Sustainability of Animal Agriculture in the Global Food System

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▪ Take Home Messages

- Agriculture contributes approximately ¼ of global greenhouse gas emissions and uses over $^{2}/_{3}$ of global freshwater water withdrawals.
- The total environmental impacts of agriculture have increased over time and are proportional to the growing population.
- When scaled per capita, agriculture has increased the food availability per person while reducing resource use.
- Approximately 30% of the global population suffers from micronutrient deficiencies. Animal products provide high-quality sources of micronutrients for human diets.
- Improving efficiency of animal agriculture has and will continue to improve sustainability of animal agriculture in the global food system.
- Advancements and adaptations in our understanding of atmospheric science must be taken into account when considering greenhouse gas emissions mitigation strategies.
- Improved discussion of the socioeconomic benefits of livestock in the global agricultural system is needed in future assessments of agricultural sustainability.

▪ Agriculture, Diets, and Sustainability on the Global Stage

Over the past several decades, a number of government, popular press, and peer-reviewed sources have propagated the idea that reducing consumption of animal source foods is beneficial for human and environmental health. Surveying the peer-reviewed literature, it is understandable that this message has been so readily adopted by such a wide variety of sources. Undoubtedly, there is a correlation between animal product production and increased environmental impact, just as there is a correlation between consumption of livestock products and negative human health outcomes. However, correlation is not causation. In response to the expanding rhetoric surrounding reducing consumption of animal products, several papers have been published highlighting logical flaws and limited causal relationships in the linkages between animal-source food products and negative human or environmental health outcomes. To better understand how the available data support (or fail to support) common discussion points regarding agricultural environmental impact and the role of agriculture in promoting healthy diets, we will assess claims made within the executive summary of the EAT-Lancet report (Willett et al., 2019) relative to the global agricultural database available from the United Nations Food and Agricultural Organization (FAO, 2019).

Is Food Production the Largest Pressure Caused by Humans on Earth?

Several popular press articles and recent peer-reviewed papers claim that agriculture is one of the major factors driving climate change. According to the Contributions of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, electricity and heat production account for 25% of emissions and other energy sources add another 10%. Industry accounts for 21%, transportation for 14%, and buildings for 6% of total global emissions. Agriculture is combined with forestry and all other land uses and accounts for 24%. From a carbon emissions standpoint, agriculture is globally responsible for just under a quarter of emissions, which is similar to the proportion of emissions assigned to the industry and electricity sectors. For countries with more developed agricultural systems, this proportion is much lower. For example, in the United States and Canada, agriculture accounts for less than 10% of total emissions (U.S. EPA, 2010).

In addition to highlighting agriculture as a major contributor to climate change, agriculture is commonly cited as being a major user of water globally. According to the UNFAO (Aquastat, updated November 2016), 2,769 km^3 of water is used for agriculture per year. This water use accounts for 69% of total global water withdrawal per year. Undoubtedly, this suggests that the claims that agriculture is a water-intensive process are accurate. To better understand where water withdrawals are occurring, we can look at the distribution of water withdrawal by region. Agriculture in Asia accounts for 2,069 km^3 (75%) of agricultural water use. Although the AquaStat database makes it difficult to discern specifically which commodities are contributing to this substantial water use in Asia, it is still an important consideration. Efforts to reduce agricultural water use would be most effective if targeted at these major water-using production systems.

Land is another resource commonly discussed when evaluating the environmental impact of agriculture. According to the UNFAO (FAO, 2019) in 2015, 32% of the global land area was tree-covered areas, 14% was terrestrial barren land, 14% was grassland, 13% was herbaceous crops, 12% was shrub-covered areas, 7% was sparsely natural vegetated areas, and the remaining 7% included artificial surfaces, inland water bodies, mangroves, glaciers, and woody crops. Of all land, only 27% is associated with agricultural activities like cropping and grassland production. Although this is a somewhat imperfect way to characterize land used for agriculture it does suggest that we feed the world's population from a fairly small land base. Continuing to preserve our non-agricultural and non-artificial land areas is a priority for numerous environmental stewardship groups.

