Trends and Opportunities in Reducing the Environmental Footprint of Dairy Farms

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Take Home Messages

- Dairy farm footprints should be considered from a systems perspective.
- Greenhouse gases are part of, but not the only component of the footprint.
- Footprint reduction technologies need to consider all footprint components.
- Improving efficiency of crop production or milk production will reduce the overall footprint of dairy farms.

Introduction

Producing milk to satisfy the growing global demand for protein by humans requires a thorough understanding of how dairy farming systems can meet this goal without compromising economic, environmental, and social sustainability. Understanding the environmental footprint of dairy farms is a key component in having a positive impact on ecosystem services. Greenhouse gas (GHG) emissions are often the focus of the footprint, but other factors such as water quality, soil health, nutrient flows and biodiversity also need to be considered. Consumer expectations regarding sustainable production practices that minimize the environmental footprint of dairies continue to increase. Optimizing the footprint of dairy production can be addressed through a social-ecological approach to ecosystem service assessment, which assesses the linkages between the different agricultural-social-ecological components of dairy production systems (Figure 1). Improvements in feed efficiency are likely to result in the greatest reduction in the milk production footprint. Feed efficiency is a complex trait because it is influenced by feed quality, digestive tract microbial populations, production environment and the genetics of the cow. This paper provides an update on the interactions among the various factors that determine the environmental footprint of milk production and outlines some of the emerging technologies that can be used to reduce its environmental footprint.

Greenhouse Gas Footprint

Globally, livestock are responsible for about 40% of agricultural GHG emissions arising directly from the animal and from manure (Figure 2). Ruminants produce methane as a natural by-product of the microbial fermentation of concentrates and forages within the rumen. Both primary and secondary microorganisms in the rumen convert these feeds into volatile fatty acids (VFA), carbon dioxide and metabolic hydrogen. Methanogens play an important role in maintaining a low partial pressure of hydrogen in the rumen by reducing carbon dioxide to methane (Leahy et al., 2022). Consequently, methane production plays a key role in the fermentation process and its production is thought to be necessary for efficient feed digestion.

