Dairy production sustainability through a one-health lens

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ABSTRACT
Dairy production provides high-quality, healthful nutrients to people on a planet soon to be inhabited by over 9 billion people. In doing so, it is ever more important to continuously improve the care of dairy animals, safeguard the environment we all share, and reliably produce nutritious food while maintaining the economic viability of the people working in dairy agriculture. In this paper, we review some associations between dairy consumption and human health along with the many interconnections between people, dairy animals, plants, and our shared environment. Understanding these relationships is an example of one health at work. In the US, total dairy consumption is at its highest point in the last 50 years, while many objective measures of cow health (eg, subclinical mastitis) have never been better since they have been recorded. Further, indications of food safety such as violative antibiotic residues in milk have never been lower. Dairy foods provide essential nutrients such as protein, vitamin B12, and calcium, while there is also evidence that they are protective against chronic conditions such as cardiovascular disease. Finally, the environmental footprint of dairy production in the US, as measured by metrics such as carbon dioxide–equivalent emissions intensity per unit of dairy nutrient, is the lowest it has ever been. The companion Currents in One Health by Nguyen et al, AJVR, January 2023, discusses some additional animal welfare and environmental impact implications of modern dairy production management in detail.

On an increasingly populated planet, where there is an impetus to do better by animals, communities, and the environment, dairy’s place in the global food system warrants examination. Animal well-being, the nutritional value of dairy products, and the environmental impact of dairy production have been and continue to be studied. Substantial evidence exists demonstrating continuous improvement in animal health and welfare among dairy cattle and dairy products as sustainable sources of nutrition. Veterinarians throughout the profession have a role to play by educating themselves and others on dairy production’s positive contributions to a modern society through a one-health lens. Among the needs of society, where dairy plays an increasingly important role, are the provision of quality nutrients to the growing population, production of larger quantities of quality food at increasingly lower environmental impact intensities, continuous improvements in animal health and welfare, and contributions to local economies.

For over 10,000 years, the cow has been integrated into human society. Evidence of domesticated ruminant species is well documented in the region of the Fertile Crescent and referenced by the ancient societies that thrived in that region and time.1 Anthropological evidence of random mutations that extended the expression of lactase enzymes into adulthood also exists.2 In the millennia following, the prevalence of the lactase enzyme spread, along with traditions of herding and dairy foods. The rapid and widespread increase in lactase persistence mutations suggests not only that our ancestors enjoyed dairy foods, but that dairy consumption likely led to survival and reproductive benefits that conferred a selective advantage.3 The herding and stockmanship traditions of certain societies allowed their people to thrive and create more nutrition for their families from the sun and soil resources available, compared with those societies without domesticated ruminants.

The ruminant and its symbiotic relationship with billions of cellulase-expressing microbes are largely responsible for the sustainability of the dairy production process and dairy foods. With the sun and soil, photosynthesis can help plants grow and develop. In doing so, they multiply, reproduce, and sequester nutrients into leaves, stems, seeds, oils, and other components. It is true that an omnivorous human can appreciate plenty of healthy nutrition from plants. Some vitamins, minerals, fats, proteins, and carbohydrates available to the human digestive process can be found in plants, but the ruminant can go much further. The lattice of complex carbohydrates that forms plant cell walls and gives plant stems their rigidity is not digestible in simple stomach species. The importance of fiber to human digestive health is another discussion, but the calories and support for energetic biological processes contained in plant fiber are more available to humans after pass-
ing through ruminants. The cow and its rumen microbes will use up to 60% of the fiber ingested. Not only does the plant fiber help cows to maintain gut health and support their microbiome, but the energy stored in these complex carbohydrates becomes available for them to metabolize. Additionally, in the process of thriving in the ideal rumen environment, after multiplying themselves millions of times over, many of the microbes flowing through the ruminant gastrointestinal tract feed the cow amino acids that would have otherwise been in unavailable forms of nitrogen. The ability of the ruminant to digest plant fiber makes them one of the green energy innovations available to humanity.

