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Nutritional Sustainability: Aligning Priorities in Nutrition and Public Health with Agricultural Production

John W Finley,[1] Dennis Dimick,[3] Elizabeth Marshall,[2] Gerald Charles Nelson,[4] Jonathan R Mein,[5] and David I Gustafson[6]

[1]*Agricultural Research Service and* [2]*Economic Research Service, US Department of Agriculture, Beltsville, MD;* [3]*National Geographic Society, Washington, DC;* [4]*Department of Agricultural and Consumer Economics, University of Illinois, Urbana-Champaign, IL;* [5]*Vegetable Seeds Division, Monsanto Company, St. Louis, MO; and* [6]*Real Whirlwind, LLC St. Louis, MO*

ABSTRACT

Nutrition science–based dietary advice urges changes that may have a great impact on agricultural systems. For example, the 2016 Dietary Guidelines for Americans (DGA) recommends greatly increased fruit and vegetable consumption, but the present domestic production is insufficient to accommodate large-scale adoption of these guidelines. Increasing production to the extent needed to meet the DGA will necessitate changes in an already stressed agriculture and food system and will require nutrition and agriculture professionals to come together in open and collegial discourse. All involved need to understand the stress placed on the food system by increasing populations, changing diets, and changing environments, and recognize the major diet-based public health challenges. Furthermore, there is a need to understand the intricate interplay of the myriad parts of the food system and the vast amount of work necessary to make even small changes. New systems approaches are needed, especially at the research level, where nutrition, public health, agriculture, and the food industry work together to solve interconnected problems. Future well-being depends on a sustainable food system that continues to deliver optimal health with minimal impact on the environment. *Adv Nutr* 2017;8:780–8.

Keywords: food policy, agriculture, climate change, sustainability, food security

Introduction

Throughout the 19th century and much of the 20th, the goals of nutrition and agriculture research in the United States were aligned mostly as agricultural research concentrated on improving the quantity and quality of the food system with the goal of improving the health of US citizens through better diets (1). For example, <30 y after its establishment in 1862, the USDA hired Wilbur O. Atwater as the Chief of Human Nutrition investigations in the Office of Experiment Stations. As Chief, he laid the groundwork for understanding how food composition influences health (2). There is a divide at present, however. This divide may have been brought on by multiple changes, including those in academic programs, such as the move of programs in human nutrition out of schools of agriculture and into other schools such as human ecology or medicine, as well as changes in research funding that have resulted in grants from institutions such as the NIH becoming relatively more important than funding from the USDA and agriculture groups. Other factors include the increase in urbanization and the loss of contact by many citizens with agriculture. Regardless of its etiology, the present system is mostly unsustainable and must be changed (3), but there is wide disagreement about how best to accomplish this goal. For instance, DeLind (4) suggests that the system is sufficiently obsolete as to require radical redesign and overhaul by switching from extensive commodity-type production to more intensive local production to decrease environmental impact and increase social well-being. Others suggest changes intended to address food availability and security and nutritional disorders, such as introducing more plant-based diets [shifting emphasis from major commodities to underrepresented crops (e.g., vegetables, pulses)] and producing leaner meats (5).

This article is a review from the symposium "Food Systems for Public Health: Assessment, Impact, and Implications of Meeting Fruit and Vegetable Consumption Recommendations on Environmental, Economic, and Agricultural Sustainability," held 3 April 2016 at the ASN Scientific Sessions and Annual Meeting at Experimental Biology 2016 in San Diego, California.
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Address correspondence to JWF (e-mail: john.finley@ars.usda.gov).

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"Sustainability" is a term without a universally accepted definition; within this article, the term "sustainable food system" is used in the context of the widely accepted Brundtland Commission definition: a food system that meets the needs of the present without compromising the ability of future generations to meet their needs (6). The concept of sustainability was addressed explicitly by the committee that produced the report used to develop the 2015 Dietary Guidelines for Americans (DGA) (7). The committee (8) wrote that it is necessary for "ensur(ing) … access (to food) for both the current population and future generations," as well as minimizing the environmental impact of producing that food. Although the finalized DGA did not address the topic directly, many of the messages had strong implications for sustainability. For example, the DGA recommendation increased the consumption of fruits and vegetables. Providing a sustainable supply of sufficient produce to reach this goal, however, will require changes to an agriculture system that is already being stressed globally.

