Meat and Muscle Biology™

Environmental Sustainability of Livestock Systems

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Abstract: Sustainability of livestock systems encompasses social, economic, and environmental concerns. Environmental sustainability issues surrounding livestock production include greenhouse gas emissions, land use, water use, and water quality. Mitigating negative environmental contributions and enhancing positive contributions from livestock production is critical for the long-term viability of the industry. While livestock production can impact the environment, livestock can in turn be affected by environmental conditions. Climate change poses unique challenges for livestock production in the future via impacts on feed availability, quality, and potential for increased thermal stress on livestock themselves. In aggregate, livestock production must adapt to both societal expectations and climatic conditions in the future, which will require both technical solutions and viable socioeconomic drivers to encourage implementation of solutions.

Key words: climate change, livestock, water, land, sustainability
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Introduction

Sustainability can be defined as meeting the needs of the present, without sacrificing the ability of future generations to meet their own needs (Brundtland, 1987). Sustainability encompasses social, economic, and environmental considerations; however, environmental issues, such as climate change, often dominate conversations about the sustainability of animal-sourced foods. Livestock production is facing increasing scrutiny and pressure to mitigate its environmental impacts, as evidenced by changes in policies and investor pressures (Ridoutt, 2024). This paper will provide a brief overview of the key environmental impacts of livestock production and the impacts of climate change on livestock systems.

Greenhouse Gas Emissions

Greenhouse gas emissions from livestock production include methane, nitrous oxide, and carbon dioxide. Each of the gases have different potentials to trap heat, or radiative forcings, which are often expressed as 100-year global warming potentials (GWP100) where each gas's warming effect is compared to the impact of carbon dioxide over 100 years. With this system, methane emissions from biogenic sources, such as enteric fermentation or manure management, have a global warming potential of 27.3. Nitrous oxide has a GWP100 value of 273 (Intergovernmental Panel on Climate Change, 2023). These values are multiplied by the mass of each respective gas to calculate carbon dioxide equivalent (CO_2e) emissions. A caveat to the GWP100 values is that, for short-lived greenhouse gases such as methane, which has an atmospheric half-life of 10–12 years, the GWP100 can overestimate the warming impacts of long-term stable emissions (Allen et al., 2016). Conversely, GWP100 can underestimate near term warming impacts, particularly in scenarios when emissions are growing (Place et al., 2022). Reducing methane emissions can lower the warming impacts of the livestock industries faster than the mitigation of other greenhouse gas emissions.

In addition to the different warming potentials of gases, another consideration for the overall climate warming impacts of livestock production is the system boundaries of the production system being assessed. One can think about classifying emissions either from a direct perspective (e.g., the emissions that directly come from the animal or its manure) or a life cycle perspective (e.g., including emissions from feed production, other inputs such as fertilizer, and energy use on farm). Building upon this classification of emissions, most processors and retailers are working within a greenhouse gas emissions system put forward by the GHG (Greenhouse Gas) Protocol, which refers to emissions as Scope 1, Scope 2, and Scope 3 emissions (EPA, 2024b). Scope 1 emissions are emissions controlled by the entity or company, for example, the emissions that would occur directly from a meat packer's own operations. Scope 2 emissions are those from purchased energy inputs, such as emissions associated with the production of electricity used by a meat packer. Scope 3 emissions are those associated with all inputs and processes required for the operation of the entity or company. In the case of a meat packer, this would include the emissions from packaging materials, employee travel, and most importantly, all emissions associated with the raising of cattle, hogs, poultry, etc. Scope 3 emissions tend to be the largest contributor to a company's emissions, and one company's Scope 1 emissions are another's Scope 3. For example, the emissions directly occurring from a feedyard (i.e., the feedyard's Scope 1) would be the input emissions for a meat processing company (i.e., the processor's Scope 3). This framing of emissions is important to understand as companies with livestock in their supply chains have made public commitments to reduce their Scope 3 emissions, even though many of those suppliers are unaware they are included in those commitments.