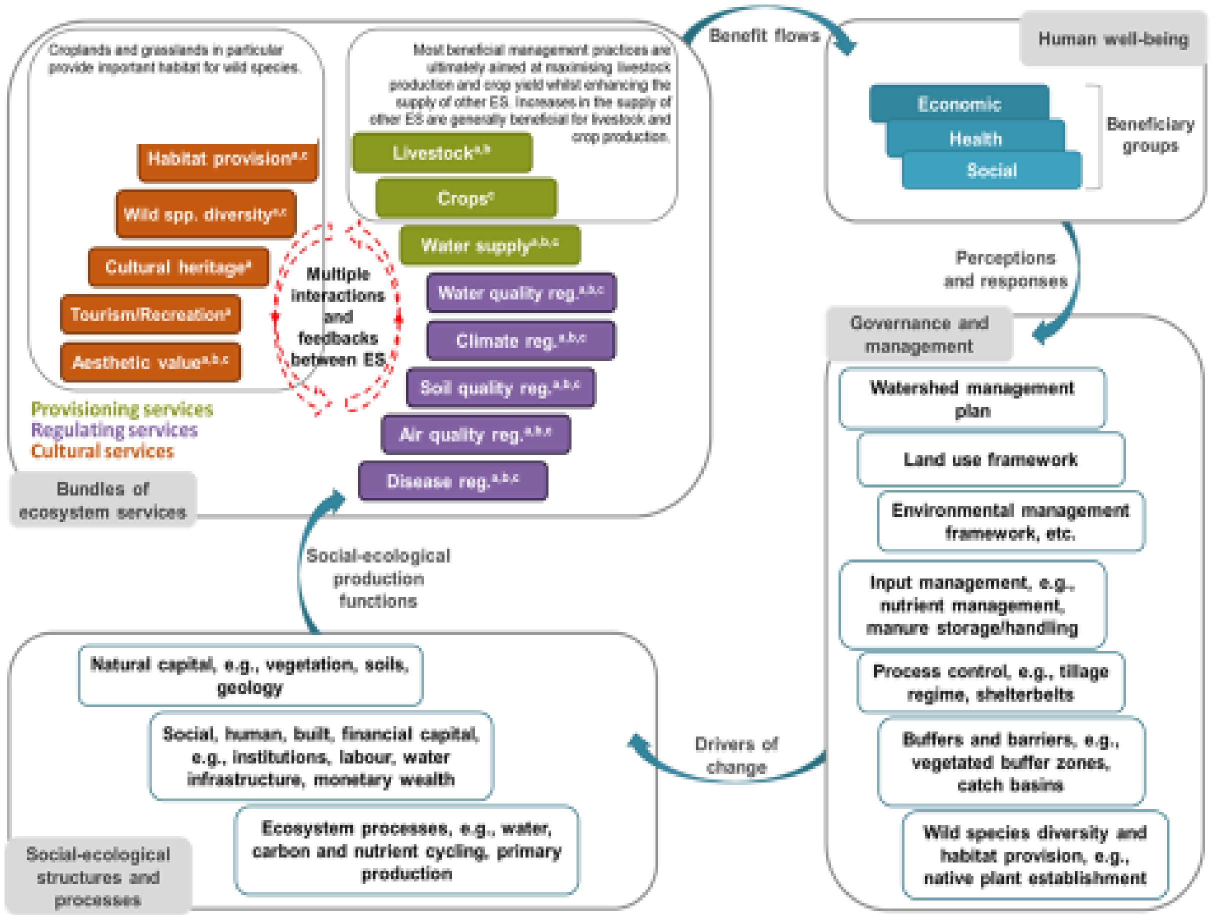

Figure 1. Conceptual ecosystem service framework for Canadian dairy production systems (Pogue et al., 2018).

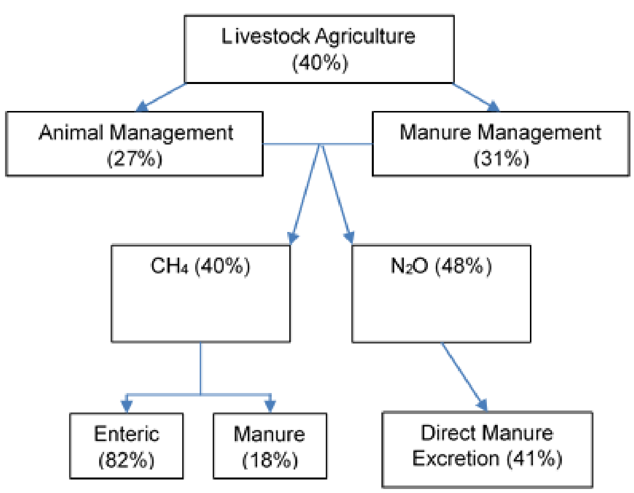

Figure 2. Greenhouse gases associated with global livestock production (Terry et al., 2020).

Methane can also be produced from dairy manure in lagoons or liquid storage structures. Sealed biodigesters can enable methane produced from dairy manure to be captured and used for heating or to generate power but require considerable capital investment and must be continuously monitored to ensure there is no leakage.

Manure can also be a significant emitter of nitrous oxide and ammonia. Factors that influence the concentration of greenhouse gases produced from manure include the type of feed, manure nutrient profile, and manure handling and storage practices. The conversion of nitrogen into gases occurs through simultaneous nitrification and denitrification processes. Nitrate is a valuable source of nitrogen for plant growth, but in excess it can also contaminate surface and ground water.

Although not a direct source of GHG, ammonia emissions from manure should also be considered when assessing the impact of management practices on air quality. Ammonia arises from the rapid hydrolysis of urea in urine and can also be a precursor to nitrous oxide. Ammonia is highly volatile and can start to cause respiratory stress to cows when concentrations in the air exceed 35 ppm. Additionally, excess levels of ammonia in soil can contribute to soil acidity and its flow into ground and surface waters can lead to eutrophication. Shifting the excretion of nitrogen from urine to feces may be more environmentally beneficial as fecal nitrogen is released at a slower rate and is more likely to be captured by soil flora and used to support plant growth. Understanding the carbon and nitrogen cycles within dairy production systems is essential to maximizing the amount of carbon, nitrogen and other nutrients that are captured in crops, milk, and meat. This reduces the movement of pollutants into the atmosphere and ground and surface water (Figure 3).