Many of the popular assumptions underlying the concept of sustainable food systems are the subject of much debate. For example, some have alleged philosophical inconsistencies in the "local" argument (9) and others have argued that sustainability is best served by intensifying production on existing lands and systems, albeit with certain changes made to address environmental concerns (10). Another example is the argument that plant-based diets are the most sustainable choice (11), but some modeling research challenges that assumption (12). Sustainability recommendations must be made in collaboration with food producers, otherwise there may be resistance within agriculture circles if it is perceived that changes shift demand and profitability in unhelpful ways within agriculture markets.

In short, many arguments for changes to the present food system are fraught with a priori assumptions, and these assumptions often arise because of an incomplete understanding of the interrelated processes, challenges, and constraints faced by agriculture. In this Perspectives article we argue that understanding the challenges, eliminating erroneous assumptions, finding common ground, and developing a course forward requires open and collegial discourse between all parties. This open discourse will allow for all sides involved in the debate to understand better the common constraints and challenges faced. Such communication has been hindered by a number of factors, including a lack of common understanding of basic constraints on the food production and distribution system and the lack of a common ontology relating public health and production agriculture.

Regardless of the potential for controversy and lack of consensus, global concerns of population, environmental changes, and public health challenges make the development of sustainable food systems a priority. Norman Borlaug, the father of the so-called Green Revolution and a 1970 Nobel Peace Prize Laureate, eloquently expressed the importance of this problem by stating that he believed the world has the ability to feed 10 billion people if all of our available technology is used, but that unless problems are addressed now, "sustainable agricultural systems in the future will be ever more difficult to achieve" (13).

Figure 1A provides a schematic of how nutrition science affects the food system. Nutrition and health professionals maintain a dialog, but other than providing information to regulatory bodies such as FDA, they have relatively little voice in agriculture and food policy. In such a system the task of balancing and integrating concerns related to nutrition, agriculture interests, and sustainability falls to policymakers who often do not have the information required to understand the tradeoffs inherent in their policy decisions. Figure 1B presents an alternative in which both the agriculture and nutrition/public health disciplines are incorporated in a comprehensive food systems approach to nutrition policy. In this approach the disciplines interact