Considering the life cycle perspective for livestock production, the profile of greenhouse gas emissions varies by species and production system. For ruminant meat production, methane emissions are the dominant source of emissions, particularly methane from enteric fermentation processes (Rotz et al., 2019; FAO, 2023). For monogastric species, feed production makes a larger contribution to the overall greenhouse gas emissions footprint. Within monogastric species, manure methane emissions contributions can vary. Methane emissions require anaerobic conditions to exist. As swine systems in the United States have become more concentrated and the need for manure storage has increased, in part due to regulations to protect water quality, methane emissions from swine production has grown since 1990 (EPA, 2024a). For poultry systems, most litter is handled aerobically as a solid; thus, minimal methane emissions arise from poultry manure (Thoma and Putman, 2021).

With the variation in emissions profiles, due to biological differences and differences in production systems, mitigation profiles vary by meat type. For ruminant meat production, enteric methane is the largest opportunity for mitigation, followed by feed production emissions. For monogastrics, reducing feed production emissions is a key opportunity, as is manure methane from swine systems. For livestock producers, feed production emissions are often outside of their direct control as they are purchasing feeds. From an emissions intensity perspective, or CO_2e emissions per kg of product, improving feed conversion can lower feed emissions (Herrero et al., 2013).

Enteric methane emissions are the dominant single source of emissions from the entire livestock industry. Currently, the US beef industry lowers these emissions via reducing forage to concentrate ratios in finishing cattle. Feeding supplemental fat, grain processing, and ionophores can also lower enteric methane emissions (Leytem et al., 2024). In the future, there is potential for chemical inhibitors for rumen methane production once they achieve regulatory approval in the US (e.g., 3-nitrooxypropanol).

Land Use

Another key environmental consideration for livestock environmental sustainability is land use. Land use is often a key area of critique for animal-sourced foods as compared to plant-sourced foods, meaning that in general land requirements per kg of food are often greater for meat as compared to plant-based alternatives. This is particularly true for ruminant meats (beef, lamb, goat meat). However, land use is complex to assess for 3 key reasons: multifunctional use, quality of use, and fungibility.

Multifunctional use refers to uses of land for multiple food or commodity purposes or use of land for multiple ecosystem services, or benefits humans can receive from nature (Maczko et al., 2011). For example, winter wheat grazing systems in the southern Great Plains of the US allow for the production of wheat for human use and live weight gain in cattle from the same acreage. These types of integrated crop-livestock systems allow for multiple income and human useable product streams, and can at times have benefits for nutrient cycling (Sulc and Franzluebbers, 2014). Additionally, lands can provide other ecosystem services, especially grazinglands. For example, native grasslands used in cattle production in the Northern Great Plains provide wildlife habitat, soil carbon storage, and water infiltration and storage services in addition to beef production (Havstad et al., 2007).

Quality of use refers to the broader long-term sustainability considerations for land use for food production. For example, energy production per acre is likely much higher for a corn-soy rotation under a conventional tillage as compared to a forage system with grazing (Cassidy et al., 2013). However, rates of erosion are likely much higher for the conventional tillage system than permanent forages. For example, average annual rates of sheet and rill erosion on cultivated cropland in Iowa was estimated as 5.79 tons/acre in 2017, compared to a rate of 1.10 per acre for pastureland in the state (USDA, 2020). Thus, reducing land use per unit of food may not at times lead to agricultural systems with the greatest long-term viability with regard to underlying natural resource bases.

Fungibility refers to whether lands can be used for different purposes with equal value. For example, many grazing lands are often on rangelands that are too arid, rocky, or steep for cultivation, or may experience higher rates of erosion. Thus, while land use may be greater per kg for product for animal-sourced foods, some of this land is not available for plant-sourced food production. Land use questions are complex, and land use changes can be driven by climate changes, policy, and economic conditions.

Water Use

Water is essential for life. Water use by agriculture is a central environmental sustainability concern, and more localized than greenhouse gas emissions. For example, in the US, water use is primarily a concern in the western portions of the country (e.g., Colorado River Basin, Ogallala aquifer), while in the eastern US water quality issues are often more of a primary concern than water use. Agriculture is the primary user of water, and for livestock systems, most water use is associated with feed production. For example, 87.5% of water used from US beef production from cradle to grave can be attributed to irrigation of the crops used to feed cattle (Putman et al., 2023). As with greenhouse gas emissions, water use can be classified in different ways. Blue water use refers to surface and ground water use, such as irrigation water or water used as drinking water for livestock. Green water use is precipitation and evapotranspiration water, which is more difficult to influence via human activities but is the largest category of water use. Gray water refers to the water use required to offset pollution (Mekonnen and Hoekstra, 2011).