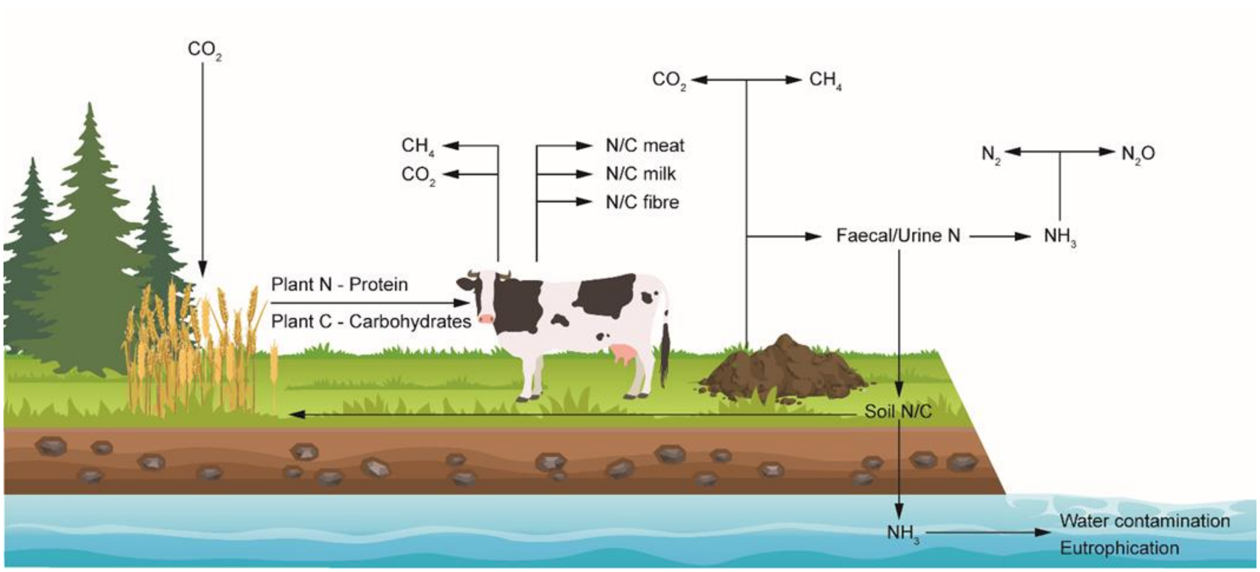

Figure 3. Carbon and nitrogen cycle in dairy cow production systems. Environmental footprint of dairy cattle production is reduced by maximizing the amount of nutrients (e.g., carbon, nitrogen, and phosphorus) that are captured by soil fauna, crops, milk, and meat (Terry et al., 2020).

▪ Reducing the Greenhouse Gas Footprint

Several approaches have been explored for their ability to lower GHG emissions from ruminants (Figure 4). Strategies targeted at reducing GHG emissions need to consider their impact on emissions throughout the dairy production cycle. Furthermore, their implications on production efficiency also need to be considered. For example, increasing the level of concentrate in the diet can reduce the intensity (methane/L of milk) of methane emissions in dairy cows, but this approach needs to be balanced against the risk of a decline in fibre digestion, rumen acidosis and milk fat depression. Any factor that lowers milk production will result in an increase in GHG emissions on an intensity basis.