Depending on the environmental impact considered, agricultural production systems contribute substantially to environmental pressures globally. In the case of water use, agricultural production is the largest single pressure. In the case of greenhouse gas emissions (GGE), agriculture is just one of many players contributing to atmospheric CO_2 concentrations. Making sure we accurately represent the role of agriculture in contributing to global environmental impact is a critical first step in characterizing strategies to maintain agricultural sustainability long-term. To simply state that agriculture is the greatest single contributor to environmental impacts globally is a gross over-simplification.

What Data are Available Regarding Food Insufficiencies Globally?

Another common discussion point surrounding the sustainability of agricultural systems centres on the challenge of feeding the growing global population. World population was approximately 1.6 billion people in 1900. That population had doubled to 3 billion by the mid 1970s and doubled again to 6 billion by the year 2000. By the year 2100, estimates suggest the population will nearly double again to roughly 11 billion people (U.S. Census Bureau, 2008). This exponential growth of the global population is concerning, namely because of the limited resources available to support the growing population. In 1798, Thomas Malthus wrote the "Essay on the Principle of Population", which put forth the idea that the power of population growth is infinitely greater than the power in the earth to produce sustenance for that growing population. The demise of society predicted by Malthus in the late 1700s did not come about thanks to the advancements in society associated with the Industrial Revolution. A second wave of concern over the growing global population was apparent in the late 1960s and early 1970s and can be attributed to a variety of sources, the most common of which is the 1972 report "Limits to Growth" put out by the Club of Rome. Again, the works of this time period focused on the feedback loop where a growing population impacts its supporting environment in a manner than negatively impacts the environment's ability to provide sustenance for that population. Although the Green Revolution is attributed to starting prior to the Club of Rome report, it was ultimately the advances in agricultural productivity associated with that movement that thwarted the demise of society projected in the “Limits to Growth” publication. Nearly 50 years later, we are undergoing a similar degree of concern regarding how we will be able to meet the needs of our rapidly growing population given the agricultural resources available.

A useful exercise to better understand exactly where our shortfalls are, in terms of feeding the global population, is to assess how well our agricultural system provides for our current population. In practice, this can be evaluated based on reports of undernourishment. According to the UNFAO (FAO, 2019) between 2015 and 2017, an average of 803 million people (approximately 10.5% of the global population) were categorized as undernourished. The FAO defines undernourishment as the proportion of the population whose habitual food consumption is insufficient to provide the dietary energy levels that are required to maintain a normal active and healthy life. According to the same data source, 685 million people (8.9% of the global population) are severely food insecure. The FAO defines severe food insecurity as a situation where a person has run out of food and gone a day or more without eating. Clearly, these are extreme examples of nutritional inadequacy, and correspondingly reflect a fairly small proportion of the population.

Possibly a greater concern regarding dietary adequacy is micronutrient deficiencies. The World Health Organization tracks micronutrient deficiencies and estimates the proportion of the global population experiencing micronutrient deficiencies to be over 2 billion (WHO/UNICEF, 1995). Micronutrient deficiencies are of greatest concern in vulnerable populations such as pregnant women, children, and the elderly. Globally, roughly 40% of pregnant women and 42% of children suffer from anemia, typically caused by insufficient consumption of Fe and vitamin B_{12}. Aggregated global estimates of the prevalence of vitamin A deficiency are more challenging to find. Vitamin A deficiencies in pregnant women range from less than 5% in the Americas, Europe and Russia to over 20% in Northern Africa, the Middle East, and Central/East Asia. Vitamin A deficiency in children is less than 5% in most countries but exceeds 60% in Sub-Saharan Africa and South Asia. Zinc deficiency is another major micronutrient deficiency globally and follows a similar pattern to vitamin A deficiency.

