IMPACTS OF HUMAN FEEDING IN A WORLD WITHOUT ANIMALS

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ABSTRACT

The objective of this summary is to describe the roles of livestock in human society with specific emphasis on feeding the growing global population. The central question framing this discussion is: why should we feed animals to feed humans? The summary explores the original motivations for domesticating livestock and how the role of animal source products in the human diet has changed over time. At present, the global population is increasing, food production resources are limited, and there is increasing concern about human contributions to climate change. As such, there is a need to enhance the sustainability of food production. Given that livestock contribute to environmental impacts of food production and consume feeds that humans could consume, it is logical to question whether livestock are a part of a sustainable food production system. The summary of literature provided herein includes economic, environmental, and social arguments for why animals should or should not be a part of a sustainable food production system. Finally, a summary of how animal production can contribute to enhanced food production sustainability is presented. The major conclusions of the work are that although livestock contribute significantly to greenhouse gas emissions, they also are a recycling engine that provides essential nutrients and economic support for society. As a result, livestock are an essential part of the global food production system.

A HISTORY OF ANIMAL USE FOR HUMAN FEEDING

Feeding animals is inherently energy inefficient in terms of conversion of feed to usable products because animals obey the laws of thermodynamics, and energy that is converted to heat through metabolic processes is lost and not retained in tissues. When considering this inefficiency, it is logical to wonder what led humans to domesticate livestock in the first place because in early human civilizations, optimizing food yield is thought to be a major motivator for food selection. Although there are several theories on why cattle were domesticated, one rather convincing idea is that cattle were domesticated by delayed-return hunter-gatherer populations to provide a stable food supply in the face of unstable, marginal environments with unpredictable access to resources[1]. In essence, cattle were domesticated to provide an edible insurance policy for when crop resources were unavailable. Accordingly, domestication of livestock changed the way animal-source proteins were used in human diets. Larsen[2] suggests that prior to 2 million years ago, meat was acquired sporadically and opportunistically. As humans became more skilled at hunting, between 2 and 1.7 million years ago, meat consumption increased. Finally, after animals were domesticated some 10,000 years ago, meat consumption decreased and increased dietary focus was placed on domesticated grains.

Although livestock domestication provided security to early humans, there are also challenges associated with domestication. Unfortunately because domestication of livestock and settling of land areas occurred in the same time frame, it is virtually impossible to distinguish which factor most contributed to the ensuing societal challenges. Some factors can be sorted out by logic, for example, the expansion of the population and the increase in epidemic infectious diseases likely occurred because of the change in housing and population density[3], not because of the domestication of livestock directly. However, other challenges are more difficult to evaluate. For example, archeological records identify reductions in dental health, increased occlusal abnormalities, increased anemia, infection rates, and bone loss occurred during domestication of animals. Given the concurrent shifts in human activity levels and diet, we cannot ascertain what contribution livestock food consumption, independent of societal behavioral shifts, had on these negative health outcomes.

"Diseases of civilization" is a common term used to describe challenges like obesity and diabetes that begun to arise as humans became more sedentary. We know these diseases are at least partially driven by nutritional factors. As more and more human nutrition research is conducted on the role of livestock product consumption on human health, consumption of animal products is highlighted again and again as a factor to be considered when designing diets for human health[4]. Although the role of livestock in human diets at the time of domestication was quite clear, their future role is uncertain because the challenges that originally motivated humans to domesticate livestock are no longer major limitations in our societies. As human society continues to evolve toward reduced voluntary activity and increased ease-of-access for foods, the food production system needs to shift to meet society's needs. Given the changes in society, the question of whether we should continue to feed animals to feed humans is paramount.

A GLOBAL SNAPSHOT OF TODAY'S SOCIETY

The global population is expected to reach 9.3 to 9.4 billion by the year 2050[5]. Along this same timescale, improved affluence in developing nations is expected to increase global demand for meat and milk[6]. Globally, land[7] and water[8] availability are already limited, as a result, concern exists about the opportunity to rely on food production, as it currently functions, to meet this demand increase. Agricultural food production also contributes to atmospheric concentrations of greenhouse gases like methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2)[9]. The current challenge requires food production to improve land and water use efficiency and decrease GHG emissions while developing adaptive capacity in the face of climate variability[10]. A commonly proposed solution to these challenges is to improve “sustainability” of food production systems. Sustainability is defined as a balance between social acceptability, environmental responsibility and economic viability[11]. By improving sustainability, ideally, the environmental impact of a system can be reduced so that societal demands for food can be met within the bounds of resource availability and climate conditions.