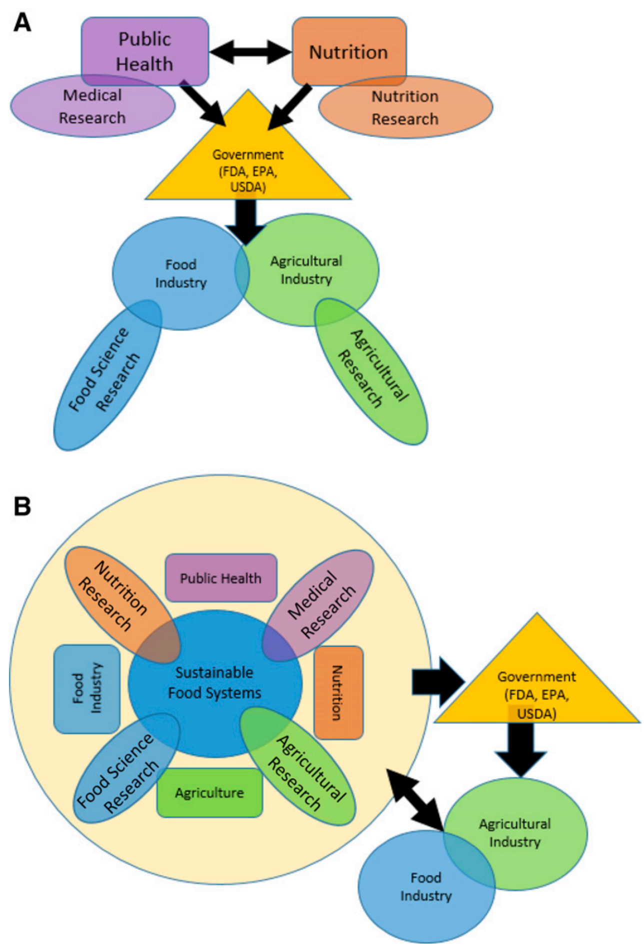

FIGURE 1 Relations between the nutrition and public health and the food manufacturer and agriculture sectors, particularly in relation to how research from one sector affects policy in the other. The system at present; nutrition and public health interact primarily with government agencies, which then interact with the food production system (A); an integrated approach in which all sectors are involved in a systems approach, particularly at the research level, thus allowing for interaction, discussion, and debate before products are produced or policy is promulgated (B). EPA, Environmental Protection Agency.

directly, particularly at the research level, where concerns can be addressed and tradeoffs identified and mapped for delivery into the policymaking process. Developing such a systems approach requires: *1*) achieving a more complete understanding of the competing demands of and constraints on the food system on regional and global scales (e.g., population, environment, agriculture infrastructure) and the health concerns affected by nutrition, *2*) articulation of the primary research gaps to be addressed, *3*) development of systems approaches to research that integrate the broad realities and demands of agricultural economics and agricultural production with environmental sustainability and nutritional demands, and *4*) design and implementation of processes to facilitate an ongoing systems approach to nutritional policy.

The purpose of this article is not to propose ideas for the redesign of the food system; that would involve a far more detailed discussion of public policy and multiple scientific topics. Instead, this article addresses briefly some of the major constraints, challenges, and bottlenecks facing the food system, primarily in the United States. We contend that large-scale shifts toward healthier dietary patterns could exacerbate many sustainability concerns. We propose that the first step is for nutrition and public health specialists to establish effective and meaningful discourse with their counterparts in the agriculture and food sectors. This would serve as the basis for a common understanding of the complexity of the present food system. Only then can we collaboratively develop integrated strategies for improving health and sustainability outcomes from food systems.

The Challenge of Feeding 9 Billion Will Be a Major Constraint to a Sustainable Food and Agriculture System

Changes to the US food system must be made within the context of global constraints. There are 3 primary global challenges: rising population, improving economic conditions among the world's previously poor, and changing climate. The world's population has tripled, from ~2.5 billion in 1950 to ≤7.5 billion in 2017, and is expected to reach >9 billion by 2050 (14). Personal income has risen (15), and in many areas this is driving demand for dietary changes (e.g., more meat and dairy), potentially increasing pressure on available resources and protecting the environment (16). At the same time, changes in climate are increasingly stressing the productivity of key commodities (17), which has led some to project a need for a substantial increase in global crop harvests by mid-century to meet future food demand (18, 19).

Publications such as "Solutions for a Cultivated Planet," "Feeding Nine Billion," and others have examined the effects of stressors such as world population trends and the impact of changing consumption patterns, climate change, energy resource availability and use, water resource availability, and soil conservation on our ability to supply a sustained source of nutrition to the planet (19–28). These publications suggest that the expanding footprint of agriculture has been responsible for ongoing deforestation, soil erosion, and surface water degradation; however, we must remember that agriculture is the basis for all of civilization—a fact that is reiterated every time we eat. We do not have the luxury of suspending the present food system while we develop a better one. Instead, we must make incremental changes while continuing to provide sustenance to the world's population, one meal at a time.

Climate Change Adds an Additional Challenge to Sustainability

A changing climate is a universal challenge to the food system, and in a world with increasingly scarce resources and growing demand for food, it is making sustainable food and nutrition security more difficult to achieve. Higher temperatures, uncertain changes in precipitation, increasing frequency of extreme weather events, and higher ozone concentrations make change the "new normal" in agriculture (29).