In the United States, many water conservation efforts are widespread, and improvements in irrigation efficiency have occurred (USDA, 2023). However, there are certain aquifers that are experiencing significant declines in water availability in the US (USGS, 2018). Total water demand may not decline significantly in response to improvements in water use efficiency; indeed, in some cases it may still increase due to expansion in total acres irrigated. Managing the water cycle and absolute use holistically is required.

Climate Impacts on Livestock

Another influence on water availability and quality is the climate. Climate change will increase the incidence of drought and high precipitation events. For example, increases in temperature in western Colorado and eastern Utah have decreased snowpacks and increased rates of spring snow melt and evaporation, leading to decreases in water availability (White et al., 2023). Many parts of the southwestern US have already experienced average temperature changes of 2°C, which is the global threshold of temperature change in the Paris Climate Agreement (Vose et al., 2017). In addition to limitations of water availability driven by climate change, more frequent extreme precipitation events are expected, which may increase soil erosion and nutrient runoff (Gowda et al., 2018).

Wildfire area burned in the US and Canada has also been increasing in the past few decades, due in part to climate changes and to human management (Ostoja et al., 2023). These fires can directly affect livestock operations via burning of grasslands and operations housing livestock; however, fires can have wider-reaching effects beyond the immediate burn area. For example, research has demonstrated that wildfire particulates can have negative implications not only on human health but also on livestock health (Pace et al., 2023).

In some regions of the US, increased temperatures and CO_2 concentrations may lead to increases in crop yields (Kukal and Irmak, 2018); however, for certain forage crops, quality may decline (Augustine et al., 2018). These impacts on forage quality could be considered indirect effects on livestock production, which may also include decreased water availability and increased disease and parasite risks. Direct impacts of climate change on livestock production include heat stress, which can cause negative effects on animal productivity and increased mortality (Cheng et al., 2022). Increased extreme precipitation events may lead to more flooding, which can negatively impact livestock productivity and potentially introduce pathogens and heavy metals to livestock operations, creating risks for livestock and consumer health (Crist et al., 2020). Additionally, heat stress and extreme precipitation events can stress social systems that support agriculture and individual farm workers. Adapting to climate change and creating resiliency that can withstand extreme weather events will be critical for the long-term sustainability of livestock systems.

Conclusion

Livestock production interacts with the environment and can make both positive and negative contributions to environmental quality. Climate change may impact livestock production directly and indirectly in the future, potentially stressing the ability of the livestock system to meet societal demands for more environmentally responsible production and increased productivity. Ultimately, sustainability is complex, requiring a balance of multiple domains of consideration (social, economic, environmental) and value judgements about what is best in each of those domains. Tradeoffs are inevitable in sustainability; however, progress is also possible. The livestock sector in the US and globally has in aggregate produced more human nutrition per unit of land and reduced greenhouse gas emissions per meal produced. While past progress is encouraging, investment in holistic and targeted strategies to improve the sustainability of livestock production are required. Further research is essential to investigate both technical solutions and broader systems approaches that critically evaluate both current production systems and the socioeconomic incentive structures required to move towards more sustainable livestock production.