	ENTERIC							MANURE					OVERALL	
DIETARY CHANGES	Fermentation	Fibre Digestion	N Digestion	Starch Digestion	pH	CH_4 PRODUCTION DAILY	CH_4 INTENSITY	Starch	Urine N	Faecal N	CH_4 EMISSIONS	N_2O EMISSIONS	DECREASE IN GHG PRODUCTION	DECREASE IN GHG INTENSITY
Concentrate/Forage														
Increased Concentrate/Forage	↑	↓	NA	↑	↓	~	↓	↑	NA	NA	↑	↑	~	✓
Acidosis	↑	↓	NA	↑	↓	~	-	~	NA	NA	~	~	~	~
High Forage	↓	↑	NA	↓	↑	↑	↑	↓	NA	NA	↓	↓	~	×
Nitrogen														
DDGS	~	↑	↑	~	~	↓	↓	↑	↑	↑	↑	↑	×	×
Fat														
< 6%	~	-	NA	-	~	↓	↓	-	NA	NA	-	-	✓	✓
> 6%	↓	↓	NA	~	↑	↓	-	↑	NA	NA	↑	~	✓	×
Inhibitors														
Nitrate	~	-	-	~	-	↓	↓	~	~	~	~	~	✓	✓
3NOP	~	-	-	-	~	↓	↓	-	~	~	-	-	✓	✓
PSC														
Tannins	↓	↓	↓	NA	NA	~	~	~	↓	↑	↓	↓	✓	~

Figure 4. Consequences of dietary manipulation on enteric production and greenhouse gas emissions. Symbols indicate: ↑ = increase, ↓ = decrease, - = no change, NA = not applicable, ~ = variable/unknown (Terry et al., 2020).

Other approaches such as adding dried distillers grains with solubles to the diet can lower rumen methane production owing to its oil content, but if it is not fully digested or increases the level of dietary protein above requirements, it can increase methane and nitrous oxide emissions from manure. Similarly, addition of oils to the diet at levels < 6% of diet can lower rumen methane emissions. However, at levels > 6%, fats can suppress fermentation and fibre digestion, lowering milk production and actually increasing emissions per L of milk. Oils are also expensive and do not always fit into the diet as a least cost energy source. Considerable research effort has also gone into the identification of methane inhibitors such as nitrate and 3-nitrooxypropanol (3NOP). Nitrate acts as an alternative electron acceptor, and its reduction to nitrite and ammonia in the rumen is thermodynamically more favourable than the reduction of carbon dioxide to methane by methanogens. However, nitrite can be toxic as it inhibits the ability of red blood cells to transport oxygen, making it unlikely that it will be used as means of reducing ruminal methane emissions. 3NOP has been shown to decrease rumen methane emissions by up to 80% and is commercially produced by the DSM corporation. 3NOP has been approved for use in cattle in Brazil and Argentina and is undergoing regulatory evaluation in the United States, Europe, and Canada.

A large variety of plant secondary compounds from a diverse range of plants have also been explored for their potential to mitigate enteric methane emissions. Secondary metabolic compounds commonly employed as feed additives include essential oils, saponins and tannins. However, over 200,000 defined phytochemicals have been identified and many have been assessed for their ability to lower methane emissions in laboratory experiments. A comparatively smaller portion of these have been tested in the animal, with many being deemed undesirable because of potential toxicity or their lack of palatability.

Tannins are in forages such as sainfoin and birdsfoot trefoil, with a number of tannin-rich forages having been shown to reduce ruminal methane emissions. Tannins can also alter protein digestion in ruminants, shifting the flow of nitrogen from the urine towards feces. When effective, tannins could reduce GHG emissions from both the animal and manure. However, care must be taken to ensure that they do not reduce ruminal methane emissions by lowering overall digestibility or nitrous oxide emissions by lowering protein digestion to the point that they compromise milk production.