Climate change affects agriculture to different degrees around the world. Chinese rice production has shifted north of its traditional areas and coffee production is shifting to higher elevations (30). The production of pasta is threatened because of the sensitivity of durum wheat to higher temperatures (31). Lobell et al. (32) reported that climate change has offset research productivity in many regions globally, although less so in the United States. The future effects of climate change on agriculture could be much greater, however. For example, Lobell and Field (33) explored 6 California perennial crops—wine and table grapes, almonds, oranges, walnuts, and avocados—and found that there will be large yield declines in avocados by 2050, whereas wine grape yield declines will be relatively small. Some have predicted even greater negative effects after 2050. For example, Nelson et al. (34) modeled irrigated rice yields in developing countries and predicted declines of 12% by 2050 and 29% by 2080.

Climate change also may affect food security, especially in vulnerable populations. Economic models show a substantial increase in the price of staple foods in recent decades (35), and the added stress of climate change could cause a further, perhaps sizable increase (36). In addition, secondary effects such as increasing ozone concentrations, more extreme weather events, increasing pressure from pests and diseases, and effects on nutritional content could magnify potential problems, making accurate assessments of future productivity and nutritional security much more difficult.

Studies of the effects of climate change have focused primarily on crop yield, but some data suggest effects on nutritional composition as well. Myers et al. (37) have argued that the atmospheric CO_2 concentrations predicted for the mid-21st century will result in lower concentrations of zinc and iron in C3 (C3 and C4 designations refer to the number of carbons in the intermediate; the photosynthesis of C4 plants is improved in higher temperatures) crops, grains, and legumes grown under field conditions. C3 crops other than legumes also may have lower concentrations of protein, although C4 crops (e.g., corn) seem to be affected less. Large intervarietal variation in some nutrients suggests that there are opportunities to breed crops for tolerance to higher CO_2 environments. Hatfield et al. (38) reported that elevated CO_2 concentrations reduced the protein content of wheat, Ainsworth and McGrath (39) found that the protein and mineral contents of nonleguminous grain crops were decreased by CO_2 concentrations of 550 ppm, and Erda et al. (40) reported similar results for crops in China. International Rice Research Institute researchers (41) reported that higher temperatures affected rice quality traits such as chalk, amylase content, and gelatinization temperature. Conversely, Wrigley (42) reported increased wheat yields from higher CO_2 concentrations, although the yield increase was a result of more rather than larger grains and the protein content was reduced. To date, few data exist for fruits and vegetables, and it will be critical to understand these negative effects on these crops. It is apparent from a nutrition perspective that such changes will have a proportionately greater impact on human populations with marginal or compromised nutritional status and communities with access only to locally grown crops.

Although these data show that climate change can have and is having an effect on agricultural production, the impact of change on and suggested mitigation options for nutrition is less well understood. Data gaps exist as to whether climate change has a meaningful impact in real-world food systems. It is likely that effects will depend on location, because current nutritionally vulnerable areas are in all probability the areas that will be affected the most (36).

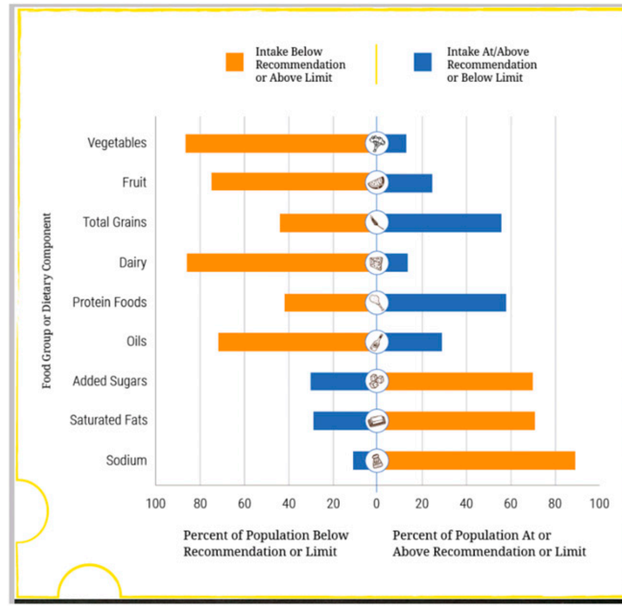

FIGURE 2 Dietary intake in the United States in relation to dietary guidance. From 2015–2020 Dietary Guidelines for Americans. Reproduced from reference 7 with permission.

