinarians and managers will endeavor to have healthy, productive cows occupying each slot at all times, thus optimizing the output of the dairy operation and maintaining the welfare status of the herd. Some have proposed that the most productive cows available to occupy dairy slots are mature cows, and, while this can be true some of the time, many younger animals will outperform mature cows because of superior genetics, normal performance variation, and failures of preventative management at any point. Additionally, some younger animals will be excellent culling candidates when the optimization of productivity per slot is prioritized. In all age groups, these variations in productivity and the failures of our management systems to produce perfect results in the health and expression of genetic potential result in opportunities to increase dairy output and efficiency through strategic culling and replacement.

Upon a culling decision of any kind, replacement of a milking cow is critical to maintaining productivity efficiency. The empty dairy slot is completely undesirable from an economic and environmental impact standpoint because of the ability of the last few animals over which fixed costs can be spread. Therefore, sufficient availability of replacements to fill open slots and allow for timely decisions is important for dairy sustainability (animal well-being, farm financial viability, and environmental stewardship). Replacement heifer availability is a complex variable to manage for a closed herd because the decision to raise heifer calves occurs approximately 32 months before they will enter the lactating herd. Additionally, such a herd will be constantly looking to balance the incoming first-lactation heifer population with their culling decisions, plus any death loss in adult cows. Thus, the availability of replacements largely governs herd turnover rate.

**Profitability**

The lactating cows in a herd pay the bills for the whole dairy enterprise. The all-too-common notion that an individual lactating cow should “pay for herself” is flawed economic thinking because of the concept of sunk costs. If a cow is making milk, the expenses the dairy incurred to rear her are sunk costs; they are in the past and they have already been accounted for. Failing to allow the most productive animal available to occupy a slot today and help pay expenses today and in the near future can be an opportunity cost for a dairy. Therefore, no matter how long or short the productive life of a
milking cow has been, if an available replacement heifer can occupy her slot and perform significantly better than the current animal, replacement is usually warranted, depending on the relative cost of the replacement transaction and the value of the production difference.

Lower herd turnover rates and smaller replacement heifer inventories do tend to lower replacement costs. It is very common to think that raising heifers is far too costly to make selling extras at an individual loss worthwhile; however, the last heifer raised does not cost the same as the average heifer raised due to the concept of marginal expenses and revenues. If a dairy producer raises 2% fewer heifers this year in an attempt to save money and increase efficiency, only variable costs disappear. In a 2019 analysis, these variable costs include feed, breeding, and health costs, roughly $1,183 per animal not raised. The total average cost of raising a heifer, averaging around $2,355 in 2019, is not disputed here, only the marginal costs of the last few heifers or the next few. This is an argument for the ability of a dairy operation to raise a modest excess of heifers without losing efficiency.

If replacement heifers are raised at a custom heifer grower and a dairy pays a per head per day rate, marginal costs are not incurred the same way as if a dairy is raising its own replacements. However, it is still advisable to raise enough replacements to maintain strategic and proactive culling options. Whether using genomics or pedigrees for genetic selection or using historical or modeled numbers for future replacement needs, these predictions are estimates based on a lot of imperfect but helpful information. The distribution of milk production phenotype, after selectively culling some bottom fraction of heifer calves based on genetic merit, illustrates this concept. When a dairy operation evaluates which heifer calves to raise and intends to only raise the best, they look at a bell-shaped curve of their heifers’ genetic merit or other characteristics (e.g., parent information), and they remove the inferior animals on the curve (Figure 1). However, when the new population of select heifers reaches their first lactation, the performance of these animals is not a bell curve with the bottom chopped off, it is a new bell curve, presumably now with a higher mean than previously and one with a new cohort of animals at the extreme left of the distribution (Figure 2). Leaving zero wiggle room in a “raise only the best” strategy will still result in underperforming first lactation animals entering the herd even though some animals have previously been removed.

The imperfect ability to know exactly what will happen with exactly which animals makes a modest surplus or cushion of heifers advisable and makes leaving the option to selectively cull young animals at the expense of average longevity advantageous to the productivity of each dairy slot. Recalling the idea that a dairy has a finite number of slots that can be filled by individual cows, producers and dairy veterinarians should strive to fill these slots with the most efficient and productive cows, take as an example, a 1,000-cow dairy raising 10% excess heifers compared to historical turnover needs. This dairy can actually incur a cost of $2,000 for every one of those heifers, sell the underperforming 5% of first lactation animals when they reach second test day (60 to 90 days in milk) for a beef revenue of just $700 per head, and the dairy is still ahead about $19,000 because they allow the most productive animals to occupy slots. Comparing income minus feed cost per day or per year and recognizing that the average productivity is higher for all approximately 400 first lactation animals remaining in the herd after culling poor performers reveals this advantage. The opportunity cost of calving in precisely the number of heifers needed historically and culling zero underperforming heifers is actually greater than the cost of raising a modest excess.
Today’s heifers are on average increasingly superior to the cows they replace. If higher quality first lactations animals are entering the herd, the opportunity cost of keeping less-productive animals goes up. A heifer who calves at 80 to 85% of mature body weight in good body condition and has maintained high average daily weight gains and good health throughout her rearing will actually be capable of outperforming a larger fraction of mature animals compared to historical first lactation performance expectations. When the quality of available replacements goes up, the likelihood that they will be able to outperform an existing lactating cow, whether an older cow or an inferior first lactation animal, increases. This means that the act of raising only an elite subset of young stock will incentivize more aggressive culling down the road.