Comparison of Diets in the Context of Feeding the Growing Global Population

In principle, we can assess global production of nutrients and how they match to a calculated global requirement of nutrients by comparing theoretical diets at the global scale. Given that the EAT-Lancet reference diet was proposed as a diet to support planetary health, it is a logical starting point for this type of comparison. If the ideal diet proposed in table 1 of the EAT-Lancet report was scaled to the current global population, it would require only 21% of current cereal grain, 15% of tuber, 75% of vegetable, 63% of fruit, 85% of dairy, 35% of meat, and 41% of egg production. Legume and nut production would require expansions of 186% and 341%, respectively. If the reference diet was scaled to feed 10 billion people, it would use 28% of the cereal grains, 20% of the tubers, 100% of the vegetables, 84% of the fruits, 47% of the meat, and 55% of the eggs produced today. To feed 10 billion people, current dairy production would need to increase 13%, and legume and nut production would need to be expanded by 280 and 486%, respectively.

Scaling the diet to meet the needs of a 10-billion-person population highlights several challenges with implementation. First, food waste, particularly waste of vegetables, fruits, legumes and nuts, would need to be virtually eliminated. Currently, the FAO estimates that 45% of fruits and vegetables are wasted globally. As such, reducing wastage represents a major undertaking. Another challenge with scaling this diet to meet the needs of 10 billion people is the need to dramatically expand production of legumes and tree nuts.

We can evaluate an alternative diet to showcase the usefulness of this comparison approach. The EAT-Lancet recommendations would limit meat consumption to 90 g/d, increase egg consumption to 23 g/d, decrease legume consumption to 25 g/d, and reduce nut consumption to 4 g/d. These recommendations can scale to 10 billion people within the bounds of the current food production system. Importantly, this diet has a lower energy excess than the EAT-Lancet reference and has a very similar pattern of nutrient excesses and deficiencies, making it equally as feasible from a human nutrition perspective. With this alternative diet, there is only one major challenge: that of amending the food waste problem.

Importantly, what the comparison of diets highlights is the fact that we can feed a population of 10 billion people with our current agricultural system. This fact in itself highlights some challenges, in principle our food production system is perfectly adequate; however, in practice a large proportion of our global population is exposed to micronutrient deficiencies, nutritional inadequacy, or severe food insecurity. This contrast between the principle and the practice suggests that socioeconomic factors play a major role in the global distribution of food resources.

Do Current Diets and Agricultural Trends Support the UN Sustainable Development Goals?

Most of the global literature on food security focused on how agricultural systems contribute to the UN Sustainable Development Goals. The UN Sustainable development goals seek to:

1. end poverty in all its forms everywhere
2. eliminate hunger
3. ensure healthy lives and promote well-being for all at all ages
4. improve availability and quality of education
5. ensure gender equality
6. ensure availability of clean water and sanitation
7. ensure availability of affordable and clean energy
8. improve accessibility to decent work and enhance economic growth
9. build resilient infrastructure, promote sustainable industrialization and foster innovation
10. reduce inequality within and among countries
11. make cities inclusive, safe, resilient and sustainable
12. ensure sustainable consumption and production patterns
13. take urgent action to combat climate change and its impacts
14. conserve and sustainably use the oceans, seas and marine resources
15. sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss
16. promote just, peaceful and inclusive societies
17. revitalize the global partnership for sustainable development.

Over the 57 years between 1960 and 2017, the UNFAO data (FAOStat data, downloaded 1/16/2019) suggest that availability of plant and animal products have increased by 3 kg/person/year and 0.36 kg/person/year, respectively (Figure 1). Over the same timescale, crop and grassland area has decreased by 0.0071 ha/person/year, agricultural water use has decreased by 2.5 cubic meters/person/year, and agricultural greenhouse gases have increased by 1.2 kg of CO_2 equivalents/person/year. The historical data suggest the agricultural system is providing more food from fewer resources.