**Animals**

The cow is at the center of the dairy universe and, happily for those involved in the dairy community, responds well to better care. While genetics, precision nutrition, and management technology have enabled many of the gains in dairy cow efficiency and productivity, a large fraction of that gain has been the result of improvements to the health and welfare of cows. It has been through the removal of barriers to allow cows to express their genetic potential for efficient feed conversion that a lot of progress has been made. Today’s dairy cows in contemporary management systems have better access to high-quality feed, water, air, light, rest, and space than most animals throughout history.

Many metrics of animal welfare are easier to scrutinize than to measure in a standardized way; however, certain data provide evidence of improvement over time. One such metric that every modern producer has available to track and is representative of nationwide production is bulk tank milk somatic cell count. Somatic cells, largely composed of neutrophils, other WBCs, and shed mammary epithelial cells, are an indicator of udder health. Somatic cell counts in milk increase dramatically when inflammation and infection are present. Although cows never produce a somatic cell count of zero, healthier cows produce milk with lower somatic cell counts. With mastitis continuing to be one of the most prevalent and impactful health conditions of dairy cows, continuous progress in managing the condition and its impact on animal welfare has been a goal for the dairy sector. While available to an individual producer, bulk tank somatic cell count is also aggregated at a national level by the USDA, and the national average shows a decrease of 128,000 cells/mL over a 20-year period (Figure 1). This substantial decrease in US average bulk tank somatic cell count can be attributed to improvements in cow housing (e.g., more comfortable stalls and bedding), milking practices and equipment function (e.g., pre- and postmilking teat disinfection and automatic milking machine removal based on flow rate sensors), and medical management of clinical and subclinical cases (e.g., pathogen-based treatment decisions). Importantly, the improvements in udder health and milk quality outcomes discussed have been achieved while judicious use of antimicrobials has been improved and while the productivity of dairy cows has continued to increase. From a one-health perspective, pathogen-based treatment decisions for mastitis and movements away from blanket therapies have reduced antimicrobial usage on dairy operations in recent years, and from the standpoint of milk quality and food safety, the frequency with which antimicrobials are found in milk shipped from farms continues to decrease (Figure 2).

Although loads of milk testing positive for antimicrobials occasionally arrive at processing plants, the milk in these tanks will never enter the food supply. In 2009, through the National Milk Producers Federation (the national organization created to be a forum for dairy producers and cooperatives to participate in public policy discussion), the dairy community created the national Farmers Assuring Responsible Management (FARM) program to drive progress in animal care, food safety, worker dignity, and environmental stewardship. The FARM program includes staff-member animal ethics agreements, quantification of several welfare metrics, and the requirement of standard operating procedures for numerous health conditions and husbandry practices. Through monitoring of lameness and hygiene scores by trained secondary-party compliance officers and a smaller number of random third-party auditors, the FARM program has documented decreasing lameness prevalence (today 97% of herds meet lameness requirements, with < 5% of the herd identified as severely lame) and improving...
hygiene (86% of herds have > 90% of animals that are considered clean or have a minimal amount of manure on their lower leg) among US dairy cows over the last 13 years (since the inception of the program). Perhaps more importantly, the program has been able to show that its implementation has motivated changes for the betterment of these welfare metrics among participating producers.

**Planet**

The dairy cow productivity discussion leads directly to understanding the current and future environmental impact of dairy production. Today, the US dairy industry produces approximately 2% of all total US greenhouse gas emissions. The dilution of maintenance requirements that the cow can accomplish with higher productivity lends a dramatic effect to the efficiency of feed-to-milk conversion. As this conversion efficiency improves, the environmental impact of each serving of dairy decreases. Enteric methane, for example, associated with dairy production on a per-cow basis has increased as the output of milk has increased over the last 30 years, from 266 kg CH$_4$/head/y in 1990 to 330 kg CH$_4$/head/y in 2020, while milk production has increased from 14,782 lb/cow/y to 23,777 lb/cow/y. These changes represent a 24% increase in methane emissions coupled with a 60% increase in milk output, thereby reducing emissions per serving of dairy food, and more production than ever is attributable to fewer cows and fewer dairy operations. Decreases in emissions per gallon of milk by 73% from 1944 to 2007 have been documented (Figure 3), and the industry achieved another 19% decrease in greenhouse gas emissions from 2007 to 2017.