Literature Cited

Allen, M. R., Fuglestvedt, J. S., Shine, K. P., Reisinger, A., Pierrehumbert, R. T., and Forster, P. M. 2016. New use of global warming potentials to compare cumulative and short-lived climate pollutants. Nat. Clim. Change 6:773–776. https://doi.org/10.1038/nclimate2998

Augustine, D. J., Blumenthal, D. M., Springer, T. L., LeCain, D. R., Gunter, S. A., and Derner, J. D. 2018. Elevated CO_2 induces substantial and persistent declines in forage quality irrespective of warming in mixedgrass prairie. Ecol. Appl. 28:721–735. https://doi.org/10.1002/eap.168

Brundtland, G. H. 1987. Our common future: Report of the World Commission on Environment and Development. United Nations (UN) Document A/42/427. UN, Geneva, Switzerland.http://www.un-documents.net/ocf-ov.htm

Cassidy, E. S., West, P. C., Gerber, J. S., and Foley, J. A. 2013. Redefining agricultural yields: From tonnes to people nourished per hectare. Environ. Res. Lett. 8:034015. https://doi.org/10.1088/1748-9326/8/3/034015

Cheng, M., McCarl, B., and Fei, C. 2022. Climate change and livestock production: A literature review. Atmosphere-Basel 13:140. https://doi.org/10.3390/atmos13010140

Crist, S., Mori, J., and Smith, R. L. 2020. Flooding on beef and swine farms: A scoping review of effects in the midwestern United States. Prev. Vet. Med. 184:105158. https://doi.org/10.1016/j.prevetmed.2020.105158

EPA (U.S. Environmental Protection Agency). 2024a. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2022. EPA 430-R-24-004. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022. (Accessed 24 June 2024.)

EPA (U.S. Environmental Protection Agency). 2024b. Scopes 1, 2 and 3 emissions inventorying and guidance. https://www.epa.gov/climateleadership/scopes-1-2-and-3-emissions-inventorying-and-guidance. (Accessed 11 May 2024.)

FAO (Food and Agriculture Organization of the United Nations). 2023. Pathways towards lower emissions: A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems. FAO, Rome. https://doi.org/10.4060/cc9029en

Gowda, P., Steiner, J. L., Olson, C., Boggess, M., Farrigan, T., and Grusak, M. A. 2018. Agriculture and rural communities [Chapter 10]. In: D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, and B. C. Stewart, editors, Impacts, risks, and adaptation in the United States: Fourth national climate assessment. Volume II. U.S. Global Change Research Program, Washington, DC. pp. 391–437. https://doi.org/10.7930/NCA4.2018.CH10

Havstad, K. M., Peters, D. P., Skaggs, R., Brown, J., Bestelmeyer, B., Fredrickson, E., Herrick, J., and Wright, J. 2007. Ecological services to and from rangelands of the United States. Ecol. Econ. 64:261–268. https://doi.org/10.1016/j.ecolecon.2007.08.005

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M. C., Thornton, P. K., Blümmel, M., Weiss, F., Grace, D., and Obersteiner, M. 2013. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. P. Natl. A. Sci. India B 110:20888–20893. https://doi.org/10.1073/pnas.1308149110

Kukal, M. S., and Irmak, S. 2018. Climate-driven crop yield and yield variability and climate change impacts on the U.S. Great Plains agricultural production. Sci. Rep.-UK 8:3450. https://doi.org/10.1038/s41598-018-21848-2

Leytem, A. B., Archibeque, S., Cole, N. A., Gunter, S., Hristov, A., Johnson, K., Kebreab, E., Kohn, R., Liao, W., Toureene, C., and Tricarico, J. 2024. Quantifying greenhouse gas sources and sinks in animal production systems [Chapter 4]. In: W. L. Hanson, C. Itle, and K. Edquist, editors, Quantifying greenhouse gas fluxes in agriculture and forestry: Methods for entity-scale inventory [Technical Bulletin Number 1939]. 2nd edition. U.S. Department of Agriculture, Office of the Chief Economist, Washington, DC.

Maczko, K., Tanaka, J. A., Breckenridge, R., Hidinger, L., Heintz, H. T., Fox, W. E., Kreuter, U. P., Duke, C. S., Mitchell, J. E., and McCollum, D. W. 2011. Rangeland ecosystem goods and services: Values and evaluation of opportunities for ranchers and land managers. Rangelands 33:30–36. https://doi.org/10.2111/1551-501X-33.5.30

Mekonnen, M. M., and Hoekstra, A. Y. 2011. The green, blue and grey water footprint of crops and derived crop products. Hydrol. Earth Syst. Sc. 15:1577–1600. https://doi.org/10.5194/hess-15-1577-2011