A Sustainable Food System Must Address Public Health Concerns

A major public health issue in the United States is the consumption of unbalanced diets. More than two-thirds of US adults are overweight and more than one-third are obese (43). Obesity is associated with many comorbidities; a systematic review and meta-analysis (44) found statistically significant associations with type 2 diabetes, cancers (except esophageal and prostate cancers), cardiovascular disease, asthma, gallbladder disease, osteoarthritis, and chronic back pain. Many factors are involved in obesity, but an energy-dense diet that is characterized by low fruit and vegetable intake is associative (45). Fewer than 30% of Americans consume the recommended amounts of fruits, vegetables, and dairy products, and >60% consume diets exceedingly high in added sugars, saturated fats, and sodium (1) (**Figure 2**).

Movement of the population toward the consumption of healthier diets will require major changes in the amounts and types of foods consumed. Although the exact composition of "healthier diets" is debatable (the composition of most healthy diets is ~50% vegetables and fruits), it is generally agreed that such a change will increase the demand for vegetables, fruits, and dairy products (7). Such changes in diet composition could have substantial effects on the sustainability of agricultural production and of food systems more broadly. Cross-disciplinary research is needed to determine the impact of proposed dietary changes on the overall sustainability of food systems, including economic, environmental, and societal factors, as well as the potential improvements in public health outcomes.

Responding to These Challenges Requires an Understanding of the Present US Food System

Because food is needed by every individual on the planet multiple times per day, the most important attribute of a food system is that it must function continuously and not stop for any reason. Regardless of the flaws in the present US food system, it does deliver a constant supply of sustenance; therefore, it is incumbent on all who propose changes to it to understand thoroughly the complexities and challenges of the existing system.

Food systems comprise all of the inputs and infrastructure required to grow, process, transport, store, sell, prepare, consume, and dispose of food. We are still in the early stages of defining, quantifying, measuring, and managing sustainable food systems to accompany healthy diets. There are social, economic, and environmental effects at every node in the system, and an assessment of sustainability must evaluate the food system as a whole. Interdisciplinary research drawing on fields such as nutrition, sociology, agriculture, economics, and political science is needed to identify potential tradeoffs and infrastructure or resource bottlenecks within the system and leakage of effects outside the system that may emerge as a result of consequential changes in consumer choice patterns. For example, increasing the supply of fruits and vegetables would entail changes in crop production and production practices, regional resource use, and commodity prices, and alter the infrastructure for the distribution, storage, and sale of perishable goods. The spectrum of potential sustainability issues associated with changing a single aspect of the supply of fruits and vegetables is extremely wide; the following sections provide samples of such issues.

Potential bottlenecks in regional fresh produce packer and shipper operations

Fresh produce supply chains are defined by seasonality and perishability of the product; as such, distribution infrastructure is critical. In 2015, California produced 57.8% of the value of fresh market vegetables grown in the United States, followed by Florida with 9.3%, and Arizona with 8.5% (46). The distribution infrastructure has developed to deliver produce from these regions to dispersed demand centers throughout the states and into export markets. Increased demand may necessitate expanding production into new or minor regions that do not have a robust distribution infrastructure. Etemadnia et al. (47, 48) have established a framework for measuring the costs, locations, and scale of the fresh produce hubs that would be necessary to accommodate increased regional production.