Food sufficiency is a critical component of a sustainable food supply. Based on a review of available data, Kearney[12] reported per capita food consumption information for the world, developed, and developing countries. In 2001, the global average per capita food consumption was 2,789 kcal with people in developing and industrial countries consuming 2,654 and 3,446 kcal respectively. Considering the mean recommendation for an adult’s daily allowance of energy is 2,000 kcal these values suggest that on average energy availability is not a major global challenge. However, considering that estimates of global food insufficiency are as high as 14% (i.e. 14% of the global population suffers from malnutrition due to limited food availability)[13], it is likely that food sufficiency does not follow a normal distribution. Despite clear understanding of the importance of vitamins, minerals, and fatty acids to human health and development, few studies have attempted to identify the global sufficiency of these nutrients. An exception to this rule is the work of Herrero[14], which evaluated global production of Ca, folate, iron, protein, vitamin D, vitamin B_{12}, and zinc and identified the U.S. and Europe as hotspots of nutrient production. Given the intensity of animal agriculture in those areas, it is possible that the high production is associated with nutrient-dense animal food products.

Another critical tenant of global food sustainability is an affordable food supply. Affordability of food is broadly defined as diet cost in the context of household income. In low-income countries, food accounts for the majority of the household budget with the average middle class household spending 35 to 65% of their gross income on food[15]. Although there is considerable error in projecting food prices, most estimates suggest food commodity prices will remain higher than they have been previously[15]. An interesting, and somewhat counter-intuitive, adaptation to increased food cost is the consumption of energy dense but micronutrient poor foodstuffs. Namely, when food is limiting, humans eat to meet their energy requirements and often fail to meet requirements for other essential nutrients. This behavior further suggests an additional human health importance of keeping food prices affordable.

A final tenant of a sustainable global food supply is one that is environmentally friendly. Several efforts have attempted to evaluate what role agriculture will have in environmental change as the population grows. For example, Tilman et al. [16] projected that 10 billion hectares of natural ecosystems would be converted to agriculture by 2050 if food production efficiencies remain constant. As food production, and livestock production in particular, increase to feed the growing global population, a corresponding increase in agricultural greenhouse gas emissions is expected because of the current contributions of agriculture to global emissions inventories[17]. Additional environmental concerns associated with food production include extensive use of non-renewable resources[18], emissions of N and P into waterways[19], and degrading soil quality[20]. For a good production system to be environmentally responsible, it must attempt to efficiency utilize land and water resources, limit emissions of greenhouse gases, and minimize degradation of non-renewable resources, waterways, and soils.

In light of the social, economic, and environmental challenges facing the development of a sustainable food supply, livestock become a pivotal part of the conversation because animal-source foods are expensive, are resource-intensive to produce, but provide a different nutrient profile from plant-source foods. In light of the differences between livestock and plant-based food production, the primary question becomes: “is the improved nutrient profile of animal-sourced foods worth the economic and environmental costs?”. Several studies investigating this question have suggested that there are advantages to plant-based diets; however, there are some important assumptions that should be reinvestigated when evaluating the results on these studies.

ARGUMENTS POSED AGAINST CONSUMING ANIMAL PRODUCTS

Based on a review of the literature the U.S. 2015 Dietary Guidelines Advisory Committee claimed that plant-based diets would promote health and improve long-term sustainability of the U.S. food supply[21]. This report, and others like it[22], assume that modification or elimination of animal agriculture would offer benefits to society with minimal and acceptable deleterious effects. Given the challenge of providing adequate nutrition for a growing global population, addressing the question of why we feed animals to feed human society is of principal interest. From a food sufficiency standpoint, feeding animals is somewhat counter-intuitive because they consume large quantities of grains that humans could also consume[23]. As such, there may be a social argument for moving toward reduced consumption of animal products.