![Change in Greenhouse Gas Emissions Intensity](image)

**Figure 3**—Greenhouse gas intensity reported in 1944 and 2007.

Enteric methane, or methane production from ruminal fermentation, is approximately one-third of the total dairy farm greenhouse gas emission footprint. The other areas of significant emissions on dairy farms are manure management (approximately one-third of total farm emissions), feed production per field work (approximately one-quarter of total farm emissions), and energy use (approximately 5% to 10% of total farm emissions). Efficiency has also been responsible for a smaller land footprint (a reduction of 90% of land used from 1944 to 2007 and an additional 21% reduction from 2007 to 2017), reduced requirements for feed by 77% from 1944 to 2007 and 17% from 2007 to 2017, and less water used per gallon of milk by 65% from 1944 to 2007 and by 30% from 2007 to 2017. In the decade from 2007 to 2017, these improvements are equivalent to decreasing the land used for dairy cattle by half of the state of Ohio, saving over three million Olympic swimming pools of water, and planting over 800 million trees.

Dairy cows also play an integral role in their ability to recycle and upcycle the by-products created through the processing of food for human use. For example, after almonds are grown and harvested from their trees, the hull (the part of the almond that surrounds the seed inside the shell) needs to be discarded. This hull makes up 52% of the weight of an almond and is inedible to humans. Because of the rumen microbes, cows can digest the almond hull and use it as energy to create milk. Almond hulls are just one of the many by-products that make their way into a cow’s diet from the human food production system; others include but are not limited to soybean meal (a by-product of soy oil production), beet pulp (a by-product of sugar production), and cottonseeds (a by-product of the fashion/clothing industry). In total, in 2019 approximately 45 million tons of by-products were fed to dairy cattle and saved from entering landfills; this would be 2.2 million garbage truck loads of waste. Cows can not only turn these inedible by-products into nutritious food, but also do so in a way that is beneficial to the environment when greenhouse gas emissions are considered. While cows do produce enteric methane from rumen fermentation, per pound of by-product consumed, cows produce methane equivalent to 32 g of carbon dioxide equivalents (CO$_2$-eq) on average. However, if this same pound of by-product ended up being composted, 149 g of CO$_2$-eq would be created, and if the same pound of by-product went to landfill, 1,567 g of CO$_2$-eq would be created; the landfill option for by-products would cause a 50-fold increase in greenhouse gas emissions compared with rumen digestion. Therefore, not only are cows able to reduce landfill waste by consuming by-products, but also they are great up-cyclers of human-inedible ingredients and able to produce products with high nutritional value from it.

**People**

The US dairy industry produced 223 billion pounds (27 billion gallons) of milk in 2021 and is on track to produce more this year. In the last census, the 31,657 farms, over 1,000 processing facilities, and the associated industry employed 3.3 million people; this is equivalent to over twice the number of Amazon employees in the world. In dairy, women have a higher rate of leadership positions than most other industries, making up 54% of farm ownership or upper management compared with the US average (21%) of women in leadership or upper management.
management. The dairy industry makes up 3.5% of the US GDP and has a total economic impact of $753 billion.