Tradeoffs between food waste and refrigeration requirements in both fresh and frozen markets

Most fresh produce requires an unbroken, temperature-controlled supply chain to maximize shelf life and minimize food safety concerns. Because constant refrigeration of food is required from harvest to retail, the greenhouse gas (GHG) emissions that are associated with distribution can represent a substantial portion of the emissions associated with the entire fresh produce supply chain, including production. Waste and degradation of quality can nevertheless occur as a result of issues associated with inappropriate or interrupted refrigeration or the grouping of frozen and refrigerated produce in transport. Distributing produce as frozen rather than fresh can reduce waste, which can in turn reduce emissions at the production end, but it also is likely to increase GHG emissions along the distribution chain. To complicate the accounting, tradeoffs between cooling requirements and GHG emissions effects also may have nutritional consequences; because fruits and vegetables that are distributed frozen are generally frozen at the peak of their nutritional quality, they may be more nutritious than fresh vegetables that degrade in quality during the distribution process.

Accounting for market and consumer feedback when calculating the supply response to reduced food waste

Estimates of the amount of food waste in the United States often fall in the range of 25–40% of total annual food production (49–53). Fresh vegetables, fruit, and dairy products are among the most wasted foods (51, 52). Such waste has substantial environmental implications; Cuéllar and Webber (51) calculated that food waste accounts for 2% of US GHG emissions, whereas Hall et al. (49) estimated that food waste accounts for >25% of total fresh water consumption in the United States. A mantra in discussions of sustainability has been that reduction of food waste is "low-hanging fruit" in the movement toward a sustainable food supply. A systems approach to analyzing the outcomes of food waste reduction, however, suggests that the change in production and distribution effects associated with food waste reduction may not be directly proportional to the amount of food waste reduction. The dynamics of the market and consumer response to changing volumes of production complicate potential impact accounting. Prices may be influenced by changes in the volume produced through a number of channels. The costs of producing and distributing a given amount of consumed produce may decrease, for instance, if the system is not also moving around a certain volume that is destined to be discarded; such reductions in cost could lead to reductions in price, which would increase or redistribute demand for food. Changes in the economies of scale in production and distribution could increase per-unit costs, forcing prices to rise as the volume distributed drops. Both production and consumption behaviors will respond to a complicated set of effects on prices, which complicates the impact accounting that is associated with food waste reduction.

Potential tradeoffs between multiple indicators of environmental sustainability across different sectors as diets shift

Studies exploring sustainability shifts as diets change often consider the effects of dietary change on a single indicator of sustainability (e.g., GHG emissions, land use, water use) (54). Indicators of sustainability may not be directly correlated; therefore, a comprehensive analysis of sustainability requires a broader look across multiple types of effects. In the United States, for instance, the production and consumption of fruits and vegetables tend to be relatively water intensive, so a shift toward healthier diets may involve a greater use of water throughout the supply chain. The effects attributable to fruits and vegetables, however, is only one component of the effects across dietary change; the total effect of water use depends on what is happening simultaneously with different food types as a result of dietary shifts. Meat, poultry, and dairy, in contrast, account for relatively more GHG emissions within the food system; shifts in GHG emissions, therefore, may not move in the same direction as shifts in water use as diets change.

Potential leakage of diet choice effects outside the US as consumption of imported fruits and vegetables increases

In systems analysis leakage of environmental impact refers to the movement of effects outside the system being analyzed. An analysis focusing on the effects of sustainability of changing US diets that exclusively measures sustainability indicators within the United States, for instance, fails to account for the sustainability implications of changing patterns of trade. Changes in the environmental impacts embedded within the products we import represents leakage that is not accounted for in domestic measures of sustainability. In 2013, the US imported 48.7% of the fruits and nuts and 20% of the vegetables (by volume) that we consumed (55); substantial production and transportation effects can be associated with producing and transporting these imports to our borders. Changing patterns and volumes of domestic demand are likely to affect produce markets and prices in ways that shift trade volumes and patterns and their embedded environmental impacts, both within and outside our borders.