Several papers have sought to evaluate whether there is an environmental argument against feeding animals to feed humans. However, these evaluations are limited because current life-cycle assessment- (LCA) based C-footprints were assumed to hold in a system where animals were no longer a part of the food chain. For example, diets with low greenhouse gas emissions were associated with consumption of more plant protein foods and less animal protein foods[24], where diets were based on food consumption reported by a survey of 13,000 Americans and GHG were based on current LCA of food. In a meta-analysis of 742 LCA, Clark and Tilman[25] concluded that plant-based foods have reduced environmental impacts compared with animal-based foods and switching to a plant-based diet confers greater environmental benefit than switching to alternative livestock production systems. A survey of 10,723 Ontario residents also found that reducing household consumption of beef, eggs, and cheese had potential to lower global warming potential of diets, when global warming potential was calculated based on GHG estimated from life cycle assessment[26]. Each of these studies implicitly assumes the current LCA of food products would be valid in a dramatically shifted system where humans have significantly reduced the consumption of livestock products. Removing or reducing animal agriculture within any economy would catalyze a dramatic shift in the physical and economic structure of that system and it is unlikely that current LCA values would be representative because many inputs to these LCA are dependent on physical relationships which are likely to change. As such, a system-expansion approach is needed to more completely evaluate tradeoffs and possible transfer of materials and foods within a shifted agricultural system.

Economic arguments against production of livestock products are limited. In a survey of French diets, meat, eggs, and fish provided only 18% of the daily calories but 35% of the diet cost[27], suggesting that animal source foods are an expensive source of nutrients on a caloric basis alone. That being said, the inclusion of animal source foods in the diet is rarely done to satisfy caloric demand. Evaluation of food costs per unit of protein, minerals, vitamins, or fatty acids would be a more appropriate method for evaluating the economic importance of livestock products in human diets.

In summary, the primary arguments against livestock products include potential negative implications of food sufficiency and the environmental impact of food production. However, there are notable logical flaws with both these arguments. In the case of food sufficiency, removing livestock would allow humans to consume the grains currently consumed by livestock species;

however, grains are rich in energy and poor in many micronutrients. As such, increasing grain availability and decreasing animal products would likely result in an unplanned shift in availability of many micronutrients. Similarly, the environmental arguments against livestock production have been based primarily on LCA estimates derived using the current food production system as inputs. If livestock production dramatically decreased, it is unlikely that these LCA estimates would be realistic representations of the true carbon footprint of products.

ARGUMENTS POSED FOR CONSUMING ANIMAL PRODUCTS

From a social standpoint, meeting nutrient requirements of a population is a key priority for preventing undernutrition. Food availability and affordability are primary barriers to meeting nutrient requirements in developing and low-income communities[28]. Based on data from the National Health and Nutrition Examination Survey (2007 to 2010), Cifelli et al[29] found that plant-based rations resulted in greater deficiencies in Ca, protein, vitamin A, and vitamin D, suggesting that unintended nutritional consequences could be expected when switching from diets that included animal source foods to plant-based diets. Payne, Scarborough and Cobiac[30] also found that diets with reduced inclusion of animal products were also often high in sugar and low in essential micronutrients. Although vegetarian diets can contribute to reduced risk of coronary heart disease and obesity, they are prone to deficiencies in Fe, Ca, Zn, and vitamins B_{12} and D[31]. Collectively, these studies suggest that switching to plant-based diets may result in some unintended challenges in meeting the micronutrient requirements of the growing global population.

Animal-to-plant ratio in a diet is also significantly correlated with bioavailability of many micronutrients[32]. Current nutrient requirement standards do not present nutrient requirements on a bioavailable basis and therefore it is difficult to account for nutrient bioavailability in analyses evaluating adequacy of human diets.

Future work in human nutrition should focus on evaluating differences in food and nutrient bioavailabilities to ensure that requirements are presented on this basis. When such requirements become available, it is likely that the role of animal source foods in meeting human micronutrient requirements will become more apparent.