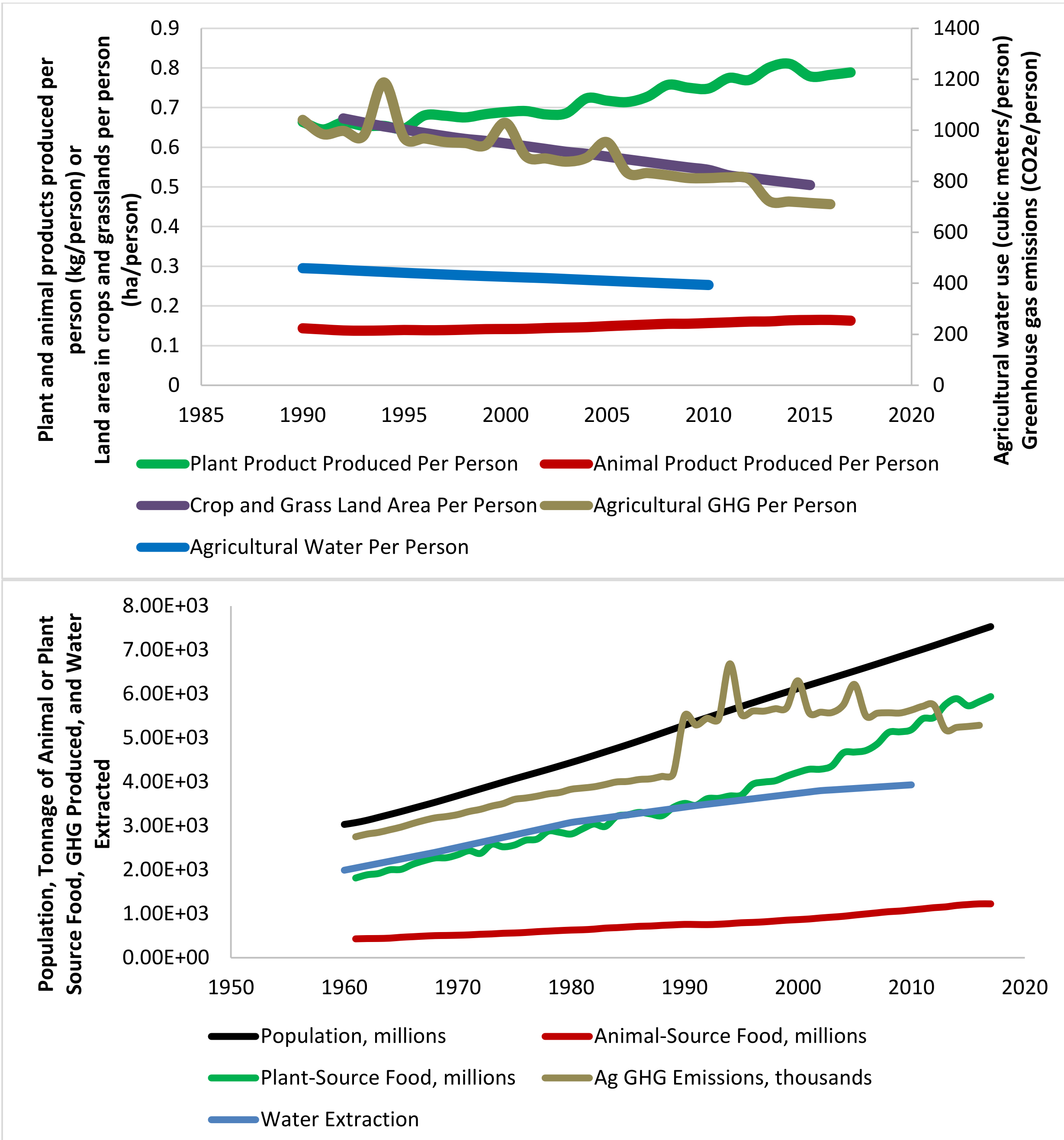

Figure 1. Per capita (upper) and total (lower) production of plant and animal products, greenhouse gas emissions, and usage of water and land for agriculture. Data obtained from UNFAO, 2019.