▪ Water Footprint

The water footprint can be described as three water types: green water, which is snow or rainwater, blue water, which is surface or ground water, and grey water, which is water that is used to dilute and transport nutrients and pollutants (Figure 5). The majority of water used in dairy production (> 90%) is associated with crop production. Consequently, strategies that reduce the use of water in feed production are likely to have the greatest impact on reducing overall water use. Water use by crops can be reduced by switching to more drought tolerant crops or breeding for drought resistant varieties. Where crops are irrigated, switching from open canals to closed pipelines and improvements in nozzle design can further reduce blue water use. Typically, water consumption by the animal accounts for < 10% of the footprint. In Canada, it has been estimated that it requires 6-8 L of blue water use in barns to produce a litre of fat and protein corrected milk. Wastewater can be a significant use of blue water within dairy barns, and recycling plate cooler and milk house water has been estimated to reduce in-barn use of blue water by as much as 20% (Al-Bahouh et al., 2021). Ensuring that there are no leaks in water troughs and pipes, and optimizing floor flush systems can further reduce blue water use. Minimizing the production of excessive nutrients by reducing the amount of manure that is produced can lower the amount of grey water used. In the future, higher ambient temperatures as a result of climate change could increase water use by both crops and dairy cows. In-barn use of blue water could also increase if sprays are required to cool the barn as a means of reducing heat stress in dairy cows.

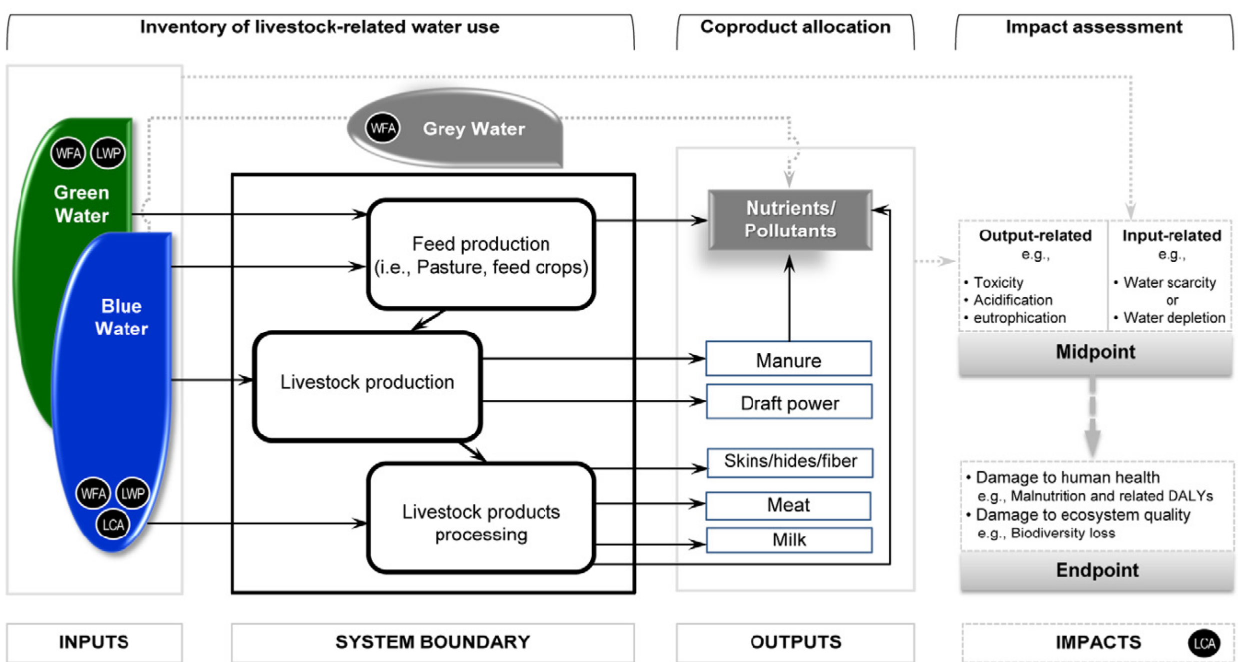

Figure 5. Approaches to the assessment of the water footprint in ruminant productions systems. The model would consider all water used to produce a L of milk. Improving the efficiency of blue and grey water use offers the easiest approach to reducing the water footprint of milk production. (Legesse et al., 2017).