The environmental argument for inclusion of livestock in human diets is twofold. First, as elaborated above, we do not currently have good evaluations of the true environmental cost of removing animals from society. As a result, most current evaluations which make an environmental argument for removal of livestock products from human diets have notable limitations. A second environmental argument for the inclusion of livestock in human diets is focused on the need to feed the growing global population. Ruminant animals are one of the only ways to farm a large portion of untillable land globally[33]. Estimates suggest agricultural output must increase 50 to 70% to feed the growing population; however, removing ruminant animals from production systems would take all nontillable land out of the food production system entirely. Furthermore, most livestock consume byproducts of human food production. These byproducts are fibrous and inedible or unpalatable to humans and recycling them through livestock generates an important source of protein and micronutrients. Livestock also provide an important source of fertilizer used in crop production worldwide. Synthesizing this fertilizer synthetically would undoubtedly provide a substantial environmental cost. Although LCA-based studies show livestock as a major and optional source of environmental impact, this contribution to agricultural environmental impact must be considered in the context of the things that livestock do provide to society. Most notable of these contributions is the fact that livestock are a natural recycling engine that convert untillable land and human inedible feeds into a source of protein and micronutrients, fertilizer, and innumerable co-products.

Unfortunately, until an appropriate LCA of systems with and without animal products has been completed, it will be difficult to highlight the challenges associated with removing livestock from agriculture. Horton et al. [34] advocated for a system-wide approach to evaluating the food supply chain that integrates separate domains and multiple disciplines, importantly suggesting that food systems must be evaluated in their totality which will allow tractable quantitative analysis using LCA and related methods. Such a method is required to complete this appropriate LCA of livestock removal. Although efforts in this area are ongoing, there is no known LCA focused on evaluating system-wide implications of removing or reducing livestock consumption.

From an economic standpoint, there are several reasons why animal agriculture should be a part of a sustainable food production system. Although the values differ by country, in the U.S. animal agriculture employs more than 1.4×10^6 Americans[35] and annual U.S. exports of animal products have a value of $\$31.8 \times 10^9$, equivalent to 22% of the income from all agricultural exports[36]. In contrast, in developing countries, livestock products may not make up a large portion of export income but livestock represent an important source of capital for farmers[37], and although it is difficult to quantify, this contribution to livelihoods should not be overlooked.

Although there is a lot of literature pointing to the opposite, the work referenced herein suggests that livestock play an important, if highly specialized, role in food production systems. Although livestock contribute significantly to greenhouse gas emissions, they also are a recycling engine that provides essential nutrients and economic support for society. These data suggest that, at the very least, the role of livestock in sustainable food production systems should be continuously explored.

TO EAT OR NOT TO EAT (ANIMALS), THAT IS THE QUESTION

If light of the central question proposed in the introduction (is the improved nutrient profile of animal-sourced foods worth the economic and environmental costs?), we must consider the relative importance of social, environmental, and economic factors to food production. In this discussion, we posit that meeting global nutrient requirements is the single most important objective for the food supply. If we degrade the environment, we will be unable to efficiently produce food from the available land, and we will fail to meet global nutrient requirements. Similarly, if food is too expensive, people will be unable to purchase enough to meet their nutrient requirements. Finally, if we simply fail to produce sufficient quantities of nutrients, we will not have enough food to meet the global demand. Considering these challenges and the arguments aligned above, it is likely that animals should be a part of a sustainable food production system because they provide essential minerals, vitamins, and fatty acids which are in low supply or, in the case of fatty acids nonexistent, in plant-source foods. If we remove this source of critical micronutrients from the diet, it is likely that we will be unable to meet these nutrient requirements as the population grows.

In a case study focused on this question, White and Hall[38] evaluated the implications of removing animals from U.S. agriculture by evaluating current contributions of animal source foods to U.S. agriculture and modeling the implications of removing animals from this system. Assumptions when animals are removed from U.S. agriculture included: 1) grain previously consumed by animals will be available for human consumption; 2) tillable land previously used for hay green chop, and silage production, as well as tillable pasture and grazing land will be used for human food production directly; 3) the nutrients from animal products previously provided to humans will no longer be available for human consumption; 4) GHG from livestock production will no longer occur; 5) a large amount of feed processing byproducts previously consumed by animals will need to be disposed of; 6) N, P, K, and S fertilizer previously sourced from manure will need to be synthesized; 7) animal production byproducts previously available for pet food production will need to be replaced with plant nutrients; 8) humans can and will consume soy flour with no negative health impacts. In the present system, animal-derived foods provided large portions of the energy (24% of total), protein (48%), essential fatty acids (23 to 100%), and essential amino acids (34 to 67%) available for human consumption in the U.S. Livestock also recycled more than 43.2×10^9 kg of human-inedible food and fiber processing byproducts, converting them into human-edible food, pet food, industrial products, and 4×10^9 kg of N fertilizer. The modeled plants-only agriculture system produced 23% more food, but it met fewer of the U.S. population's requirements for essential nutrients. Nutrient deficiencies in the system without animals included minerals and vitamins (Ca, 60% of requirement; K, 75%;vitamin D, 15%; choline, 73%), and essential fatty acids (linoleic, 90%; α-linolenic, 71%).