In addition to the environmental and food availability trends discussed above, the UNFAO data (FAOStat data, downloaded 1/16/2019) suggest that undernourishment has decreased by 11.8 million people per year from 2000 to 2016. Similarly, the proportion of people using safely managed sanitation has increased by 0.75% per year, the dietary energy adequacy of diets has increased by 0.41% per year and the per capita protein supply has increased by 0.30 kg/person/year. The historical data suggest that shifts and improvements in the agricultural system over the past 15 years have supported improved food availability (goal 2), enhanced accessibility of sanitation (goal 6), reduced climate intensity of agriculture per person (goal 13), and limited expansion of cropping and grazing land (goal 15). As such, a major goal of our agricultural systems moving forward should be to maintain these positive trends to continue to contribute to the UN Sustainable Development Goals.

▪ Considerations for Animal Product Production

It is quite common to discuss the importance of animal-source foods independent of the rest of the agricultural system, even though these foods are implicitly linked to other aspects of the food production system. Animal source foods are commonly cited as major contributors of greenhouse gas emissions and resource use. Animal products are also touted as contributing to negative human health outcomes like cardiovascular disease, colorectal cancers, and all-cause mortality.

What Nutrients are Provided by Animal-Source Foods?

Animal source foods, such as meat, milk and eggs, provide high concentrations of essential micronutrients in a food that also contains relatively low concentrations of energy (Gleason and White, 2019). Meat, milk and eggs are classified as complete proteins, meaning that they contain all ten essential amino acids. Amino acids are the building blocks of protein and are essential for the majority of biological processes. Meat is also a major source of Vitamin B_{12}, a nutrient essential for maintaining brain and nervous system function, and normal energy metabolism. Meat, milk and eggs also provide high concentrations of other important vitamins such as choline (nervous system development) niacin (energy production and metabolism), riboflavin (energy metabolism), thiamin (energy production and nervous system function), and vitamin B_6 (brain and nervous system function). These foods also provide high concentrations of essential minerals like iron (cognitive health and oxygen delivery), phosphorus (bone and tooth health), potassium (blood pressure), selenium (cellular integrity), and zinc (immune system function).

The FAO and WHO data on food insecurity provide some interesting insight into which nutrients are most important for human health globally. Only 10% of the global population classify as being unable to access sufficient energy (undernourished); however, over 28% of the global population experiences micronutrient deficiencies. The ‘obese and undernourished’ phenomenon is an embodiment of this issue — humans have adequate access to energy resources, but we lack availability of high-quality (and low energy) sources of micronutrients. Animal source foods are exactly that; they provide high concentrations of micronutrients with comparatively low concentrations of energy. This means that humans can consume animal products to meet their micronutrient needs without exceeding their energy requirements. It is particularly important to note that animal-source foods are good sources of several of the micronutrients with particularly high global deficiency prevalence, such as iron, vitamin B_{12}, and zinc. Improved focus on the global importance of micronutrient supplies will be critical to better characterizing the importance of animal-source foods in feeding the growing global population.

How Have the Environmental Impacts of Producing Animal-Source Foods Changed Over Time?

Globally, as the population has increased, so too has the production of animal-source foods and the environmental impact of agriculture (Figure 1). However, adoption of more advanced farming practices over this timescale has also contributed to the reduction in per-capita environmental impact of agriculture. Similar comparisons of historical versus modern environmental impacts of beef and dairy products in the United States also suggest that as livestock operations modernize and improve efficiency, they also reduce environmental footprints (Capper, 2011; Capper and Bauman, 2013).