▪ Biodiversity Footprint

Adequate biodiversity is an essential trait of adaptive and productive ecosystems. Land use change such as the conversion of grasslands and forests to croplands is typically the greatest driver of biodiversity loss. For example, conversion of grasslands to croplands reduces soil diversity by decreasing the abundance of mosses, lichens, and soil mites. Perennial forages and grazing systems have greater biodiversity than continuous cropping systems, but often at the expense of lower crop and milk yields than mixed concentrate – forage diets. Consequently, dairies can make the greatest contribution to biodiversity by ensuring that the vast array of fauna that contribute to soil health remain active (Figure 6). Manure can play a key role in promoting soil biodiversity and health because it contains an array of substrates for soil fauna. However, care must be taken to ensure that the application rate of manure does not exceed the nutrient requirements of soil fauna or the crop, so as to avoid the flow of nutrients into ground and surface water. Unlike chemical fertilizer, manure directly increases soil organic matter.

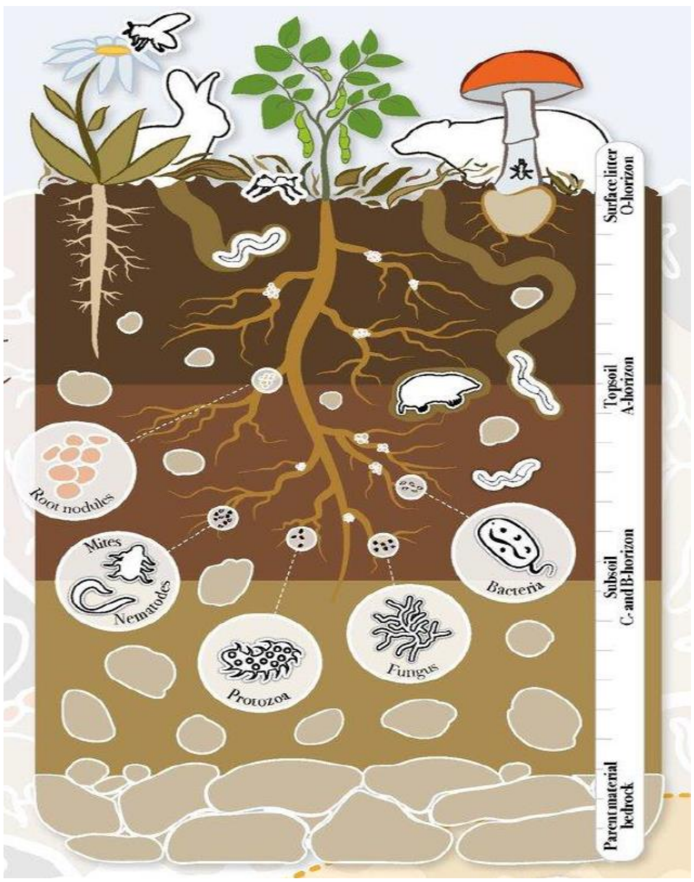

Figure 6. Confined dairies can optimize their biodiversity footprint by ensuring a rich diversity of fauna which contribute to soil health. Proper manure management plays a key role in this process. Increasing the use of perennial forages and grazing can also enhance biodiversity. Adapted from Global soil biodiversity initiative (https://www.globalsoilbiodiversity.org/resources-1).

▪ Efficiency and the Environmental Footprint

Canadian dairy farms already have one of the lowest carbon footprints for milk production in world (Figure 7). The continued reduction in the footprint of Canadian dairy production will arise as a result of improvements in system efficiency. This efficiency can arise from various points throughout the dairy production system. For example, improvements in crop yields can reduce the amount of land required for crop production and increase the extent to which nutrients in chemical fertilizers and manure are captured by the plant. This in turn can reduce the water footprint because less blue water is required for crop production and less grey water is needed for nutrient disposal. Genetic selection for improved feed efficiency reduces the amount of feed required by the cow and the amount of manure produced. This can also result in the reduction of the amount of land required for feed production. Land that is not required to produce feed can remain as perennial grassland so as to promote biodiversity in these threatened ecosystems. Consequently, it is critical that approaches to reduce the footprint of dairy production do not compromise the efficiency of milk production because such practices will increase, not decrease, the overall footprint.