When dairy is examined in comparison with other food ingredients, the macro- and micronutrients as well as vitamins provided are unmatched. Today’s dairy industry provides sufficient fluid milk to meet the annual energy requirements for 71.2 million people (26% of the US population), protein requirements for 169 million people (51% of the US population), and calcium requirements of 254 million people (77% of the US population). Similarly, the dairy industry supplies a high proportion of vitamins, providing 39% of the vitamin A, 47% of the riboflavin, 57% of the vitamin B12, and 29% of the choline available for human consumption in the US. Due to the large amount of nutrition that dairy foods supply and the increasing attention paid to the environmental impact of dairy, researchers modeled the available nutrients for people if the US dairy herd was depopulated or moved to an entirely pasture-based system compared with the baseline case of dairy today. This model predicts that if the dairy herd were depopulated and all land that had been used by the dairy industry now grew food solely for human consumption, the dietary availability of choline, vitamin B12, vitamin A, and calcium would decrease, showing that as many as half of the people who currently have access to their nutritional requirements would no longer be able to meet their annual dietary needs. In the scenario where the US dairy system became completely pasture based, 44% of the US dairy herd would disappear to maintain similar land use compared with today, and this would result in more than a 20% reduction in availability of calcium, α-linolenic acid, vitamin A, vitamin B12, choline, and many essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine) compared with the current production system. These reductions are equivalent to 254 million fewer people meeting their dietary calcium requirements and 500 million fewer meeting their B12 requirements. The greenhouse gas impacts of these scenarios did lead to less agriculture-related emissions (7% less in the depopulation scenario and 11% less in the pasture-based system); however, the emissions reductions in that scenario create an inability to supply valuable nutrition to the US population. Given the relatively minor impact the dairy industry has on total US greenhouse gas emissions (<2% of total) and the large impact dairy products have on meeting human nutritional needs, dairy should continue to be part of a well-balanced diet into the future.

In human health, a lot of work has been done on the role of dairy foods in growth and development, chronic diseases such as diabetes and heart disease, and health outcomes such as fractures and survival. It has been found through meta-analyses that dairy intake contributes to meeting nutrient recommendations for all age groups and may protect against several of the most common chronic diseases, with few adverse effects. Around the world, there continue to be wide swaths of the population going undernourished, and unfortunately, these populations include many children at times. In studies examining stunting (defined as growth achieving a height below 2 SDs of the median for their age) by country, the availability of animal-sourced foods is associated with lower rates of stunting. Further, cognitive and physical development among growing children has been shown to be improved by regular access to dairy and eggs in repeatable data from developing nations. Even in wealthier countries where many food and beverage options exist for average consumers, drinking milk has been shown to reduce the likelihood of fractures among young children exposed to everyday tumbles, sports, and other risks. Similarly, in a large study of elderly patients, the study participants in the group who had higher milk consumption had a lower risk of fractures as well.

In some contemporary literature investigating the association of dairy consumption and chronic disease, particularly cardiovascular disease, there is indication that higher levels of consumption are associated with lower cardiovascular disease risk. These protective effects against major cardiovascular disease events and mortality appear to have an impact across diverse multinational cohorts or are not negative effects in others. For diseases that are inflammatory or metabolic in nature, the literature on dairy consumption is more mixed; however, the high calorie count of dairy fats is no longer as readily vilified as it once was. While all fats are calorie dense, the length of fatty acid chains, their patterns of double bonds, cis and trans enantiomers, and other properties have been shown to affect the potency of some bioactive molecules synthesized from fatty acid precursors. Some studies examining this effect in detail have shown that inflammatory mediators are less potent when synthesized from the conjugated linoleic fatty acids found in milk. Other studies of obesity, eating habits, and satiety have demonstrated that full-fat milk can help reduce cravings and assist in weight loss.

**Conclusion**

Dairy has and continues to make continuous improvements in animal care, environmental impact, and nutrition while contributing to strong communities across the US and the globe. It is important for veterinarians to consider the one-health impacts that the dairy sector has and their ability to play a role in the continued progress of dairy agriculture and public education on dairy foods. This is especially true as global populations continue to rise and climate change becomes an increasingly high priority: the community and animal impacts will always have a place in conversations regarding humanity’s sustainable future.

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