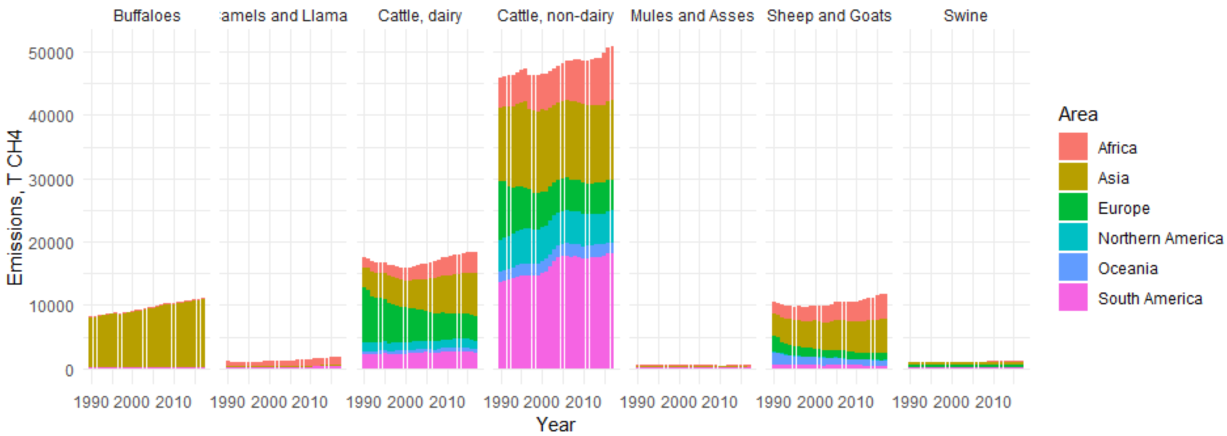

Figure 2. Breakdown of enteric methane emissions globally based on livestock species and emissions area. Data obtained from UNFAO, 2019.

There are important regional differences in environmental impacts of livestock products that should be considered when characterizing agricultural environmental impact and identifying areas for most optimal improvements. If we look at enteric (expelled by burping) and manure methane emissions, for example, these differences become quite apparent. For example, the enteric methane emissions from dairy cattle decreased between 1990 and 2000, largely led by decreases in Europe. However, as the dairy industry in Asia and Africa has expanded, emissions from those locations have replaced the emissions previously produced from the European herd.

It is also useful to compare the relative importance of different species in contributing to global emissions. Beef cattle (categorized above as Cattle, non-dairy) contribute the majority of methane emissions globally. While emissions in North America, Asia, and Oceana have remained fairly constant over the past several years, emissions increases in South America and Africa have contributed to a consistent rise in methane emissions since 1990. Similarly, increasing populations of buffalo in Asia have contributed to a similar rise in methane emission from these animals since 1990. Emissions from camels, llamas, mules, donkeys and swine are fairly minimal compared with emissions from cattle, sheep, goats, and buffaloes.

Enteric emissions, although a major contributor to emissions from animal agriculture, represent a controversial source of environmental impact because they are short-lived in the atmosphere. Currently, when estimating a carbon footprint, methane emissions are multiplied by a global warming potential to convert to carbon dioxide equivalents. Allen et al. (2018) highlighted that this somewhat misrepresents the true importance of methane because it is a short-lived pollutant. If we are not adding any new methane to the atmosphere, we are not adding 'new warming'. Thus, Cain et al. (2019) proposed an alternative, time-based method for accounting the global warming potential of methane emissions. Improved incorporation of this approach into agricultural environmental impact assessments will be crucial in determining where and how we should invest our mitigation efforts.

What is the Impact of Removing Agricultural Animals?

The common methods for comparing environmental impact of livestock products (comparing based on environmental footprints or comparing dietary environmental footprints) is logically flawed. First, it is not logical to compare food products based on their environmental footprints both because humans consume differing quantities of food products and because humans obtain different utility from different food products. Utility here is used as a nebulous term on purpose and can represent the net of nutrient provision, gustatory satisfaction, and all other immediate benefits obtained from consumption of food. Although it is more appropriate to compare foods based on how they are implemented into different diets, comparison of diets in terms of health and environmental outcomes largely ignores the practical consideration of how the agricultural system will support scaling of such diets to population level.

The above example of the EAT-Lancet diet scaled to a population level highlights why this consideration is important. We have a finite timescale within which we must make alterations to our agricultural system to support the growing global population. If solutions will take longer than that timescale to implement, or are otherwise physically challenging to implement, it is unlikely that they will be truly sustainable solutions. Massive, wholescale changes in the agricultural system take time to implement, and the nature of these changes must be considered when evaluating the true benefits or challenges associated with different dietary patterns.