In the simulated system with no animals, estimated agricultural GHG decreased (28%), but did not fully counterbalance the animal contribution of GHG (49% in this model). This assessment suggests that removing animals from U.S. agriculture would reduce agricultural GHG emissions and but would also create a food supply incapable of supporting the U.S. population's nutritional requirements. Although some consequences of removing animals were accounted for in the estimation of agricultural greenhouse gas emissions, the analysis still relied primarily on LCA-based greenhouse gas emissions estimates and thus likely fails to represent the true consequences of removing animals from U.S. agriculture.

Using the available food quantities in the current U.S. food production system and the modeled system without animals, White and Hall[38] also evaluated adequacy of possible human diets from both systems in comparison to the current U.S. consumption pattern. When nutritional adequacy was evaluated using least-cost diets produced from foods available, more nutrient deficiencies, a greater excess of energy, and a need to consume a greater amount of food solids were encountered in plants-only diets. Additionally, the diets optimized from foods available in the plants-only diets had very high dry matter intake daily and may be infeasible for actual human consumption. The reason for this high dry matter intake was the low nutrient density of foods in the plants-only diet compared with the current U.S. diet or the optimized U.S. diet from currently available food sources.

This study concluded that overall, the removal of animals resulted in diets that are nonviable in the long or short term to support the nutritional needs of the U.S. population without nutrient supplementation. As such, livestock play an important role in food production systems by providing a nutrient dense source of essential vitamins, minerals, and fatty acids. Based on this preliminary investigation, it can be suggested that livestock should be a part of a sustainable food production system.

MAJOR TARGETS FOR FUTURE LIVESTOCK PRODUCTION SYSTEMS

If we believe the general arguments that livestock production should likely be a part of a sustainable food supply, it is useful to query what factors can enhance the sustainability of livestock production systems. Whole-farm models have integrated different levels of biological organization to compare management strategies that reduce environmental impact[39]. These models indicate that improved cattle production efficiency is frequently tied to reduced environmental impact[40]. Until recently, the link solidifying environmentally-oriented management practices with economic viability[41] and social acceptability[42] was less well investigated. In work by White et al. reproductive, genetic, nutritional, and pasture management strategies in ruminant production systems which enhance efficiency also promoted sustainability[43]. General consensus of the available whole-farm modeling work evaluating sustainability of ruminant production systems suggests that any management practice that enhances efficiency can also positively influence sustainability. As such, the primary focus of future work aimed at developing sustainable ruminant production systems should be to enhance farm system (reproductive and feed) efficiency.

To better evaluate the role of feed efficiency in promoting sustainable ruminant production systems, White[41] constructed a farm-scale diet optimization model to identify opportunities to reduce land use, water use, and greenhouse gas emissions within dairy production systems and to assess how improved energy and protein use efficiency affect opportunities to reduce these environmental impacts of dairy production systems. Non-linear programming was used to adjust monthly diets fed to 10 cattle groups to minimize environmental impacts associated with an average United States dairy farm. Environmental impacts were considered from the inputs to the cropping system to the dairy farm gate. The effects of improved feed efficiency were modeled as a 15% decrease in maintenance energy or metabolizable protein requirements in scenarios where allowable diet cost increases were adjusted from 1% to 20% above baseline diet cost. In the system with average feed efficiency environmental impact metrics could be simultaneously reduced by 4.4 to 25.5% within the range of allowable cost changes. When both energy and protein efficiency were improved, land use, water use, and GHG emissions reductions ranged from 23.4 to 35.5% within the same cost range. This work demonstrates the significant economic and environmental importance of enhancing feed efficiency of catle.

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