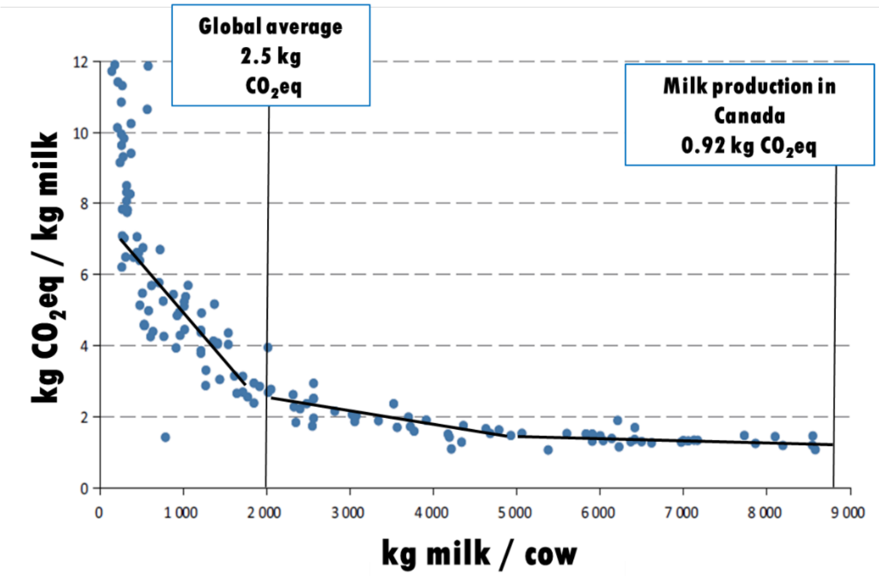

Figure 7. Carbon footprint of Canadian milk production compared with the global average. Any factor that lowers milk production will result in an increase in the footprint of dairy production on an intensity basis.

▪ Conclusion

Characterizing and defining the footprint of livestock products is becoming increasingly common because retailers and consumers wish to know the contribution of livestock to climate change. Canada's dairy industry already has one of the lowest carbon footprints for milk production in the world, but to sustain consumer confidence the industry needs to continue to strive for improvement. Improvements need to be implemented from a systems perspective, with attention paid to footprint factors other than just GHG emissions. To some extent, most Canadian dairy production systems are sheltered from climate change as cows are housed within controlled environments. However, as was aptly demonstrated by the latest floods in the Fraser valley, even these systems are not immune to the impacts of climate change.

▪ References

Al-Bahouh, M., V. Osborne, T. Wright, M. Dixon, A. VanderZaag, and R. Gordon. 2021. Blue water footprints of Ontario dairy farms. Water. 13:2230. https://doi.org/10.3390/ w13162230.

Leahy, S.C., P.H. Janssen, G.T. Attwood, R.I. Mackie, T.A. McAllister, and W.J. Kelly. 2022. Electron flow: key to mitigating ruminant methanogenesis. Trends in Microbiology. 30:209-212. https://doi.org/10.1016/j.tim.2021.12.005

Legesse, G., K.H. Ominski, K.A. Beauchemin, S. Pfister, M. Martel, E.J. McGeough, A. Hoekstra, R. Kröbel, M. Cordeiro, and T.A. McAllister. 2017. Board-Invited Review: Quantifying water use in ruminant production. J. Anim. Sci. https://dx.doi.org/10.2527/jas.2017.1439.

Terry, S.A., C.M. Romero, A.V. Chaves, and T.A. McAllister. 2020. Nutritional factors affecting greenhouse gas production from ruminants: implications for enteric and manure emissions. In: Improving rumen function, Burleigh Dodds Science Publishing Limited, Burleigh Dodds Science Publishing, Cambridge, UK. (ISBN: 978 1 78676 332 7) doi: http://dx.doi.org/10.19103/AS.2020.0067.16

Pogue, S.J., R. Kröbel, H.H. Janzen, K.A. Beauchemin, G. Legesse, D.M. de Souza, M. Iravani, C. Selin, J. Byrne, and T.A. McAllister. 2018. Beef production and ecosystem services in Canada's prairie provinces: A review. Agricultural Systems. 166:152-172. https://doi.org/10.1016/j.agsy.2018.06.011.


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