Dramatic shifts within the agricultural system also may have unintended, collateral effects. The analysis by White and Hall (2017) suggested that when animals were removed from the U.S. agricultural system, a 2.9% reduction in total U.S. greenhouse gas emissions could be anticipated with addition of several nutrient limitations at a population scale. This analysis highlighted the importance of collateral effects like increasing production of synthetic fertilizer, reduced access to byproduct disposal from animal products, and increasing emissions accounted to field crop production in the event that animal agriculture is disbanded. Although a preliminary discussion, the work highlights the need to take a more systems-oriented view on evaluating the impacts of shifts in our agricultural system.

Suffice to say, animal agriculture is an important part of our agricultural system because the system evolved with animals as a part. The practice of agriculture is said to originate in the Neolithic Revolution, where early humans transitioned from hunter-gather societies to agricultural societies. This revolution occurred independently and at different times in developing societies around the globe. In each case, cereal grains were domesticated, followed by livestock (Scanes, 2018). This co-evolution of crop and animal agriculture is evidenced by all societies today. Not a single agricultural system globally contains only one of these types of agriculture because animals and crops co-exist and provide complementary utility to human societies. Improved attention to the historical linkages and progress of global agricultural systems is another useful strategy to assess those factors that influence the sustainability of food production systems. Fundamentally, the fact that the agricultural system has been able to adapt and improve to meet the growing needs of the global population speaks to the sustainability of its basal structure.

▪ Socioeconomic Considerations for Animal Product Production

A final factor important to consider when discussing sustainability of animal products in the global agricultural system is socioeconomic considerations. Sustainability is broadly defined as a balance of social, environmental, and economic considerations. Although it is relatively easy to quantify and make numeric comparisons on economic and environmental bases, social dimensions of livestock production are consistently more challenging to benchmark.

There are several different social dimensions considered by previous analyses. These dimensions include things like the social acceptability of products produced, the welfare of businesses and employees, and the linkages (or lack thereof) between the consumers and producers of a product. More broadly, the social contract within human societies regarding choosing one’s own lifestyle also falls under the social dimension. It is perhaps because of the complexity and wide-ranging nature of these social considerations that they are not widely incorporated into assessments of agricultural sustainability.

Accounting for factors like worker welfare and business health can be readily accomplished through surveys and assessment of business finances. It is sensible that these factors must be considered when assessing sustainability of an agricultural production system because economics and the well-being of a business operator are major factors contributing to the longevity of a business. If workers are in danger or do not enjoy their jobs, it is unlikely that they will continue to participate in that job long term. High worker turnover rates can be a challenge for animal health and well-being because it takes time for new employees to be trained. Perhaps more importantly, if sole proprietors or business owners cannot make a living by their chosen occupation, we cannot expect them to continue that occupation long term. As such, ensuring the security of working conditions on farms and the economic viability of farming operations is an important component of ensuring the sustainability of agricultural systems long term.

Another dimension of the socioeconomic component of sustainability is the linkage, or lack thereof, between consumers and producers. Globally, the fraction of the population associated with agriculture is shrinking rapidly. This shrinking means that fewer people grow up with an understanding and appreciation of where their food comes from. As a result, we have a number of disconnects in understanding regarding agricultural practices and how or why they are implemented. These disconnects are present both within the developed world and within the developing world. Unfortunately, they often focus on technologies employed to enhance efficiency. Use of technologies such as antibiotics, hormones and growth promoting technologies dramatically impacts the efficiency and the economics of livestock operations. As our social license to operate and use these products is impaired either by public opinion, purchasing choices, or policy decisions, it becomes increasingly apparent that improved communication between food producers and food consumers is needed to ensure the long-term sustainability of agricultural operations. This need extends beyond animal agriculture, including all other aspects of the global agricultural system.

The long-term role of socioeconomic pressures in dictating the sustainability of the global agricultural system should not be underestimated. Major objectives in this area should include fostering improved communication and transparency within and outside the agricultural system, working to improve economic viability of businesses and welfare of workers, and the social license to grow animals for food.

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