Welfare

Raising additional replacements and having a higher replacement rate can be beneficial for animal health and welfare as well as for profitability. This may seem counterintuitive because high cull rates are often viewed as negative indicators of health and welfare. However, this assumes that culling occurs primarily as the result of death, disease, or welfare; however, that is much less common in modern dairy management systems.

Health and fertility outcomes that allow the best cows to reach the sixth, seventh, and eighth lactations successfully should constantly be pursued, but younger, more genetically advanced animals will readily outperform the average and below-average mature animals, presenting an opportunity for progress. When dairy managers proactively recognize underperforming animals and choose to selectively cull with replacement, welfare outcomes have the opportunity to improve. Considering the relative risk for health disorders in transition cows illustrates this point. A cow who is culled in early lactation is far more likely to experience suboptimal welfare in her final days on the dairy, during the sale, transport, and slaughter process. These cows are often experiencing energy deficit and are thinner, and their reasons for culling are frequently more health-related than cows culled in later lactation. Later lactation cull cows can be chosen long before the day they leave the dairy, they are often heavy, healthy, and robust; they tolerate transport and slaughter better. Sensible, timely, culling decisions that do not over-prioritize herd longevity result in better welfare. Data from cull cows leaving the Cornell Teaching Dairy Barn over a 12-month period from August 2020 to August 2021, help to numerically demonstrate this opportunity. Through health management, a commitment to fitness for transport, a disregard for managing herd longevity, and a healthy supply of replacements, the Teaching Dairy culled cows with an average body weight of 715 kg, price per kilogram at the local sale barn averaged $1.30, and average days in milk at departure was 249. During this same time period, cull cows in the northeast averaged 648 kg at $1.26 per kilogram.

Sustainability

Environmental sustainability of the dairy and global food system is improved when the replacement rate is higher than “all that is needed” so that the most efficient animal can fill each slot. If the US dairy herd is considered today, it is comprised of approximately 9.4 million cows making 226 billion pounds (103 billion kg) of milk each year with a replacement rate of 37%. This is approximately 66 pounds (30 kg) of milk per cow per day. There are approximately 4 million replacement animals needed to enter the US dairy herd each year.
The US dairy herd is currently responsible for < 2% of total US greenhouse gas emissions;\textsuperscript{15} however, the US dairy industry has made a commitment to reduce emissions and reach greenhouse gas neutrality by 2050.\textsuperscript{16} The relationship between herd turnover rate and greenhouse gas emissions from dairy production is often questioned.