The complexity of the infrastructure of agriculture as illustrated by the development of new plant varieties

The food supply chain in the United States is a highly interconnected network with many stakeholders between agriculture producers and consumers that is embedded in and influenced by the biophysical environment, social organizations, science and technology, policies, and markets (56). Changes within the broader context can have profound and unforeseen implications. The foundation of the US food system is the ability of agriculture producers to grow high-yielding, nutritious crops in an economical manner that results in profit that is sufficient to allow the enterprise and all connected to it to continue production. One important aspect is the ability to access crop varieties that continue to produce large yields while incorporating new traits such as improved nutritional value or decreased environmental impact. Understanding the challenges and constraints around developing a new crop variety illustrates the complexities that must be understood and incorporated into integrated research targeting a sustainable food system.

The development and commercial launch of a new vegetable variety requires ≥4–15 y, depending on the crop type and associated genetic complexity, required breeding effort, environmental adaptability trials, and seed production and manufacturing. Selecting relevant breeding targets (e.g., traits, trait combinations) therefore requires a perspective on both present and future market needs. Selected targets typically deliver value to one of the various stakeholders—grower, shipper/packer/wholesaler, processor/manufacturer, retailer, and/or consumer—in the value chain. Consumers are not typically first-line purchasers of raw commodities such as fruits and vegetables, although this is changing with the growth of farmers' markets. Nonetheless, the primary stakeholders for plant breeders are agriculture producers; therefore, selecting traits for disease resistance, yield, uniformity, adaptability, and postharvest handling are paramount. Although most agriculture producers do not sell their products directly to consumers, consumers ultimately influence the development of new varieties through their changing preferences and food consumption patterns. Given the timelines involved in the development of new agricultural products, swift and adaptive change is difficult, although the agriculture system adapts to meeting changes in supply to changes in demands. Advances in agriculture technology, such as genetic improvements, data management, and agronomic practices, continue to drive yields and efficiencies to supply present demand.

Consumers are able to influence the food system through their preferences and eating patterns, with taste, flavor, convenience, and nutritional value often stated as primary concerns. For example, smaller, pre-washed and -cut fruits and vegetables are considered convenient. Developing new varieties that deliver a better flavor experience, have enhanced nutrition, or both presents a complex set of challenges because this requires a multidisciplinary approach, bringing together sensory, analytical, biochemical, genetic, and agriculture sciences. The tomato, for instance, has inspired much research into flavor, and researchers continue to search for the right combination of agronomic performance, postharvest performance, and shipability, along with great taste and flavor (57). The complexity of tomato flavor overlaid with the complexity of the human perception of flavor creates a challenge. Many other factors, such as harvest maturity, agronomic practices, and postharvest handling, affect the taste and flavor of tomatoes. Thus, the ability to deliver better-tasting tomatoes to consumers requires a coordinated effort between producers, supply chain stakeholders, and retailers.

The challenges in developing products with enhanced nutritional value are illustrated clearly in the case of broccoli that is high in glucosinolates. In addition to several key micronutrients, broccoli is a rich source of the phytonutrient glucoraphanin, which is associated with a decreased risk of several types of cancer (58). Varieties of broccoli high in glucosinolates were developed that deliver 2–3 times the concentration of glucoraphanin compared to standard commercial broccoli varieties grown in the same field. The development and validation of this trait involved conducting 54 trials in 3 y in California, Arizona, Mexico, Spain, Italy, and the United Kingdom to demonstrate performance and environmental stability of the trait (59). This occurred after >10 y of breeding and selection to produce a hybrid variety that was acceptable for commercial broccoli production (i.e., one that had the yield, uniformity, and postharvest survivability required by broccoli producers).

The goal of agriculture and nutrition is to maintain optimal human health. Substantial progress could be made toward this goal by increased fruit and vegetable consumption. The ability to meet changing demand through increased supply will rely on our ability to continue to increase yields through better genetics, better agronomic practices, and reduced waste. Maintaining and sustaining the consumer experience, however, will be critical to shifting and capturing changing consumer demand. Changing consumption patterns by bringing consumer-oriented traits to market, however, is not simply a function of breeding better-tasting or more nutritious varieties, because each step along the supply chain has its own set of requirements and limitations. Furthermore, we need to assess whether these changes are having a meaningful effect on human health. If we are simply displacing the present amount of consumption with a similar amount of consumption of a different product, are we truly making any progress in improving health?