Ostoja, S. M., Crimmins, A. R., Byron, R. G., East, A. E., Méndez, M., O'Neill, S. M., Peterson, D. L., Pierce, J. R., Raymond, C., Tripati, A., and Vaidyanathan, A. 2023. Focus on western wildfires. In: Crimmins, A. R., C. W. Avery, D. R. Easterling, K. E. Kunkel, B. C. Stewart, and T. K. Maycock, editors, Fifth national climate assessment. U.S. Global Change Research Program, Washington, DC. https://doi.org/10.7930/NCA5.2023.F2

Pace, A., Villamediana, P., Rezamand, P., and Skibiel, A. L. 2023. Effects of wildfire smoke PM2. 5 on indicators of inflammation, health, and metabolism of preweaned Holstein heifers. J. Anim. Sci. 101:p.skad246. https://doi.org/10.1093/jas/skad246

Place, S. E., McCabe, C. J., and Mitloehner, F. M. 2022. Symposium review: Defining a pathway to climate neutrality for US dairy cattle production. J. Dairy Sci. 105:8558–8568. https://doi.org/10.3168/jds.2021-21413

Putman, B., Rotz, C. A., and Thoma, G. 2023. A comprehensive environmental assessment of beef production and consumption in the United States. J. Clean. Prod. 402:136766. https://doi.org/10.1016/j.jclepro.2023.136766

Intergovernmental Panel on Climate Change (IPCC). 2023. Technical summary. In: Climate change 2021: The Physical Science Basis [Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change]. Cambridge University Press, Cambridge, UK, and New York, NY. pp. 35–144. https://doi.org/10.1017/9781009157896.002

Ridoutt, B. 2024. Drivers of sustainability credentialling in the red meat value chain—A mixed methods study. Agriculture-London 14:697. https://doi.org/10.3390/agriculture14050697

Rotz, C. A., Asem-Hiablie, S., Place, S., and Thoma, G. 2019. Environmental footprints of beef cattle production in the United States. Agr. Syst. 169:1–13. https://doi.org/10.1016/j.agsy.2018.11.005

Sulc, R. M., and Franzluebbers, A. J. 2014. Exploring integrated crop–livestock systems in different ecoregions of the United States. Eur. J. Agron. 57:21–30. https://doi.org/10.1016/j.eja.2013.10.007

Thoma, G., and Putman, B. 2021. Broiler production system life cycle assessment: 2020 update. https://www.nationalchickencouncil.org/wp-content/uploads/2021/09/Broiler-Production-System-LCA_2020-Update.pdf. (Accessed 11 May 2024.)

USDA (U.S. Department of Agriculture). 2020. 2017 National resources inventory: Summary report. Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, IA. (Accessed 11 May 2024.)

USDA (U.S. Department of Agriculture). 2023. Irrigation & water use. https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use.aspx (Accessed 11 May 2024.)

USGS (U.S. Geological Survey). 2018. Groundwater decline and depletion. https://www.usgs.gov/special-topics/water-science-school/science/groundwater-decline-and-depletion. (Accessed 11 May 2024.)

Vose, R. S., Easterling, D. R., Kunkel, K. E., LeGrande, A. N., and Wehner, M. F. 2017. Temperature changes in the United States [Chapter 6]. In: D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, and T. K. Maycock, editors, Climate science special report: Fourth national climate assessment. Volume I. U.S. Global Change Research Program, Washington, DC. pp. 185–206. https://doi.org/10.7930/J0N29V45

White, D. D., Elias, E. H., Thomas, K. A., Bradatan, C. E., Brunson, M. W., Chischilly, A. M., Enquist, C. A. F., Fisher, L. R., Froehlich, H. E., Koebele, E. A., Méndez, M., Ostoja, S. M., Steele, C., and Vanos, J. K. 2023. Southwest [Chapter 28]. In: A. R. Crimmins, C. W. Avery, D. R. Easterling, K. E. Kunkel, B. C. Stewart, and T. K. Maycock, editors, Fifth national climate assessment. U.S. Global Change Research Program, Washington, DC. https://doi.org/10.7930/NCA5.2023.CH28