It is well documented that welfare and herd performance have continued to improve and will continue to improve over time with continued progress in the dairy industry on animal management, herd health, genetics, nutrition, and more. A model examining the relationship between herd turnover and productivity can approximate the role that increased selective replacement could have on greenhouse gas emissions. When morbidity and mortality remain constant and the only reason for an increase in culling is the ability to replace an underperforming animal with a higher-performing animal in her slot, enteric methane emissions will decrease. Enteric methane emissions are modeled because it is the largest emission source on US dairy farms, and with methane’s ability to warm the atmosphere at 25 times carbon dioxide, methane is a greenhouse gas of utmost importance to US dairy.\textsuperscript{17} In a simple model created by the authors where milk demand is constant, the higher-turnover scenario creates an opportunity to produce the same amount of milk with fewer animals. Applied to the US dairy herd (9.4 million cows), and assuming a constant demand for milk (103 billion kg)\textsuperscript{12}, this model predicts that increased herd turnover will decrease US dairy enteric methane emissions (Table 1). A 3% increase in the US dairy herd turnover rate (from 37% baseline to 40%), after raising additional heifers (approximately 154,000 additional animals over baseline) and providing the opportunity to replace underperformers more aggressively, increases total milk production per cow by a few kilograms of milk (30 kg/cow to 31.8 kg/cow, assumed) on average because the most productive cows are filling the available slots. In this scenario, fewer total lactating cows are needed to meet milk demand, and the combined total number of dairy animals (replacements and lactating) in the US herd decreases. Adult lactating animals emit more per head than heifers do. However, with more efficient, higher-producing, lactating animals, fewer adults are needed, and the emissions of the additional heifers needed for an increased herd turnover rate will displace only part of the adult cow emissions avoided. The model assumes a baseline scenario where the average US dairy cow produces 30 kg of milk, consumes 8 kg of feed for maintenance, and has a marginal feed efficiency of 2 kg milk/kg dry matter intake (DMI). The additional feed consumed by the cows in the higher culling scenario that make 1.8 additional kilograms of milk is accounted for in this model, as is the additional feed consumed by the additional heifer population. DMI is known to be the primary driver of enteric emissions.\textsuperscript{18} Using the enteric methane production factor of 0.46 kg methane per kg DMI\textsuperscript{15} and assuming a global warming potential of 25 for methane\textsuperscript{19}, the 3% increase in replacement rate, with no other changes, results in a 1.8% decrease in enteric methane emissions. Decreases in emissions like this have already been shown to be associated with higher production per cow. In a comparison of 2007 to 2017, the dairy industry made great strides in greenhouse gas emissions per gallon of milk produced (a 19% decrease), mortality decreased, heifer rearing success increased, and replacement rate increased accordingly.\textsuperscript{20} Conversely, this model shows that an insufficient supply of replacements constraining turnover rate might increase enteric methane emissions from dairy production by not having the most productive lactating cows in each slot. In our model, demand for dairy was held constant; however, as the global population is expected to rise and year-over-year consumption of dairy products continues to increase with the growing population,\textsuperscript{21} it is likely that demand will increase. With increased demand, it is even more important to raise a modest surplus of replacements so the most productive animals can fill the available slots, and production can meet demand in the most resource-efficient and sustainable way. Although the detail is beyond the scope of this brief article, other aspects of dairy environmental sustainability such as water use, land use, and nutrient (including nitrogen and phosphorus) management are similarly impacted by systems that optimize production efficiency.

When dairy is considered in the context of the entire sustainable food system, the displacement of animals raised for beef by underperforming first-lactation animals and other selectively culled animals

Table 1—Comparison of enteric emissions across herd turnover rates.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline (2021)</th>
<th>Increased herd turnover</th>
<th>Reduced herd turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk demanded (billion kg)</td>
<td>103\textsuperscript{12}</td>
<td>103</td>
<td>103</td>
</tr>
<tr>
<td>Milk production (kg/cow/day)</td>
<td>30.0</td>
<td>31.8</td>
<td>28.2</td>
</tr>
<tr>
<td>Herd turnover rate</td>
<td>37%</td>
<td>40%</td>
<td>34%</td>
</tr>
<tr>
<td>Adult lactating herd size (thousand cows)</td>
<td>9,404</td>
<td>8,867</td>
<td>10,010</td>
</tr>
<tr>
<td>Total replacements in herd (thousand heifers)</td>
<td>7,999</td>
<td>8,153</td>
<td>7,825</td>
</tr>
<tr>
<td>Total herd size (thousand animals)</td>
<td>18,808</td>
<td>18,345</td>
<td>19,332</td>
</tr>
<tr>
<td>Total herd enteric methane emissions (MMT CO\textsubscript{2}e)</td>
<td>43.8</td>
<td>43.0</td>
<td>44.7</td>
</tr>
<tr>
<td>% Change enteric emissions from baseline</td>
<td>–</td>
<td>-1.8%</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

Dry matter intake was estimated for milk production, milk production changes due to culling was estimated, and enteric emissions were calculated using the Nui et al\textsuperscript{11} equation and Intergovernmental Panel on Climate Change Global Warming Potential (IPCC GWP) 2007.\textsuperscript{14}
in higher herd turnover rate scenarios can also be considered. The carcass value of a first lactation, otherwise healthy dairy animal can be a valuable contribution to the beef supply and helps spread the costs and environmental impact of her rearing over more servings of food. Thus, the benefits of proactively culling dairy cows to a sustainable food system go further than milk production.

**Conclusion**

As the global population grows and people become more discerning consumers of food, a sustainable supply of quality nutrition will continue to be critical to society. Dairy meets the needs of society in a variety of valuable ways and can continue to make progress in sustainability goals that are common to many sectors. Profitability, animal welfare, and environmental impacts should be among the sustainability considerations of the dairy production system. The relationship between herd turnover, profitability, welfare, and sustainability should be carefully considered because of the influence of timely replacement on production efficiency and welfare. A sufficient supply of dairy replacements makes good culling decisions possible, and, for all sustainability goals, an approach to culling that does not overemphasize herd longevity and low herd turnover rates is sensible.

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**References**