Moving Forward Requires That We Develop a Dialog between All Parties

Developing an effective dialog between the nutrition and agri-food scientific communities is challenging for a number of reasons. Although these communities are trained largely by the same set of academic institutions, the curricula are completely different and lead to completely different perspectives on the global agri-food system. Some within the nutrition community tend to view the system negatively, as one that focuses on profits but does not address health as a priority. Conversely, many agriculture scientists tend to view their role as being important innovators in helping the agri-food system to become more productive and profitable. These divergent perspectives often create tension and reduce communication and collaboration. As a consequence, the agri-food system often is perceived as inadequate from a nutritional and environmental sustainability perspective, and the nutrition and public health research community may be seen as ineffective at providing input into discussions that could help correct the problems. New arenas for engagement where mutual learning can occur, mechanisms for more effective communication and collaboration, and a systems approach to integration of research agendas across the disciplines may help to reduce the challenges.

An example of a way to move forward is a multidisciplinary effort led by the International Life Sciences Institute Research Foundation, which developed a novel food system assessment methodology (60)—sustainable nutrition security—that explicitly addressed both nutrition and sustainability outcomes. Sustainable nutrition security uses 7 science-based metrics relevant to policy making that can categorize and compare different scenarios and evaluate the likely impact of potential food system interventions that are intended to improve food security and human nutrition outcomes. The 7 food system metrics are food nutrient adequacy, ecosystem stability, food affordability and availability, sociocultural well-being, resilience, food safety, and waste and loss reduction. These metrics were selected because of their importance as measures of the overall food system and its impact on human health, as well as their influence on social, economic, and environmental sustainability.

These metrics were used initially to evaluate food system performance at the national level, but they also may be deployed to characterize the intrinsic tradeoffs and constraints associated with the agri-food system. Some examples include increasing water use with greater fruit and vegetable production and consumption, nutrition and sustainability consequences of plant-versus-animal–sourced protein, and implications of increased trade as a way to meet fruit and vegetable demand globally. Many other applications are possible, including assessment of the effectiveness of other food system policies and practices intended to improve human nutrition and sustainability outcomes.

In conclusion, multiple lines of evidence confirm that population growth, climate change, increased numbers of extreme weather events, and dwindling natural resources pose serious challenges to food systems in providing food and nutrition security in the United States and globally. These challenges suggest that effective future food systems should operate in a manner that will both sustainably meet human nutrition needs and comply with planetary constraints. Innovative agriculture research will be needed to underpin new approaches and efforts. A major challenge to attaining this goal will be for the world's nutrition and agriculture science communities to emerge from their intellectual silos and develop complementary research strategies and systems based on communication and collaboration.

A constructive dialog between the world's nutrition and agriculture science communities requires each discipline to understand the functions of and constraints on the other. By communicating processes and constraints clearly, the agriculture community can facilitate the establishment of realistic strategies for food system development and reasonable expectations for the magnitude and pace of change. Similar strategies will help the nutrition community, ever mindful of public health, to ensure that nutritional adequacy (and appropriateness) of the food supply receives the same degree of attention as traditional agronomic concerns. Although there is some disagreement, consensus also is growing for "no regret" actions. For example, sustainable food production depends on freezing agriculture's footprint, growing more on existing farms, using resources more efficiently, shifting diets, and reducing food waste. Addressing climate change requires replacing existing crops with more heat-tolerant varieties or switching to different crops and using less water-intensive crops and more heat-tolerant animal varieties. From a nutritional point of view, shifts to more sustainable and healthy diets should be encouraged. Giovannucci et al. (61) eloquently expressed the challenge: "New options are available now to begin a shift and to create a more sustainable food and agriculture system. We need not be bogged down in the areas of disagreement when there are so many areas of common agreement… We can build on that and there is much that can be done. We need only begin."

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